



United States
Department of
Agriculture

Animal and
Plant Health
Inspection
Service

Plant Protection
and Quarantine

New Pest Response Guidelines

Synchytrium endobioticum (Schilb.) Percival

Potato Wart Disease



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Introduction

Plant Protection and Quarantine (PPQ) develops New Pest Response Guidelines (NPRGs) in preparation for potential future pest introductions. This document is based on the best information available at the time of development and may not reflect the latest state of knowledge at the time the pest is detected. In addition, the PPQ response must be tailored to the specific circumstances of each pest introduction event, which cannot be predicted. Therefore, this document provides general guidelines that can be used as a basis for developing a situation-specific response plan at the time a new pest is detected.

Pest Overview

Key Information

- ◆ *Synchytrium endobioticum* is listed as a Select Agent by the USDA Select Agent Program. Only the USDA APHIS PPQ Science and Technology Beltsville Laboratory should attempt molecular diagnostics for identifying *S. endobioticum*. For more information, please visit <https://www.selectagents.gov/>.
 - ◆ *Synchytrium endobioticum* produces sporangia that can remain dormant and viable in soil for 30–50 years.
 - ◆ Human-assisted movement of infected potato tubers and infested soil spreads *S. endobioticum* to new locations.
 - ◆ Currently, quarantine regulations are in place to prevent the introduction of this fungal pathogen into potato production systems in the United States. There are no chemical or non-chemical treatments available for use against *S. endobioticum*.
 - ◆ *Synchytrium endobioticum* has different pathotypes that continue to change, complicating possible control and eradication options.
-

Taxonomy

Scientific Name

- ◆ *Synchytrium endobioticum* (Schilb.) Percival

Synonym(s)

- ◆ *Chrysophlyctis endobiotica* Schilb.
- ◆ *Synchytrium solani* Masee

Common Name(s)

- ◆ potato wart disease
- ◆ black wart of potato

- ◆ wart disease
 - ◆ black scab
-

Biology and Ecology

Life Cycle

Synchytrium endobioticum has two reproductive cycles (Franc, 2007). The asexual reproduction cycle occurs during spring and summer when favorable conditions (adequate water supply for germination of sporangia) occur. The sexual reproduction cycle occurs during autumn and winter when conditions are unsuitable (inadequate water supply) for sporangia germination. Both cycles produce sporangia that germinate into infectious mobile spores. However, the sexual cycle produces resting sporangia that can survive up to 50 years at depths up to 50 cm (20 inches) in the soil (Franc, 2007). The sporangia produced during the asexual cycle are short-lived and responsible for the secondary disease cycle. Each reproductive cycle takes about 10-12 days to complete (Weiss, 1925).

Synchytrium endobioticum depends on live hosts to complete its life cycle. In the spring, resting sporangia germinate in decaying warts and soil, releasing their mobile spores (Franc, 2007; Hampson, 1993). These mobile spores can travel up to 2 inches in wet soil and infect new growth of susceptible hosts (Franc, 2007). After the mobile spores infect the host, characteristic warty galls are produced (Fig. 3-4). As long as conditions are suitable, including adequate water, the disease cycle will continue with the production of more sporangia. When adverse conditions (including water shortages) occur, galls decay and release resting sporangia into the soil.

Potato wart disease can occur when summers are cool with an average temperature of 18°C (64°F), winters are long (160 days) with an average temperature of 5°C (41°F), and precipitation levels are moderate (28 inches). During ideal conditions, potato wart disease can develop from an inoculum density of less than one resting sporangium per gram of soil (Hampson, 1992).

Hosts

Potato, *Solanum tuberosum* L., is the only known cultivated host of *S. endobioticum* (Obidiegwu et al., 2014). *Solanum lycopersicum* L. (tomato), may be a host of *S. endobioticum* but the data to support this is unclear. We found no evidence that *S. endobioticum* damages tomato plants. Researchers think that

tomato may just be a reservoir host (a host that does not develop severe symptoms but provides inoculum for spreading *S. endobioticum* to new areas) (Baker et al., 2007; Lyman et al., 1920). Some uncultivated solanaceous plants are considered experimental hosts (Table 2-1).

Table 2-1 List of reported experimental plant hosts of *S. endobioticum* in Solanaceae

Scientific name	Common name	References
<i>Datura</i> spp.	jimsonweed	Hampson, 1979
<i>Nicandra physalodes</i> (L.) Gaertn.	apple-of-Peru	Martin, 1929 Phadtare and Sharma, 1971
<i>Nicotiana rustica</i> L.	Aztec tobacco	Phadtare and Sharma, 1971
<i>Nicotiana</i> spp.	tobacco	Phadtare and Sharma, 1971
<i>Physalis alkekengi</i> L. var. <i>franchetii</i> (Mast.) Makino (= <i>Physalis franchetii</i> Mast.)	hozuki	Hampson, 1979
<i>Schizanthus</i> spp.	schizanthus	Hampson, 1979
<i>Solanum americanum</i> Mill. (= <i>Solanum nodiflorum</i> Jacq.)	American nightshade	Martin, 1929 Phadtare and Sharma, 1971
<i>Solanum chacoense</i> Bitter	wild potato	Weiss, 1925
<i>Solanum commersonii</i> Poir.	Commerson's nightshade	Weiss, 1925
<i>Solanum dulcamara</i> L.	bitter nightshade	Cotton, 1916
<i>Solanum dulcamara</i> L. var. <i>villosissimum</i> Desv.	climbing nightshade	Martin, 1929
<i>Solanum jamesii</i> Torr.	wild potato	Weiss, 1925
<i>Solanum lycopersicum</i> L.	tomato	Lyman et al., 1920
<i>Solanum nigrum</i> L.	black nightshade	Cotton, 1916
<i>Solanum pimpinellifolium</i> L. (= <i>Lycopersicon pimpinellifolium</i> (L.) Mill.)	currant tomato	Phadtare and Sharma, 1971 Sarbhoy et al., 1975
<i>Solanum pseudocapsicum</i> L.	Jerusalem-cherry	Phadtare and Sharma, 1971 Sarbhoy et al., 1975
<i>Solanum sisymbriifolium</i> Lam.	sticky nightshade	Sarbhoy et al., 1975
<i>Solanum</i> spp.	nightshade	Alvarez, 1976
<i>Solanum villosum</i> Mill.	red nightshade	Martin, 1929

Dispersal

Human-Assisted Spread

Humans can disperse *S. endobioticum* through movement and trade of infected potato tubers or tubers contaminated with infested soil (Obidiegwu et al., 2014).

