Pest Management Regulatory Agency
Agence de réglementation de la lutte antiparasitaire

S96-01

Sustainable Pest Management Series

Integrated Management of Late Blight on Potatoes

The Pest Management Regulatory Agency (PMRA) has a mandate to protect human health and the environment by minimizing risks associated with pest control products, while enabling access to pest management tools.

The PMRA is committed to encouraging the development of sustainable pest management systems, which are those that are economically viable, and meets society's needs for human health protection, food and fibre production, and resource utilization, while conserving or enhancing natural resources and the quality of the environment for future generations. Alternative pest management strategies and integrated pest management are fundamental elements of sustainable pest management and can make significant contributions to reducing risks to humans and the environment.

The purpose of this document is to provide an overview of the current information on late blight on potatoes. The intent is to provide information on the disease, to heighten the awareness of the need for an overall integrated management approach, and to describe the elements of that approach. Representatives of grower groups, pesticide manufacturers, provincial and federal governments have jointly developed this document.

(publié aussi en français) **June 7, 1996**

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This document and a factsheet were produced by a working group consisting of representatives of grower groups, pesticide manufacturers, provincial governments, research scientists, the Canadian federal government and the United States Environmental Protection Agency.

The project was coordinated by the Pest Management Regulatory Agency, the Canadian Horticultural Council and Agriculture and Agri-Food Canada.

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Table of Contents

1.0 Introduction 1

2.0 Biology of Late Blight Fungus 1
- 2.1 Disease Symptoms 1
- 2.2 Reproduction, Strains and Mating Types 2
- 2.3 Disease Development 3

3.0 Elements of Integrated Management of Late Blight on Potatoes 4
- 3.1 Healthy Seed 4
- 3.2 Crop Varieties and Resistant Cultivars 5
- 3.3 Sanitation and Cull Clean-up 6
- 3.4 Cultural Practices and Rotation 7
- 3.5 Forecasting Techniques and Scouting Systems 8
- 3.6 Application Technology 9
- 3.7 Scheduled Fungicide Programs 10
- 3.8 Harvesting, Grading and Storage Monitoring 12
- 3.9 Considerations for Home Gardens, Greenhouse Operations and Specialized Farms 12

4.0 Recommendations 13

Recommendations for Implementation of Integrated Management of Late Blight 13
Recommendations for Further Work and Development of Elements of IPM for Late Blight 15

Acknowledgements 16
Additional Sources of Information 17

1.0 Introduction

The purpose of this document is to provide an overview of the current information available on late blight on potatoes in order to respond to the increase in disease, and of its impact in Canada. The intent is to provide information on the disease, to heighten the awareness of the need for an overall integrated management approach to this disease, and to describe the elements of that approach. The document is not intended to cover all aspects of management of late blight on potatoes in all areas, but will provide a reference list for more detailed information.

Late blight is a community disease, that is, it is easily spread from farm to farm and over greater distances. Therefore, effective management of late blight requires participation of all operators. Strategies for control of late blight must be communicated to, understood by, and used by all those involved in potato production and processing. The information should be made available through as many venues as possible. Special attention is needed to ensure that home gardeners and greenhouse operators are informed.

2.0 Biology of Late Blight Fungus

Late blight has been a problem for potato growers in Canada since the 1840s. The disease is caused by the fungus *Phytophthora infestans*, which can also attack tomato, pepper, and some weeds of the solanaceous family such as hairy nightshade. The disease originated in central Mexico, moved to New York around 1840, and then spread via airborne spores to Canada in about three years. At the same time, the disease spread to Europe, causing serious crop losses and the strife of the Irish Potato Famine.

2.1 Disease Symptoms

Prevention is critical for adequate management of this disease. Early detection of hot spots can contribute to its successful management. Late blight symptoms can be similar to the symptoms of other diseases, and the growth characteristics of the fungus can be similar to those of other fungi. Therefore, diagnosis by trained and knowledgeable individuals is important.

Seasonal late blight development often begins when airborne spores (sporangia) of the fungus infect leaves, stems or flower parts in wet weather. Fungal growth within the plant becomes visible as water-soaked spots at the edge or tips of leaves in high moisture areas of the plant canopy. These spots appear four to eight days after infection and enlarge daily, becoming brown with a light green border. Sometimes these symptoms are similar to those of the diseases grey mould and early blight.

