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European and Mediterranean Plant Protection Organization
Organisation Européenne et Méditerranéenne pour la Protection des Plantes PM 3/089 (1)

Phytosanitary procedures

PM 3/089 (1) Control of volunteer potato plants

Specific scope

This Standard describes measures which can be used by the farmer for the management of volunteer potato plants. It also provides guidance on the official control to be performed by NPPOs in an outbreak situation for certain quarantine pests to check that potato volunteer management has been correctly performed.

Specific approval and amendment

First approved in 2020–09.

Definitions

Volunteer potato plants are defined as plants of *Solanum tuberosum*, growing in the succeeding seasons' crop(s). Remark: Volunteer potato plants can grow from tubers or true seed, in a different crop, or in a potato crop (a different variety or the same variety). They include growth from tubers left in the field, from tubers returned to a field after harvest, or from tubers returned with soil from a processing facility.

Other terms are used as defined in ISPM 5 (FAO, 2019), such as 'field', 'pest', 'plants' and 'production site'.

1. Introduction

World-wide, potato is one of the most important food crops grown, with about 374 million tonnes produced per year (FAOSTAT, 2018). In many countries in the EPPO region, potato is the most important cash crop.

Potatoes are usually grown in rotation, often every 3 or 4 years, but can be grown continuously, as is often the case in starch potato production.

When harvesting potatoes, some of the tubers will remain in or on the soil at the production site. These tubers will survive if not sufficiently exposed to freezing temperatures during winter. Tubers as small as 10 mm in size may sprout and start growing in the succeeding crop(s), producing volunteer potato plants (Steiner *et al*., 2005). Most volunteer potato plants grow from tubers that, at time of harvest, are too small to be picked up by modern harvesters. Estimations of the number of tubers left on the soil surface or up to 20 cm underground varies widely throughout production areas. Rahman (1980) reports 367 000 tubers per hectare remaining post-harvest, which translates to 10% of the potential yield or one to four tonnes per hectare, representing a potential volunteer potato plant population of 2–30 plants/m^2. Other publications report figures from 180 000 up to 460 000 tubers per hectare remaining on a field after harvest (Lumkes, 1974; Perombelon, 1975; Lutman, 1977; Steiner *et al.*, 2005; Boydston *et al.*, 2006). More recently, Phelan *et al.* (2015) reported an average tuber loss of 142 000 tubers per hectare, ranging from about 39 000 to 210 000 tubers. Not all tubers produce plants that survive to the following crop. Establishment of volunteer plants in the following crop ranged from about 400 plants to 55 700 plants per hectare. These figures correspond to values reported by Anderson & de Vincente (2010) of up to 20% of tubers left in the soil being able to sprout in the next season. In South Africa, it is estimated that the equivalent of approximately 20–25% of the weight of tubers planted is left behind after harvesting (Allemann & Allemann, 2013). In areas with mild winters, it is estimated that with active management it still takes up to 4–5 years in most arable crops to eliminate potato volunteers which have grown from daughter tubers (Makepeace & Holroyd, 1978).

Small tubers may also be left intentionally in the field when it is decided to only harvest large tubers.

Furthermore, potato plants can also grow in the succeeding crop(s) from true potato seeds (TPS), but this is considered to be less significant. The amount of true seed produced in a given potato crop will depend on the cultivar as well as environmental conditions such as photoperiod, temperature, plant density and nitrogen supply (Askew, 1993). Field experiments suggest that TPS can remain viable for at least 7 years (Askew & Struik, 2007). However, early growth of seedlings from TPS is slow compared to that of plants growing from tubers, and daughter tubers are generally smaller (Perombelon, 1975; Rowell *et al*., 1986). Therefore, the vast majority of volunteer potato plants would originate from tubers (Bond *et al*., 2007).

Consequently, volunteer potato plants are among the most important weeds in crops grown in rotation with potatoes.

This Standard does the following:

(a) Provides information on the importance of the management of volunteer potato plants. They can have negative impacts on yield (e.g. due to competition) and quality (e.g. reduction in size, contamination of the harvested crop with potato leaves and berries), and increase production costs. In addition, the presence of volunteer potato plants in the following crops can in effect break a rotation by allowing a quarantine pest (or other pests) to survive and be maintained in these crops, or even allow pest levels to increase, causing phytosanitary issues. In addition, the requirement for the complete absence of volunteer potato plants in subsequent crops is included in several EPPO Standards as a control measure for the eradication of a pest, but no further details are given.

(b) Gives details on the management methods to be used. Successful management of volunteer potato plants can only be achieved by taking multiple measures over successive years.

(c) Provides guidance on the official controls to be performed by NPPOs to confirm, through inspections at proper times, that the required 'freedom from volunteer potato plants' has been achieved when such a measure is necessary in the framework of the eradication of a quarantine pest.

2. Importance of the management of volunteer potato plants

2.1. Phytosanitary issues

When potato is a host of a pest, the presence of volunteer potato tubers may be essential for the survival of the pest at a production site until the next growing period. This is all the more important for monophagous pests or pests with a very limited host range [e.g. *Clavibacter sepedonicus* (potato ring rot) and *Ralstonia solanacearum* (potato brown rot)]. For (more) polyphagous pests (e.g. *Meloidogyne chitwoodi*), the management of volunteer potato plants can still contribute to the management of the pest, even though other measures such as the planting of non-host crops and the elimination of (host) weeds would be equally or more important to apply.