The pathogen can also spread by moving infested soil on farm machinery, equipment and tools, and footwear (Hampson and Coombes, 1996; Hampson and Coombes, 1989; Obidiegwu et al., 2014).

Natural Dispersal

In wet soil, *Synchytrium endobioticum* mobile spores can swim a distance of up to 2 inches (Franc, 2007; Weiss, 1925). These mobile spores remain viable in the soil for a maximum of 2 hours after forming, depending on temperature (Curtis, 1921; Franc, 2007; Percival, 1910). Earthworms may disseminate *S. endobioticum* over a small area (4 to 10 inches) (Hampson and Coombes, 1989).

Synchytrium endobioticum can be spread over longer distances in 1) manure from animals that have ingested infected tubers, 2) infested soil on animals' hooves, 3) runoff of contaminated irrigation water, and 4) windblown dust from infested fields (Hampson, 1981, 1996; Hampson and Coombes, 1989; Joestring, 1990; Obidiegwu et al., 2014).

Pest Identification

Species ID/Diagnostic

Synchytrium endobioticum lacks hyphae and instead produces mobile zoospores within sporangia. *Synchytrium endobioticum* is most readily detected by surveying field soil ([Chapter 4](#) of this document). The sporangia must be extracted from soil prior to identification.

Extracting the Pathogen from Soil

The sporangia are usually found in small aggregates or clumps of soil that measure 0.1 to 2.0 mm in diameter (depending on soil type). These soil aggregates must be broken up to extract, and then examine and count the sporangia (Pratt, 1976). The soil must be dried completely before extracting the sporangia. Various extraction methods have been developed that vary by the volume of soil that can be processed (20 to 100 grams), the sieving system (electro-magnetic or manual), and the reagents (chloroform, calcium chloride, and zinc sulphate) used (van Leeuwen et al., 2005; Pratt, 1976). Each technique has its limitations, and the extraction method should be chosen based on the equipment and supplies already available. Below are the extraction methods routinely recommended:

- ◆ The European and Mediterranean Plant Protection Organization Modified Standard PM 3/59 method consists of wet sieving a 100 grams soil sample with two stacked sieves, (upper sieve, 75µm and lower sieve, 25µm), drying the sediment on filter paper, centrifuging with chloroform or CaCl₂, collecting on filter paper, and resuspending in lactoglycerol (van Leeuwen et al., 2005).
- ◆ The Dutch Plant Protection Service (PPS) method is capable of processing smaller sample sizes (20 to 80 grams), wet-sieving with stacked sieves, 75 µm (upper) and 25µm (lower), centrifuging with CaCl₂, and then counting the sporangia in CaCl₂ (van Leeuwen et al., 2005).

Morphological Identification

Summer sporangia

Synchytrium endobioticum may produce a sorus, a cluster of one to nine sporangia that measures 0.025–0.038 × 0.062–0.087 mm. The sporangia are polyhedral, ovoid to almost round, light golden brown, aseptate, transparent, smooth, and thin-walled. Each sporangium measures 0.041–0.064 × 0.047–0.075 mm (Obidiegwu et al., 2014; SPHDS, 2016; Walker, 1998).

Resting sporangia

Resting sporangia are thick-walled structures, usually spherical to ovoid in shape, golden brown, and 0.024–0.075 mm in diameter. The wall is ornamented with irregularly shaped wing-like protrusions (EPPO, 2004; Pratt, 1976) (Figs. 3-1 to 3-3).

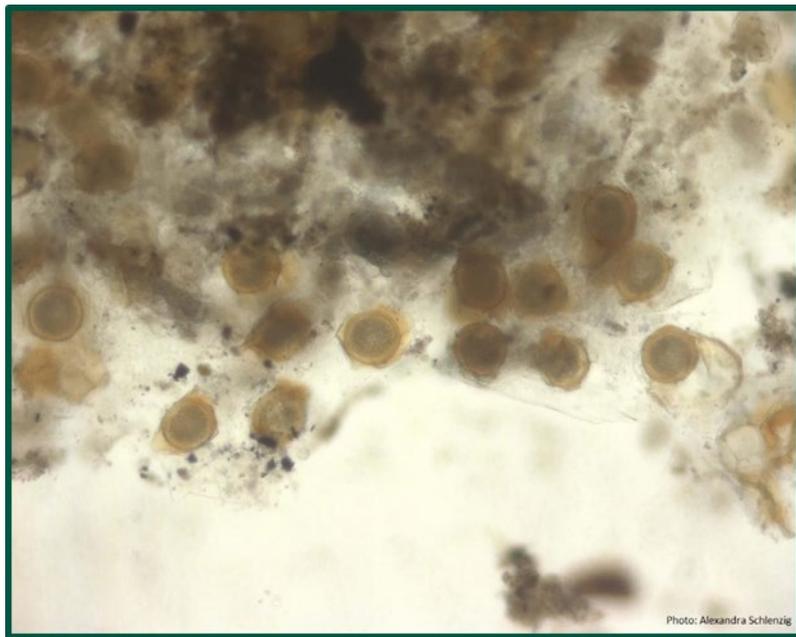


Figure 3-1 Resting sporangia of *S. endobioticum* magnified 100× (image credit Alexandra Schlenzig, Science and Advice for Scottish Agriculture (SASA))

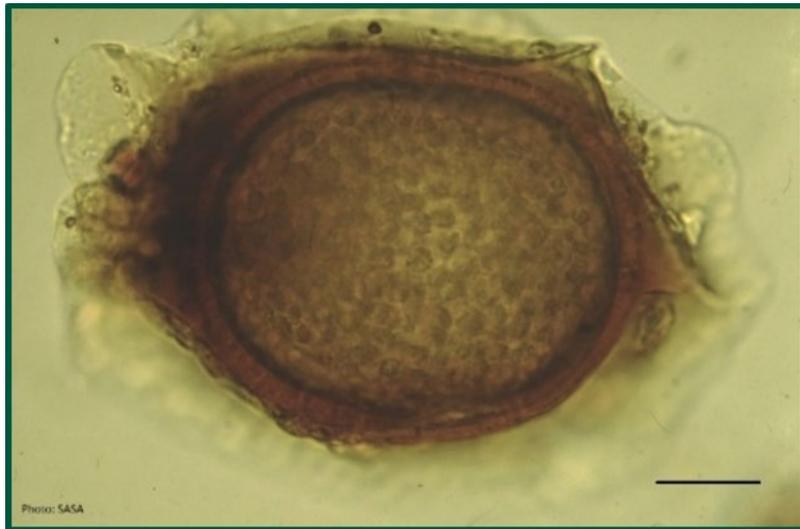


Figure 3-2 Single resting sporangia of *S. endobioticum* (image credit A) Science and Advice for Scottish Agriculture (SASA)



