SEASON-LONG MANAGEMENT OF LATE BLIGHT ON POTATO AND TOMATO IN WESTERN WASHINGTON

This publication replaces out of print WSU EB 1812 and 0958: *Controlling Late Blight in Commercial Potato Fields in Washington* and *Late Blight of Potato and Tomato and Its Control in the Home Garden*. Additional sources of information for home gardeners can be found at *Potato: Late Blight*, *Tomato: Late Blight*, and *Gardening in Washington State*.

Abstract

Late blight is a historically famous plant disease that can be very serious in western Washington. It affects potatoes and tomatoes and certain nursery plants and weeds in the *Solanaceae* (potato family). The disease is capable of causing devastating crop losses, primarily because of the region's mild, marine climate, which often favors rapid spread. Regardless of the crop or production system—potato or tomato; large or small farms either under conventional or organic management; greenhouses, hoop houses or high tunnels; nurseries or home gardens—late blight can be a problem whenever host plants are present. Successful management in western Washington requires comprehensive cultural and sanitation practices throughout the entire year along with regional cooperation, and, often times, applying protectant fungicides during the growing season.

History of the Pathogen in Western Washington

Late blight is caused by an oomycete (a type of water mold), *Phytophthora infestans*. This plant pathogen has a notorious history and was one of the main causes of the Irish Potato Famine in the 1800s (The History Place 2000). In western Washington, late blight has been a recurring disease since the advent of potato production in the early 1900s. When protectant fungicides (products that prevent or inhibit a pathogen) first became available in the 1940s, control generally was adequate if spray applications were timely and repeated. With the introduction of the fungicide, metalaxyl, in the 1970s, late blight control became less complicated. (Note: "metalaxyl" was later reformulated and renamed as "mefenoxam," but resistance in *P. infestans* still remains a problem.) Metalaxyl was highly effective because it was a systemic fungicide (taken up by plant roots and distributed internally) in the plant. Thus, only one or two applications ever were needed and the necessity of strict sanitation and cultural control measures lessened. However, in the late 1980s and early 1990s, new, aggressive, and metalaxyl-insensitive strains of *P. infestans* were detected in western Washington (Deahl et al. 1993; Deahl and Inglis 1995) and also throughout the United States (Fry et al. 1993). The new strains still dominate populations of the pathogen in the region (Derie and Inglis 2001), as well as throughout the world, and present continued challenges in late blight control.

The metalaxyl-insensitive strain of *P. infestans* recovered in western Washington in the early 1990s was designated US-11 (Goodwin et al. 1998). Plant pathologists hypothesized that it arose in Mexico before being introduced to the west coast of the United States via tomato transplants. US-11 proved very aggressive to tomato and also to potato and is an A-1 mating type. *P. infestans* has two mating types, designated A-1 and A-2. Only if the two mating types are genetically compatible and in close proximity to one another do specialized long-term survival spores, called oospores, form. Oospores are thick-walled sexual spores that can persist for long periods of time (Figure 1, top). In contrast, asexual spores of *P. infestans*, called sporangiospores (Figure 1, bottom), do not require two mating types in order to form and may be produced abundantly leading to severe disease epidemics. The sporangiospores have limited survival time and require warmer temperatures, free water, and high humidity in order to germinate, however.

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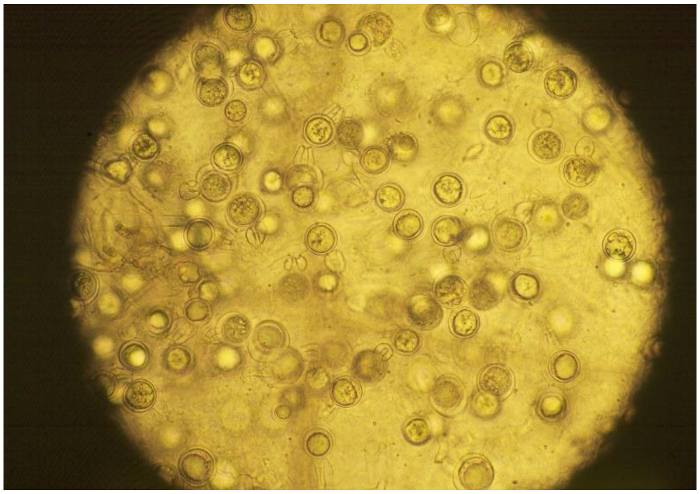

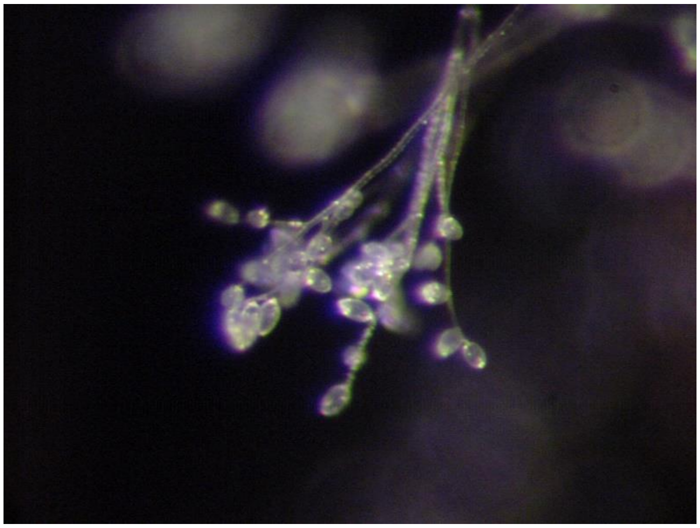

Figure 1. Oospores (top photo) and sporangiospores (bottom photo) of Phytophthora infestans. (Photos by M. Derie and R. Spence.)

After the introduction of US-11, several serious late blight epidemics threatened the future of western Washington's potato industry, and many greenhouse growers and home gardeners lost their tomato plantings. A second metalaxyl-insensitive strain of *P. infestans* was detected on potato in 1997 (Dorrance et al. 1999) and designated as US-8. It was very aggressive to potato, but somewhat less so on tomato. Nevertheless, it was an A-2 mating type and raised the possibility that oospores potentially could form in the region. However, as of this writing, oospores of *P. infestans* have not been detected nor are they known to function in the survival or spread of this pathogen in western Washington field settings, or for that matter, in any area of the United States.

In the late 2000s, a late blight pandemic (a widespread and destructive disease epidemic) occurred on tomatoes throughout the eastern United States (Fry et al. 2013). It was caused by a different strain of *P. infestans* designated US-22. It proved to be an A-2 mating type, was insensitive to mefenoxam, and spread via infected tomato transplants. Since that time, other strains, such as US-24 (Porter et al. 2017), have been described on potato and tomato from numerous locations, including parts of Washington. Reports of late blight in the United States over the past several years can be accessed on the USABlight website. Suspect samples from Washington can be sent to personnel at the WSU Puyallup Plant & Insect Diagnostic Laboratory who can forward isolates for strain identification. As of this writing, US-11 remains the most recently confirmed strain in western Washington. Interestingly, it first was isolated in the region from hairy nightshade. Weedy hosts like nightshade have been linked to high aggressiveness in *P. infestans* populations (Grönberg et al. 2012).