A long interval between two succeeding potato crops (e.g. more than 3 years, with no other host plants grown during this period) is essential to avoid the build-up of certain pests and to limit subsequent spread. Indeed, the effective control of volunteer potato plants over several successive years is a key element in contributing to the eradication of certain quarantine pests (Table 1). In addition, the absence of volunteer potato plants as a measure to eradicate a regulated pest from a production site or place of production is mentioned in several PM 9 Standards on National regulatory control systems.

Crop rotation together with the management of volunteer potatoes is also a good agricultural practice to prevent an increase of pest inoculum. This is true for several regulated non-quarantine pests and quality pests (Table 2). When volunteer potato plants are present in a succeeding crop, pest populations may increase on them, build up in the soil and later infest the next potato crop grown. Therefore, the presence of volunteer potato plants during a rotation limits the benefits of the crop rotation. The presence of very high numbers of volunteer potato plants may in effect be similar to the continuous cropping of potato.

Volunteer potato plants are also a source of infestation for neighbouring crops (e.g. Late blight *Phytophthora infestans*, several common potato viruses, Colorado beetle *Leptinotarsa decemlineata* and *Epitrix* spp.).

Volunteer potato plants growing from true seeds will not be a primary source of pests except in the case of viroids, such as *Potato spindle tuber viroid* (PSTVd).

2.2. Impact on yields, quality and production costs

Volunteer potato plants behave like weeds in other crops, competing for water, space, sunlight and nutrients, often resulting in yield losses. Impacts on yield depend mainly on the crop species, the number of volunteer potato plants, their time of emergence and the effectiveness of the methods available and used to control volunteer potato plants in the crop. Yield losses of 23–62% have been observed in maize, and up to 90% in onions and carrots. Volunteer potatoes in onion crops affect both the size of the bulbs and yield, with reductions reported of 27–82% (Steiner *et al*., 2005). Weed control in carrots is problematic due to the sensitivity of the crop to herbicide treatment and the limited availability of effective herbicides (Williams & Boydston, 2006). Yields of bean, sugar beet, other legumes and wheat are also negatively affected.

In field trials (undertaken in 1978 in the Netherlands) where potato tubers (size 25/28 mm) were planted at a density of 80 000 tubers/ha to represent volunteer tubers, it was observed that sugar beet crops were completely overgrown by the volunteer plants, resulting in an estimated loss of 60–70%. Maize was also completely overgrown and harvesting the crop was not worthwhile (100% loss), winter wheat had an average yield loss of 7% (3–14%) and summer wheat an average yield loss of 14% (10–18%) (van Sabben, 1978).

Table 1. Examples of pests recommended for regulation as quarantine pests by EPPO that can persist on volunteer potato plants and their additional host plants

Scientific name	Common name (in English)	Categorization (EPPO Lists)	Existing PM 9 Standard where absence of volunteer potato plant is a measure	Examples of additional host plants possibly grown in rotation with potato in the EPPO region
Bacteria				
'*Candidatus* Liberibacter solanacearum' (LIBEPS)	Zebra chip	A1 List (Solanaceae haplotypes)	PM 9/25 *Bactericera cockerelli* and '*Candidatus* Liberibacter solanacearum' (EPPO, 2017b)	*Anthriscus cerefolium*, *Apium graveolens*, *Capsicum annuum*, *Capsicum frutescens*, *Daucus carota*, *Foeniculum vulgare*, *Nicotiana tabacum*, *Pastinaca sativa*, *Petroselinum crispum*, *Solanum lycopersicum*, *Solanum melongena* (EPPO GD, 2020) Host plants also include wild plants/weeds such as *Anthriscus sylvestris*, *Daucus aureus*, *Fallopia convolvulus*, *Lycium barbarum*, *Persicaria lapathifolia*, *Solanum americanum*, *Solanum dulcamara*, *Solanum elaeagnifolium*, *Solanum umbelliferum*, *Urtica dioica* (EPPO GD, 2020)
Clavibacter sepedonicus (CORBSE)	Potato ring rot	A2 List	PM 9/2 *Clavibacter michiganensis* subsp. *sepedonicus* (EPPO, 2011a)	*Beta vulgaris*, *Solanum lycopersicum*, *Solanum melongena* (EPPO GD, 2020)
Ralstonia solanacearum (RALSSL)	Potato brown rot	A2 List	PM 9/3 *Ralstonia solanacearum* (EPPO, 2011b)	*Nicotiana*, *Solanum lycopersicum*, *Solanum melongena* (EPPO GD, 2020) Host plants also include wild plants/weeds such as Solanaceous weeds
Fungi				
Synchytrium endobioticum (SYNCEN)	Wart disease	A2 List	PM 9/5 *Synchytrium endobioticum* (EPPO, 2017a)	Herbaceous ornamental plants and others
Insects				
Epitrix cucumeris (EPIXCU)	Flea beatle	A2 List	PM 9/22 *Epitrix* species damaging potato tubers (EPPO, 2016)	*Beta vulgaris*, *Brassica oleracea*, *Capsicum annuum*, *Cucumis sativus*, *Lactuca sativa*, *Nicotiana tabacum*, *Phaseolus vulgaris*, *Physalis alkekengi*, *Physalis peruviana*, *Solanaceae*, *Solanum lycopersicum*, *Solanum melongena*, *Solanum pseudocapsicum* (EPPO GD, 2020) Host plants also include wild plants/weeds such as *Atropa belladonna*, *Datura stramonium*, *Physalis angulata*, *Physalis pubescens*, *Physalis virginiana* var. *sonorae*, *Solanum americanum*, *Solanum carolinense*, *Solanum dulcamara*, *Solanum nigrum*, *Solanum physalifolium*, *Solanum rostratum*, *Solanum torvum* (EPPO GD, 2020)
Epitrix papa (EPIXPP)	Flea beatle	A2 List	PM 9/22 *Epitrix* species damaging potato tubers (EPPO, 2016)	*Solanum melongena* (EFSA, 2019) Host plants also include wild plants/weeds such as *Datura stramonium*, *Solanum nigrum*, *Solanum triflorum* (EFSA, 2019)
Epitrix subcrinita (EPIXSU)	Flea beatle	A1 List	PM 9/22 *Epitrix* species damaging potato tubers (EPPO, 2016)	*Capsicum annuum*, *Lycium* , *Solanum lycopersicum*, *Solanum melongena* (EPPO GD, 2020) Host plants also include wild plants/weeds such as *Datura innoxia*, *Hyoscyamus niger*, *Nicandra physalodes*, *Nicotiana attenuata*, *Physalis lobata*, *Physalis longifolia*, *Solanum carolinense*, *Solanum dulcamara*, *Solanum nigrum*, *Solanum rostratum*, *Solanum triflorum*, *Solanum villosum* (EPPO GD, 2020)

