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Managing Late Blight on Irrigated Potatoes in the Pacific Northwest

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INTRODUCTION

Late blight, a disease caused by the organism *Phytophthora infestans*, has been one of the most damaging plant diseases worldwide. Until the early 1990s, only a single genotype or strain—A1 mating type, metalaxyl (Ridomil®)-sensitive—called US-1, was present in North America. When metalaxyl was introduced in the 1970s, the disease was relatively easy to control with this chemical.

In the early 1990s, other genotypes such as US-8 and US-11, which are insensitive to metalaxyl, began spreading across the potato-production areas of North America. Unfortunately, US-8 and US-11 had characteristics that differed significantly from those of US-1. Most notably, they were better able than US-1 to cause late blight on potato—commonly referred to as being more aggressive.

Sexual recombination between A1 and A2 mating types that occur by chance in the same field (for example, between US-1, an A1 mating type, and US-8, an A2 mating type) can result in additional genotypes that can also be aggressive and metalaxyl-resistant. Data suggest the development of US-11 is from one of these chance events. The occurrence of new genotypes of *P. infestans* has resulted in increased levels of disease and higher costs of control throughout the United States, especially in the major potato-producing states of Idaho, Oregon, and Washington.

This publication discusses the use of an integrated management program for late blight on irrigated potatoes in the Pacific Northwest, including cultural practices, host resistance, disease forecasts, and chemical applications. Definitions of technical terms are included at the end.

LATE BLIGHT SYMPTOMS

Recognizing symptoms and thoroughly understanding the biology of the organism causing late blight on potatoes is essential to understanding how to control this disease.

Foliar symptoms

Leaf lesions are circles or semi-circles, often surrounded by a light green to yellow halo (figure 1). Lesions are more likely to begin at the leaf edge than in the middle of the leaf. Active late blight lesions commonly have white mycelium growing on the underside of infected leaves (figure 2). The mycelium can be seen particularly easily on most leaves in the morning hours when dew is present and, later in the day, on leaves found lower in the canopy where humidity is higher. Late blight lesions, unlike those of early blight (figure 3), will grow through leaf veins;

Figure 1. Late blight lesion on a potato leaf has a dark-brown area bordered by a light green to yellow halo. *Photo by Philip B. Hamm*

Figure 2. White mycelium containing spores develops on the underside of a potato leaf infected with late blight. *Photo by Philip B. Hamm*

Figure 3. Early blight lesions on a potato leaf do not cross major veins in the leaf. *Photo by Phillip Nolte*

Figure 4. Black-purplish late blight stem lesion on a potato plant. *Photo by Philip B. Hamm*

hence, the generally circular or half-circle shape in contrast with the angular-shaped early blight lesions. Actively growing late blight lesions have a water-soaked appearance and are gray-green in color; older lesions are usually dry, brown, and brittle.

Late blight symptoms can appear on stems, leaves, or both. Stem infections appear as black-purplish lesions covered with mycelium that appears as a light, white-colored coating (figure 4). Sporangia identified through microscopic examination will confirm a late blight infection (figure 5). In most areas of the Pacific Northwest, the stem area where a late blight lesion is located is particularly brittle so the stem breaks easily at the infected site. However, in areas of high humidity and/or rainfall, the stem may not be brittle. Ultimately, a lesion will girdle a stem, producing plant symptoms that appear at first glance similar to Rhizoctonia stem canker; however, late blight is generally found higher on the stem. Frequently, aerial black leg will develop in late blight stem lesions.

In many areas of the Pacific Northwest, plants can have significant numbers of stem lesions with few leaf infections, a situation seldom seen in late blight epidemics prior to the 1990s. In areas with high humidity and/or rainfall, leaf lesions are more common and easily seen, along with varying levels of stem lesions.

Tuber symptoms

Late blight tuber infections occur in the field, but may not be visible until approximately three weeks after tubers are placed in storage, and symptoms can continue to appear throughout the storage season. At first, the infected portion of a tuber is dry and firm with a coppery-brown discoloration of the flesh just under the skin (figure 6). Tubers infected with late blight will form irregular sunken patches that stay firm. Under dry conditions, tubers may shrink inward, but remain firm. If the relative humidity is high or if there is free water on the tuber, the whole tuber decays from other tuber-rotting organisms that invade the tuber through the late blight infection sites.