Late Blight Disease Cycle

In western Washington, *P. infestans* overwinters on volunteer potato and tomato plants, potatoes and tomatoes in cull piles, infected seed potatoes and tomato transplants, and weeds like hairy nightshade. Once the pathogen sporulates on infected materials, the sporangiospores are disseminated by rain and wind. Upon contact with a host plant, sporangiospores germinate directly by a germ tube or by producing numerous motile spores called zoospores. Sporangiospores and zoospores are not long-lived and require free moisture (e.g., a wet leaf surface) in order to survive and germinate. Even so, they can be dispersed by air over distances of many miles before desiccating. Thus, the overwintering sources of inoculum in one field or location can infect the hosts of another, making late blight a regional disease problem requiring concerted approaches for effective management.

Late blight and wet, humid conditions always go hand in hand. When the weather is favorable, symptoms and signs of the disease can occur on all plant parts, e.g., sprouts, leaves, stems, flowers, tubers, and fruits (Figures 2–7). On potato leaves and stems, dark-colored lesions are typically surrounded by a white fluffy perimeter, which harbor masses of sporangiospores and zoospores. Because millions of spores can form from one single lesion, *P. infestans* is infamous for its ability destroy plants rapidly; new generations of spores may be produced in only three days. Potato tubers also can become infected if spores contact them, either by washing into the hill or by spreading from infected tubers during storage. Blighted tubers take on a copper colored discoloration and are prone to bacterial decay from infection, resulting in soft rot of tubers.

The stems, leaves, and fruits of tomato are similarly infected. Occasionally, leaf and stem lesions on tomato consist of mostly dried, dead tissue and sometimes lack the obvious evidence of *P. infestans* sporulation (Figure 6) as typically noted on potato. Like potato tubers, though, blighted tomato fruits take on a copper colored discoloration and can rot quickly (Figure 7). Figure 8 shows the progress of a late blight epidemic in a potato field in western Washington where most plants were either blighted or killed within two weeks.

Figure 2. Late blight lesions on the sprouts of a potato seed piece. (Photo by J. Gigot.)

Figure 3. Late blight lesion on a potato leaf. (Photo by B. Gundersen.)

Figure 4. Late blight lesion on the stem of a potato plant within the plant canopy. (Photo by B. Gundersen.)

Figure 5. Late blight on a potato tuber. Note the grainy copper discoloration of the flesh. (Photo by B. Gundersen.)

Considerable research shows that *P. infestans* is transmitted from seed potato tubers harboring this pathogen to germinating potato sprouts (Powelson et al. 2002; Gigot et al. 2009; Figure 9). Seed tubers can be infected with the pathogen, but show no symptoms—a condition called latent infection. When tubers with latent infection survive long-term cold storage (Johnson and Cummings 2009), spore production by the pathogen may develop on sprouts after planting, but before disease symptoms appear in the canopy (Johnson 2010) making early detection of late blight in the field nearly impossible. Moreover, if spores are present in seed potato storages, the surfaces of freshly cut seed pieces can become contaminated during seed cutting operations, leading to infection and sporulation by the pathogen and spread to healthy seed tubers right before planting (Lambert et al. 1998).

For this reason, controlling seed tuberborne late blight with appropriate seed potato fungicides is essential (Inglis et al. 1999; Powelson and Inglis 1999). Reports of late blight transmission through true tomato seeds (Rubin and Cohen 2004) are rare although the disease is known to spread readily in tomato via infected tomato transplants (Fry et al. 2013), including in greenhouse settings. However, other sources of late blight inoculum for both field and greenhouse-grown tomatoes include petunia, which can be susceptible (Becktell et al. 2005), weeds in the potato family, like nightshade, neighboring potato and tomato volunteers, and tomato and potato cull piles.

It is important to remember that because oospores are not believed to play an active role in the disease cycle, late blight is *not* considered a soilborne disease. Hence, measures like crop rotation are not effective for control, unlike what is commonly assumed. However, many other cultural, sanitation, and chemical control approaches are effective, and all are necessary to manage the various facets of the disease cycle.

Figure 6. Blighted leaves and stems on a tomato plant. (Photo by B. Gundersen.)

Figure 7. Blighted fruits on a tomato plant leading to rot. (Photo by B. Gundersen.)

Figure 8. Potato field at the beginning of a late blight epidemic (top photo) and dead or dying plants 16 days later (bottom photo). (Photo by J. Gigot.)

Figure 9. *Phytophthora infestans* sporulating in the eyes of a seed potato infected with late blight (top photo) leading to late blight infection on germinating sprout (bottom photo). (Photos by J. Gigot.)

Late Blight and Western Washington's Environment

Western Washington's climate can be quite favorable to late blight. Even though the majority of the region's annual precipitation is received during the fall, winter, and spring months, moist conditions can occur throughout the summer in the form of light rains, low cloud ceilings, heavy dews and occasional fog, and also irrigation. Typically, symptoms of late blight are first observed in northwestern Washington production areas, around late June or early July. The progress of the disease then may diminish if rainfall is typically low (one inch or less), but can increase again by early-to-mid August if warm temperatures with moist conditions prevail. Periods (48 to 72 or more consecutive hours) of high relative humidity (75 to 100%) and rainfall (greater than one inch) with moderate temperatures (60 to 80°F) can be highly conducive in favoring the disease (MacKenzie 1981). In tomato greenhouse settings, the disease can become a serious problem when there is inadequate airflow within and around plants and foliage remains wet (Becktell et al. 2005) due to crowding, poor ventilation, water condensation, overhead watering, and high humidity.

Because the environment plays such a critical role in late blight development, protective structures which modify the environment have been investigated for managing late blight on tomato in western Washington (Inglis et al. 2009 and 2011). Although Reemay-covered cages proved ineffective (Vestey et al. 2000), a three-year study with five tomato cultivars showed that hours of leaf wetness were fewer, late blight severity was significantly less, and tomato yield was higher in open-ended high tunnel compared to open-field plots. The combination of rain protection and polyethylene mulch with drip irrigation provided by the high tunnel system helped to lower leaf wetness duration. Even so, pruning, trellising, and end wall management were required to avoid high humidity and water condensation on plants, especially during periods of penetrating fog (Powell et al. 2014).

