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MICHIGAN Potato Diseases

Late Blight

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Late Blight
Phytophthora infestans (Mont) De Bary
(Oomycetes, Pythiales)

Introduction
Late blight of potato, caused by the water mold *Phytophthora infestans*, has the potential to be a very destructive disease of potato in Michigan. The pathogen favors wet weather with moderate temperatures (60 to 80 °F), high humidity and frequent rainfall. Under such conditions, the disease can spread extremely rapidly and has the potential to completely defoliate fields within 3 weeks of the first visible infections if no control measures are taken. In addition to attacking foliage, *P. infestans* can infect tubers at any stage of development before or after harvest. Soft rot of tubers often occurs in storage following tuber infections.

Symptoms
The first symptoms of late blight in the field are small, dark, circular to irregularly shaped lesions, which appear 3 to 5 days after infection (Fig. 1). These usually appear first on the lower leaves, where the microclimate is more humid. However, they may occur on upper leaves if weather conditions are favorable and the pathogen has been carried into the field by air currents. Lesions often begin to develop on the compound leaf near the point of attachment to the petiole (which is often cupped) or at the leaf edges, where dew is retained longest. During cool, moist weather, lesions expand rapidly into large, dark brown or black spots, often surrounded by a pale green to yellow border (Fig. 2). Lesions are not limited by leaf veins, and if formed at leaf tips or edges, they can cause young expanding leaves to be misshapen. As new infections occur and existing lesions coalesce, entire leaves may become blighted and killed within a few days (Fig. 3). On stems, lesions are often initiated at the point of attachment to the stem, and leaves become detached shortly after infection (Fig. 4). The lesions continue to develop along the length of the stem and can remain active even in hot, dry weather.

In the early morning or during cool, damp weather, a white, velvety growth may be seen on infected leaves

Figure 1. Small, dark, circular to irregularly shaped lesions appear on leaves 3 to 5 days after infection.

Figure 2. Lesions expand rapidly in cool, moist weather into brown to black spots that are often surrounded by a green border.

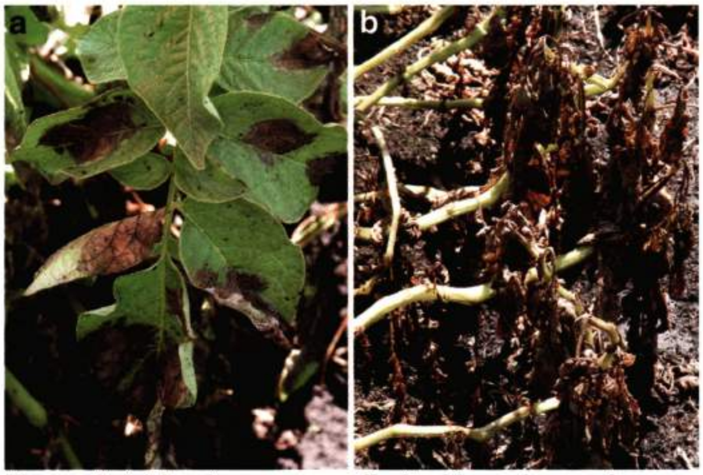

Figure 3. (a) Lesions are not limited by veins and expand rapidly. (b) Entire leaves may become blighted within days of the intial infection.

and stems (Fig. 5). This white, velvety growth distinguishes late blight from several other foliar diseases of potato. Plants severely affected by late blight also have a distinctive odor resulting from the rapid breakdown of potato tissue. This odor is similar to that produced by chemical vine-kill or occurring after severe frost.

Late blight infection of tubers is characterized by irregularly shaped, slightly depressed brown to purplish areas on the skin. These symptoms may be less obvious on russet and red-skinned cultivars. A tan to reddish brown, dry, granular rot is found under the skin in the discolored area, extending into the tuber usually less than 1/2 inch (Fig. 6). The extent of rotting in a tuber depends on the susceptibility of the cultivar, temperature and length of time after the initial infection. The margin of diseased tissue is not distinct and is marked by brown finger-like extensions into the healthy tissue of the tuber. In time, the entire tuber becomes blighted and discolored. Late blight rot of tubers is often accompanied by soft rot.