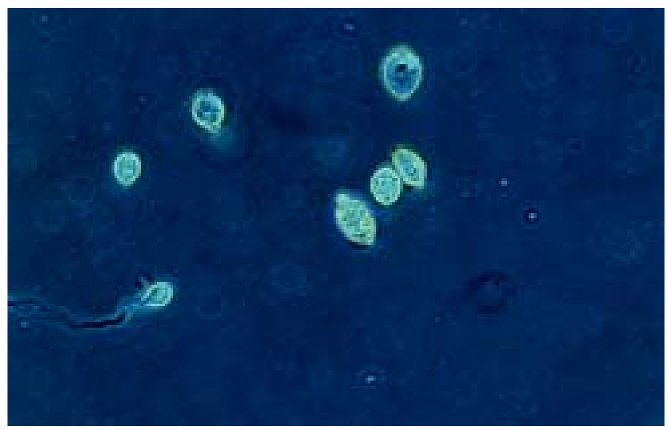


Figure 5. Late blight can be positively identified by using a microscope to observe the presence of sporangia. *Photo by Philip B. Hamm*

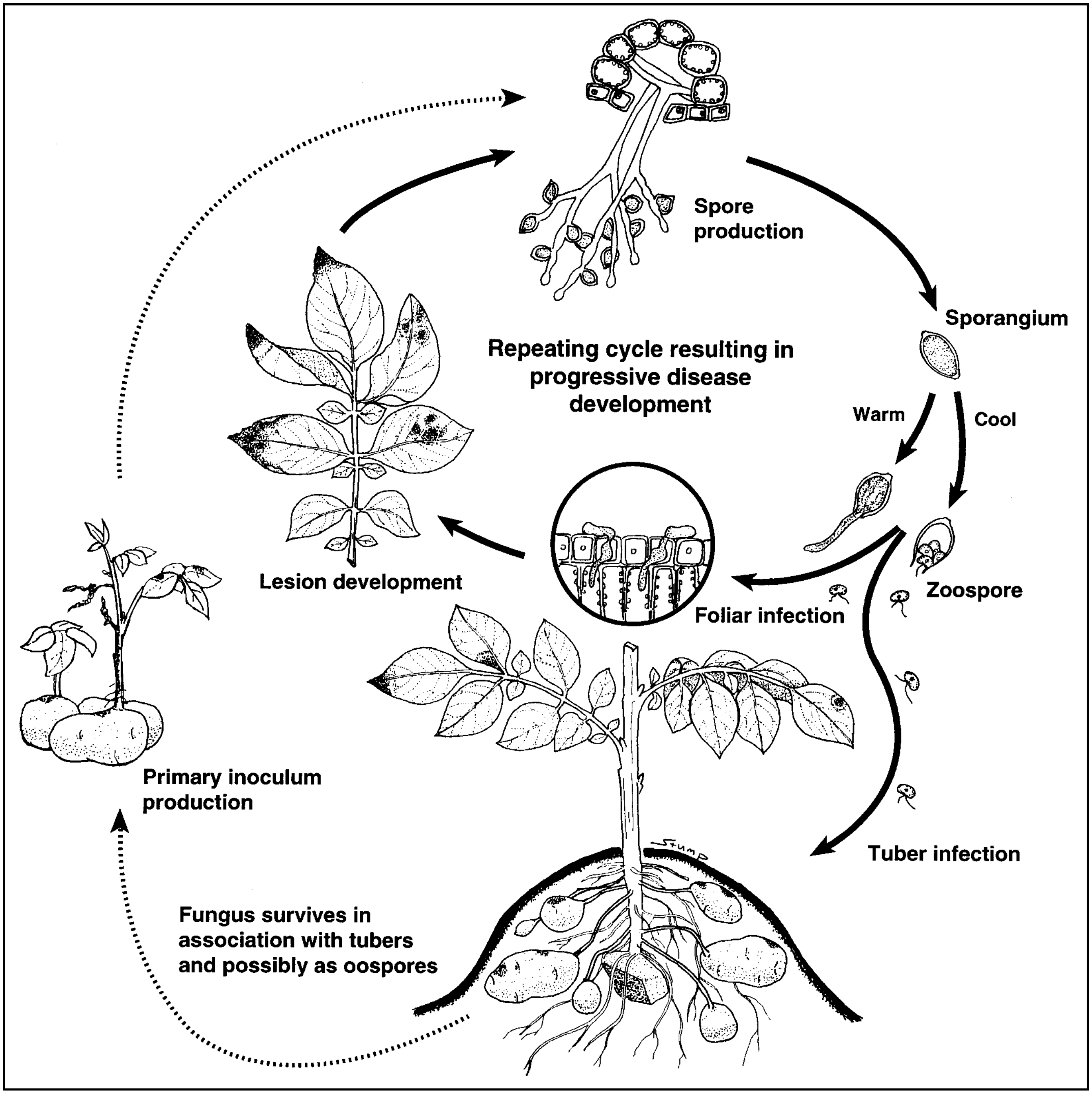
Figure 6. When first infected, late blight-infected tubers will show a coppery-brown discoloration just under the tuber skin. *Photo by Philip B. Hamm*

BIOLOGY OF LATE BLIGHT

Free moisture on the foliage and an air temperature of 45° to 79°F are required for the late blight organism, *Phytophthora infestans*, to infect a potato plant. Late blight occurrence since 1974 has been during years with a higher than normal number of rainy days just prior to or during the growing season.