When to Apply Fungicides

Since the introduction of US-11 and US-8 *P. infestans* in the region, protectant foliar fungicide sprays have become essential components of successful control programs. At this time, such applications are used mostly on commercial potatoes in the region. In settings like greenhouses, high tunnels, home gardens, and in organic production systems, repeated fungicide applications may not be practical or appropriate, and the choice of registered products is limited. Moreover, some growers may not always have access to high-pressure sprayers which often are necessary for fungicides to fully penetrate dense plant canopies and cover the under surfaces of leaves. Thus, many small farmers, greenhouse operators, and home gardeners mainly rely on cultural methods and sanitation practices for controlling the disease. However, without protectant fungicide treatments, crop losses due to late blight may be extensive when weather is favorable. Figure 10 dramatically illustrates the difference in late

Figure 10. Experimental field plots at WSU Mount Vernon NWREC, either treated in advance with protectant fungicides (background) or not treated (foreground) as assessed during a naturally occurring late blight epidemic in 1998. (Photo by D.A. Inglis.)

blight severity between potato plots where protectant fungicides were used versus not used in a WSU Mount Vernon NWREC experimental field trial that was affected by a naturally-occurring epidemic during the 1998 late blight favorable year.

Ideally, protectant fungicides are applied *before* late blight symptoms are ever observed—such products *protect* the plant from infections and generally do not have the ability to eliminate infections once they occur. Unless having systemic or limited systemic activity, fungicides that are applied *curatively* (i.e., after infections occur) are not very effective. Moreover, protectant fungicides need to be re-applied onto foliage as plants continue to grow or if the fungicide is washed off by rain or irrigation water.

Numerous computer-based disease forecasting systems that utilize seasonal environmental data have been developed to alert growers as to when weather conditions are favorable for late blight (Krause et al. 1975; Taylor et al. 2003; UC Davis IPM, n.d.) for the purpose of better timing of spray applications and reducing unnecessary fungicide applications. Johnson et al. (1996 and 1998) developed a late blight forecasting method specific to potatoes grown in the dryland areas of the inland Pacific Northwest where overhead sprinkler irrigation is used. For western Washington, a forecasting system called IPM WISDOM was evaluated instead, because western Washington has a moderate climate with annual rainfall. Although no longer available, IPM WISDOM was based on BLITECAST (MacKenzie 1981) and part of an integrated potato crop management program developed at the University of Wisconsin (Stevenson 1993). In IPM WISDOM, a potato late blight epidemic is forecast to begin 7 to 14 days after 18 DSV (disease severity values) accumulate, post-plant first emergence. Table 1, modified from IPM WISDOM (1995), gives an example of the assignment of late blight DSV based on temperature and relative humidity. Table 2 from IPM WISDOM (1995) shows how once 18 DSV accumulate, IPM WISDOM continues to calculate DSV in order to make spray recommendations based on precipitation and irrigation amounts.

Table 1. Assignment of late blight disease severity values in WISDOM for temperature and relative humidity (adapted from IPM WISDOM, 1995).

Average temperature range[a,b]	**Disease severity values according to hours of ≥ 90% relative humidity**				
	0 (none)	**1 (trace)**	**2 (slight)**	**3 (moderate)**	**4 (severe)**
45–53°F	15	16–18	19–21	22–24	25–27
54–59°F	12	13–15	16–18	19–21	22–24
60–80°F	9	10–12	13–15	16–18	19–21

[a] Average temperature of the period when relative humidity was greater than or equal to 90%.

[b] WISDOM also required data on emergence, evapotranspiration, irrigation events, and fungicide applications.

Table 2. WISDOM fungicide spray interval recommendations (adapted from IPM WISDOM, 1995).

Total rainfall/irrigation for the past 10-day period[a]	Total disease severity values during the last 7 days					
	< 3	3	4	5	6	> 6
	Suggested spray interval for late blight control (in no. of days)					
> 1.2 inches	10–14	10	7	5	5	5
< 1.2 inches	10–14	10–14	10	7	7	5

[a] WISDOM also required data on emergence, evapotranspiration, irrigation events, and fungicide applications.

In the Mount Vernon study, 13 years (1993 to 2003; 2008 and 2009) of the Center's historical field records on late blight onset and spread on potato were recovered and compiled (Table 3). Daily rainfall, average maximum and minimum temperatures, evapotranspiration, hourly temperatures, and relative humidity (recorded by WSU PAWS and WSU AgWeatherNet) also were acquired when available. Complete weather data were available all years except 1993, and only partially available in 1998. Late blight severity assessments were based on visual ratings made weekly on randomized and replicated (four times) non-fungicide treated experimental plots planted to approximately 100 plants of 'White Rose' (except in 1999 when 'Russet Burbank' was planted). Both 'White Rose' and 'Russet Burbank' are intermediate in resistance to late blight (Inglis et al. 1996). Information on protectant fungicide applications times (either mancozeb as Dithane DF or chlorothalonil as Bravo WS) from adjoining treated plots in each trial also was reviewed when available.

Late blight incidence and severity data, by year, then were averaged and organized into three categories: lesion onset (less than one percent late blight or only one or two lesions per 100 plants); the beginning of disease spread (greater than or equal to one percent late blight, or the equivalent of one out of 100 plants with symptoms); and disease development as based on area under disease progress curve (AUDPC) and relative area under disease progress curve (RAUDPC) values. A disease progress curve, simply, is disease severity plotted on a graph over the growing season with the area below the curve on the graph summarized as a single value. A relative value is disease severity plotted just over the length of the observed epidemic to enable comparisons among dissimilar epidemics over different years. For either, the higher the value, the more severe the epidemic. The 13 years of environmental and disease data were entered into the WISDOM software and the recommended spray times then overlaid onto each year's disease progress curve (Figure 11, A–M). Comparisons of dates when WISDOM successfully predicted lesion onset (18 DSV) versus disease spread and number of WISDOM-recommended sprays versus actual sprays then were done. Figure 11, D–F highlight how disease progress diminished when protectant fungicides were applied versus not applied under the very high disease pressure situations of 1996, 1997, and 1998, respectively.

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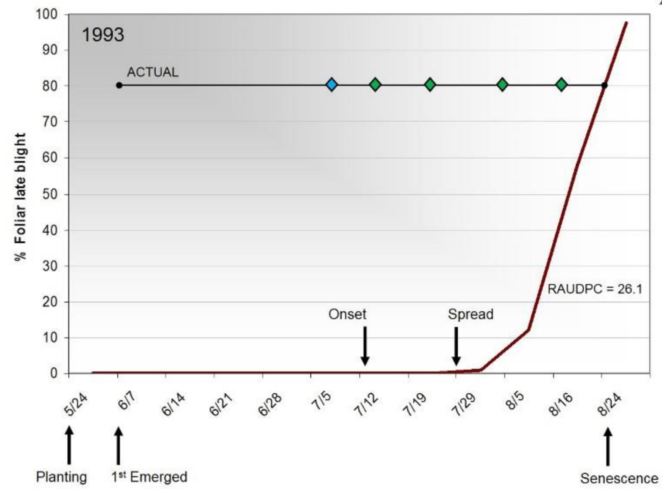