(continued)

Table -0001 *(continued)*

Scientific name	Common name (in English)	Categorization (EPPO Lists)	Existing PM 9 Standard where absence of volunteer potato plant is a measure	Examples of additional host plants possibly grown in rotation with potato in the EPPO region
Epitrix tuberis (EPIXTU)	Flea beatle	A1 List	PM 9/22 *Epitrix* species damaging potato tubers (EPPO, 2016)	*Beta vulgaris*, *Brassica oleracea*, *Capsicum frutescens*, *Cucumis sativus*, *Lactuca sativa*, *Lycium*, *Nicotiana tabacum*, *Phaseolus vulgaris*, Solanaceae, *Solanum lycopersicum* (EPPO GD, 2020) Host plants also include wild plants/weeds such as *Datura innoxia*, *Datura stramonium*, *Nicandra physalodes*, *Physalis lobata*, *Physalis longifolia*, *Physalis philadelphica*, *Physalis pubescens*, *Solanum carolinense*, *Solanum dulcamara*, *Solanum nigrum*, *Solanum rostratum*, *Solanum triflorum*, *Solanum villosum* (EPPO GD, 2020)
Leptinotarsa decemlineata (LPTNDE)	Colorado beetle	A2 List	–	*Brassica oleracea*, *Cichorium endivia*, *Daucus carota* subsp. *sativus*, *Lactuca sativa*, *Petroselinum crispum*, *Solanum lycopersicum*, *Solanum melongena*, *vegetable plants*, Solanaceae (EPPO GD, 2020) Host plants also include wild plants/weeds such as *Solanum* (EPPO GD, 2020)
Nematodes				
Globodera pallida (HETDPA)	White potato cyst nematode	A2 List	PM 9/26 *Globodera rostochiensis* and *Globodera pallida* (EPPO, 2018)	*Solanum*, *Solanum lycopersicum*, *Solanum melongena*, *Capsicum* spp. and other plants (EPPO GD, 2020)
Globodera rostochiensis (HETDRO)	Golden potato cyst nematode	A2 List	PM 9/26 *Globodera rostochiensis* and *Globodera pallida* (EPPO, 2018)	*Solanum*, *Solanum lycopersicum*, *Solanum melongena*, *Capsicum* spp. and other plants (EPPO GD, 2020)
Meloidogyne chitwoodi (MELGCH)	Columbia root-knot nematode	A2 List	PM 9/17 *Meloidogyne chitwoodi* and *Meloidogyne fallax* (EPPO, 2013)	*Avena sativa*, *Beta vulgaris*, *Daucus carota* subsp. *sativus*, *Hordeum vulgare*, *Medicago sativa*, *Phaseolus vulgaris*, *Pisum sativum*, *Poaceae* , *Solanum lycopersicum*, *Scorzonera hispanica*, *Taraxacum officinale*, *Triticum aestivum*, *Zea mays* (EPPO GD, 2020)
Meloidogyne fallax (MELGFA)	False Columbia root-knot nematode	A2 List	PM 9/17 *Meloidogyne chitwoodi* and *Meloidogyne fallax* (EPPO, 2013)	*Asparagus officinalis*, *Daucus carota* subsp. *Sativus*, *Fragaria × ananassa*, *Scorzonera hispanica*, *Solanum tuberosum* (EPPO GD, 2020)
Viruses and viroids				
Potato spindle tuber viroid (PSTVD0)		A2 List	PM 9/13 PSTVd on potato (EPPO, 2011c)	*Capsicum annuum*, *Dahlia*, *Ipomoea batatas*, *Physalis peruviana*, *Solanum*, *Solanum lycopersicum* (EPPO GD, 2020)

Table 2. Examples of other pests recommended for regulation as Regulated Non-Quarantine Pests* and of quality pests that can persist on volunteer potato plants and additional host plants