The late blight organism produces three different spore types: sporangia, zoospores, and oospores, each having a specific purpose (figure 7). Sporangia are produced on microscopic stalks that are mostly found in lesions on the undersides of infected leaves or on stems. Sporangia are thin-walled spores that can easily dry out. Sporangia

Figure 7. Late blight disease cycle. The organism survives in infected tubers and volunteer plants. Spores are only produced on the surface of living host plant tissue. Disease progression is influenced by many factors, including host susceptibility, fungicide use, and environmental conditions. Cool, wet conditions favor disease progression. Simultaneous plant infection by the A1 and A2 mating types may result in sexual spore (oospore) production and soil survival. *Prepared by G. D. Franc and W. L. Stump. Reprinted by permission from G. D. Franc, University of Wyoming.*



serve a dual role in the disease cycle of late blight. In one, these spores can be carried by wind and water—sometimes over long distances—from an infected plant to a noninfected one. Recent research has shown sporangia to be easily killed by ultraviolet light, so the most effective movement of sporangia occurs by wind on cloudy days or at night. The production of sporangia is so vigorous that movement of sporangia via air can infect even isolated potato fields. Depending on environmental conditions, sporangia could move 20 to 30 miles, and with heavy cloud cover and a high amount of moisture in the air, they may move even farther.

When these spores contact a susceptible host, they can begin growing and/or germinating within as little as 2 hours and infect the host if the plant surface remains wet. Within 5 to 7 days, depending on temperature (optimum is about 60° to 70°F), visible lesions develop from these infections. New sporangia are continually produced as long as humidity is high and the lesions are viable. Sporangia dislodged from leaf or stem lesions by changes in humidity, by wind, by irrigation water, or by rainfall can move downward in the crop canopy causing new infections on stems or leaves. Sporangia can also fall onto the soil, increasing the risk of tuber infections, or land directly on exposed tubers, causing infections.

The second role sporangia can serve is in the production of zoospores. Zoospores are mobile spores that actually swim in water and locate host plants by following a gradient of naturally produced chemicals leaching from susceptible plants. Sporangia can produce zoospores when environmental conditions are favorable, particularly late in the growing season when air temperatures are cool and soils are moist. One sporangium may produce six or more zoospores; however, zoospores are very susceptible to drying. Zoospores swim in leaf moisture to cause new foliar infections or swim in soil water to cause tuber infections.

Late blight-infected tubers will decay in the soil, but if infected tubers are harvested before they are completely decayed, late blight can survive in tubers in storage. Late blight-infected tubers, which can produce spores and infect growing potato plants, should not be allowed to collect in cull or tare dirt piles when removing potatoes from storage for shipment. Tubers infected with late blight can cause severe storage problems. However, spore production and secondary infection usually is not a problem in storages where good management practices are used.

The last type of spore, an oospore, is the result of sexual reproduction. Late blight is a heterothallic pathogen. That is, sexual recombination takes two mating types, A1 and A2, growing together in a host plant to form oospores. These spores possess a thick wall that enables the pathogen to survive adverse environmental conditions. Research indicates that oospores can survive at least 12 months in soil without a host. Oospores germinate based on temperature, moisture, and the presence of naturally occurring chemicals from a susceptible host. Although oospores can be part of the late blight disease cycle, their frequency of occurrence in the Pacific Northwest is not known and could vary from season to season.

There are at least two reports of both mating types being found in the same area and producing new strains. One, from the Columbia Basin in Oregon, documents the possible production of oospores from a mating between US-7 and US-6, producing US-11. Interestingly, although US-7 is one of the likely parents of US-11, US-7 is no longer found in potato-production areas. Fear that sexual recombination could lead to new strains has apparently come true.

INTEGRATED PEST MANAGEMENT STRATEGIES

Using integrated pest management (IPM) effectively requires an understanding of all issues related to late blight and involves implementing several individual management practices. Relying on one control method, such as chemical control, will not work as successfully as an IPM approach. Late blight affects the entire industry and requires the cooperation of everyone to reduce losses; thus, adoption of IPM strategies regionwide is important.

Between-season management considerations

Plant pathologists coined the term "primary inoculum" for the spores that start an epidemic. Controlling inoculum sources that can survive from one growing season to the next is extremely important. The disease organism can survive in infected seed tubers, in tubers and pieces of tubers in cull potato piles, and in tubers left in the field that produce volunteer potato plants the following season. Weeds such as nightshade can also serve as a "bridge" from one of these sources to an emerging potato crop.

Dispose of cull potatoes and potato waste properly.