Figure 3-3 A) Resting sporangia; B) germinating resting sporangia of *S. endobioticum* (image credit Donna Smith, Canadian Food Inspection Agency)

Mobile spores (zoospores)

Mobile spores are pear-shaped and measure 0.0015 to 0.0022 mm in diameter. They have a posterior flagellum approximately 0.0025 mm in length (Lange and Olson, 1978; Walker, 1998) that allows them to swim in water through soil (Fig. 3-4).

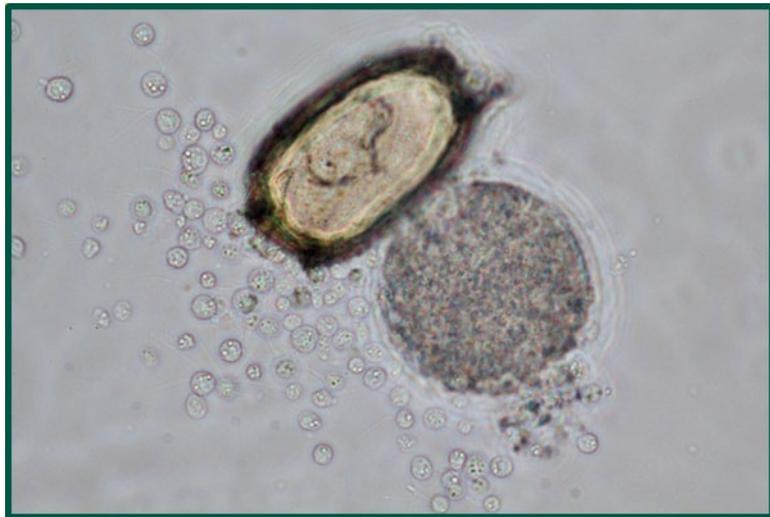


Figure 3-4 External sporangia releasing *S. endobioticum* zoospores (image credit Donna Smith, Canadian Food Inspection Agency)

Molecular Identification

- ◆ Polymerase Chain Reaction (PCR) can accurately detect and quantify *S. endobioticum* from soil extracts and infected plants (van den Boogert et al., 2005).
- ◆ Microarray-based hybridization can detect *S. endobioticum* along with other pathogens in infected plants (Abdullahi et al., 2005).
- ◆ Real-time PCR can accurately quantify potato wart from soil extracts, warts, and different parts of infected plants (Smith et al., 2014; van Gent-Pelzer et al., 2010).

Signs and Symptoms

The main diagnostic symptoms of potato wart disease are galls that form on plant parts below ground (i.e., stolon bud, stem base, and tuber eyes) (Figs. 3-5 and 3-6). Young developing tubers infected with *S. endobioticum* can be spongy and distorted. As the tubers mature, the eyes can develop galls (Obidiegwu et al., 2014). Tubers may be mangled or entirely replaced by galls (Stevenson et al., 2001). Sprouts can also be so severely infected that the potato plant fails to develop from planted tubers (Hampson, 1993). Galls rarely form on above-ground plant parts such as leaves, flowers, and upper stems and do not form on roots (Hampson and Coombes, 1985; Stevenson et al., 2001). Galls are initially white to brown, but they turn black at maturity and eventually decay (Putnam and Sindermann, 1994; Stevenson et al., 2001) (Figs. 3-7 to 3-9). They are mostly round and measure on average between 0.40 to 3.20 inches in diameter

(Stevenson et al., 2001). Galls in decaying tissues contain microscopic sporangia (Figs. 3-1 to 3-3).

Potato wart symptoms can be confused with other potato diseases. Powdery scab (causal agent: *Spongospora subterranea*) is soil borne, affects stems and stolons, and causes wart-like galls on tubers (Fig. 3-10) (Merz, 2008). Potato smut (causal agent: *Thecaphora solani*), is characterized by warty swellings on the surface of potato tubers (Fig. 3-11) (Chalkley, 2016). False wart or pseudo-wart, like potato wart, can have outgrowths in the eyes of tubers. However, false wart may be caused by a chemical contaminant rather than a pathogen (EPPO, 2004; USDA-APHIS, 1990).



Figure 3-5 Galls on stem (image credit Alexandra Schlenzig, Science and Advice for Scottish Agriculture (SASA))

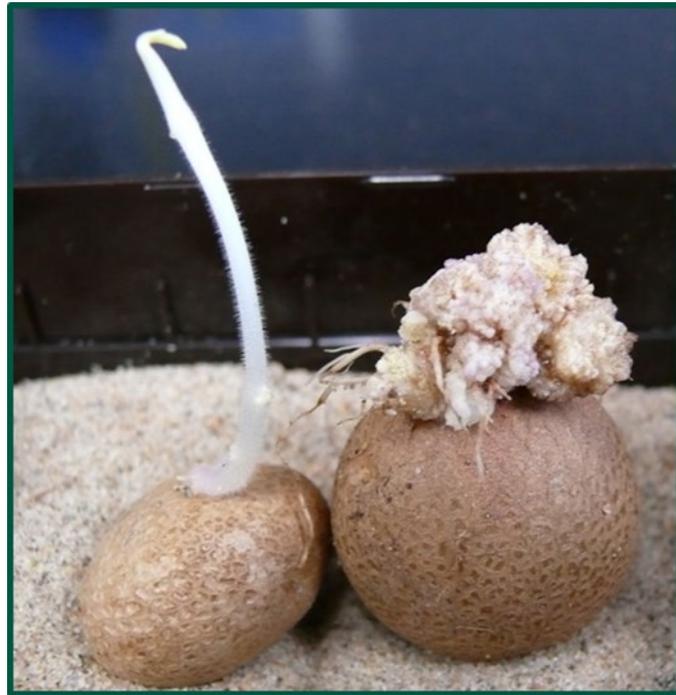


Figure 3-6 Healthy sprout (left) and infected sprout (right) (image credit Donna Smith, Canadian Food Inspection Agency)