Positive identification of late blight can be made by microscopic examination of lesions from infected leaves or tubers collected when the fungus is producing spores (Fig. 7). The water mold can be quickly identified by the distinctive size and shape of the spores and spore-bearing stalks.

Disease cycle

Phytophthora infestans, the causal agent of late blight, is not a true fungus but a water mold belonging to the phylum Oomycetes. Oomycetes such as *P. infestans* form large, clear, lemon-shaped spores called sporangia on stalks called sporangiophores (Fig. 7).

Figure 4. (a) Stem lesions often start where leaves attach to the stem and spread along the stem (arrows). (b) Leaves may become detached shortly after infection.

Though they are relatively large in comparison to those of true fungi, they cannot be seen without the aid of a microscope that can magnify at least 100 times. The sporangiophores have distinct periodic swellings at points where sporangia were produced.

Sporangia may germinate at temperatures between 44 and 55°F when free water is present on leaves and form 8 to 12 motile zoospores per sporangium (Figs. 7, 8). These swim freely in water films, attach to the leaf surface (encyst) and infect the plant. Encysted zoospores infect leaves by penetrating the leaf surface with a germ tube, either through stomata (breathing pores) or by means of direct penetration (Fig. 8). At temperatures of 55 to 70°F, sporangia germinate by means of a single germ tube. Night temperatures of 50 to 60°F accompanied by light rain, fog or heavy dew and followed by days of 60 to 75°F with high relative humidity are ideal for late blight infection and development.

Tubers may become infected if sporangia produced on the foliage are washed down into the soil by rain or irrigation water. Water-borne spores appear to follow stems and stolons in a water film into the soil, reach tubers and cause infection (Fig. 8). Tubers near the soil surface are thus more likely to be infected. *Phytophthora infestans* can survive only in living potato tissue. It usually survives from year to year in infected tubers placed in storage, in piles of cull potatoes or in infected tubers missed during harvest that remain unfrozen over the winter (volunteer potatoes). In the spring, the pathogen can be transmitted from infected tubers in cull piles or volunteers to potato foliage by airborne spores. Infected

Figure 5. (a) A white, velvety growth (arrows) may be seen on the undersides of leaves in the early morning. (b, c) It may also occur on the surface of leaves and stems during cool, damp weather.

seed potatoes are also an important source of disease. Some infected tubers may rot in the soil before emergence, and not every plant that emerges from an infected tuber will contract late blight. Sporangia of *Phytophthora infestans* may be spread from infected plants in one field to healthy plants in surrounding fields by wind, splashed rain, mechanical transport and animals, thereby continuing the disease cycle. The fact that many reproductive cycles are possible within a season accounts for the rapid increase in disease once it becomes established in a field.

Four genotypes of *P. infestans* are known to occur in the United States: US-1, US-6, US-7, US-8 and US-14. Before 1993, only the US-1 genotype had been found in Michigan. The US-1 genotype is mating type A1. *Phytophthora infestans* requires two mating types, A1 and A2, to come into contact to produce a sexual spore known as an oospore. Oospores are resistant to freezing and other environmental extremes and can survive in diseased leaves and stems or free in soil. When only one of the mating types is present, the fungus can survive over winter only as vegetative mycelium in infected tubers. If infected tubers freeze and die over winter, or if they are buried deeply enough in soil to sprout, the disease cycle is broken, and very often the disease does not appear even when the weather conditions are favorable. With the arrival in Michigan of the US-7, US-8 and US-14 genotypes which are A2 mating types, the potential exists for the production of resistant overwintering oospores that can survive in dead leaves or free in the soil. It has not yet been proven that oospores are important in the disease cycle, but the possibility exists. If the pathogen does start to produce overwintering oospores, it may be able to overwinter more easily and may become a factor in