Cull potatoes and potato waste are likely sources of primary late blight inoculum (and many other diseases as well) and therefore must be rendered nonviable. Culls and waste material include potatoes remaining after filling a storage facility or removing potatoes from it and potato pieces and soil containing potato pieces remaining from seed cutting operations. Potato waste and cull potatoes coming out of storage in late winter or early spring are especially threatening sources of late blight inoculum because infected tubers or tuber pieces have been protected from freezing temperatures and are viable.

There are several methods of rendering cull potatoes and potato waste nonviable. If freezing temperatures are anticipated, cull and waste material may be spread in a thin layer on fields not intended for potato production the next year and allowed to freeze. Large cull potatoes may need to be macerated in a wood chipper or snow blower or smashed with heavy equipment before spreading. If freezing is not an option, then cull and waste material must be destroyed by some other method such as complete chopping or burying. Check with local officials for acceptable disposal methods.

Nontreated cull potatoes could be fed to livestock, but precautions must be taken to prevent the culls from sprouting or establishing volunteer plants. Truckloads of cull potatoes should be covered during transport, dumped only in specified areas, stored only on impervious surfaces, and fed or ensiled before the current-season potato crop emerges.

Plant certified seed potatoes.

Purchase and plant only certified seed from a supplier with whom you are familiar, or ask the supplier specific questions and/or visit the supplier's field during the growing season to determine the occurrence of late blight in the area the year the seed was grown. The occurrence of late blight in a region does not mean seed tubers will be infected, nor does the lack of reported late blight ensure that late blight will not be present in seed tubers. However, the occurrence of late blight in a seed-production area does increase the risk of having infected seed tubers. If you are concerned about the possibility of having late blight in your seed, use a seed piece treatment labeled for controlling late blight to prevent spreading late blight from one seed piece to another.

Before purchasing seed, visit the seed storage facility to look for signs of tuber decay that could suggest the presence of late blight-infected tubers. Tubers suspected of having late blight should be sent to a qualified laboratory for disease confirmation. Field inspection and shipping-point inspection reports should always be checked for information about late blight.

Eliminate volunteer potato plants.

Volunteer potato plants could be a significant source of late blight inoculum. Volunteer potatoes are found in many rotation crops such as wheat, corn, or onions. These crops do not receive applications of late blight fungicides so the opportunity for late blight to develop on the volunteers and spread to potato fields goes unchecked.

Volunteers may be especially numerous in areas where the soil temperature at 4 to 6 inches deep was not less than 28°F for any period of time during the winter. Surveys have shown that following a relatively mild winter, more potato plants grew in some rotation crops as volunteers than grew in the same fields as a planted crop the previous year (figure 8). To minimize over-winter survival of potato tubers left in a field following harvest, use shallow cultivation in the fall to increase the likelihood of exposing them to freezing temperatures. If you decide not to harvest a section of a field because of the presence of late blight, be sure at least to lift the tubers to the surface in the fall.

In the spring, control emerging volunteer potato plants as quickly as possible. Because neither cultivation nor herbicides are 100 percent effective in controlling volunteers, a combination will likely need to be used. Products for use in rotation crops that will suppress or control volunteer potatoes are continually being tested so check with a qualified specialist for the latest information on registered herbicides.

Control weeds.

Nightshade can become infected with late blight; consequently, it is important to control nightshade plants along field borders early in the spring before the current-season potato crop emerges.

Current-season management considerations

Select field planting sites carefully.

Late blight is favored by moisture on plants, so it is advisable not to plant potatoes under the first half tower of a center pivot irrigation system, in low areas in fields where water accumulates, or where water from two adjacent center pivot systems may overlap. If fungicides will be applied by aircraft, avoid planting potatoes in places that are not easily sprayed such as under trees or power lines or near buildings.

Plant at the correct depth.

Recent research has confirmed that potato tubers that form closer to the surface are more likely to be infected with late blight spores originating from infected aboveground plant parts. Consequently, one suggestion for controlling tuber infection has been to plant seed pieces deep to produce a soil barrier. Although deep planting will increase tuber depth, planting deeper than 6 inches has also been shown to negatively impact yield. Therefore, tubers should not be planted deeper than 6 inches.

Scout fields for late blight.

Scout each potato field for late blight at least twice each week beginning when plants are about 5 inches tall. Scout fields more frequently when late blight-prediction models indicate a high risk of late blight or weather conditions are more favorable for late blight development. Plants with symptoms suspected to be late blight should be collected and diagnosed immediately.

Submit an entire plant to a qualified laboratory for accurate identification. Transport each plant in a plastic bag out of the sun, and do not add moisture to the sample. Commercial late blight detection kits are available, but to get accurate results you need first to gain experience by working with a person who has previously used the kits. Early diagnosis is helpful in managing late blight in a geographical area and provides valuable information to other growers.