With rain or wet periods (dew or crop irrigation), white growth and spores of the fungus causing late blight will form every night on the underside of infected leaves, or on diseased spots on lower stems. Production of spores occurs through asexual reproduction. With prolonged wet conditions, new infections and disease symptoms appear rapidly, even on the upper leaves and floral parts of the plant. The spores are easily carried by wind, rain and irrigation water to other plant tissues, and can be washed into the soil to infect tubers.

Tuber rot lesions are irregularly-shaped, dark areas on the tuber's surface, below which the tuber tissues display a granular, moist, reddish brown appearance. Tuber dry rot progresses slowly unless moisture conditions are high or secondary decay organisms are present. Then, a rapidly decaying wet rot develops. Spores are formed on the tuber's surface under moist conditions and can be moved by air or water, causing new infections.

Late blight is an unforgiving disease. **When symptoms are visible in the field, the disease has already been present for four to eight days.** Because it reproduces at extremely high rates and responds rapidly to favourable weather and crop conditions, late blight can quickly destroy a whole crop. It is a community disease, whose spores are easily spread from farm to farm, and sometimes over greater distances, by farm equipment, wind and rain.

2.2 Reproduction, Strains and Mating Types

For many years, the late blight fungus that was responsible for major crop losses around the world belonged to a genetically uniform population. It was designated as the A1 mating type of the fungus, based on research in the 1950s which discovered that the pathogen had two mating types while the A1 mating type was widely distributed, the A2 type, the sexual partner for A1, was initially found only in central Mexico. This stable situation changed in the 1980s with the movement of the A2 mating type and new strains of the A1 type from Mexico to Canada, the United States and Europe.

Fungi of either A1 or A2 mating type can undergo asexual reproduction. Asexual reproduction involves the very large number of spores (sporangia) produced daily on plant tissue which lead to the disease transmission traditionally encountered, and described above. The spores directly, or indirectly (zoospores), infect living tissue. They do not survive long outside living plant tissues. **The generation time of the asexual cycle is five to seven days.** Millions of spores can be produced on a single plant during the growing season. The disease can, therefore, become established and spread very quickly.

The occurrence of both the A1 and A2 mating types in potato fields provides conditions for sexual mating between the two types and the production of sexual spores (oospores). However, **the A1 and A2 mating types must be in physical contact to produce the oospores**. Unlike the asexually-produced spores (sporangia), oospores are produced in much smaller numbers (hundreds per plant per season), and can survive outside of living plant tissues.

Sexual reproduction between the two mating types also results in genetic mixing and production of a greater variety of characteristics which could improve pathogen survival and disease potential. New strains or genotypes of the fungus have occasionally been created by the A1 mating type during asexual reproduction. For example, strains have been found in Canada that differ in their response to the fungicide metalaxyl: some strains are sensitive and some are insensitive. These exist in both A1 and A2 populations. However, many more new strains of the fungus may become established throughout North America and elsewhere when the A1 and A2 mating types are together, and produce spores by sexual reproduction.

The migration of the A2 mating type and new strains of the A1 type into potato-producing areas may result in a rapid change in the genetics of the fungal population and the formation of many new strains of *P. infestans*. This is a serious concern for the potato industry, specialty operations, and home gardeners, since the new strains of the fungus appear to be more aggressive pathogens. In addition, new strains may overcome genetic resistance in some potato cultivars, and may become resistant to some fungicides. Based on pathogen population studies since 1990, both the A1 and A2 mating types have been detected in almost all potato production areas in Canada and the United States. In addition, new genotypes have been found that probably arose from sexual reproduction. The impact of these new strains is yet to be fully studied and understood.

Regardless of the pathogen type, disease management remains difficult due to the dramatic effects of weather conditions and the aggressiveness of the fungus.

2.3 Disease Development

Epidemics of late blight result from the spread of airborne spores from infected to healthy plants under cool, moist weather conditions. The late blight fungus does not require stressed plants in order to thrive and cause the disease.

Airborne spores may be produced daily and can travel several kilometres in a day, easily crossing field, provincial and national borders, causing new infections which remain active over a wide range of temperatures (10-30EC). **Under weather and crop conditions favourable to late blight, a field of potatoes can be defoliated in two to three weeks.** Tuber yields may be reduced and late blight tuber rot may cause extensive crop losses in storage. The establishment and development of late blight is affected more by moisture than by temperature such that spores generally do not survive more than four to six hours at relative humidities below 80%. While moisture effects are difficult to quantify precisely, more disease symptoms are found on lower plant parts where canopy moisture levels are highest, except during prolonged wet periods when all plant parts can become severely diseased.