Scientific name	Common name(s) (in English)	Examples of additional host plants possibly grown in rotation with potato in the EPPO region
Bacteria		
Dickeya (1DICKG) and *Pectobacterium* (1PECBG)*	Aerial stem rot, black leg, soft rot	Wide host range
This includes: *Pectobacterium atrosepticum* (ERWIAT), *Pectobacterium carotovorum* subsp. *brasiliensis* (PECBCB), *Pectobacterium carotovorum* subsp. *carotovorum* (ERWICA), *Pectobacterium parmentieri* (PECBPA), *Dickeya dianthicola* (ERWICD) and *Dickeya solani* (DICKSO)		
Fungi and fungus-like organisms		
Alternaria (1ALTEG)*	Dry rot, early blight	Wide host range (e.g. *Solanum lycopersicum*)
This includes *Alternaria alternata* and *Alternaria solani* (ALTESO)		
Boeremia exigua var. *exigua (Phoma exigua)* (PHOMEX)*	Thumbmark rot	–
Boeremia foveata (*Phoma foveata*) (PHOMEF)*	Gangrene	*Chenopodium quinoa* (EPPO GD, 2020)
Geotrichum candidum (GEOTCA)*	Rubbery rot	Wide host range
Helminthosporium solani (HELMSO)*	Silver scurf	–
Phytophthora erythroseptica (PHYTER)*	Pink rot	*Tulipa* hybrids (EPPO GD, 2020)
Phytophthora infestans (PHYTIN)*	Late blight	*Solanum lycopersicum* (CABI, 2020) Host plants also include wild/weeds such as Solanum nigrum (CABI, 2020)
Sclerotinia sclerotiorum (SCLESC)*	White mould	Wide host range (e.g. *Lactuca sativa*, *Brassica napus*, legumes) (CABI, 2020)
Spongospora subterranea (SPONSU)*	Powdery scab	–
Thanatephorus cucumeris (Rhizoctonia solani) (RHIZSO)*	Black scurf	–
Verticillium dahliae (VERTDA) and *Verticilium albo-atrum* (VERTAA)*	Verticilium wilt	Wide host range
Viruses and viroids		
Potato viruses (common)	Potato virus	–

*Pest recommended for regulation as a Regulated Non-Quarantine Pest (RNQP) during the EU Quality Pest Project (Picard *et al.*, 2018).

Contamination of succeeding crops by volunteer potato plants can cause significant problems during the processing and packaging of harvested produce and therefore have a direct effect on marketability and price. Potato leaves and berries can easily contaminate mechanically harvested crops such as peas, beans, carrots and spinach. This can lead to the complete rejection of the harvest, particularly those products for the freezing industry which have to be completely free of contaminants.

The presence of volunteer potato plants in a crop of seed potatoes, which is certified for varietal purity, can lead to rejection for further seed production.

Control of volunteer potatoes means additional costs, for example in terms of increased labour, machinery and agrochemical costs.

3. Management of volunteer potato plants

The measures described below are methods that farmers could apply to minimize the occurrence of volunteer potato plants.

These measures consist of preventive measures aiming to reduce the numbers of tubers remaining in the soil after harvest, their survival and the subsequent emergence of the volunteer potato plants. Management measures to control the volunteer potato plants which have emerged are also outlined.

Some of these measures may be used by NPPOs in the framework of the official control of regulated pests after an outbreak, in particular for the eradication of certain quarantine pests. For farmers, the primary reason for managing volunteer potato plants aims to limit yield losses and quality reductions in crops grown in rotation.

An integrated management system approach is usually required as none of the measures individually is 100% effective. High levels of control require good harvesting efficiency, cultivation practices that do not invert the soil and herbicide treatments.

The applicability of the various management options will depend on different factors such as production methods and the level of mechanization in potato production, weather and soil conditions during harvest, winter temperatures, the crops grown in rotation with potato and types of soil. Different management tools may be relevant for different parts of the EPPO region. For example, the use of freezing winter conditions to help reduce the number of viable tubers will only be possible in certain EPPO countries.

The management measures are described in chronological order.

3.1. Precautionary measures prior to planting potato to minimise potato volunteer plants

Good production measures which facilitate harvesting help to reduce the number of tubers left in the field at the production site after harvest. In particular, the following should be considered:

- Selection of the potato production site. Criteria such as the type and structure of soil, its water permeability and the slope of the production site should be taken into account.
- Selection of the potato cultivar:
  - Early vs. late cultivars. Early cultivars are likely to be harvested in better conditions, and therefore fewer tubers are expected to remain at the production site.
  - Ease of tuber removal from the haulm. When tubers are difficult to remove from the haulm, there is a higher chance that they are not removed by the harvester and so will remain at the production site (Steiner *et al*., 2005).
  - Position of tubers in the ridge. Tubers are easier to harvest if they remain close to the mother tuber rather than being widely separated and deep in the ridge.
  - Tendency to produce small tubers. Small tubers are more likely not to be harvested.
- Decisions concerning (nitrogen) fertilizing. Excess application of nitrogen should be avoided because it can delay crop maturation and increase harvest losses.
- Use of high-quality seed potatoes. This helps to ensure a high rate of emergence and uniform development of the plants. This favours homogenous tuber development with a low proportion of small tubers.
- Good preparation of the soil and seed bed: this is important to allow a uniform development of the crop. Ideally planting and the forming of the ridges should be undertaken under dry soil conditions.