Concentrate scouting in areas that are usually wet, including low spots, and areas that are shaded or protected from wind. Pay special attention to areas where an irrigation system drains or a leak results in water accumulation (figure 9). Additional areas to intensely scout include near the center of a pivot irrigation system, along irrigation system wheel tracks, and at pipe joints of set-and-move or solid-set irrigation systems. Also, examine places where it is difficult to apply fungicides such as under power lines or trees and close to buildings. Pay special attention to fields planted to more susceptible varieties (see section on variety susceptibility).

Schedule irrigations to minimize periods of wetness.

Extended wet periods favor late blight infection, so schedule irrigations to minimize the length of time of “wetness” on plants, and avoid irrigating during rainy, cool, or cloudy weather. Heavy, less frequent irrigation applications are better than light, frequent ones. Minimize the period of plant wetness by scheduling water applications so the foliage has a chance to dry between irrigations and before cool evening temperatures result in dew formation.

Center pivot or lateral-move systems wet the crop canopy for only a short time, so generally there is ample time for the plants to dry during daylight hours. However, irrigating with these systems during late evening or early morning likely will result in wet plant conditions for an extended time period, particularly when dew occurs. Also, plants under the innermost section of a center pivot seldom have adequate time to dry between irrigations because of the difficulty of not being able to use small enough nozzles and the short distance this section travels. Solutions are to leave this area unplanted or to modify the system to allow irrigating the innermost section every other time.

Set-and-move, solid-set, and wheel line systems pose other challenges. Operate these systems just long enough to refill the rooting zone. Leaking pipes provide ideal conditions for late blight and should be replaced or repaired immediately. Place portable mainlines for these systems in a location that prevents possible leaking water from flowing into the potato field.

Irrigation timing, frequency, and duration not only affect the chances of aboveground infection of potato plants but also influence the likelihood of tuber infection. Tubers in the soil may become infected by sporangia and/or zoospores washed by irrigation water from infected plants. Sporangia in soil, particularly later in the season with cool temperatures and proper moisture, can release zoospores that swim and follow a naturally produced chemical gradient coming from potato plants.

As plants begin using less water later in the season, match the amount of water applied to the amount the plants are using. To determine if you are applying too much water, look for enlarged lenticels on tubers. Their presence indicates higher than needed soil moisture. Excessive late-season water applications, coupled with dew formation and a potentially reduced frequency or complete elimination of fungicide applications, may be responsible for many tuber infections.

Harvest and storage management considerations

If a field has been diagnosed with late blight foliage infection, there are several management practices you should consider to reduce tuber infection.

Manage vines before harvest.

Late blight spores can be produced as long as potato foliage is green. When potato plants die, late blight spores are no longer produced. Before digging tubers, be sure the vines are completely dead for 2 to 3 weeks. (See, however, the last paragraph in this section discussing vine management in the Columbia Basin.) This interval minimizes the chances of tubers becoming infected from late blight-infected vines and allows any late blight-infected tubers to rot in the soil. Research indicates that no single vine-killing method—chemical, mechanical, or natural vine death—is better than another.

It is especially important that stems are completely dead in fields with a high incidence of late blight stem lesions. Continue fungicide applications until all plant material is completely dead. Applying fungicides until vines are completely dead will help minimize late blight tuber infection during harvest. Remember to follow label directions, especially instructions on the total amount of any fungicide that may be applied during one season and the preharvest application intervals.

Research has demonstrated that chemical defoliation of potato vines in the Columbia Basin does not necessarily reduce late blight tuber rot when the crop is watered properly, severity of foliar late blight is less than 10 percent, and fungicide applications are continued until harvest. Fungicides that inhibit spore production applied after the tuber-bulking period may be effective against late blight tuber infections. Vine killing is still recommended in fields or sections of fields where the crop has been overwatered by irrigation or by excessive rainfall or where late blight severity exceeded 10 percent. Weather and soil conditions in Idaho and other potato-growing areas in the Pacific Northwest differ from those in the Columbia Basin so fields in these areas should be vine-killed until research indicates otherwise.

Harvest during the right conditions.

Avoid harvesting when free moisture is present on foliage or tubers or before skins are mature. Do not harvest in the rain if the tubers are going into storage. Even in dry weather, areas of fields that are severely infected with late blight should be identified and marked before vines are killed or completely die. Tubers from severely infected areas should be positioned near a storage door so they can be removed early if necessary. Avoid harvesting tubers with pulp temperatures over 65°F because organisms that rot tubers, including late blight, are more active at higher temperatures.

While filling a storage, remove as many "wet-decayed" tubers as possible. Also, try to eliminate all foreign material (dirt and debris) to aid in air circulation in the storage pile. Although the late blight organism does not need a wound to infect, tubers that are cut, skinned, or shatter-bruised are more likely to become infected because damaged areas on tubers remain wet for an extended period. Therefore, minimize tuber damage whenever possible.