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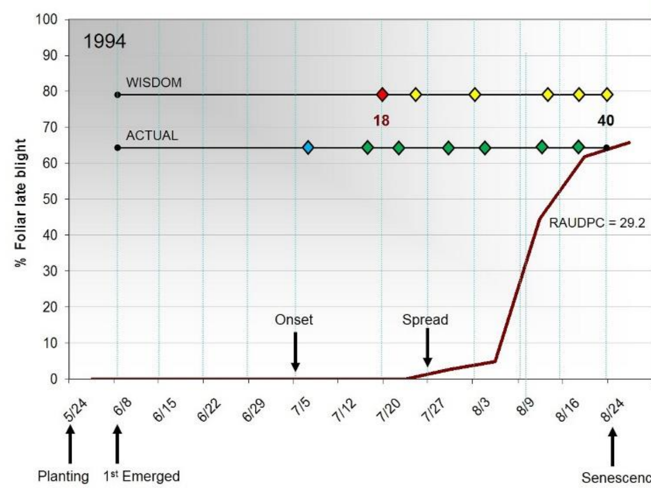

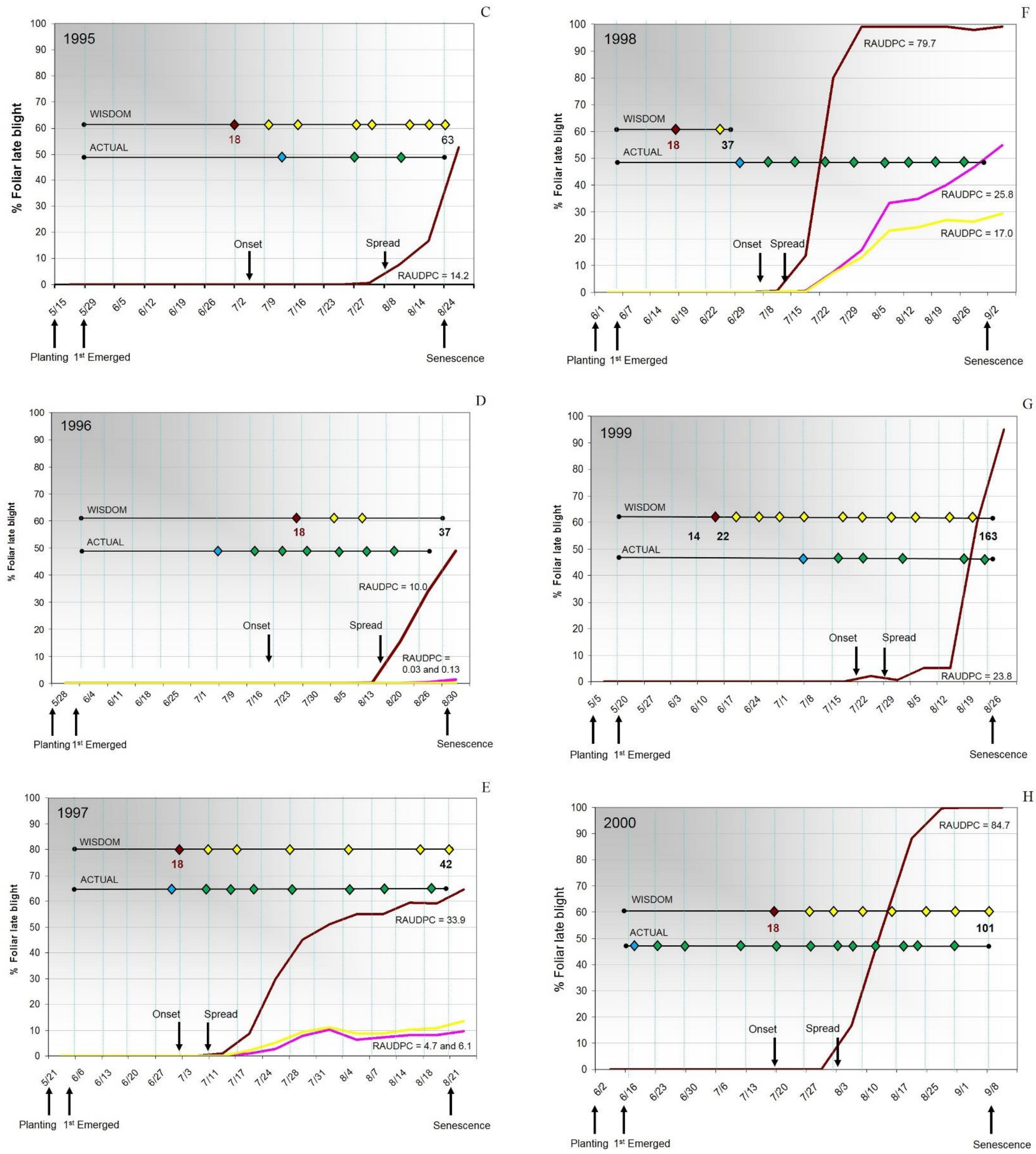
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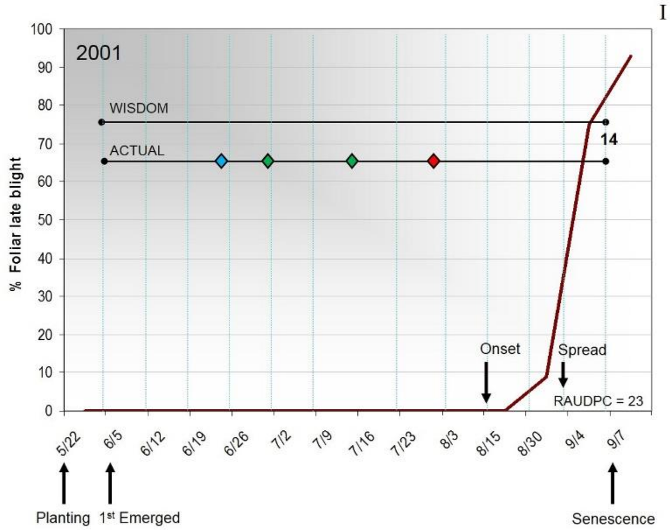