The presence of late blight later in the season increases the risk of disease during the following year. Since spores of the fungus can survive only in living plant tissues, infected tubers, potato cull piles, volunteer plants and some perennial weed species are typical overwintering sites of the fungus, and are, therefore, significant sources of late blight. However, unlike the short-lived airborne spores produced asexually, the oospores produced sexually may survive outside of living plant tissues, e.g., in soil and plant debris, thus increasing the potential for new sources of late blight.

Although late blight typically causes a dry rot in tubers, which can be managed to reduce losses, the disease enables entry of other secondary organisms. This often results in wet rots which are difficult to control, and can lead to substantial tuber losses. Minimizing late blight tuber rot is also important, as it is a source of disease for next season.

Potato late blight can enter fields and production areas despite the best efforts of an individual, e.g., via airborne spores. The pathogen adapts quickly, and rapidly takes advantage of favourable weather conditions and weaknesses in disease control practices. Therefore, adequate disease management requires that everyone utilize all tools in an integrated disease management package.

3.0 Elements of Integrated Management of Late Blight on Potatoes

3.1 Healthy Seed

The use of healthy, disease free seed pieces is always beneficial, and is an important part of an integrated management strategy for late blight. This is vital for home gardeners, greenhouse operations, and specialized farms, as well as potato producers with a large acreage.

As with other tuber borne diseases, it is recommended that seed be obtained from sources with effective disease management practices, i.e., inspected seed production systems. However, late blight is not a quarantinable disease and the seed certification system was designed for quarantinable diseases such as viruses and bacterial ring rot. Therefore, it is incumbent on the potato producer to examine all seed prior to use to determine the risk of late blight.

Current protocols for examination of potatoes rely on visual inspection of unwashed tubers for signs of dry rot. On unwashed potatoes, the rot symptoms on the tuber surface are difficult to see unless they are large, or have secondary organisms causing wet rots. Below the surface, the tuber tissue displays a reddish-brown grainy appearance, unless secondary rot organisms have also entered. Infected tubers which are removed from seed lots should be destroyed (buried, composted, etc.) to eliminate them as disease sources.

The infection can be difficult to detect, especially if it is of a minor nature. Washing potatoes is sometimes necessary to detect the infection. Washing is very costly, however, and increases the potato's susceptibility to other diseases. Cost-benefit considerations usually argue against washing very large seed lots for the purpose of inspection. For smaller operations, carefully grade out suspicious looking tubers when preparing seed for planting. Look for tubers that are partially decayed or mummified, yet still sound enough to send up some sprouts. Separate these and dispose of them in a secure manner, off your farm if possible, and where they will not be a source of disease. Seed lot samples can be incubated in cool (10-15EC), moist, dark conditions for three to five days, then examined for growth (different than other fungi) of the late blight pathogen.

Visual inspection of seed tubers is useful to remove heavily infected tubers, to prevent high levels of disease spread during seed handling operations, and to reduce disease risks at and after planting.

There are many factors which limit the effectiveness of tuber inspection. Because the fungus is airborne, and because of the large influence of weather on spread of the disease, even a low level of infection, i.e., one infected tuber, can lead to an outbreak. On the other hand, the use of infected seed does not necessarily lead to a high risk, as dry weather can reduce the risk of disease. To further complicate matters, diseased tubers are often not distributed evenly throughout a seed lot. Therefore, to inspect for late blight with the intention of eliminating the disease would require an inspection of each tuber.

While seed cutting does not always result in disease spread, especially if the pathogen is not forming spores on the diseased areas, the risk of disease spread would increase as the amount of disease present increases. Unfortunately, no post-harvest or pre-plant tuber treatment fungicides are currently registered for the control of late blight tuber rot. **Prevention, coupled with the removal of diseased tubers, is the most cost effective control method**.

It is difficult to guarantee a high level of disease freedom using tuber inspection. Control of late blight requires an integrated strategy, employing all of the available tools. The use of healthy seed is an important part of this strategy. The healthier the seed, the lower the risk of late blight infection. The issue of healthy seed may increase in importance as more information becomes known about transmission of the disease via oospores produced through sexual reproduction.

3.2 Crop Varieties and Resistant Cultivars

Utilizing resistant varieties is another important tool in the integrated management of late blight. Some cultivars, such as Kennebec and Sebago, have demonstrated some resistance to late blight caused by traditional pathogen strains. Others, including some which are used in high acreage production, are more susceptible, such as Superior, Norchip, Shepody, Red Pontiac, and Russet Burbank. Local potato production guides, such as the *Atlantic Canada Potato*

Guide, provide information on the resistance of cultivars to late blight. Significant research activity is underway in Canada to determine the disease response of current varieties to the new strains of the pathogen.