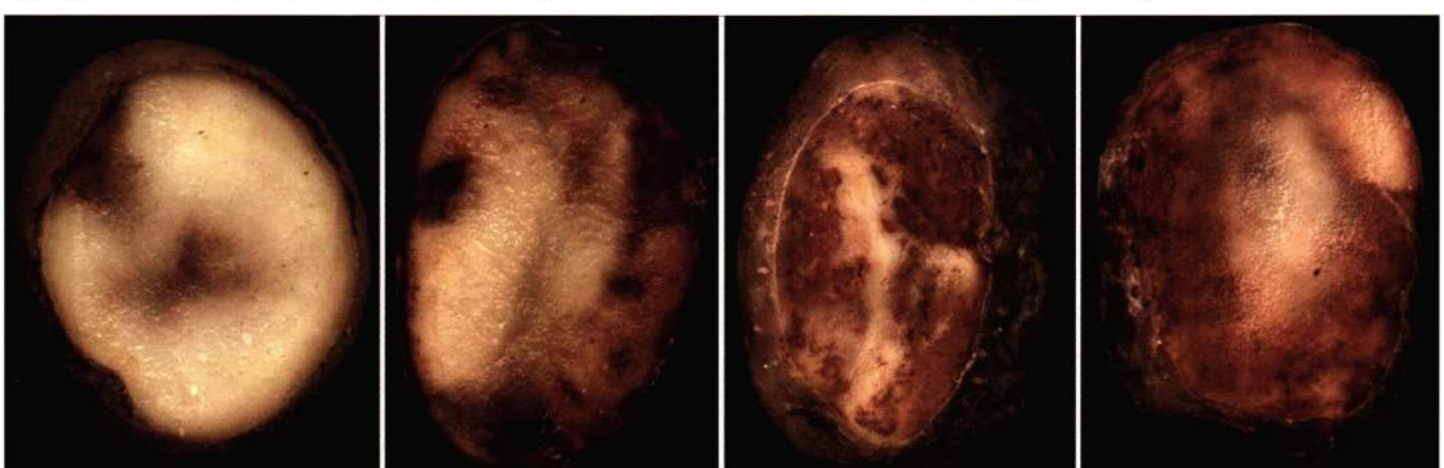

Figure 6. Tuber late blight symptoms, characterized by discoloration of the potato skin and a tan to reddish brown, dry, granular rot underneath the discolored skin.

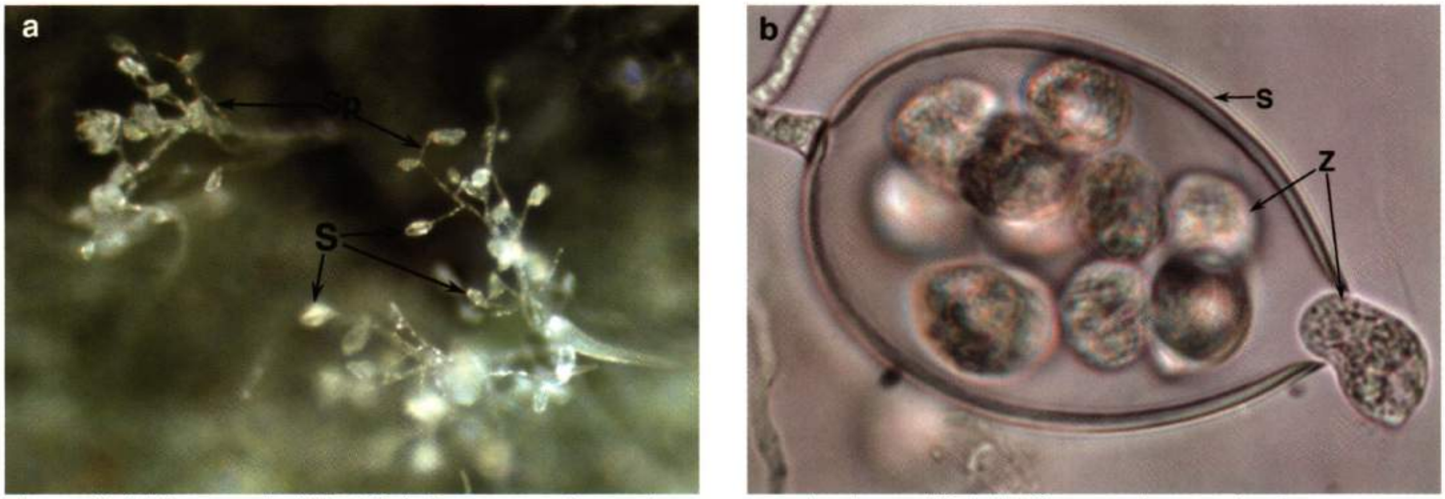

Figure 7. (a) Sporangia (S) of *P. infestans* are formed on sporangiophores (Sp). (b) Sporangia germinate, producing 8 to 12 zoospores (Z), which are released through a pore at the front of the sporangium.

virtually every growing season when conditions favor the development of late blight.

