***Potato mop-top virus* infection of potato:**

**information review, research gaps and industry responses following identification of this pathogen in New Zealand potato crops**

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1. **Introduction**

*Potato mop-top virus* (PMTV) was first reported in potato crops in New Zealand in September 2018 (Biosecurity New Zealand 2019a). Official response was instigated relating to PMTV as a notifiable plant pathogen, as mandated in the Biosecurity Act 1993. This was after positive identification of the virus in two potato fields in Canterbury. The response was a joint initiative between Biosecurity New Zealand (the Ministry for Primary Industries) and Potatoes New Zealand Inc. (Biosecurity New Zealand 2019b).

The present review was initiated and solicited by Potatoes New Zealand Inc., to outline relevant available knowledge of PMTV that may be useful for the New Zealand potato industry and biosecurity authorities. This was to assist development of the mandatory official and practical industry responses to the identification PMTV in this country, to summarize available knowledge of PMTV to assist with development of appropriate PMTV management strategies, and to highlight potential research requirements relating to this virus.

For the present report, key topics are reviewed (including some highlighted by Mr Chris Claridge, Dr Iain Kirkwood (Potatoes New Zealand Inc.), and Ms Verity Halkett (Environment Canterbury), using information from relevant research papers and current knowledge. Literature that is accessable through on-line searches has been assessed, but this review has not attempted to catalogue all knowledge on these topics. Several scientific reviews relevant to PMTV have been published, including those by Harrison (1977), Santala et al. (2010), Tamada & Kondo (2013) and Abbas & Madadi (2016).

This present report firstly describes details of PMTV, and symptoms of infections of the virus in potato plants, and then covers several topics (in separate Sections), and points that have been raised by potato industry representatives. Comment is provided for each of the topics considered. “Research questions”, relating to specific knowledge gaps relevant to the PMTV outbreak in New Zealand, and “Industry recommendations” are also listed, and these are collated at the end of the report. The questions and recommendations are provided to assist regulatory authorities and components of the New Zealand potato industry in development of strategies for limiting the spread and effects of PMTV in this country.

1. ***Potato mop-top virus***

***2.1 Description***

PMTV was first described in 1966 (Calvert & Harrison 1966), from potato plants and tubers grown in Northern Ireland and England. PMTV is the type virus of the genus *Pomovirus*, characteristics of which are outlined in The ITCV Report (2019). *Pomovirus* members have genomes consisting of three molecules of single stranded RNA. They have rod-shaped particles with predominant lengths of 65-80, 150-160 and 290-310 nm, and diameters of 18-20 nm. Jones & Harrison (1969) presented evidence that PMTV was transmitted by *Spongospora subterranea*, which is the only known vector of the virus. The particles of PMTV have been visualised in host plants and the resting spores of *S. subterranea* using electron microscopy, and the virus occurs within host cells and microscopy preparations as aggregated or singly dispersed particles (White et al. 1972; Roberts & Harrison 1979; Merz 1995; The ITCV Report 2019). The nucleotides of specific PMTV isolates have been fully sequenced (Ramesh et al. 2014; Gil et al. 2016), and three “groups” of the virus have been defined as RNA2I, RNA2II and RNA2III (Latvala-Kilby et al. 2009; Beuch et al. 2015; Gil et al. 2016).

Kalyandurg et al. (2017) described molecular and pathobiological characterization of PMTV from Peru and other regions. They demonstrated that the virus was highly variable in Peru, but much less so from other international areas. They also classified strains of the virus as “S (severe)” and “M (mild)”, and demonstrated that strains of PMTV from Europe, Asia and North America were severe types, while Peruvian strains were mild types.

***Research questions***

* What are the genetic (molecular) characteristics and variability of PMTV in New Zealand, and are New Zealand strains of the virus different from those elsewhere in the world?
* Can genetic characteristics of New Zealand PMTV strains indicate their international geographical origins, and dates of introduction into New Zealand?

***2.2 Transmission, distribution, and economic effects of PMTV***

PMTV is transmitted to potato plant hosts through virus-infected seed tubers, and is vectored, via root and stolon (tuber) infections, by zoospores of the Cercozoan (plasmodiophorid) plant pathogen *Spongospora subterranea* (Jones & Harrison 1969; Arif et al. 1995). *Spongospora subterranea* is the only known vector of PMTV. Experimental mechancical transmission of the virus using sap from infected plants is also possible (e.g. Nielsen & Nicolaisen 2003; Gil et al. 2016), so short distance transmission of the virus through inter-host contact may be possible between closely associated potato plants in crops and associated weed hosts (see **Section 9**). Molecular biology research (see Cowan et al. 2018) has revealed genetic and biochemical characteristics of PMTV that allow systemic movement and distribution of the virus within host plant vascular systems (phloem). The virus may also occur at dissimilar amounts in different organs of infected hosts plants (roots, tubers or leaves).