Base storage decisions on the level of late blight.

Do not store tubers from fields with more than 3 percent of the tubers infected with late blight. Fields with extensive foliage late blight infection need to be closely examined for tuber infection. However, even fields with little foliar infection can have infected tubers. If you do store tubers from fields with more than 3 percent of the tubers infected with late blight, monitor storage temperature and humidity daily and maintain storage conditions that are unfavorable for late blight.

Some of the factors that contribute to tuber infection are not fully understood; consequently, tubers may develop late blight symptoms in storage even when little or no late blight was observed in the field. Although it is believed that late blight does not readily spread in storage, bacterial soft rot can invade decaying tubers and form localized rotting spots, causing complete loss of the potatoes.

Carefully manage stored potatoes.

It is impossible to remove all rotted tubers while placing them into storage, but removing as many as possible will reduce the risk associated with decaying tubers. Tubers should be dry when placed into storage. Initially, it may be necessary and prudent to continually run the ventilation system with reduced humidity, but for no longer than required to completely dry tuber surfaces. Expect shrink losses and pressure bruise to be higher than normal when running a ventilation system with reduced humidity.

Remove tubers suspected of having late blight as soon as possible. If harvested tubers had a pulp temperature above 55°F, use refrigerated air, if available, to rapidly cool these tubers to the desired wound healing temperature of 50° to 55°F. When tuber pulp temperature is less than 50°F, do not bring in outside air that has high relative humidity and is warmer than the tuber pulp temperature because this may result in water condensing on tubers. It will still be necessary to supply intermittent ventilation air for at least one hour per day to these cool tubers, but the pile will naturally warm to the wound-healing temperature due to heat given off during tuber respiration. After wound healing is completed, reduce pile temperature to the desired holding temperature.

It is especially important to continually monitor the storage facility for any disease development. Tubers that do not show late blight symptoms during storage may develop symptoms during reconditioning or while in transit if they are shipped at ambient air temperatures that encourage late blight development (45°-79°F).

CHEMICAL CONTROL IN IPM

Part of an integrated pest management program for controlling late blight on potatoes is using chemical controls at the proper time, rate, and frequency.

Seed piece treatments

Although research has shown that most late blight-infected seed pieces will decay before producing a plant, it is still possible for an infected plant to develop from an infected or contaminated seed piece. Few infected plants are needed to begin an epidemic, particularly with favorable weather conditions. Also, late blight spores can spread from infected seed pieces to healthy ones during cutting and handling.

To help protect healthy seed pieces, use a seed piece treatment labeled for controlling late blight. Although seed piece treatments labeled for controlling late blight do not kill late blight spores, they will minimize the infection of healthy seed pieces. Keep in mind, however, that you should not try to "rescue" a badly infected seed lot with a seed piece treatment. Rather, purchase noninfected seed. If you find later that late blight is present in the seed lot, use a seed piece treatment labeled for late blight, try to plant that seed in a separate field, and begin a regular late blight fungicide spray program shortly after plants emerge.

Fungicides for use in the field

An integrated late blight disease management program must include protecting plants with approved fungicides. Most fungicides used for controlling late blight are considered to be "protectants" only; they do not kill the late blight organism. For that reason, protectant fungicides must be applied before the disease is present. Chemicals recommended for late blight control continue to be developed so check with your local university or crop consultant for the latest recommendations. For a list of materials that are currently available for managing late blight, go to your state's department of agriculture web site.

Regardless of the chemical applied, use the following general guidelines to get the most benefit.

Get complete crop coverage.

It is critical to completely cover the potato foliage with a fungicide prior to plants being exposed to late blight. Fungicides applied with a ground applicator generally protect the entire canopy at application time, whereas aircraft application requires some redistribution of the fungicide to get complete plant coverage.

The initial fungicide application needs to be made early in the season to protect the lower portions of the plants. In areas where late blight is prevalent, begin fungicide applications when late blight is forecasted or when plants are 5 to 8 inches tall (before plants touch within the row). In areas where late blight is less prevalent or conditions are less conducive for disease development, make the first application before plants touch across the rows and make a second application 7 to 10 days later.

Apply fungicides at the correct frequency.

After the initial applications, continue applying fungicides on a regular schedule until disease pressure no longer exists or the vines are completely dead. Applications as frequent as every five days may be required with heavy disease pressure, a susceptible potato variety, or wet weather conditions. Conversely, with light disease pressure, dry weather, or both, fungicide application frequency may be lengthened to once every 14 days.

Apply the proper amount of fungicide.