Figure 3-7 Fresh tuber gall (image credit Donna Smith, Canadian Food Inspection Agency)

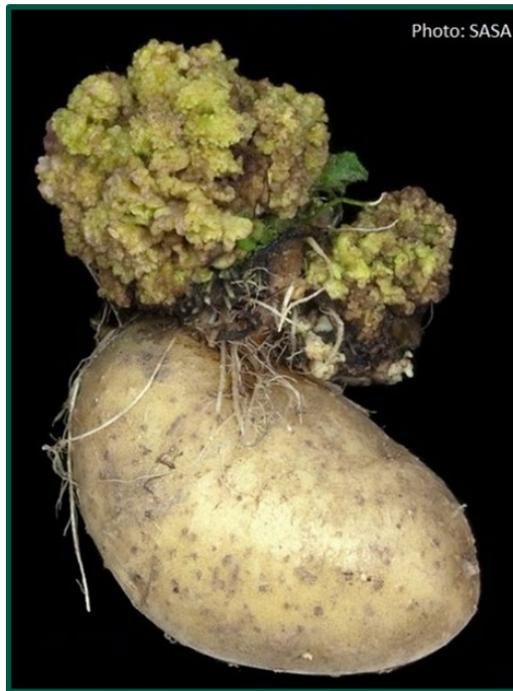


Figure 3-8 Potato tuber with fresh galls (image credit Science and Advice for Scottish Agriculture (SASA))



Figure 3-9 “Potato tuber covered in galls” [image credit 2012, Her Majesty the Queen in Right of Canada (Canadian Food Inspection Agency)]



Figure 3-10 Powdery scab (*Spongospora subterranea*) lesions on potato courtesy of Ministry of Agriculture, Food and Rural Affairs, Ontario CropIPM.



Figure 3-11 Potato smut (*Thecaphora solani*) Barrus on *Solanum tuberosum* L. (potato) William M. Brown Jr., photographer, Bugwood.org licensed under a Creative Commons Attribution 3.0 License.

Survey

Survey Types

Plant regulatory officials will conduct detection and, where appropriate, delimitation surveys for *S. endobioticum*. The purpose of a detection survey is to determine the presence or absence of *S. endobioticum* in an area or in fields where it is not known to occur. Fields that shared farm equipment with an infested field or received seed from the same seed source or farm as an infested field should be targeted for detection surveys (CFIA, 2002).

After a new detection is confirmed in a field, state and federal inspectors may use a delimitation survey to define the spatial extent of the infestation in a field.

Timing of Surveys

In fields currently planted in potatoes, surveys are ideally conducted near or at tuber harvest. In fields that are fallow or planted with another crop, there is no preferred time for the survey.

Detection Survey

Synchytrium endobioticum produces symptoms mainly on below-ground plant parts. Therefore, a visual survey of the above-ground parts is not reliable for detecting the pathogen. Instead, we recommend sampling the field soil. Most potatoes grown in North America are harvested with mechanical harvesters, but they can also be harvested using other tools like a spading fork or plough (Bohl and Johnson, 2010). Consider the safety of surveyors when collecting samples.

The distribution of *S. endobioticum* in fields is patchy and unpredictable, most likely from random planting of diseased seed tubers. For the detection survey, surveyors will systematically collect soil samples throughout the field to obtain a representative sample of the field. For instructions on pre-survey preparation, sanitation, and clean-up, refer to [Appendix A](#).

Collecting Soil Samples

1. Determine the size of the field.
2. Look at [Table 4-1](#) to decide how many soil samples to collect. For example, if your field is larger than 1 acre, then collect one subsample (soil core) every 8 paces, which is roughly 20 feet. [Figure 4-1](#) demonstrates how to survey a 1.5 acre-field.

Table 4-1 Sampling frequency using a square grid pattern for potato wart disease survey activities (CFIA, 2002).

Size of Field	Grid sampling frequency
< 0.5 acres	2 x 2 pace *
0.5 - 1.0 acres	4 x 4 pace
> 1.0 acres	8 x 8 pace

* One pace is approximately 2.5 feet. Therefore, if the field size is less than 0.5 acres, a soil core would be collected at every 5 feet in a square grid pattern covering the entire field.

3. Begin sampling by walking the specified number of paces from [Table 4-1](#) or use a mechanical sampler calibrated with the specified number of paces (distance). Take soil cores using a 1.9 cm soil probe (Oakfield model L or equivalent) along a square grid pattern ([Fig. 4-1](#)).
4. Combine 60 soil cores into a clean bucket and mix well. Transfer the 60 soil cores to a double-walled paper bag (or two single paper bags placed inside one another). This bag represents one composite sample.
5. Securely close the bag and record collector's name, grower's name, field location, and date on the outside of the bag.
6. Continue to move the specified number of paces down the field and collect soil cores along the grid in the direction of the arrow ([Fig. 4-1](#)) until the survey is complete.
7. Make sure all bags containing the composite samples are in a secure container for transportation to a designated laboratory.