Canadian potato researchers are developing new varieties with stable, horizontal, resistance (multi-gene). Unlike the previously sought vertical resistance (single gene) which the pathogen overcame quite quickly (Kennebec), horizontal resistance is desirable as the fungus cannot overcome it as quickly (Sebago). Resistant varieties can be used to reduce pesticide use without increasing disease risk.

The use of resistant varieties may be limited by customer preference for major varieties in production that are not resistant. New, resistant lines may not have sufficient quality and yield characteristics to warrant production. However, home gardeners, greenhouse operators and specialized farmers could employ late blight resistant varieties such as Brador, Dorita, Island Sunshine, and so on. While some potato quality characteristics may differ from those of traditional varieties, **there are varieties with some disease resistance traits that contribute to an effective integrated disease management program**.

Although breeding programs aimed at enhancing resistance and quality in new cultivars are increasingly important, they must be integrated with disease research findings on the new strains of the fungus, and producer and end-user preference. The fungus has shown itself capable of overcoming resistance in certain cultivars, jeopardizing the resistance of some current varieties. Therefore, the use of resistant varieties must be combined with the use of other management tools.

3.3 Sanitation and Cull Clean-up

A program of sanitation of storage facilities and equipment can help control sources of the fungus.

After they have been emptied in the spring, storage facilities and containers should be cleaned using a high pressure spray to remove dirt, and then disinfected. Disinfection of all space and material with a recognized disinfectant is recommended. Ideally, all mud and dirt should be removed from the walls and floors and then surfaces kept moist with disinfectant for 20-30 minutes.

Unmanaged potato cull piles and trash heaps can be sources of initial infections of late blight all season long. Therefore, proper management of cull piles should be a major part of integrated management strategies for late blight.

The methods for handling cull piles are varied, and include burying, composting, feeding to livestock, and spreading on fields in winter to be frozen. Alternatively, they can be baked under black polythene sheets during the growing season. The main requirement is to avoid leaving tubers in cull piles for any length of time and, especially, to avoid uncovered cull piles from April to September.

Burial or disposal of cull piles should take place before the crop emerges in the spring. Any debris or slivers of potatoes left after seed cutting operations should be treated in the same manner. If volunteer plants grow in the burial site they should be rogued, or treated with a herbicide.

A problem with burial is that it takes more than a year for the potatoes to rot and some concerns have been expressed about pollution from the rotting process. Composting may offer a reasonable alternative. Properly composted potatoes effectively reduce disease risk. However, studies are needed to determine if oospores can survive composting. Compost should not be spread on potato land until such studies are completed.

Local conditions and legal requirements may dictate the method of managing cull piles. Permits may be required. For example, British Columbia does not recommend spreading culls on fields to freeze, as the province's climate may inhibit successful freezing and result in a potential source of oospores. Prince Edward Island requires pre-approval of burial of large cull piles due to groundwater concerns. Also in Prince Edward Island, a permit is required to feed culls to cattle in the summer, and is subject to a number of stipulations concerning how long this feed supply can remain uncovered.

For home gardens, greenhouse operations, and specialized farms, sanitation is a major method for disease prevention and control. Unlike very large potato operations, smaller-scale producers can more effectively clean up facilities and equipment, destroy infected crop debris and tubers, and so on. Since the pathogen can also attack tomatoes and peppers, these methods must be applied to the entire operation and all crops.

3.4 Cultural Practices and Rotation

Crop rotation is a necessary practice for late blight management. A minimum two year rotation of non-late blight hosts (crops other than potatoes, tomatoes and peppers), has been shown to be effective in late blight management. Rotational crops that include legumes or cereals have been shown to be beneficial. It is important to monitor rotational crops to destroy or remove any volunteer potato plants before new tubers are set. If volunteer plants are infected, they should be bagged and removed from the field. Weeds that are host to late blight, e.g., hairy nightshade, should also be controlled in rotational crops or waste areas.

Planting in well-drained soils with good exposure to drying winds, and without excessive shaded areas due to tree lines, reduces the disease risk. Forming hills that provide run-off away from the stem and adequate soil coverage above the tubers can reduce the opportunity for the spores to reach the tubers.

Well-spaced plants can increase air movement in the lower canopy, improve opportunities for spray coverage, promote more rapid drying, and generally provide a less conducive environment for disease development. In small scale operations, do not use floating mulches or row covers on early potatoes unless the field is completely isolated from other plantings (both yours and your neighbour's). Covers encourage early succulent growth and make spraying difficult. Alternating rows of resistant and susceptible varieties can also reduce the disease risk.