Additional decisions concerning the crop rotation can help to facilitate the control of the volunteer potato plants in the succeeding crop(s):

- Interval between potato crops (e.g. more than 2 years with crops other than potato). Normally tubers left in the soil will sprout in the following growing season (or in the next crop). However, it appears for some cultivars that tubers can lie dormant and viable for at least 18 months (Askew & Struik, 2007). It is estimated that it takes up to 4–5 years in areas with mild winters to eliminate potato volunteers grown from daughter tubers in most arable crops (Makepeace & Holroyd, 1978). To facilitate the elimination of potato volunteers, crop rotations as long as possible should be maintained.
- Choice of the crops and their order in the rotation. A crop's characteristics (e.g. inter row distance, growth rate) and the possible measures available in these crops to eliminate any remaining potato tubers and volunteer potato plants should be considered. In particular, the sowing date (e.g. sowing in spring is more favourable than in autumn), herbicide treatments available (e.g. cereals offer more possibilities of using herbicide treatments than dicotyledonous crops), crops with an earlier harvest give more opportunities for post-harvest mechanical and herbicide treatments than those with a long period of growth and late harvest (e.g. sugar beet is one of the most unfavourable succeeding crops).

In addition, the selection of the potato cultivar may limit the formation of berries/seeds (Askew & Struik, 2007) which will remain in the field and act as a source of volunteer potato plants.

3.2. From planting to harvest of the potato crop

3.2.1. Before harvest

As a general principle, all measures which encourage good growth and uniform development of the potato crop should be taken. This will facilitate harvesting and therefore reduce the number of tubers left at the production site. The following factors are relevant in this regard:

- Avoid causing soil compaction during all activities in the crop until the harvest: soil compaction has adverse effects on plant development and may also directly increase harvest losses.
- Use of GPS during all machinery work (e.g. during planting, ridging, spraying and harvesting) improves accuracy (e.g. uniform ridges and exact row distances with connecting rows).
- Adapt (nitrogen) fertilization to avoid the risk of late maturation of the crop.
- Leave potato ridges intact as much as possible. Minimize driving with tractors and machinery in the crop, and use narrow tyres and tramlines (paths created by planting rows at a distance corresponding with the width of the spraying machine).
- Maintain a healthy and weed-free crop using plant protection measures.
- Carry out homogeneous irrigation, if required.

Additional treatments can limit the sprouting of volunteer potato plants in the succeeding crop. *Whether these treatments can be applied for the control of volunteer potato plants depends on whether they comply with national legislation*:

- Consider treating ware potato crops with maleic hydrazine at the latest 3 weeks before harvest or before haulm killing as a sprout inhibition measure (De Blauwer *et al.*, 2012). The main objective of this measure is usually to suppress germination when the potatoes are stored. However, at least one product also has the official indication that it would limit the presence of volunteers at the production site (Buckley *et al.*, 2006). After application of maleic hydrazine, only 4–6% of the tubers were able to produce volunteer plants in the following year (Kürzinger, 2016). The treatment must be agreed with the intended buyers of the potatoes because some of them do not accept any residues.

3.2.2. During harvest

Potatoes should be harvested in a way and in the best conditions to minimize the number of viable tubers remaining at the production site. The following factors and measures should be considered in this regard:

- Harvest at the proper time and under optimum soil moisture conditions, taking into account hardening of the skin and ease of separation of the tubers from the plant. In particular, green or immature crops that have not completed their growth have a higher proportion of small tubers at harvest compared to crops which are fully grown and harvested when haulms are dead. Dry soil conditions often result in tuber damage; wet soil conditions often result in (extra) spillage of tubers and excessive amounts of soil associated with the harvested tubers.
- Optimize harvester settings (e.g. correct gap size of chains, managing the blade depth, chain speed and driving speed, haulm separator).
- Avoid spillage of tubers while loading trailers from the harvester to trailers.
- Do not return tubers associated with soil and stones to the production site.
- Damage volunteer tubers or waste tubers if practicable (Askew & Struik, 2007). Crushing of waste tubers was used in practice on a limited scale in the late 1970s in the Netherlands. Different systems were developed and incorporated in harvesting machines to retain and collect waste tubers or crush the waste tubers by using rotating drums and letting them fall through the machine. Subsequently, tubers are subject to natural rotting, which further reduces sprouting. Neither method has been implemented on a large scale because of variable results and reduced harvesting capacities (slowing down the harvesting process).

3.3. After harvesting potatoes and before the next crop

Some of the cultural measures may only be applicable to part of the EPPO region because they rely on climatic conditions (subzero temperatures) during the winter period.

Potato tubers are susceptible to frost, with 50 frost-hours at or below −2°C required to kill them (e.g. 25 h at −2°C or 5 h at −10°C) (Rahman, 1980; citing Lumkes & Sijtsma, 1972). Laboratory and field test results on the freezing behaviour of potato tubers in soil were reported by Boydston *et al.* (2006). In laboratory tests with soil hydrated to 7% soil water content, the freezing point of tubers was near −1.9°C. Tubers exposed to temperatures near the freezing point (−1.4 to −1.9°C) for periods varying from 1 min up to 24 h exhibited varying degrees of injury, which increased with time of exposure. Tubers held at −1°C for 4 to 24 h were unharmed and were able to sprout. In field trials conducted from 1993 to 1999 in the Colombia Basin of Washington, tubers buried at shallow depths (5 cm) were much more likely to experience lethal cold temperatures than tubers buried deeper. Extensive tuber death occurred when soil temperature reached −2.8°C or lower.

The following measures aim to increase the chance of tubers freezing under natural winter conditions and at improving conditions for optimal future (chemical) control. It should be noted that in areas with mild winters, freezing of the soil rarely goes deeper than 10 cm.