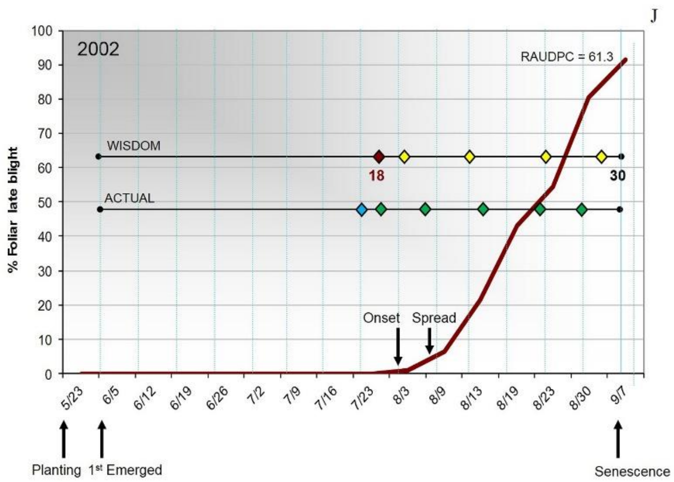

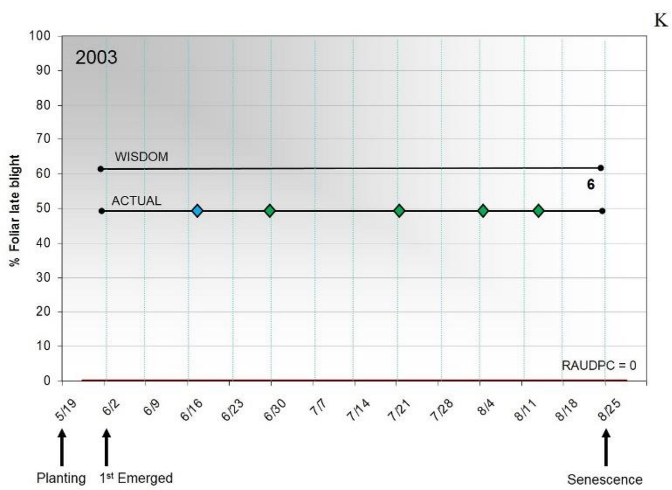

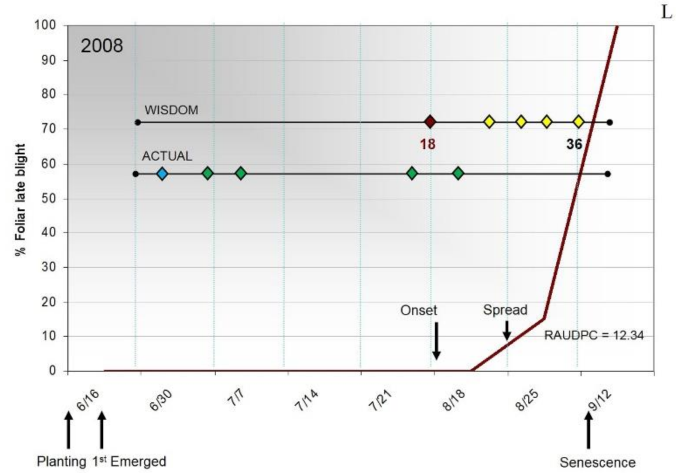

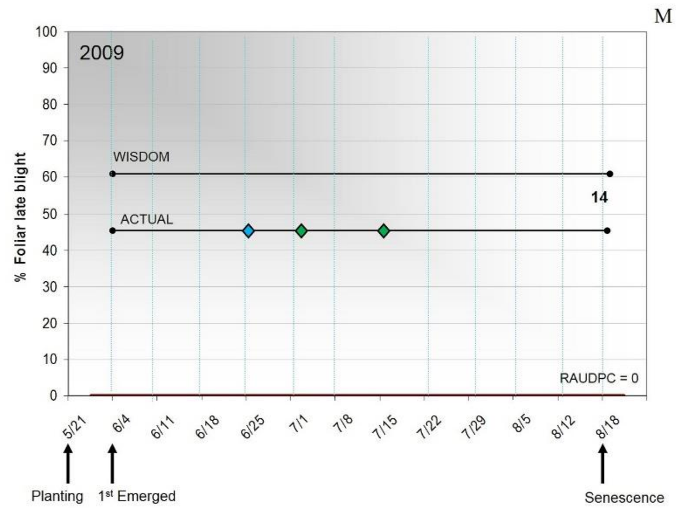

Key:

- = Late blight in non-fungicide treated control plots
- = Late blight in plots treated with Bravo WeatherStik (chlorothalonil) via STRETCH
- = Late blight in plots treated with Dithane DF (mancozeb) via STRETCH

- ◆ = WISDOM-recommended fungicide spray date at 18 disease severity values (DSV)
- ◆ = Other WISDOM-recommended spray dates
- ◆ = First actual fungicide spray date
- ◆ = Subsequent actual fungicide spray dates

Figure 11, A–M. Disease progress curves generated from naturally-occurring late blight epidemics at WSU Mount Vernon, 1993–2009. Environmental data and late blight severity ratings were entered into WISDOM software, with the recommended and actual spray times, later overlaid.

Table 3. Historical summary of WSU Mount Vernon NWREC late blight epidemics that occurred in non-fungicide treated control plots of experimental field trials exposed to naturally-occurring late blight epidemics.

Year; (planting date)[a]	**DAP to full emergence; (date)[b]**	**DAP to disease onset (< 1% foliar infection); (date)[c]**	**DAP to disease spread (> 1% foliar infection); (date)[d]**	**DAP when WISDOM accumulated 18 DSVs; (date)[e]**	**Maximum foliar rating[f]**	**RAUDPC value for epidemic[g]**	**Total DSVs calculated by WISDOM**	**WISDOM correctly predicted lesion onset**	**WISDOM correctly predicted disease spread**
1993 (May 24)	24 (Jun 17)	50 (Jul 13)	63 (Jul 29)	---[h]	98%	26.1	---	---	---
1994 (May 24)	24 (Jun 17)	43 (Jul 6)	64 (Jul 27)	51 (Jul 14)	66%	29..2	40	No	Yes
1995 (May 15)	24 (Jun 8)	51 (Jul 5)	85 (Aug 8)	49 (Jul 3)	53%	14.2	63	Yes	Yes
1996 (May 28)	24 (Jun 21)	56 (Jul 23)	84 (Aug 20)	61 (Jul 28)	49%	10.0	37	No	Yes
1997 (May 21)	20 (Jun 10)	43 (Jul 3)	51 (Jul 11)	44-45 (Jul 4-5)	64%	33.9	42	No	Yes
1998 (Jun 1)	25 (Jun 26)	37 (Jul 8)	44 (Jul 15)	18 (Jun 19)	99%	79.7	---	Yes	Yes
1999 (May 5)	27 (Jun 17)	63 (Jul 22)	70 (Jul 29)	55-56 (Jul 14-15)	95%	23.8	163	Yes	Yes
2000 (Jun 2)	34 (Jul 6)	48 (Jul 20)	62 (Aug 3)	48-49 (Jul 20-21)	99%	84.7	101	No	Yes
2001 (May 22)	32 (Jun 23)	85 (Aug 15)	104 (Sep 4)	---	93%	23.0	14	No	No
2002 (May 23)	32 (Jun 24)	72 (Aug 3)	78 (Aug 9)	62 (Jul 24)	100%	61.3	30	Yes	Yes
2003 (May 19)	31 (Jun 19)	---	---	---	0%	---	6	Yes	Yes
2008 (Jun 6)	21 (Jun 27)	73 (Aug 18)	80 (Aug 25)	72-73 (Aug 17-18)	100%	43.4	36	Yes	Yes
2009 (May 21)	33 (Jun 23)	---	---	----	0%	---	14	Yes	Yes

[a] Planting date arbitrarily selected each year according to weather conditions and personnel availability. The plots of non-fungicide treated 'White Rose' and 'Russet Burbank' (in 1999) at WSU-Mount Vernon NWREC generally consisted of four replications of single rows of 20–25 plants randomly assigned within the field trial.
[b] DAP = days after planting. Full emergence assigned when no new sprouts emerged, based on daily visual observations.
[c] DAP to first visual observation of late blight; usually, only one or two leaf or stem lesions.
[d] DAP when visual ratings exceeded 1% of foliage affected by late blight.
[e] DSV = disease severity values in WISDOM.
[f] Highest visual rating during season based on percentage of infected plant tissue on a per plot basis.
[g] RAUDPC = relative area under disease progress curve based on weekly foliar late blight ratings during the disease epidemic in calendar days.
[h] --- denotes missing data due to unavailability of complete weather records.