When using fungicides, always follow label directions. Be sure to apply the correct rate using the proper method at the appropriate interval. Because of the cost to apply a fungicide and the need to maintain an adequate concentration on the crop, using the highest labeled rate is generally suggested. All label directions are important, but pay particular attention to the directions concerning the pre-harvest interval and the maximum allowable amount of active ingredient that can be applied per acre per season because these two factors differ for each fungicide. Also important, regardless of application method, is making sure the correct amount of product is being applied with properly working nozzles or sprinklers.

Apply fungicide by the proper method.

Depending on the product selected, fungicides can be applied by aircraft, with a ground applicator, or through an irrigation system (chemigation). Each method has advantages and disadvantages (table 1), but all will provide satisfactory results if the correct amount of fungicide is applied at the appropriate interval.

Use each method properly.

After selecting an application method, keep these points in mind for the one you choose.

Ground Applicator: Generally, ground applicators will uniformly apply the fungicide to the crop. To avoid skips, frequently check nozzles to be certain that all are working properly. As the crop grows, it may be necessary to raise the boom height above the crop to ensure proper spray coverage.

Aircraft: Although you likely will not be flying the aircraft, you still need to be certain the fungicide is uniformly applied to the entire crop. Be sure there are no skips, which result from not having adequate overlap between passes. To minimize the potential for skips, in-

Table 1. Advantages and disadvantages of four fungicide application methods.

Application method	Advantages	Disadvantages
Ground applicator	1. No waiting for equipment if owned by the grower. 2. Uniform distribution of chemical throughout the crop canopy. 3. The best overall method for applying protectant fungicides.	1. Few acres can be covered per hour. 2. Small yield loss due to wheel traffic between rows. 3. Difficult to use with set-and-move irrigation systems. 4. Expensive.
Aircraft	1. Large acreage can be covered in a short time period. 2. Can be used with set-and-move irrigation systems. 3. No wheel traffic in the field. 4. Provides good initial coverage to the upper and middle canopy areas.	1. Fungicide is deposited primarily on top of the crop canopy. 2. Sprinkler irrigation required to redistribute chemical downward in the canopy. 3. Difficult to spray near trees, power lines, or buildings. 4. May not be able to get a field sprayed when needed due to wind, rain, or other commitments by applicator. 5. Moderately expensive.
Chemigation	1. Equipment already in place so there is no waiting; less expense. 2. Uniform application as long as the system is applying water correctly. 3. Fungicide is immediately distributed throughout the crop canopy. 4. Most expenses of labor and operation of irrigation system already calculated by grower.	1. Lower amount of fungicide is deposited on the plants. 2. Corners of center pivot systems irrigated with an end-gun may not receive adequate fungicide coverage.
Aircraft/Chemigation in rotation	1. Maintains good fungicide levels throughout canopy (better than chemigation) but at a reduced cost over using just aircraft.	1. See above disadvantages for respective application methods.

stall permanent markers in the field and have the applicator alternate spraying between the markers and on the markers for successive applications. If possible, you could also alternate spray applications between an east-west direction and a north-south direction. Additionally, skips can be avoided if the aircraft uses a correctly calibrated global positioning system (figure 10).

Applying more than 5 gallons water per acre provides no additional disease-control benefit. Be sure the aircraft operator considers distance to the canopy, droplet size, humidity, wind speed, and temperature when spraying because all these can affect the quality of application.

Although aircraft applications leave most of the chemical on top of the canopy, research has shown that water from rain or irrigations will redistribute the material down into the canopy. How much redistribution occurs primarily depends on the amount of water. In the Columbia Basin, where it is common to apply about 1/2 inch of irrigation water every 36 hours, fungicides applied to the top of the canopy are sufficiently moved downward to maintain adequate product levels in the lower canopy if chemical applications by aircraft are made weekly. In areas with lower amounts of water being applied, fungicides would move downward more slowly.

Chemigation: Applying fungicides through an irrigation system provides thorough and complete coverage of the crop, but much of the product is washed off the canopy because of the high volume of water used during irrigation. Even a center pivot system applying as little as 1/10 inch of water per application will put on approximately 2,750 gallons of water per acre. In view of that, the frequency of fungicide application should be based upon the frequency of irrigation. If you irrigate once or twice per week, you may need to apply a fungicide less often than if you irrigate three or more times per week.

All potatoes must be within the area covered by the sprinkler system and water must be evenly distributed so proper nozzle maintenance is essential. The area irrigated by an end-gun of a center pivot irrigation system needs special attention because this area usually does not receive adequate coverage. Do not plant potatoes in this area, or, if you do, spray the potatoes with a ground applicator. If spraying with a ground applicator, be sure not to apply more than the allowable amount of fungicide to the corner areas. Where wheel lines, solid-set, or set-and-move irrigation systems are used, inject fungicides near the end of the irrigation cycle to reduce fungicide wash-off.