The use of irrigation can create conditions in the field that are conducive to disease development, and that are quite different from surrounding fields. Therefore, when using irrigation, greater vigilance is needed to prevent disease onset. Irrigation should be done during the day in order to avoid prolonged periods of wet foliage during the night.

When disease does occur in a field and is relatively confined, i.e., a hot spot, **rapid and complete destruction of the source of disease is vital**. Single plants with symptoms could be bagged and destroyed. Larger areas should be chemically destroyed, following up with a fungicide treatment to prevent spore formation. If late blight is identified in a field, workers should wear pants and boots that can be rinsed with water or disinfected between fields or farms. Equipment should be washed or disinfected.

Topkill along with a fungicide at least two weeks prior to harvest to allow time for infected tubers to rot, and to promote tuber maturity and thicker skins at harvest. Vines should be completely dead at harvest. Spores survive longer in wet soils; therefore, harvest when the soil surface is dry or windrow the potatoes to allow the surface of tubers to dry before harvest. Dig sprayer rows and low areas last, and store these potatoes where they can be easily moved in case of problems.

3.5 Forecasting Techniques and Scouting Systems

For fungicide applications to be effective as part of late blight management, and to avoid incorrect use, predicting the likelihood of disease outbreak is essential. **Forecasting techniques provide information on when to start applications and adjust timing.**

Forecasting models primarily use information on weather conditions in order to predict the likelihood of disease outbreak. Information on temperature, precipitation and relative humidity is collected from local monitoring stations or Environment Canada weather data. The models provide a determination of when fungicide treatments are recommended to begin, often by providing a severity index and a threshold value. The threshold may need to be adjusted to suit local conditions.

In order for the forecasts to be useful, they must be made readily available to growers. A variety of methods are used to provide forecasts or report on outbreaks. Some of the methods currently in use are newsletters, mailing or faxing to growers who subscribe to a service, toll-free phone numbers, radio broadcasts, and commercially available insect and disease monitoring services. Information provided is usually updated once or twice weekly.

Scouting fields for signs of the disease is also an important tool for predicting outbreaks. Scouting is generally done by growers or by private monitoring services. Differentiating late blight from diseases with similar symptoms by knowledgeable and trained personnel capable of recognizing the disease at very low levels is crucial to successful disease control. Diagnostic kits are available to detect fungi in the genus *Phytopathora*, but they do not distinguish the late blight fungus from other species, nor do they determine strain or fungicide sensitivity. Producers may rely on the advice of other people who are visiting their fields. This information is valuable if they are trained and knowledgeable in the identification of late blight. It is important to check places in fields where moisture persists after rains or dew, such as low areas and tree lines, and the lower parts of plants, and to report any incidence of late blight as soon as it is found, or to call a specialist if late blight is suspected.

In addition to providing an early warning about possible outbreaks, scouting provides an opportunity to destroy infected plants to reduce early sources of infection. If infected plants are rogued, they should be bagged and removed. Plants that are removed can be sent to local extension authorities for diagnosis and confirmation of the disease.

Forecasting and scouting are effective tools for late blight management, but must be combined with effective spray application and judicious selection of control materials to provide effective disease management.

3.6 Application Technology

The goal of the application is to deliver the fungicide to the target, namely, the potato plant. For the most part, **complete coverage of the plant surface is the goal of a fungicide application.** Complete coverage of the plant surface requires depositing spray material on both sides of the leaf and the stems.

The shape and density of the plant canopy affects spray coverage and, therefore, the adequacy of protection by fungicides. A dense canopy makes it harder for the spray droplets to penetrate through to the leaf material. There needs to be a good degree of penetration through the canopy to ensure coverage on the lower leaf surfaces. The volume of water required for good spray coverage increases as the size and density of the crop increases. Sprayer calibration is essential to ensure that the desired water volume is being delivered. A grower should refer to sprayer manuals and sprayer information available through local extension services.

The appropriate rate of fungicide will also change as crop growth increases. The range of rates available on most labels should be consulted.

The volume of the spray mixture used can affect the degree of coverage obtained. Lower water volumes are often perceived by growers to be beneficial as the spraying operation can be completed in a shorter period of time. However, lower volumes reduce coverage. In addition, equipment designed for herbicide application has neither the pressure capability nor the volume capacity for fungicide applications. Growers seeking more efficient sprayer operations should, instead, consider using water nurse tanks in the field. In addition, sprayer acreage capacity should not be exceeded and, where necessary, additional application equipment should be used for efficient spray operations. Where aerial application involves too low a volume to provide efficient coverage of plants, disease outbreaks often occur.