Monitoring and control

Effective management of this disease requires implementation of an integrated disease management approach. Although the most important measures are cultural, resistant cultivars and chemical controls should also be utilized.

Monitoring and disease forecasting

Efforts must be made to monitor crops closely for the incidence of disease. Scouting for signs of late blight should begin as soon as green tissue emerges. When a canopy develops, look for late blight in the lower portions of the plant, where the foliage stays wet longer. Scouting efforts should also be concentrated in areas of the field most likely to have high moisture dew, or relative humidities for the greatest length of time or areas missed by fungicide applicators. Low spots where soil moisture is highest and parts of the field shaded by windbreaks are examples of areas where scouting should be intensified. Care should be taken not to spread late blight from field to field when scouting. Disposable pants and rubber boots that can be washed after leaving a field, should be worn if disease is present. Late blight inoculum can also be spread from field to field on equipment, so this should also be washed after leaving the field. As the risk of disease becomes greater, crop monitoring should be intensified. As soon as the disease is detected, interventive chemical control measures should be used.

Computer-based programs (e.g., Blightcast) are available to track weather conditions and help predict or forecast when the disease may occur. Disease forecasting programs predict when environmental conditions are most favorable for disease and recommend when fungicide applications should be applied. Disease forecasting systems express the effects of temperature and relative humidity on disease development as "severity values." Local late blight forecasts are available for many potato production areas in Michigan <www.lateblight.org>. However, accurate weather data are required for accurate disease prediction, and this is best achieved with weather monitoring machines in each field, especially if fields vary greatly in location and topography. Unless you know that the forecast information is appropriate for your fields, the forecasts should be used only as a general indication of how favorable weather has been for late blight.

Resistant cultivars

No potato cultivars are immune to late blight, and most cultivars planted in Michigan are susceptible. The MSU-bred cultivar, Jacqueline Lee (yellow-flesh table stock), and cultivar Defender (lightly russeted long type) are highly resistant to the US-8 genotype of late blight and are currently being used as a parent for the production of new chip and processing cultivars. MSU is also considering the release of MSJ461-1 (round white) as a late blight-resistant chip-processor and/or tablestock cultivar. Several moderately susceptible cultivars (e.g., Pike and some FritoLay varieties) are available and could be planted if late blight is expected to be a problem.

Cultural control

Cultural practices are the first line of defense against late blight. Before planting, growers should take