- Most favourable in this respect is not applying tillage before winter, therefore leaving waste tubers in the position as they were lost during harvest. However, this is not applicable for all soils and more specifically for soils which are prone to slaking. In such a case, soil preparation should take place before winter.
- Keep waste tubers as much as possible in the upper soil layer when preparing the soil for the next crop by using soil cultivation techniques that favour this. Therefore, the use of straight-tine cultivation instead of ploughing is advised. This will increase the chance of tubers freezing. Research in the Netherlands demonstrated that a straight tine cultivator with tines set at approximately 60° buries fewest tubers (Lumkes & Beukema, 1973; Lumkes, 1974). Moreover, in the absence of a crop, emergence of volunteer potato plants will primarily depend on the temperature of the soil and on the depth of tubers in the soil. Volunteer potato plants emerge earlier from tubers near the surface than those positioned deeper in the soil. The more the position of tubers in the topsoil varies in depth, the longer the period of sprout emergence will be (up to 2–3 months). Keeping all tubers in the upper soil layer would therefore considerably shorten the sprout emergence period and thus improve conditions for and optimum timing of herbicide applications.
- Maintain bare ground during wintertime. Since the soil underneath a crop experiences less extreme temperatures than bare ground, the presence of crop cover during winter increases the survival rate of waste tubers (any crop, stubbles or snow covering fully or partially the soil during winter acts as insulation). However, whether it can be applied for the control of volunteer potato plants depends on whether it complies with national legislation (e.g. legislation in place to avoid nitrogen-leaching during winter).

Additional measures to help in reducing of the number of viable waste tubers present at the production site are:

- Use animals for biological control. Sheep or cattle may effectively control the carry-over of potatoes by eating tubers remaining at the production site just after harvest.
- Do not return waste soil containing tubers directly to the field. Such waste soil should preferably be stored for more than 1 year at the farmyard, covered with a black plastic tarpaulin.

3.4. During subsequent crops

The growing of 'competitive' crops after a potato crop helps limit both the emergence of volunteer potato plants and their capacity to produce tubers. Sprout emergence is considerably delayed by crops that have a high light interception at their early stages of growth (e.g. cereals such as winter barley and winter wheat) (Aarts & Sytsma, 1981). The persistence of volunteer potatoes in the rotation depends on the production of tubers by volunteer plants. In competitive crops (i.e. with a high light interception at an early stage), volunteer plants produce up to three daughter tubers, seldom more than 1−3 cm in diameter. In less competitive crops (e.g. sugar beet, maize, onions and cabbage), more and larger daughter tubers are produced (Steiner *et al*., 2005, citing Aarts & Sijtsma, 1978).

It is important to note that after harvest of cereal crops, attention should be paid to volunteer plants present as they will – due to less competition – start growing again. Herbicide treatments can be applied (see below).

In addition, treatments are available to control volunteer potato plants in the succeeding crops:

- Mechanical treatment:
  - Use crop rotation with pasture for several years. This is a very effective way to control volunteer potatoes and may be relevant for land rented for a potato crop on dairy farms.
  - In crops with a row spacing that allows mechanical weed control (e.g. sugar beet, maize, onions), repeated mechanical control can be applied. The operation must be repeated because of the risk of regrowth from the tubers and because sprout emergence can occur over an extended period. Mechanical control is more effective when it follows the application of herbicides. Mechanical removal of sprouts of volunteer potatoes is only effective when it is repeatedly carried out over a long period of time.
  - Weed by hand. This is a safe and effective way to control volunteers in a crop. However, it is labour intensive and therefore not always feasible or economic to undertake on a large scale. It can be applied on a small scale, such as in fields where volunteer potato plants are limited to small areas. Hand-roguing is, however, a common practice in seed potato crops to ensure varietal purity for certification.
- Herbicide treatments:

Use of herbicides – in specific conditions – to control volunteer potato plants should comply with national legislation.

Volunteer potato plants are extremely difficult to kill with herbicides. Most herbicides applied in subsequent crops are at best only partially effective. The size of the food reserves in the parent tuber enables the plant to recover from damage which is lethal to other weeds. Because of the late emergence of potatoes in many crops, it is often not possible to apply herbicides against the volunteers without damaging the crop.

- Glyphosate is the most effective herbicide against volunteer potato plants. Both aerial and subterranean parts, including the early-formed tubers, are killed when it is applied at the rate indicated on the label, provided that all sprouts are fully emerged when the herbicide is applied. Any sprouts that have not yet emerged will not be killed. Selective application of glyphosate is not possi-

ble in any arable crops. For application in row crops, inter-row shielded sprayers have been developed. Contact herbicide applicators have also been developed and the system makes use of the differences in height between the volunteer potato plants and the crop being grown. Best results are obtained under adequate soil moisture conditions and at about 20°C. However, during dry and warmer weather control can be less effective because the aerial parts of volunteer potato plants die off too rapidly after treatment (Sijtsma *et al.*, 1978).
- Fluroxypyr in cereals and Mesotrione in maize are effective active substances that may be used to control volunteer potato plants.

The use of an appropriate application method (e.g. optimal spraying coverage and repeated applications) and technology (e.g. to allow under leaf spraying in maize crops) is important for efficient control.