There cannot be one set of recommendations about best application methods. Every producer will need to make individual choices based on their circumstances. Generally the principles involved in application technology such as canopy density, water volume, and droplet penetration, are relatively simple to comprehend, but growers need to gain a thorough understanding of the interactions between all of the different principles to ensure acceptable disease management.

3.7 Scheduled Fungicide Programs

Fungicides should be applied as part of a disease prevention program. In preventative applications, **it is important to apply fungicides before late blight occurs**. This is true for both contact and systemic fungicide actives. Fungicides are primarily applied to prevent the initial occurrence of the disease and subsequently to retard the rapid development of the disease until after crop growth and tuber production has been completed. This would also reduce tuber infections and therefore disease carryover risks for the next growing season.

Good protection by fungicides requires good coverage of the leaves and stems, proper rates of application, adequate water volume and proper timing of applications. The timing of the first spray should be determined by forecasting coordinated with the stage of crop development, and should occur prior to closure of the crop within the row. Neither frost nor top-killing completely eliminates the production or presence of fungal spores. The application of fungicides should continue at and after top killing, until the plants are completely dead, to reduce the risk of late blight tuber rot.

Repeated sprays are required. The spray interval will depend on the product selected, the late blight forecast, stage of crop development, and the need to protect against other diseases, such as early blight. The required spray intervals for contact fungicides tend to range from five to ten days, while those for contact/systemic fungicide combinations are ten to fourteen days, interspersed with a contact fungicide at five to seven day intervals. Contact fungicide actives (anilazine, chlorothalonil, copper oxychloride, copper sulphate, copper sulphate (tribasic), cupric hydroxide, mancozeb, maneb, metiram, zineb, etc.) remain on plant surfaces, and act by direct contact with fungi. The shorter spray intervals for contact fungicides are required because the fungicide can be washed off plant surfaces or degraded by sunlight. Repeated applications are also required to provide protection for new plant growth. Currently registered contact fungicides act by interfering with several chemical processes, i.e., they have multi-site activity. Resistance is less likely to develop against such fungicides.

Systemic fungicide actives such as metalaxyl are absorbed and distributed throughout plant tissues and, therefore, provide a longer period of protection than contact fungicides. This is important during rapid growth phases of the crop where newly emerged foliage would not be protected by a contact fungicide applied earlier. Metalaxyl has single-site activity, however, and some strains of the late blight fungus have developed a resistance to this fungicide. Therefore, there are restrictions on the number of sprays that can be used in a year, and metalaxyl is now available only in combination with contact fungicide actives that can control metalaxyl resistant strains. In addition, it is important to monitor fungal populations for resistance when using this fungicide.

New chemicals currently under study have 'translaminar' or 'restricted systemic' activity. These chemicals enter plant tissues and may move short distances within a leaf or petiole, or farther in the plant (e.g., from stems into leaves), but do not move throughout the whole plant, as do true systemics. Some of these new chemicals have single or limited-site specific activity against the fungus, while others have multi-site activity similar to contact fungicides. As with metalaxyl, the use of these new chemicals that enter plant tissues will require care to prevent the development of resistant strains of the fungus. Most importantly, the systemic action of these fungicides, including metalaxyl, should not be confused with eradicative or curative action.

Two of these new fungicide actives (dimethomorph and propamocarb) have recently been accepted for registration in Canada adding to the list of tools that can be used by farmers against late blight. Providing new and different modes of action against disease organism that can produce a wide range of variants in nature, the new products are able to provide disease control by entering plant tissues as well as preventing disease by protecting plant surfaces for various periods of time. Propamocarb will provide some systemic translocation but only via upward movement from stems to leaves or within leaves, not downward or across from one leaf to another. Dimethomorph also provides some systemic translocation, and following foliar application, penetrates and moves within the treated leaf and across the leaf surface.

Expanding the range of control options available for use within an integrated strategy can contribute to proper management of resistant organisms. However, if these new fungicides re used improperly, resistance to them may develop within the pathogen population leaving farmers without the necessary tools to properly manage the disease. Like all fungicides for management of late blight, these fungicides must be used in preventative applications, and pathogen populations should be regularly tested for the occurrence of fungicide resistant strains. rotation of fungicides and use of mixtures are useful practices for avoiding resistance.