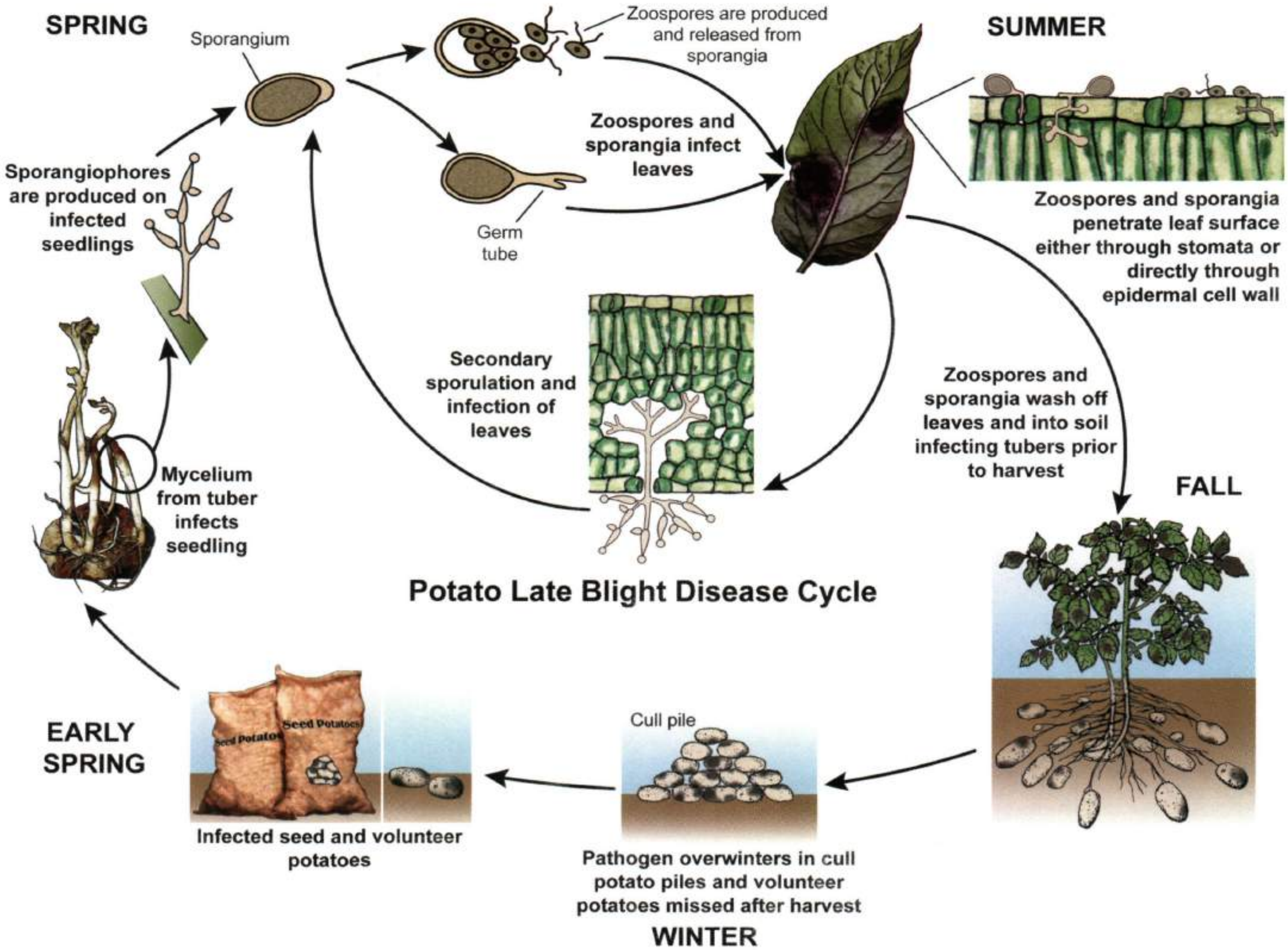

Figure 8. The disease cycle of the late blight pathogen, *P. infestans*.

several measures to control late blight.

First, it is important to eliminate sources of inoculum. The initial sources of inoculum are likely to be infected potatoes in cull piles, infected volunteer potato plants that have survived the winter and infected seed tubers. Therefore, it is important to keep a clean operation by destroying all cull and volunteer potatoes. Cull piles should be kept as small as possible because piles of about 500 hundredweight (cwt) do not freeze throughout. Piles should be covered with plastic tarpaulins to increase the temperature within the piles in the fall and accelerate breakdown. Waste potatoes can be spread onto fields in the fall at a rate of about 400 cwt/A as supplemental fertilizer. After spreading, the tubers should be pulverized and left near or on the surface of the field to allow them to freeze. Rock piles that are deposited after planting contain rocks and potato seed pieces and should also be monitored carefully throughout the growing season. Emerging plants should be killed off with glyphosate (e.g., Roundup). It is also very important to make sure that you plant only certified seed. Using seed saved from local crops may increase the risk of late blight. Seed sources should be selected carefully to avoid bringing in late blight on seed, especially new strains of the pathogen. Look for characteristic brown discoloration of the potato flesh under the skin of seed tubers. Any tubers suspected of being infected with late blight should be tested to confirm its presence. Contaminated loads of seed should be rejected.