Naturally-occurring epidemics of late blight occurred all years except 2003 and 2009. WISDOM correctly predicted late blight onset in only 7 of 12 available years (58% of the time), but accurately forecasted disease spread in 11 of 12 available years (92% of the time). In contrast, actual spray times, which were based on the assumption that seedborne *P. infestans* could initiate an epidemic each year, showed that late blight, in fact, did occur in 11 of 13 years (85% of the time). For the two years in which late blight did not occur, WISDOM predicted no sprays. However, WISDOM failed to predict late blight in 2001 when RAUDPC values reached 23. The total number of recommended WISDOM sprays for all 13 years of the study was 53 and the spray intervals general ranged between 5 and 10 days. The total number of actual sprays was 81.

The study results implied that an *integrated* approach of using (i) a seed potato fungicide and an in-furrow fungicide at planting, (ii) an early calendar-based protectant spray to foliage, and then (iii) repeated protectant foliar sprays as needed is an effective way to manage late blight on potatoes in western Washington. We refer to this program as *STRETCH* because spray intervals either expand or contract depending on environmental conditions. In implementing *STRETCH*, it is essential to apply a seed piece or in-furrow fungicide treatment at planting plus one early foliar spray at "green row" (when plants first touch in the row) stage. In this way, seed tuber transmission of *P. infestans* is accounted for. Accordingly, spray intervals then can be widened to two weeks or more, or narrowed to ten days or less, based on whether there are 48- to 72-plus hours of high relative humidity and rainfall when temperatures are moderate (60 to 80°F). Paying close attention to environmental conditions, learning about the presence and absence of late blight in the region, and employing comprehensive cultural and sanitation practices throughout the entire year are *essential* to insure success with this integrated method.

For any late blight spray program on any susceptible crop, the efficacy of the fungicide(s) being used needs to be kept in mind. In conventional potato production, there are numerous protectant foliar fungicide options with some having limited systemic activity (See Potato [Solanum tuberosum]-Late Blight [Hamm and Ocamb, n.d.]). Also, there are several fungicides that can be used to protect tomatoes in both field and greenhouse settings (See Tomato [*Lycopersicon esculentum*]-Late Blight). At this time copper-based foliar fungicides are registered for organic uses, but their application is somewhat controversial since they need to be applied at regular intervals and may contribute to the build-up of copper in the environment (Dorn et al. 2007). Other measures, like sanitation and avoiding susceptible cultivars of potato and tomato crops, then become the alternative control methods. The Pacific Northwest Plant Disease Management Handbook (n.d.) tomato late blight section lists Serenade (a biocontrol agent) as suppressing late blight on tomato when used in rotation with copper.

For a listing of efficacy of different fungicide products tested against naturally-occurring late blight epidemics at WSU Mount Vernon NWREC over the years, see the Further Reading section. Products currently registered in Washington can be found on WSU's PICOL website, which is updated each year.

Late Blight Resistant Cultivars

Host resistance is a highly desirable way to manage late blight. However, only a few resistant and tolerant cultivars and breeding lines have been deployed successfully. Numerous evaluations, again based either on naturally-occurring late blight epidemics or greenhouse inoculations (Dorrance et al. 1997 and 1998), have been done at WSU Mount Vernon NWREC to determine levels of resistance in selected potato and tomato germplasm entries (see the Further Reading section). On potato, cultivar rankings in response to infection by the new US-11 and US-8 strains of *P. infestans* proved nearly identical to the rankings reported for the former US-1 strain. Although no entries were resistant, 'Ranger Russet,' 'Russet Burbank,' and 'White Rose' were less susceptible than 'Goldrush,' 'Hilite,' 'Russet Norkotah,' 'Norchip,' and 'Shepody,' 'Elba,' and 'Kennebec' were less susceptible than 'Russet Burbank' (Inglis et al. 1996). 'Defender,' a high-yielding, processing potato cultivar with strong foliar and tuber resistance to late blight was identified (Corsini et al. 1999; Novy et al. 2006; Stevenson et al. 2007; Figure 12) and *Solanum hougasii*, a wild tuber-bearing species, proved a source of resistance to late blight for potato breeding (Inglis et al. 2007; Dorrance et al. 2001). All table stock potatoes were susceptible in Mount Vernon tests, but Douches et al. (2001) in Michigan have released 'Jacqueline Lee' as a late blight resistant, table stock potato variety. On tomato, resistance tests at WSU Mount Vernon NWREC indicated that 'Legend' (Inglis et al. 2009; Miles et al. 2010) and 'Matt's Wild Cherry' (Inglis et al. 2001; Inglis et al. 1999; Figure 13) had tolerance to western Washington populations of *P. infestans*. UMass Extension lists some other tomato varieties with resistance, but their performance under western Washington conditions is unknown. For an excellent article about tomato cultivars with differing levels of resistance according to the various strains of *P. infestans*, see McGrath (2019).

Outside of potato and tomato, there are other hosts to late blight. Twenty-two weed and ornamental plants in eleven genera of the Solanaceae were evaluated at WSU Mount Vernon NWREC for susceptibility to *P. infestans* against high disease pressure caused by the US-8 and US-11 strains. Disease progress was significantly greater on bittersweet nightshade (*S. dulcamara*), potato (*S. tuberosum*), potato vine 'Glasnevin' (*S. crispum*), and red and yellow currant tomato (*Lycopersicon pimpinellifolium*) compared to the other plants tested. Although some symptoms of late blight were detected, *P. infestans* could be recovered from petunia, potato, potato vine 'Glasnevin', and red currant tomato. These hosts do not appear to play major roles in the pathogen's disease cycle in the region (Inglis et al. 2000). However, since petunias can be a host, they should not be grown in close proximity to tomatoes in greenhouse production.

Figure 12. Experimental potato field plots at WSU Mount Vernon NWREC, showing resistance in ‘Defender’ (left side of photo) as compared to ‘Russet Burbank’ (right side of photo) as observed during a naturally occurring late blight epidemic. (Photo by D.A. Inglis.)