Most notably, relying on the use of fungicides as curatives or eradicants, that is, to eradicate the disease once it is established, is not effective. It can lead to development of fungicide resistant strains, and can result in significant yield losses due to tuber rots. Fungicides are most effective when used as part of a total disease management program for both the growing crop and the tubers.

3.8 Harvesting, Grading and Storage Monitoring

The late blight fungus grows on living tissue, including tubers. If infected tubers and wet soil go into storage, the fungus may sporulate and spread to other tubers. In addition, infected tubers may be entry points for wet rots, which can result in a loss of the entire storage.

Harvesting in dry weather, when vines have been dead for at least two weeks will reduce chances of tuber infection during the harvest operation, and will allow recognition and grading out of tubers that were infected in the field. Therefore, there is value in grading potatoes and removing infected tubers before they are put into storage.

Storage monitoring should be a routine matter for all producers. At the very least producers should visit the storage at least once a week to check for are hot spots, which indicate the start of storage breakdown due to rots. Essentially the hot spots must be cooled down, and the potatoes dried using ventilation.

Late blight can survive the storage season in tubers and become a source of disease the following year. This is particularly true for seed potatoes stored at low temperatures. Proper handling of tubers at the end of the storage season is essential to reduce disease risk.

3.9 Considerations for Home Gardens, Greenhouse Operations and Specialized Farms

Home gardens, greenhouse operations and specialized farms present special risks of late blight to themselves and to commercial producers. The disease can occur on many of the crops grown: potatoes, tomatoes, and peppers. Disease free seed, resistant varieties, removal of disease sources (volunteers and trash piles), and the use of various cultural practices to reduce disease risk are attainable and useful disease management methods.

It is important that home gardeners, greenhouse operators and specialized farmers read and use all of the practices described above, and adapt them as appropriate. Specific guides for home gardeners are available from the sources listed in at the back of this document.

4.0 Recommendations

Recommendations for Implementation of Integrated Management of Late Blight

1. Successful management of late blight requires an integrated pest management (IPM) strategy. An IPM strategy should be used in all potato production areas. Application of the IPM elements must be tailored to local conditions. The key elements of an IPM strategy, as described in Section III of this document, are as follows.

   ! **Healthy Seed:** Healthy seed is the foundation of successful disease management. Obtain seed from sources with effective disease management practices. Examine all seed prior to use, to determine late blight risk.

   ! **Crop Varieties and Resistant Cultivars:** Select varieties with resistance to late blight, wherever practical.

   ! **Sanitation and Cull Clean-up:** Follow a program of sanitation for storage facilities and equipment in order to eliminate sources of the disease. Avoid leaving tubers, including debris or slivers from seed cuttings, in cull piles for any length of time, and especially avoid uncovered cull piles from the start of planting to the beginning of harvest.

   ! **Cultural Practices and Rotation:** Use proper cultural practices, including the following, as the first line of defence.
   - Rotate potato crops with non-late blight hosts.
   - Use proper hilling to reduce infection in tubers.
   - Increase spacings of plants to reduce canopy density.
   - Carefully manage irrigation use to avoid increasing disease risk through prolonged periods of wetness.
   - Identify and destroy hot spots of infection in a field to reduce production and spread of spores by destruction and bagging of individual plants, or chemical destruction and fungicide treatment of larger areas.
   - Avoid fields that cannot be easily sprayed with fungicide.
   - Control weed hosts, such as hairy nightshade.
   - Remove or destroy volunteer potatoes found in other crops.

   ! **Forecasting Techniques and Scouting Systems:** Use forecasting to identify conditions conducive to disease development in order to effectively schedule preventative fungicide applications. Scout fields to identify hot spots and other sources of disease.

- **Application Technology:** Complete coverage of the foliage with fungicide is necessary to enable disease prevention, regardless of the application method, ground or air, traditional or newer application technology. To ensure adequate coverage of plants, use equipment designed for and appropriate to fungicide applications. Do not over extend acreage beyond what a sprayer can cover in the **minimum** time available, including bad weather, i.e., no more than two to three days acreage capacity per machine. Use adequate water volume, and increase water volume as the crop grows. Ensure regular and proper equipment calibration.

- **Scheduled Fungicide Programs:** Use fungicides as part of a preventative program. No fungicide is effective in curing disease that has already set in. Attempting to use fungicides as curatives can promote the spread of fungicide resistance.

- **Harvesting, Grading and Storage Monitoring:** Harvest only when vines are completely dead. Harvest suspect, shaded or wet areas after the rest of the harvest is complete. Grade potatoes and remove infected tubers **before** they are put in storage. Monitor storage facilities for hot spots, which indicate the start of storage breakdown due to rots. Carefully manage air flow, humidity, and temperature to reduce storage losses.