Second, avoid conditions that favor late blight. Weather conditions strongly influence the incidence and severity of late blight. Although weather conditions are beyond control, field selection and carefully managed irrigation practices can help reduce the extent of periods favorable for disease development. Fields with good water infiltration and drainage characteristics are desirable for planting potatoes. If irrigation is used, try to apply water between midnight and 8 a.m. to avoid prolonging the length of time leaves are wet. Leaves are often wet with dew during these hours anyway, so irrigation during this period does not unduly prolong the leaf wetness period. Alternatively, apply irrigation during daylight hours, beginning after leaves have been dry for at least 2 hours and ending 2 hours before dark, so leaves have a dry period before and after irrigation. Most disease-causing spores are released into the air between 9 a.m. and 1 p.m.

After planting and early in the season, it is important to get rid of cull potatoes and potato pieces resulting from seed cutting operations or left after loading or unloading at storage facilities as these may support the production of inoculum whether or not the pieces are sprouting. It is also beneficial to control weeds and alternative late blight hosts such as hairy nightshade, which may contribute to disease spread under some conditions. Although weed species are not late blight hosts, they can contribute to conditions that favor disease development by restricting air movement within the canopy. Heavy weed infestations also prevent adequate coverage of potato foliage with fungicides. Current research also indicates that when late blight infestations are found early in small patches, it may be beneficial to disk, burn with a propane burner or spray these patches with a desiccant (e.g., Reglone or Gramoxone) to remove these local sources of inoculum. For destruction of affected areas within crops the rule is that 30 rows on each side of the newest lesions at the border of the late blight locus and 100 feet along the row (each side) should be killed. Although this sounds harsh, trials at MSU have shown that the latent period between infection and symptom development is about 7 days, and although symptoms are not visible, plants within this area are already infected.

Late in the season, it is advisable to avoid excessive irrigation because tubers become infected with late blight when spores wash down through the soil from infected leaves. Late-season fertilizer applications should also be limited. Although maintaining green vines promotes tuber bulking, green and vigorous vines can also be difficult to kill with desiccants, and immature tubers are more prone to skinning and, therefore, infection at harvest. Green vines may also harbor inoculum that can infect tubers during harvest. At the end of the season petiole nitrate levels should drop down to levels that encourage vine senescence. Vines should also be killed at least 2 weeks before harvest, especially in blight-infected fields. This interval minimizes the chance of tubers getting contaminated with late blight inoculum during harvest and allows previously infected tubers to decompose in the field. If blight is present in the field or in the vicinity of the field at harvest, it may also be beneficial to spray foliage after vine killing with labeled fungicides to kill living late blight spores on the foliage.

Finally, after harvest tubers to be stored should be dry when placed in storage, and the storage air temperature and humidity should be managed so that the tubers remain dry. Condensation of moisture on tubers, resulting from air circulating through the tubers that is warmer than the tubers, will cause any late blight present to form spores, and late blight may spread in the pile. Potatoes should be held at the lowest temperature possible consistent with their ultimate use (table stock or chipping). Most fungi do not grow much at temperatures of 38°F or lower, but some development will occur at higher temperatures.

Chemical control

Under high disease pressure situations, programs incorporating Acrobat 50WP, Curzate 60DF or Previcur should be used. In Michigan, both Headline and Amistar have provided very effective late blight control, but these products should be used in strict adherence with anti-resistance development strategies, i.e., always mix with a protectant fungicide (e.g., EBDC or chlorothalonil-based products) and never apply consecutive treatments of the same product. Consult your local advisor for appropriate rates and additional combinations. New products of note include Tanos [Group 11, duPont, 25% cymoxanil (as in Curzate) + 25% famoxadone], which should be applied at 6.0 oz/A. Do not apply Tanos more than six times per year, and mixing with Manzate or chlorothalonil is recommended. Do not mix or follow Tanos with a Group 11 fungicide (e.g., Amistar). Applied within a protectant program, all of these products give excellent late blight control. In addition, trials over several years at MSU have shown that Amistar and Headline are still exceptionally good for early blight control. Gavel, a new product from Dow (released in 2003), is also best used as a protectant and has been reported to reduce tuber blight.