Figure 13. Experimental tomato field plots at WSU Mount Vernon NWREC showing limited resistance among germplasm entries with the exception of ‘Matt’s Wild Cherry,’ as observed during a naturally occurring late blight epidemic. (Photo by D.A. Inglis.)

Seasonal Guidelines for Integrated Late Blight Control

In western Washington, like other potato and tomato growing regions of the world, the presence of new strains of *P. infestans* and the loss of metalaxyl as a relatively straightforward late blight control measure has meant reviving traditional cultural management practices and devising new approaches in late blight control. Because the most effective late blight management is based on year-long integrated and regional strategies, the following recommendations for western Washington (Table 4) are organized accordingly by season.

Table 4. Seasonal guidelines for integrated late blight control in western Washington.

<table>
<tr><th>Potato</th><th>Tomato (field and greenhouse)</th></tr>
<tr><td colspan="2"><u>Spring</u></td></tr>
<tr><td colspan="2">1. Eliminate potential overwintering sources of inoculum, which can lead to the production of late blight spores.</td></tr>
<tr><td>- Before newly planted crops emerge, destroy tare dirt piles that originate when potato storages are cleaned-out in preparation of new seed potato shipments in the spring.
- Destroy or bury cull piles of non-decomposed potato tubers.
- Do not spread tare dirt in fields destined for potato planting.
- Eliminate overwintered or newly emerging volunteer potatoes as well as weeds like hairy nightshade growing near the planting site.
- Avoid dumping left-over seed potato pieces from planter boxes into ditch banks at field margins.
- Pay attention to adjoining fields and gardens that may not benefit from recommended sanitation measures.</td><td>- Destroy or bury cull piles of non-decomposed tomato fruits.
- Eliminate overwintered or newly emerging volunteer tomatoes.
- Remove weeds that are members of the potato family growing in and around greenhouses, like hairy nightshade.
- Pay attention to adjoining fields and gardens that may not benefit from recommended sanitation measures.</td></tr>
<tr><td colspan="2">2. Choose potato and tomato cultivars that have some level of late blight resistance, when available.</td></tr>
</table>

Potato	**Tomato (field and greenhouse)**
- Few potato cultivars have reliable resistance to late blight (see text above). - It is important to remember that even for cultivars reported to have a moderate level of resistance, serious losses have been sustained on them in western Washington during highly favorable late blight years.	- Few tomato cultivars have reliable resistance to late blight (see text above). However, using them is especially important for home gardeners, greenhouse tomato, and organic growers who may have limited fungicide choices. - It is important to remember that even for cultivars reported to have a moderate level of resistance, serious losses can be sustained on them in western Washington during highly favorable late blight years.
3. Use disease-free seed potatoes and tomato transplants.	
- Plant certified, limited-generation seed potatoes that are disease free, and purchase them from seed potato farms where comprehensive late blight management is practiced. Inspecting seed potato fields and interviewing seed growers before purchase is highly recommended.	- Carefully inspect tomato transplants for any signs or symptoms of late blight before purchasing and planting them. - In greenhouse settings, also use care in selecting petunia transplants.
4. Limit transmission of *P. infestans* from seed potato tubers to emerging potato sprouts and via tomato transplants.	
- Sanitize knives during seed potato cutting operations and either plant cut seed pieces that have been treated with an appropriate seed treatment fungicide immediately, or make sure that subsequent to cutting and treating, seed pieces are adequately suberized before planting. - Use recommended seed potato fungicide treatments. See listings in the Pacific Northwest Plant Diseases Management Handbook (Hamm and Ocamb, n.d.) and via the WSU Pesticide Information Center Online (PICOL) databases. - Use in-furrow fungicide treatments at planting that have activity against oomycetes (water mold fungi) to limit *P. infestans* transmission opportunities. This practice can be strategic because late blight infections that might occur early, before there is time to make the first protectant foliar fungicide application, can be minimized thereby increasing the chances of successful control throughout the remainder of the year. - Currently, there are no seed potato or in-furrow fungicide treatments registered for organic potato production in Washington.	- Tomato greenhouse growers and home gardeners need to make sure that tomato seed is purchased from reputable vendors and that growing conditions do not promote late blight spread among emerging seedlings. - Avoiding overhead irrigation, reducing opportunities for moisture accumulation on leaves, and maximizing plant spacing can be helpful in tomato transplant operations to minimize late blight occurrence and spread. - Scout for the disease early, especially during cool, wet periods. Removal and destruction of infected plants can minimize spread of the disease later on, especially in greenhouse settings.
5. Adjust the planting time.	
- Generally, earlier planted (first two weeks of May) potatoes fare better than later planted potatoes (mid-May to early June) in terms of late blight in western Washington. Early plantings can "escape" spore showers that result from disease outbreaks at other locations, which tend to accelerate as the growing	- Tomatoes generally cannot be transplanted early (before late May) in western Washington because they are a warm season crop and temperatures during this time are usually too cool for them. The use of protectant coverings and high tunnel structures can help to facilitate earlier planting dates by sustaining warmer growing conditions. However, if

Potato	**Tomato (field and greenhouse)**
season progresses. Furthermore, temperatures tend to be cooler during this time, which also slows disease progress.	used, periods of high humidity, free moisture, and tunnel condensation need to be managed carefully.
6. Consider the field location.	
- Avoid planting potatoes in places shaded by trees or buildings. Orient the rows to the direction of the prevailing wind—in western Washington that most often is west to east.	- Avoid planting tomatoes in places shaded by trees or buildings and orient the rows in the direction of the prevailing wind. - Keep tomato and petunia plantings in greenhouses, separated. - Use outdoor structures like hoop houses and high tunnels. They can help minimize late blight occurrence and spread, *provided* that the structures are open-ended and can be managed to minimize water condensation on interior walls, relative humidity and leaf wetness, as well as prolonged soil moisture which can contribute to heavy dews.
<u>*Summer*</u>	
7. Learn to recognize the symptoms of late blight and scout for the disease on a regular basis (see Figures 2–7).	
- Do not neglect scouting shaded areas and the north borders of fields and even the north sides of plant rows where foliage may be shaded longer and symptoms may appear first. - Be sure to inspect stems near soil-line within the plant canopy. - Confirm diagnosis through WSU Puyallup Plant & Insect Diagnostic Laboratory.	- Do not neglect scouting shaded areas and north sides of plant rows where foliage may be shaded longer and symptoms may appear first. - Confirm diagnosis through WSU Puyallup Plant & Insect Diagnostic Laboratory.
8. Rogue-out diseased plants.	
- Although rogueing only is practical for small-scale farm operations, greenhouses, and home gardens, rogue-out infected plants at first lesion onset, and bag and dispose of all plant material. Never compost plant material that is infected or sporulating—bury it instead.	- Rogue-out infected plants at first lesion onset, and bag and dispose of all plant material. Never compost plant material that is infected or sporulating—bury it instead. - Disposal of diseased plant material near greenhouse air intakes should always be avoided.
9. Limit excessive plant canopy growth, which can limit air flow and promote high humidity and leaf wetness.	
- Avoid excessive fertilization with nitrogen. - Practice good weed management to insure adequate air flow throughout the crop canopy. - Make sure that species of nightshade (which are susceptible hosts) are eliminated at locations in, and neighboring, the field site.	- Avoid excessive nitrogen fertilization. - Manage weeds and eliminate species of nightshade (which are susceptible hosts).
10. Do not over-irrigate, and avoid overhead irrigation whenever possible.	