2. The following recommendations apply to the use of fungicides as part of an IPM strategy, and will help to minimize development and spread of resistance.

   - Use fungicides only as protectants before disease occurs, and never for disease eradication. Labels or use recommendations should specifically emphasize protectant use of all fungicides and should not refer to curative or corrective use, because of the risk of resistance.

   - Rotate between different fungicide groups or use tank mixtures of different fungicides, particularly when using fungicides that enter plant tissues or have single or limited-site activity against the fungus.

   - Begin fungicide applications early in the season, always before the disease develops, and continue through until harvest.

   - Ensure thorough coverage of potato plants with fungicide (stems and leaves, top to bottom of canopy) by using adequate water volumes. Less than thorough coverage will provide inadequate disease control.

   - Select fungicides and timing of applications as per label instructions, supported by scouting programs and forecasts based on local conditions. When disease potential is high, e.g., during rapid plant growth or heavy rains, the shorter labelled spray intervals should be used. When disease potential is low, e.g., extended hot dry weather, the longer labelled spray intervals are appropriate.

- ! Ensure that full fungicide programs continue throughout the season, until no further green tissue is present in the field, i.e., up to harvest.

- ! Crops should be monitored throughout the growing season (spring culls to harvested crops) for late blight. Pathogen populations should be monitored for sensitivity to metalaxyl or other fungicides for which resistance may be a problem by sending samples to a qualified laboratory for analysis.

3. Information provided to growers with respect to fungicide use, as in provincial production guides, should be updated to describe the elements of proper fungicide use, e.g., early treatment and scheduling applications using forecasts of conditions favouring late blight development. It is especially important to always indicate that fungicides used for late blight must be used in a **preventative program**. All late blight fungicides, including those with systemic action, should **not** be used for eradication of disease. Eradicative or curative use leads to the development of fungicide resistant strains of the pathogen.

Recommendations for Further Work and Development of Elements of IPM for Late Blight

1. Processors and other groups should be encouraged to consider resistance to late blight when selecting varieties. Continued and increased support is needed for the development of potato varieties with resistance to late blight, including new developments using biotechnology.

2. Development of rapid large-lot diagnostic methods for late blight are needed to continue monitoring pathogen populations for the occurrence and impact of fungicide resistance, to improve detection of late blight in seed stocks, and to identify the presence and impact of oospores, and new genotypes of the pathogen.

3. Investigation is needed of changes in patterns of disease development due to new genotypes, and the impacts of these changes on disease occurrence and management practices.

4. The effect of composting and burying of culls or diseased material on oospore survival needs to be determined in order to safely manage cull piles.

5. New knowledge is needed about how to better use crop rotation for late blight management, especially with regards to the impact and presence of oospores.

6. The performance of the traditional hydraulic sprayer needs to be maximized. Work is needed to document the factors affecting spray applications and fungicide efficacy, in order to provide growers with a better basis to make choices regarding applications. Suggested priority issues to be investigated are the effects of the following on coverage, penetration, and efficacy: water volume, varying spray qualities (fine, medium and coarse), boom height over canopy, and the redistribution properties of fungicides, especially with regard to dew and rainfall.

7. Development of resistance management labelling for fungicides should be accelerated and implemented.

Acknowledgements

The following individuals provided input, comments, and participated in the inaugural workshop for this project:

Les Armstrong
Pierre Beauchamp
Jim Beechey
Allan Brown
Ron Cameron
Adrian Carter
Shannon Coombs
Rick Delbridge
Denise Dewar
Douglas Doohan
Caroline Dykstra Nielsen
Al Edie
Doug Goudy
Andreas Hopf
David Hughes
Craig Hunter
David Kaminski
Ken Lingley
Scott MacDonald
Peter MacLeod
Al McFadden
Brent McLennan
Kit Nelson
David Ormrod
Sandy Perley
Bud Plat
Gary Platford
Karen Ryan
Tanya Saunders
Irwin Schmidt
Ferdie Schniedersmann
Wendy Sexsmith
Judy Shaw
John Smith
Tony Sturz
Leon Tartier
Dave Thompson
Robert Trottier
Patty Vandierendonck
Bob Vernon
Madeline Waring

The Drafting Group for preparation of the document was:

Les Armstrong
Craig Hunter
Wendy Sexsmith
Shannon Coombs
Ferdie Schniedersmann
John Smith

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