4. Official control

Freedom from volunteer potato plants is a requirement for eradication of certain quarantine pests. In such a case, the NPPO may stipulate/require specific measures to contribute to the control of volunteer potato plants at a single production site or a collection of production sites (e.g. applying herbicide treatments, maintaining bare ground during winter time or during a longer period and defining a minimum break period from potato cropping).

The objective of removing volunteer plants is to prevent any new formation of tubers which would subsequently produce plants in the following season and potentially allow survival of the pest.

During the eradication campaign, the NPPO should check how volunteer potato plants are managed and the effectiveness of the control.

4.1. Information to be collected

For these inspections, the NPPO will need to collect information about the cultivation techniques used as well as measures which have been applied by the grower, whether or not imposed by the NPPO (e.g. what herbicides have been applied). In addition, the NPPO should ascertain whether any soil has been returned to the production site after harvest and if so where it is deposited. This could help identify spots where there is a higher risk that volunteer plants occur in the production site.

4.2. Timing for the inspection(s)

Depending on the succeeding crops grown, the management techniques which have been used and on past winter temperatures, the NPPO needs to assess whether a single inspection during the growing season is sufficient. In many situations, however, multiple inspections at different times will need to be performed to give the assurance of the effectiveness of measures and of the volunteer freedom as required by the NPPO for the eradication of a quarantine pest. For example, an additional post-harvest inspection of the production site may be necessary in case of cereals, or when mechanical control consisting only of cutting the above-ground parts of volunteer potato plants has been used because regrowth from tubers is likely to occur.

In the Netherlands, growing-season inspections are carried out in (early) June to allow enough time for the sprouts of tubers present in the soil to emerge.

4.3. Inspection to be performed

The size of the production site should be taken into consideration to determine whether the entire site should be inspected or whether only spot inspections are performed: small production sites can be inspected in their entirety. For large production sites, spot inspections (with GPS coordinates) can be performed for a certain prescribed area (e.g. 15 spots of 4 × 10 m). The inspection consists of counting the number of volunteer potato plants present.

The crop and its growth stage at the time of inspection can have a major influence on how easily volunteer potato plants can be found. For example, in a broad-leaved crop such as sugar beet, volunteer potato plants can easily be detected and a judgement on the presence of potato volunteer plants over large areas can easily be made, whereas in a cereal crop such as winter wheat, where volunteer potato plants are often small in size due to crop competition, volunteer potato plants can be much more difficult to detect and so a closer and more detailed inspection is required.

The NPPO should consider whether modern techniques can be applied to detect volunteer potato plants (e.g. using drones and/or camera detection techniques).

4.4. Evaluation of conformity

The NPPO should evaluate whether the number of volunteer potato plants present in the succeeding crop(s) is acceptable or not. Complete freedom from volunteer potato plants may not be achievable, especially in the first succeeding crop. If too many volunteer potato plants are found, the NPPO should require additional management measures and official inspections. Alternatively, the NPPO may decide that effective treatments are impossible and conclude that the requirement of freedom from volunteer plants has not been satisfied. The presence or absence of viable tubers on volunteer plants will be an important factor that should be considered.

During the inspection(s) performed in the first year:
- If an average of ≤3 volunteer potato plants/ha is observed at the production site, it is considered that appropriate measures have been applied by the producer. The volunteer potato plants which have been found during this inspection should be rogued out.

- If an average of >3 volunteer potato plants/ha and ≤1 volunteer potato plant/10 m^2 is observed at the production site, the NPPO should impose an appropriate herbicide treatment or the roguing out of all the remaining volunteer potato plants. Another inspection should be performed during the same year. During this additional inspection, no volunteer potato plants should be found.
- If an average of >1 remaining volunteer potato plants/10 m^2 is observed at the production site, this should not be considered as acceptable and should result in the prolongation of the measures for 1 extra year (the inspection is carried out the following year as if it were the first year of inspection).

During the inspections performed in the second and subsequent years, no volunteer potato plants should be found. If further volunteer potato plants are found, the rotation should be extended for one additional year.

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References

Aarts HFM & Sijtsma R (1981) De invloed van cultuurgewassen op aardappelopslag (The influence of crops on volunteer potatoes). *De Pootaardappelwereld* **35**, 16–18.

Allemann J & Allemann A (2013) Control and management of volunteer potato plants – Literature review. Potatoes of South Africa. 1–46

Andersson MS & de Vicente MC (2010) *Gene Flow between Crops and their Wild Relatives*. The Johns Hopkins University Press, Baltimore (US).

Askew MF (1993) Volunteer potatoes from tubers and true potato seed. *Aspects of Applied Biology* **35**, 9–15.

Askew MF & Struik PC (2007) The canon on potato science: 20. Volunteer potatoes. *Potato Research* **50**, 283–287.

Bond W, Davies G & Turner R (2007) *The Biology and Non-chemical Control of Volunteer Potato (Solanum tuberosum)*. HDRA, Coventry (UK). https://www.gardenorganic.org.uk/sites/www.gardenorganic.org.uk/files/organic-weeds/volunteer-potato.pdf [accessed on 19 February 2020].

Boydston RA, Seymour MD, Brown CR & Alva AK (2006) Freezing behavior of potato (*Solanum tuberosum*) tubers in soil. *American Journal of Potato Research* **83**, 305–315.

Buckley D, Duncan H & Anderson E (2006) British Potato Council. Maleic hydrazide in potato volunteer control. *Research Review* **R275**, 1–48.