Potato	Tomato (field and greenhouse)
- Proper irrigation management is essential. Refer to *Managing Late Blight on Irrigated Potatoes in the PNW* EB 555 for more information (Bohl et al. 2003). The goal is to minimize extended periods of leaf wetness within the plant canopy to the extent possible. - Irrigate plants only when needed, and try to avoid situations leading to puddling of water within the rows. - To insure that there is time for foliage to dry throughout the day, do not irrigate late in the day or evening.	- For small farm operations and home gardens, consider installing a drip irrigation system that delivers water at ground level, rather than overhead to the canopy, in order to minimize prolonged periods of leaf wetness as well as puddling of water within the rows. - Avoid overhead watering, especially in greenhouses where foliage may remain wet for prolonged periods of time. - Hanging baskets and sub-irrigation may be feasible for petunias or tomatoes in pots or flats. These plants should not be sub-irrigated on shared systems due to the risk of other diseases (Becktell et al. 2005). - Even with a drip system, irrigate early in the day to allow ample time for foliage to dry during the day and to minimize the likelihood of dew formation in the evening.
11. Use protectant fungicides.	
- Make one or two early and routine protectant fungicide applications at green row stage (when the leaves on the plants within a row first touch one another), and approximately 7–14 days later, depending on the weather. These calendar sprays help insure that plants will be protected from spores either produced on sprouts within the field as a result of seed tuberborne inoculum and transmission of *P. infestans* to sprouts, or spores that originate from outside sources. Early fungicide applications also are the most satisfactory way of insuring that leaves near the ground in a plant canopy (i.e., the oldest leaves) receive sufficient fungicide protection. If fungicide applications are only made mid-to-late season, it often is difficult for small sprayers to have sufficient pressures and water volumes to penetrate the plant canopy to bottom leaves where humidity may be highest. Thus, older foliage may never be protected and may serve as a source of late blight spores. - In making any spray application follow label rates and recommended application methods, including sprayer pressure and water volume. Also, make sure that total fungicide amounts applied per season, the pre-harvest intervals, and the appropriate tank mixes are used. - Be alert to updates and reports of late blight occurrences in the region, especially during favorable late blight weather (dew, drizzle, fog, low cloud ceilings, sunshine late in the day, rain). WSU AgWeatherNet hosts several weather stations in western Washington which report environmental information daily; plan spray programs accordingly. Also, some WSU County Extension offices send out late blight alerts. This information can be helpful in initiating and timing fungicide applications.	- WSU Pesticide Information Center Online (PICOL) Databases is a very useful resource for obtaining current fungicide labels and registered uses. Likewise the Pacific Northwest Plant Disease Management Handbook has useful information on both chemical and cultural control options. - All products used in organic production must be approved for this purpose. - Be alert to updates and reports of late blight occurrences in the region, especially during favorable late blight weather (dew, drizzle, fog, low cloud ceilings, sunshine late in the day, rain). WSU AgWeatherNet hosts several weather stations in western Washington which report environmental information daily; plan spray programs accordingly. Also, some WSU County Extension offices send out late blight alerts. This information can be helpful in initiating and timing fungicide applications.
12. Employ sanitation practices throughout the growing season.	

Potato	Tomato (field and greenhouse)
- Potato hilling operations need to be done so as to insure good coverage of tubers by soil and to minimize cracks in the hill. The cracks otherwise allow late blight spores to wash into the soil and contact tuber tissues. - Eliminate volunteer potato plants growing or re-growing in the vicinity since they are usually not treated with fungicide. Even a few sporulating lesions on them can serve as a late blight source. - Remain vigilant about other potential outside sources of inoculum, such as cull piles, non-fungicide treated fields, and plants and weeds in the potato family that may be growing in ditchbanks and gardens.	- Eliminate volunteer potato and tomato plants growing or re-growing in the vicinity since they are not usually treated with fungicide. Even a few sporulating lesions on them can serve as a late blight source. - Remain vigilant about other potential outside sources of inoculum, such as cull piles, non-fungicide treated fields, and plants and weeds in the potato family that may be growing in ditchbanks and gardens.
<u>*Fall*</u>	
- Remain cognizant of the fact that late blight can occur anytime and that in years when disease pressure has been low during the growing season, the disease can appear suddenly late in the season if weather conditions become favorable. - Sporulating lesions on dying potato vines are a primary way in which tubers can become infected if spores wash into the hill. This is one reason that adequate hilling is essential, and also why some growers apply copper fungicide to vines at the end of the season so as to protect tubers. - Before initiating harvest operations, make certain that potato vines are completely dead. Some specialty potato cultivars grown in western Washington require that vine kill operations are repeated, otherwise vines can remain green for a long time and harbor lesions with spores. - A complete vine kill also helps to assure that any blighted tubers will rot before harvest and that healthy tubers will have adequate skin set and few pathogen routes of entry.	- Harvest fruit while green and ripen them indoors when weather conditions become favorable for disease. Even if only a few late blight lesions are detected in the planting late in the season, fruit losses can occur quickly. - Remove and destroy infected tomato fruits and vines.
<u>*Winter*</u>	
- Blighted tubers break down in storage very quickly. Learn to recognize the symptoms of tuber blight (Figure 5), and avoid storing blighted tubers for any prolonged period of time. Sort out and destroy or bury harvested diseased tubers before they are put into storage. Keep the storage pile as shallow as possible, maintain storage temperatures below 50°F, operate fans to reduce buildup of moisture in the pile and high humidity, avoid introducing warm outside air which could lead to condensation on the pile, and monitor the pile daily (Knowles and Plissey 2008). - Do not create cull piles of potato tubers discarded from the field or potato storages. Disposal of cull potatoes can be done instead by using the culls as cow feed, spreading the culls in a thin layer to rot on the soil surface over the winter, or by burial in the field after tubers freeze or rot.	- Do not create cull piles of rotten tomatoes.

Potato		Tomato (field and greenhouse)
	- If used as cow feed, cull potatoes should be: (i) secured from falling or rolling off trucks, (ii) dumped only onto impervious surfaces (asphalt or concrete), (iii) completely fed or ensiled after delivery, and (iv) managed to prevent volunteer plants.	

Further Reading

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