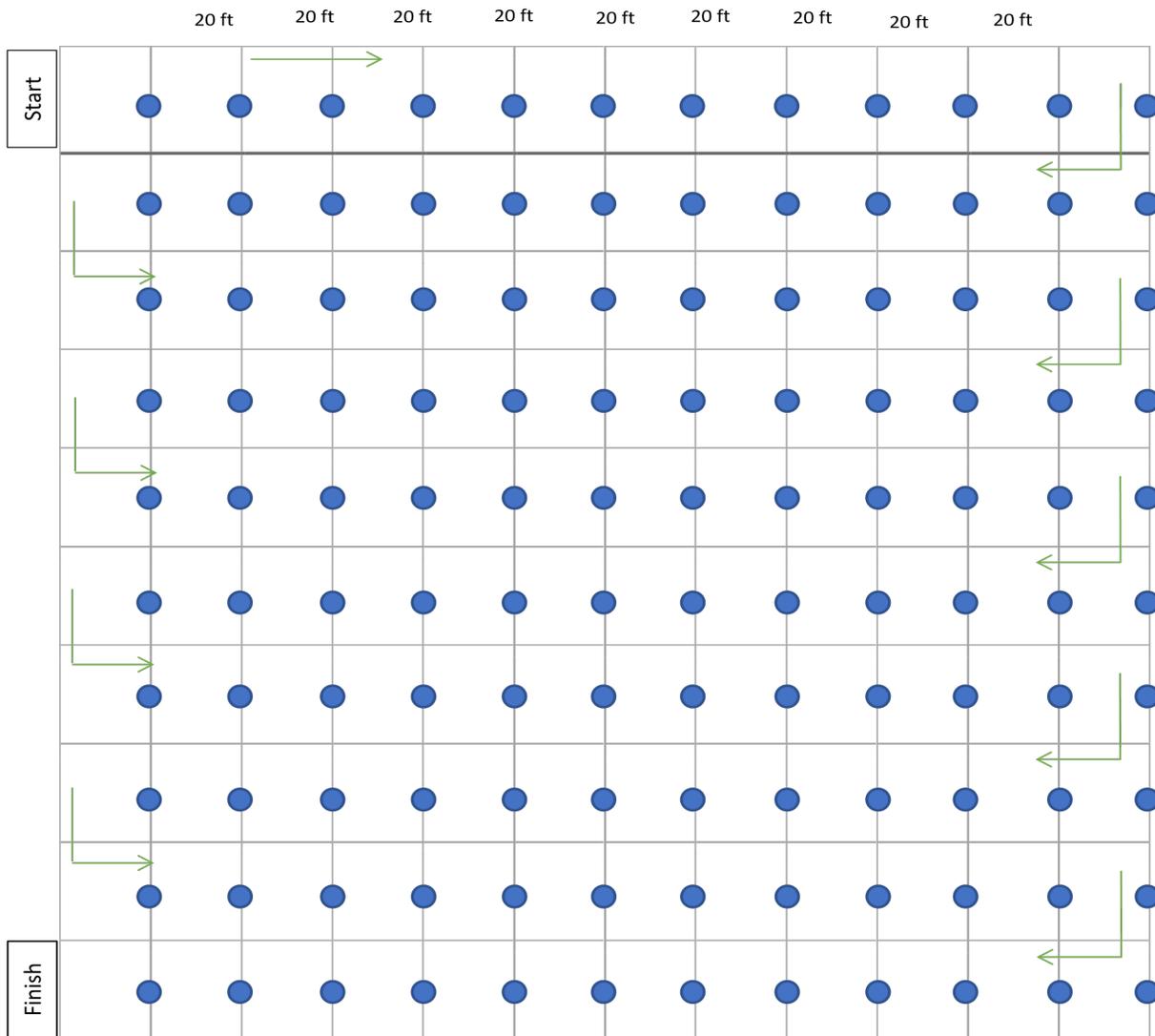


Figure 4-1 1.5-acre field (256 ft x 256 ft) overlaid with a square grid pattern and grid sampling frequency of 8 x 8 paces. The blue dot represents where you should take 1 soil core.

Symptomatic tubers

1. At harvest, if symptomatic tubers are present, place 1 to 3 symptomatic tubers in a paper bag and seal. The number of tubers per bag will depend on the number of symptomatic tubers and their size.
 - a. Do not add any extra moisture into the bag.
 - b. Label the paper bag with the grower's name, location (field and/or storage bin), host cultivar, collector's name, and date.
 - c. Make sure the bag is in a secure container for transportation to a designated laboratory.

Delimitation Survey

After *S. endobioticum* has been detected and confirmed by USDA-APHIS, a delimitation survey can help determine to what extent the pathogen has spread across the field (Laidlaw, 1985). Random planting of infected seed potatoes and the movement of farm equipment across the field may randomize spread in the field.

Collecting Soil Samples

1. Follow the same instructions for the detection survey to collect soil cores (Fig. 4-1 and Table 4-1), but do not combine soil cores into a composite sample.
2. Place each soil core into a double-walled paper bag.
3. Securely close the bag and record collector's name, grower's name, field location, within-field location, and date on the outside of the bag.
4. Place the samples in a secure container appropriate for transport to the laboratory.

Sample Submission and Identification Confirmation

1. Soil samples should be sent to a laboratory capable of extracting sporangia from the soil and making a tentative identification of suspect sporangia. PPQ may designate a laboratory for processing these samples.
2. After using a procedure for extracting sporangia from soil in Chapter 3 of this document, laboratory staff will view the sample under the microscope.
3. If a *S. endobioticum* suspect is found using morphological criteria, stop processing the sample. Depending on the extraction method used, transfer the sample to a labelled centrifuge tube or a petri dish and wrap it with bubble wrap. Laboratories should not attempt molecular diagnostics for identifying *S. endobioticum* because of the special authorizations and strict requirements for handling select agents.
4. Place the centrifuge tubes upright in a cooler with freezer bags/cold packs and close the lid. DO NOT freeze the samples.
5. Tape and package the box for shipment.
6. Fill out a PPQ Form 391
https://www.aphis.usda.gov/library/forms/pdf/PPQ_Form_391.pdf.
7. Send the suspect sample along with the printed copy of the PPQ Form 391 to the address below. Time the shipment so that it does not arrive on a Friday, Saturday, or Sunday.

Sample Diagnostics

USDA APHIS PPQ
S&T Beltsville Laboratory
Bldg. 580

9901 Powder Mill Rd.
Laurel, MD 20708
Phone 301-313-9208 or 301-313-9271

8. After mailing the specimens, send an email with the tracking number of the package to APHIS-PPQCPHSTBeltsvilleSampleDiagnostics@usda.gov.

Eradication and Control Options

Overview

This information can be used by PPQ decision-makers after a detection to assess the suitability of potential actions to eradicate, contain, or suppress *S. endobioticum*. The efficacy and feasibility of each control option will depend on the pest situation at the time of detection. Factors including detection location (e.g., natural or urban environment, agricultural crops, greenhouses, orchards), area of spread, the climatic region, the time of year, the phenology of the host, and current practices already in place contribute to determining whether a particular control option is appropriate.

Eradication Options

Quarantine and Regulatory Procedures

Eradication of *S. endobioticum* in the United States will be difficult due to its ability to persist in the soil for years and the lack of adequate available resistant potato cultivars. The first eradication of this pathogen in the United States took 70 years (Putnam and Hampson, 1989; Hartman, 1955; Laidlaw, 1985; McDonnell and Kavanagh, 1980). The quarantine area for this pathogen includes all positive fields and any fields that have come in contact with infected crop residue, seed, or infested soil. Movement of potentially infected host materials and potentially infested soil on equipment should be limited within and not allowed out of the quarantine area.