De Blauwer V, Demeulemeester K, Demeyere A & Hofmans E (2012) Maleic hydrazide: sprout suppression of potatoes in the field. *Communication in Agricultural and Applied Biological Sciences* **77**, 343–351.

EFSA (European Food Safety Authority) (2019) Pest survey card on *Epitrix cucumeris*, *Epitrix papa*, *Epitrix subcrinita* and *Epitrix tuberis*. EN-1571, 24 pp. https://doi.org/10.2903/sp.efsa.2019.EN-1571

EPPO (2011a) Standard PM 9/2(2) National regulatory control systems: *Clavibacter michiganensis* subsp. Sepedonicus. *EPPO Bulletin* **41**, 385–388.

EPPO (2011b) Standard PM 9/3(2) National regulatory control systems: *Ralstonia solanacearum*. *EPPO Bulletin* **41**, 389–393.

EPPO (2011c) Standard PM 9/13(1) National regulatory control systems: PSTVd on potato. *EPPO Bulletin* **41**, 394–399.

EPPO (2013) Standard PM 9/17(1) National regulatory control systems: *Meloidogyne chitwoodi* and *Meloidogyne fallax*. *EPPO Bulletin* **43**, 527–533.

EPPO (2016) Standard PM 9/22(1) National regulatory control systems: *Epitrix* species damaging potato tubers. *EPPO Bulletin* **46**, 556–566.

EPPO (2017a) Standard PM 9/5(2) National regulatory control systems: *Synchytrium endobioticum*. *EPPO Bulletin* **47**, 511–512.

EPPO (2017b) Standard PM 9/25(1) National regulatory control systems: *Bactericera cockerelli* and '*Candidatus* Liberibacter solanacearum'. *EPPO Bulletin* **47**, 513–523.

EPPO (2018) Standard PM 9/26(1) National regulatory control systems: *Globodera rostochiensis* and *Globodera pallida*. *EPPO Bulletin* **48**, 516–532.

FAO (2019) Glossary of phytosanitary terms. International Standard for Phytosanitary Measures No. 5. Rome. Published by FAO on behalf of the Secretariat of the International Plant Protection Convention (IPPC). 35 pp. https://www.ippc.int/en/publications/glossary-phytosanitary-terms/ [accessed on 1 June 2020]

FAOSTAT (2018) Food and Agriculture Organization of the United Nations (FAO). Crop statistics for year 2018 (production in tonnes). from http://www.fao.org/faostat/en/#data/QC [acessed on 18 June 2020]

Kürzinger K (2016) Keimhemmung mit Maleinsäurehydrazid in Kartoffeln. *Kartoffelbau* **7**, 18–20.

Lumkes LM (1974) Aardappelen als onkruid. Proefstation voor de Akkerbouw Publicatie 15. (Potato as a weed. Research station for arable crops Publication 15.)

Lumkes LM & Beukema HP (1973) The effect of cultivation procedures on the liability to freezing of ground keepers. *Potato Research* **16**, 57–60.

Lumkes LM & Sijtsma R (1972) Mogelijkheden aardappelen als onkruid in volgewassen to voorkomen en/of te bestrijden (Measures to prevent and/or control potatoes as a weed in crops). *Landbouw en Plantenziekten* **1**, 17–36.

Lutman PJ (1977) Investigations into some aspects of the biology of potatoes as weeds. *Weed Research* **17**, 123–132.

Makepeace RJ & Holroyd J (1978) Weed control. In *The Potato Crop: The Scientific Basis for Improvement*(ed. Harris PM), pp. 376–406. Chapman & Hall, London (UK).

Perombelon MCM (1975) Observations on the survival of potato ground-keepers in Scotland. *Potato Research* **18**, 205–215.

Phelan S, Fitzgerald T, Grantc J, Byrneb S, Meade C & Mullins E (2015) Propensity for seed-mediated gene flow from potato crops and potential consequences for the coexistence of GM and non-GM potato systems. *European Journal of Agronomy* **67**, 52–60.

Picard C, Afonso T, Benko-Beloglavec A, Karadjova O, Matthews-Berry S & Paunovic A *et al*. (2018) Recommended regulated non–quarantine pests (RNQPs), associated thresholds and risk management measures in the European and Mediterranean region. *EPPO Bulletin* **48**, 552–558.

Rahman A (1980) Biology and control of volunteer potatoes – a review. *New Zealand Journal of Experimental Agriculture* **8**, 313–319.

Rowell AB, Ewing EE & Plaisted RL (1986) Comparative field performance of potatoes from seedlings and tubers. *American Potato Journal* **63**, 219–227.

Sijtsma R, Aarts HFM & Lumkes LM (1978) The control of volunteer potatoes with different herbicides and the application of a non-selective herbicide in some crops. Proceedings, British Crop Protection Conference – Weeds, 363–372.

Steiner CM, Newberry G, Boydston R, Yenish J & Thornton R (2005) Volunteer Potato Management in the Pacific Northwest Rotational Crops. *Washington State University Extension Bulletin* **EB1993**, 1–12.

van Sabben MJ (1978) Onderzoek naar de mogelijkheden om aardappelopslag te bestrijden met cultuurgewassen (Research project: possibilities for elimination of volunteer potato plants by use of crops). PAGV 222–1978. Study project and internal report/research for reference Aarts H F M & Sijtsma R (circa 1980) De involved van cultuurgewassen op aardappelopslag.

Williams MM & Boydston RA (2006) Volunteer potato interference in carrot. *Weed Science* **54**, 94–99.