In seasons when the weather conditions would not favor severe late blight development, programs based on chlorothalonil (e.g., Bravo WS 6SC, Echo 6SC, Equus 6SC) or EBDC-containing products (e.g., Dithane 75DF, Manzate 75DF, Manex 4FL, Penncozeb 75DF, Polyram 80WP) will reduce the risk of disease establishment. The addition of TPTH 80WP to any of the protectant programs will enhance disease control, particularly toward the end of the growing season. Note that TPTH 80WP has a 7-day preharvest interval, and the maximum use rate since 2002 is 11.25 oz/A per season. Fixed copper-based products such as Champ and Kocide can also be used in protectant programs. These products are best used early in programs or immediately post-harvest for killing inoculum that may have come from adjacent crops. They should always be applied at the full recommended rate of application. The observations of individuals responsible for implementing spray programs should determine when best to change from one product to another. Of major note is that the Fungicide Resistance Action Committee (FRAC) has specific recommendations for mixing fungicides with high risk of resistance development. As of 2003, fungicides are now labeled with a group number–e.g. Headline, Tanos, Amistar, Gem are all Group 11. These fungicides should not be mixed or immediately alternated in a fungicide-based protectant program. The application of these fungicides as stand-alone products has never been recommended by MSU for late blight control. They

Table 1. Suggestions for appropriate fungicides for late blight control, including residual contact and semi-systemic fungicides under various late blight conditions in susceptible potato varieties.

Disease category	Fungicide [active ingredient (FRAC Group)]
0) none	Bravo, Echo, Equus [chlorothalonil-based (M)] Manzate, Penncozeb, Dithane, Polyram [EBDC-based (M)] Omega [fluazinam (29)], Curzate [cymoxanil (27)], Tanos [cymoxanil (27) + famoxadone (11)], Acrobat [dimethomorph (15)], Previcur Flex [propamocarb (28)] + EBDC or + chlorothalonil Gavel [zoxamide (22) + EBDC] Champ, Kocide [or other fixed copper-based products; both contain copper hydroxide (M)] and/or Phostrol [phosphonic acid (33)] The above fungicides should be applied at 7- to 10- day intervals, depending on late blight risk for the area[z]
1) few random lesions even distribution throughout field (0 - 1% foliar infection)	As above but with the addition of triphenyltin hydroxide [TPTH (30)], e.g., Super Tin or Agri Tin, at 5-day application intervals until lesions have dried out and are no longer spreading. Then revert to recommendations in category 0.
2) one to five loci spreading from the edge or from several centers within the field (1% overall field infection but locally heavily infected plants, 5 -20%)	As for category 1 but kill infected area with Reglone[y]. When lesions are no longer spreading, revert to recommendations in category 0.
3) 20-100% crop infection with large loss of green leaf area	Kill infected area with Reglone. Then apply: Bravo, Echo, Equus [chlorothalonil-based] Manzate, Penncozeb, Dithane, Polyram [EBDC-based] + TPTH Gavel [zoxamide (22) + EBDC] +TPTH until vines are completely desiccated.

[z]See (http://www.lateblight.org) for late blight disease forecasting for Michigan counties.
[y]Reglone is not a fungicide it is a non-volatile desiccant herbicide used as a preharvest aid to desiccate the potato leaf canopy to facilitate harvesting.

should always be mixed with a protectant surface residual fungicide.

The appropriate placement of translaminar and other systemic products within programs is determined by the mode of action of the product in relation to host and disease development, but all products are best used within a preventative protectant program. For example, Previcur, Acrobat, Amistar, Headline, Gem, Gavel or Curzate may be applied to protect new growth early in plant development. Curzate and Previcur may be applied while the canopy is expanding but before senescence, and Acrobat is most effective as a postsenescence product and can be applied up to late crop senescence.

Recommended programs for late blight control are not straightforward. The product of choice may well depend on how and from where the disease has developed. Some possible scenarios are shown in Table 1, where a range of containment procedures are described for susceptible varieties and various levels of disease in the field.

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For more information, please visit: **http://www.lateblight.org**.

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