Host Removal

All potato crops growing in the quarantine area must be destroyed using glyphosate or a similar herbicide at the labeled rate (Baker et al., 2007; USDA-APHIS, 1990). This includes all remaining potatoes and plant parts. All dead plant material must be burned in place, removed, double bagged, and sent to an approved landfill (EPPO, 2007; USDA-APHIS-PPQ, 2008; USDA-APHIS, 1990). Check local ordinances for guidelines and documentation for burning material.

Chemical Control

Methyl bromide has been used in limited areas for eradication (Rasmussen and Mygind, 1977). However, we do not recommend using this chemical in a field setting because of potential serious environmental effects. If a storage building needs to be decontaminated with methyl bromide, use the following application rate (Rasmussen and Mygind, 1977; USDA-APHIS, 1990):

- ◆ Apply methyl bromide at a rate of 240 g/m³ for 24 hours at 15.5 °C (60 °F) or above.
 - ◆ Seal or tarp building to ensure effective treatment.
-

Alternative Control Techniques

Non-Chemical Treatments

There are no non-chemical treatments available for use against *S. endobioticum* (Baker et al., 2007).

Host Resistance

The main control method for *S. endobioticum* is the use of resistant potato varieties. Researchers have conducted host resistance experiments in the European Union, but not in the United States (Baker et al., 2007); therefore, little is known about the resistance to or susceptibility of preferred U.S. potato varieties to *S. endobioticum* (Baker et al., 2007).

Environmental Compliance

Overview

Program managers of Federal emergency response or domestic pest control programs must ensure that their programs comply with all Federal Acts and Executive Orders pertaining to the environment, as applicable. Two primary Federal Acts, the National Environmental Policy Act (NEPA) and the Endangered Species Act (ESA), often require the development of significant documentation before program actions may commence. Environmental and Risk Analysis Services (ERAS), a unit of APHIS' Policy and Program Development Staff (PPD), is available to provide guidance and advice to program managers and prepare drafts of applicable environmental documentation. In preparing draft NEPA documentation ERAS may also perform and incorporate assessments that pertain to other Acts and Executive Orders, described below, as part of the NEPA process. The Environmental Compliance Team (ECT), a part of PPQ's Emergency Domestic Programs (EDP), assists ERAS in development of documents and implements any environmental monitoring. Program leadership is strongly advised to consult with ERAS and/or ECT early in the development of a program in order to conduct a preliminary review of applicable environmental statutes and to ensure timely compliance.

Environmental monitoring of APHIS pest control activities may be required as part of compliance with environmental statutes, as requested by program managers, or as suggested to address concerns with controversial activities. Monitoring may be conducted with regards to worker exposure, pesticide quality assurance and control, off-site chemical deposition, or program efficacy. Different tools and techniques are used depending on the monitoring goals and control techniques used in the program. Staff from ECT will work with the program manager to develop an environmental monitoring plan, conduct training to implement the plan, provide day-to-day guidance on monitoring, and provide an interpretive report of monitoring activities.

The following is list of pertinent laws and Executive Orders:

National Environmental Policy Act (NEPA) – NEPA requires all Federal agencies to examine whether their actions may significantly affect the quality of

the human environment. The purpose of NEPA is to inform the decision-maker prior to taking action and to inform the public of the decision. Actions that are excluded from this examination, actions that normally require an Environmental Assessment, and actions that normally require Environmental Impact Statements are codified in APHIS' NEPA Implementing Procedures located in 7 CFR 372.5.

The three types of NEPA documentation are:

1. Categorical Exclusion

Categorical exclusions are classes of actions that do not have a significant effect on the quality of the human environment and for which neither an environmental assessment (EA) nor an environmental impact statement (EIS) is required. Generally, the means through which adverse environmental impacts may be avoided or minimized have actually been built into the actions themselves (see 7 CFR 372.5(c)).

2. Environmental Assessment (EA)

An EA is a public document that succinctly presents information and analysis for the decision-maker of the proposed action. An EA can lead to the preparation of an environmental impact statement (EIS), a finding of no significant impact (FONSI), or the abandonment of a proposed action.

3. Environmental Impact Statement (EIS)

In the event that a major Federal action may significantly affect the quality of the human environment (adverse or beneficial), or, the proposed action may result in public controversy, an EIS is prepared.

Endangered Species Act (ESA) – This statute requires that programs consider their potential effects on federally protected species. The ESA requires programs to identify protected species and their habitat in or near program areas and documentation of how adverse effects to these species will be avoided. The documentation may require review and approval by the U.S. Fish and Wildlife Service and the National Marine Fisheries Service before program activities can begin. Knowingly violating this law can lead to criminal charges against individual staff members and program managers.

Migratory Bird Treaty Act – This statute requires that programs avoid harm to over 800 endemic bird species, eggs, and their nests. In some cases, permits may be available to capture birds, which require coordination with the U.S. Fish and Wildlife Service.

Clean Water Act – This statute requires various permits for work in wetlands

and for potential discharges of program chemicals into water. This may require coordination with the Environmental Protection Agency, individual states, and the Army Corps of Engineers. Such permits would be required even if the pesticide label allows for direct application to water.

Tribal Consultation – This Executive Order requires formal government to government communication and interaction if a program might have substantial direct effects on any federally-recognized Indian Nation. This process is often incorrectly included as part of the NEPA process, but must be completed prior to general public involvement under NEPA. Staff should be cognizant of the conflict that could arise when proposed federal actions intersect with tribal sovereignty. Tribal consultation is designed to identify and avoid such potential conflict.

National Historic Preservation Act – This statute requires programs to consider potential impacts on historic properties (such as buildings and archaeological sites) and requires coordination with local State Historic Preservation Offices. Documentation under this act involves inventorying the project area for historic properties and determining what effects, if any, the project may have on historic properties. This process may require public involvement and comment prior to the start of program activities.

Coastal Zone Management Act – This statute requires coordination with states where programs may impact Coastal Zone Management Plans. Federal activities that may affect coastal resources are evaluated through a process called “federal consistency”. This process allows the public, local governments, Tribes, and state agencies an opportunity to review the federal action. The federal consistency process is administered individually by states with Coastal Zone Management Plans.