Aircraft/Chemigation Rotation: Research has shown that aircraft application rotated with chemigation is very effective in maintaining fungicide levels in the canopy while reducing costs. When alternating methods, apply a fungicide first by aircraft then by chemigation a week later. This research indicated that alternating application methods was not as effective when the first application was chemigation.

Use a late blight forecasting system.

Forecasting systems help identify specific weather conditions that favor late blight development and enable growers to protect plants by applying a fungicide before late blight is found in a field. The Columbia Basin late blight forecasting model predicts the likelihood of a late blight threat in the Columbia Basin and roughly allows for determining when fungicide applications should be initiated in central Washington and Oregon. Unfortunately, reliable forecasting systems have not yet been developed for all regions in the Pacific Northwest, but research is being conducted to develop them. Check with your state's land-grant university to determine if a reliable forecasting system is available for your use.

VARIETY SUSCEPTIBILITY

Potato varieties differ in their susceptibility to late blight. Late blight will develop more slowly in some varieties compared with others. A large number of late blight spores can build up on a susceptible variety and spread to a field planted to a less susceptible variety and overcome resistance. Remember, late blight is a community disease; it can rapidly spread from field to field.

Table 2 shows the relative susceptibility of several varieties to foliar late blight. Additionally, Russet Norkotah, Shepody, Ranger Russet, and Bannock Russet are very susceptible to late blight tuber rot so it is important to take precautions during harvesting and storage to minimize tuber infections (see "Harvest and Storage Management Considerations").

The ultimate goal in late blight control is the development and use of resistant varieties. However, developing a new variety takes 12 to 15 years or more, and the variety must have acceptable processing and/or fresh market characteristics. Transgenic methods may enable these characteristics to be combined in a single variety more quickly than traditional variety development methods, but whether transgenic methods will be accepted in the future is unknown.

Table 2. Relative susceptibility of several potato varieties to foliar late blight.

Moderately susceptible	Susceptible	Highly susceptible
Bannock Russet	Atlantic	Frontier Russet
Chipeta	Shepody	Gemchip
Gem Russet		Goldrush
Ranger Russet		Hilite
Russet Burbank		Norchip
Umatilla Russet		Red LaSoda
White Rose		Russet Norkotah
		Superior

Figure 8. A corn field heavily infested with volunteer potatoes, a possible source of late blight. *Photo by Robert E. Thornton*

Figure 9. Late blight may first develop in areas where water accumulates from leaks in an irrigation system. Look in these areas for early late blight infections. *Photo by William H. Bohl*

Figure 10. An airplane applying a fungicide. Regardless of application method, make certain skips do not occur. *Photo by Philip B. Hamm*

GLOSSARY

Aggressive—Used to describe the potential of a late blight genotype (strain) to cause damage to potato. Aggressive genotypes produce more sporangia (spores), cause larger leaf and stem lesions, and may also have a shorter latent period.

Asexual—Reproducing or producing spores (sporangia and zoospores) without mating (without sex).

Genotype—A population of the late blight organism with similar traits. Late blight genotypes found in the United States are designated using the letters "US" followed by a number, such as US-8 (the 8 refers to the eighth unique genotype identified in the United States).

Inoculum—Structures of the late blight organism capable of infecting plants.

Latent period—The period of time from when a late blight spore(s) infects a plant to when new spores are produced.

Lesion—Area on a leaf, stem, or tuber showing symptoms of late blight.

Mating type—Term used to distinguish the "sexes" of late blight. Mating type is used rather than male and female because the two mating types are indistinguishable outside the laboratory. Both types, referred to as A1 and A2, must be present and growing together in the same plant for the late blight organism to sexually reproduce and form oospores.

Oospore—A thick-walled structure produced from the sexual mating of A1 and A2 mating types and capable of surviving unfavorable environmental conditions outside a living host.

Spore—A structure containing one or more cells capable of reproducing, germinating, and causing infection.

Sporangia—Asexual reproductive structures of the late blight organism that can germinate directly or germinate indirectly by producing zoospores. Sporangia can be moved in air or water, spreading the disease (see also zoospores).

Strain—see genotype

Zoospores—Spores produced inside a sporangium (plural, sporangia) that have limited locomotive (swimming) ability in water and are capable of infecting a susceptible host. Zoospores can be carried in water for great distances and can follow naturally occurring chemical gradients originating from a susceptible host and cause infection.

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Using Pesticides

Pesticide Residues—Any recommendations for use are based on currently available labels for each pesticide listed. If followed carefully, residues should not exceed the established tolerances. To avoid excessive residues, follow label directions carefully with respect to rate, number of applications, and minimum interval between application and reentry or harvest.

Groundwater—To protect groundwater, when there is a choice of pesticides, the applicator should use the product least likely to leach.

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