Environmental Justice – This Executive Order requires consideration of program impacts on minority and economically disadvantaged populations. Compliance is usually achieved within the NEPA documentation for a project. Programs are required to given consider if the actions might disproportionately impact minority or economically disadvantaged populations, and if so, how such impact will be avoided.

Protection of Children – This Executive Order requires federal agencies to identify, assess, and address environmental health risks and safety risks that may disproportionately affect children. If such a risk is identified, then measures must be described and implemented to minimize such risks.

Literature Cited

- Abdullahi, I., M. Koerbler, H. Stachewicz, and S. Winter. 2005. The 18S rDNA sequence of *Synchytrium endobioticum* and its utility in microarrays for the simultaneous detection of fungal and viral pathogens of potato. *Applied Microbiology and Biotechnology* 68(3):368-375.
- Alvarez, M. G. 1976. First Catalog of Mexican Plant Diseases. Secretaria de Agricultura y Ganaderia, Direccion General de Sanidad Vegetal, Mexico. 181 pp.
- Baker, E. H., D. Bell, T. Bourgoin, L. Brown, R. Bulluck, J. Floyd, L. Goldner, R. Hammerschmidt, Hesvick, S., L. Jess, S. B. Johnson, W. Kirk, L. Lopex, S. Perry, S. Poe, G. Secor, J. Sheldon, K. Smith, and W. Stevenson. 2007. Recovery plan for potato wart disease: *Synchytrium endobioticum* (Schilberszky) Percival. United States Department of Agriculture, Animal and Plant Health Inspection Service, Plant Protection and Quarantine. 23 pp.
- Bohl, W. H., and S. B. Johnson (eds.). 2010. Commercial potato production in North America. The Potato Association of America, Livonia, MI. 85 pp.
- CFIA. 2002. Establishment of a pest free area Prince Edward Island, Canada. Area free of potato wart disease [causal pathogen, *Synchytrium endobioticum* (Schilb.) Perc.]. Canadian Food Inspection Agency. 1-27 pp.
- Chalkley, D. 2016. Invasive and Emerging Fungal Pathogens - Diagnostic Fact Sheets: Potato smut - *Thecaphora solani*. Systematic Mycology and Microbiology Laboratory, ARS, USDA. <https://nt.ars-grin.gov/taxadescriptions/factsheets/index.cfm?thisapp=Thecaphorasolani>.
- Cotton, A. D. 1916. Host plants of *Synchytrium endobioticum*. Studies from the pathological laboratory: IV. Bulletin of Miscellaneous Information (Royal Gardens, Kew) 10:272-275.
- Curtis, K. M. 1921. The life-history and cytology of *Synchytrium endobioticum* (Schilb.), Perc., the cause of wart disease in potato. Philosophical Transactions of the Royal Society of London. Series B, Containing Papers of a Biological Character 210:409-478.
- EPPO. 2004. EPPO Standards: Diagnostic protocols for regulated pests. *Synchytrium endobioticum* (PM 7/28(1)) (2). European and Mediterranean Plant Protection Organization. 155-157 pp.
- EPPO. 2007. National regulatory control systems, *Synchytrium endobioticum*. Bulletin OEPP/EPPO Bulletin 37:221-222.
- Franc, G. D. 2007. Potato wart. APSnet Feature. Last accessed 16 September 2016, <http://www.apsnet.org/publications/apsnetfeatures/pages/potatowart.aspx>.

- Hampson, M. C. 1979. Infection of additional hosts of *Synchytrium endobioticum*, the causal agent of potato wart disease: 2. Tomato, tobacco and species of *Capsicastrum*, *Datura*, *Physalis* and *Schizanthus*. Canadian Plant Disease Survey 59(1):3-6.
- Hampson, M. C. 1981. Potato wart caused by *Synchytrium endobioticum*: Past and future emphases in research. Canadian Journal of Plant Pathology 3(2):65-72.
- Hampson, M. C. 1992. A bioassay for *Synchytrium endobioticum* using micropropagated potato plantlets. Canadian Journal of Plant Pathology 14(4):289-292.
- Hampson, M. C. 1993. History, biology, and control of potato wart disease in Canada. Canadian Journal of Plant Pathology 15(4):223-244.
- Hampson, M. C., and J. W. Coombes. 1985. Stress and stimulus modifications of disease severity in the wart disease of potato. Phytopathology 75.
- Hampson, M. C., and J. W. Coombes. 1989. Pathogenesis of *Synchytrium endobioticum* VII. Earthworms as vectors of wart disease of potato. Plant and Soil 116(2):147-150.
- Hampson, M. C., and J. W. Coombes. 1996. Spatial distribution of *Synchytrium endobioticum*, the cause of potato wart disease, in field soil. Plant Disease 80:1006-1010.
- Hartman, R. E. 1955. Potato wart eradication program in Pennsylvania. American Journal of Potato Research 32(9):317-326.
- Joestring. 1990. The prevention and control of potato wart disease. Deutsche Landwirtschaftliche Presse 36(88):941.
- Laidlaw, W. M. R. 1985. A method for the detection of the resting sporangia of potato wart disease (*Synchytrium endobioticum*) in the soil of old outbreak sites. Potato Research 28(2):223-232.
- Lange, L., and L. W. Olson. 1978. The zoospore of *Synchytrium endobioticum*. Canadian Journal of Botany 56(10):1229-1239.
- Martin, M. S. 1929. Additional hosts of *Synchytrium endobioticum* (Schilb.) Perc. Annals of Applied Biology 16(3):422-429.
- McDonnell, M. B., and J. A. Kavanagh. 1980. Studies on *Synchytrium endobioticum* (Schilb.) Perc. in Ireland. Journal of Life Sciences 1(2):177-182.
- Merz, U. 2008. Powdery scab of potato—Occurrence, life cycle and epidemiology. American Journal of Potato Research 85(4):241-246.
- Obidiegwu, J. E., K. Flath, and C. Gebhardt. 2014. Managing potato wart: A review of present research status and future perspective. Theoretical and Applied Genetics 127(4):763-780.
- Percival, J. 1910. Potato “wart” disease: The life history and cytology of *Synchytrium endobioticum* (Schilb.) Perc. Zentralblatt Bakteriologie Parasitenkunde Infektionskrankheiten 25:440-447.
- Phadtare, S. G., and K. P. Sharma. 1971. Additional hosts of *Synchytrium endobioticum*. Indian Phytopathology 24:389-392.

- Pratt, M. A. 1976. A wet-sieving and flotation technique for the detection of resting sporangia of *Synchytrium endobioticum* in soil. *Annals of Applied Biology* 82:21-29.
- Putnam, M. L., and M. C. Hampson. 1989. Rediscovery of *Synchytrium endobioticum* in Maryland. *American Potato Journal* 66(8):495-501.
- Putnam, M. L., and A. B. Sindermann. 1994. Eradication of potato wart disease from Maryland. *American Potato Journal* 71(11):743-747.
- Rasmussen, A. N., and H. Mygind. 1977. Control of potato wart disease (*Synchytrium endobioticum*) through methyl bromide soil disinfection. *Tidsskrift for Planteavl (Denmark)* 81(1):25-31.
- Sarbhoy, A. K., G. Lal, and J. L. Varshney. 1975. *Fungi of India*. Navyug Traders, New Delhi, India. 1-148 pp.
- Smith, D. S., H. Rocheleau, J. T. Chapados, C. Abbott, S. Ribero, S. A. Redhead, C. A. Lévesque, and S. H. De Boer. 2014. Phylogeny of the genus *Synchytrium* and the development of taqman PCR assay for sensitive detection of *Synchytrium endobioticum* in soil. *Phytopathology* 104(4):422-432.
- SPHDS. 2016. National diagnostic protocol for potato wart, caused by *Synchytrium endobioticum*. Subcommittee on Plant Health Diagnostic Standards. 17 pp.
- Stevenson, W. R., R. Loria, G. D. Franc, and D. P. Weingartner. 2001. *Compendium of potato diseases* (2nd ed.). The American Phytopathological Society, St. Paul, MN. 106 pp.
- USDA-APHIS-PPQ. 2008. *New Pest Response Guidelines: Synchytrium endobioticum* (Schilberszky) Percival, potato wart disease. United States Department of Agriculture, Animal and Plant Health Inspection Service, Plant Protection and Quarantine.
- USDA-APHIS. 1990. *Action Plan: potato wart disease Synchytrium endobioticum* (Schilb.) Percival. United States Department of Agriculture, Animal and Plant Health Inspection Service.
- van den Boogert, P. H. J. F., M. P. E. van Gent-Pelzer, P. J. M. Bonants, S. H. De Boer, J. G. N. Wander, C. A. Levesque, G. C. M. van Leeuwen, and R. P. Baayen. 2005. Development of PCR-based detection methods for the quarantine phytopathogen *Synchytrium endobioticum*, causal agent of potato wart disease. *European Journal of Plant Pathology* 113(1):47-57.
- van Gent-Pelzer, M. P. E., M. Krijger, and P. J. M. Bonants. 2010. Improved real-time PCR assay for detection of the quarantine potato pathogen, *Synchytrium endobioticum*, in zonal centrifuge extracts from soil and in plants. *European Journal of Plant Pathology* 126(1):129-133.
- van Leeuwen, G. C. M., J. G. N. Wander, J. Lamers, J. P. Meffert, P. H. J. F. van den Boogert, and R. P. Baayen. 2005. Direct examination of soil for sporangia of *Synchytrium endobioticum* using chloroform, calcium chloride and zinc sulphate as extraction reagents. *OEPP/EPPO Bulletin* 35:25-31.
- Walker, J. C. 1998. *CMI Descriptions of Pathogenic Fungi and Bacteria No. 755 Synchytrium endobioticum*. CAB International.
<http://www.cabi.org/dfb/FullTextPDF/2005/20056400755.pdf>.

Weiss, F. 1925. The conditions of infection in potato wart. American Journal of Botany 12(7):413-443.

Survey Preparation, Sanitization, and Clean-Up

Introduction

Use *Appendix A* for instructions on how to prepare for and conduct a survey, as well as instructions for proper cleaning and sanitizing of supplies and equipment after the survey.

1. Prior to beginning a survey, determine whether there have been recent pesticide applications that would render it unsafe to inspect the plants and soil. Look for posted signs indicating recent pesticide application. Ask the property owner or manager if there is a re-entry period in effect due to pesticide application. If there have been recent pesticide applications, then wait the appropriate re-entry period.
2. Determine whether quarantines for other pests or crops are in effect for the survey area. Comply with all quarantine requirements.
3. When visiting the area to conduct surveys or take samples, take strict measures to prevent contamination by *S. endobioticum* or other pests between properties during inspections. These strict measures include wearing protective clothing, gloves, and footwear and changing them before entering and exiting each site. Other strict measures include sanitizing vehicles, equipment, and tools.
4. Clean and sanitize equipment and tools after each use:
 - a. Disinfect tools and equipment with any contaminating soil by spraying or immersing them in 0.15 percent a.i. solution of quaternary ammonium (quat) or 10 percent hypochlorite solution (bleach). Allow the tools to air dry.
 - b. Use quat carefully in non-planted areas because it can kill vegetation on contact.
 - c. Do not remove soil from survey equipment (small or hand-held) before treatment if there is a possibility the soil will contaminate the site. Saturate the contaminating soil with quat or bleach prior to its removal; once the soil is saturated, it is no longer considered contaminated.
 - d. Disinfect footwear at a designated area, such as the entrance of a property, when entering and leaving a site.

- e. To disinfect storage areas, drench the area thoroughly with quat or bleach. Do not rinse.
- 5. Designate a flat area or an area with a buffer around it to capture runoff when disinfecting large pieces of equipment. Disinfect the equipment with a high-pressure delivery system, such as a steam pressure wash system to penetrate the soil and debris that may still adhere to it. After the equipment is clean, saturate it with quat.
- 6. Disinfect vehicles including tires, wheel wells, and under the chassis using the following instructions:
 - a. Make sure equipment is dry at the time of treatment to facilitate efficacy of the solution.
 - b. Wash thoroughly with quat.
 - c. Do not rinse for at least 1 hour; after 1 hour, rinse equipment only if specifically required by owner or operators.

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Cover Image

Potato tubers with galls from Prince Edward Island, Canada (image credit 2012 and 2014 Her Majesty the Queen in Right of Canada (Canadian Food Inspection Agency))