Northern South America is the likely centre of origin for the *Solanum* spp. plant hosts of PMTV (particularly *S. tuberosum*; Harris 2001). That region is also the probable centre of origin for PMTV (Gil et al. 2016; Kalyandurg et al. 2017), and for the PMTV vector *S. subterranea* (Gau et al. 2015). The known geographical range of PMTV has expanded over the five decades since the virus was first described (Santala et al. 2010; Tamada and Kondo 2013).This has been as the virus and vector have been carried around the world (probably associated with potato seed tubers), to most regions and countries where potato crops are grown as key sources of food and/or industrial starch. Some countries, however, are officially free of PMTV (e.g. South Africa).

Deleterious effects of PMTV on potato tuber yields from infected crops have rarely been reported (see below), but potato tuber symptoms (spraing) caused by the virus are well-recognised as economically important (Santala et al. 2010). Spraing symptoms are unacceptable quality defects in potato tubers for processing and fresh markets. The PMTV vector *S. subterranea* is also an economically important quality- and yield-limiting pathogen of potato, causing powdery scab on tubers, root galling, and disruption of root function (Falloon et al. 2016). Although both pathogens (vector and virus) are necessary for widespread PMTV infection of potato crops, research reports on PMTV have not considered, or have only rarely acknowledged, the economic effects of the vector *S. subterranea*. Together, both pathogens may have additive or synregistic deleterious effects on potato yields, but this has not been confirmed experimentally in research literature.

***2.3 Disease symptoms***

PMTV causes “spraing” symptoms in of potato tubers (**Figures 1 and 2**) and “mop-top” and leaf lesions on potato plants (**Figures 3, 4 and 5**).

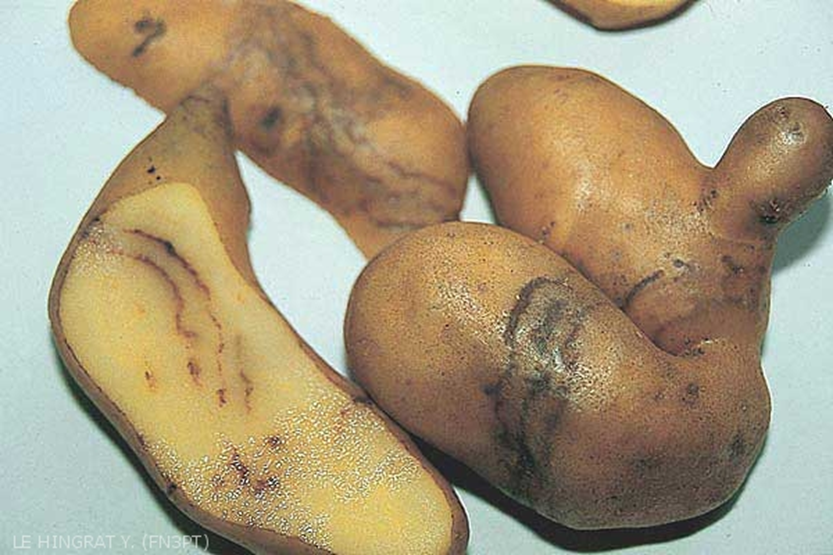
Spraing symptoms caused by PMTV in tubers include necrotic concentric cresent-shaped rings (1-5 cm in length) on tuber surfaces. These may be close together or spaced apart on individual tubers (**Figure 1**). Typical internal tuber symptoms include flecks, arcs or streaks of necrotic tissue, that may or may not be associated with surface symptoms. The internal tuber necroses are from light to darker brown (“rust”) in colour (**Figure 2**). Other tuber symptoms associated with PMTV infections include misshapen tubers sometimes with reticulate surface cracking, termed “elephant hide” (Tenorio et al. 2006; Carnegie et al. 2010).

Symptoms of PMTV infections on stems and leaves of potato plants include light green leaves, and shortened stem internodes with compacted leaf arrangments (“mop-top”) (**Figure 3**). Leaves may be chlorotic (lighter green than normal) and have distorted wavy margins (**Figure 4**), and can also develop large yellow lesions with necrotic centres (**Figure 5**).

It is well recognised that PMTV-infected potato plants and tubers may not present typical mop-top and/or spraing symptoms (e.g. Germundsson et al. 2002; Santala et al. 2010), and symptom expression can be affected by several factors:

* Potato tubers which are positive for PMTV infection may not express spraing symptoms (Latvala et al. 2009), and PMTV infections may occur in tubers that do not have powdery scab (caused by *S. subterranea*) (Sangren et al. 2002).
* Expression of symptoms can be greater in some potato cultivars than others, and almost non-exsistant in yet other cultivars (see **Section 5**).
* Survival of PMTV in stored potatoes may differ in different potato cultivars (Yellareddygari et al. 2017).
* Symptom expression may depend on environmental (climate, soil, storage) conditions (Cooper & Harrison 1973; Mølgaard & Nielsen 1996; Latvala-Kilby 2009; Domfeh et al. 2015).
* PMTV symptoms in tubers may not be related to severity of powdery scab (caused by the PMTV vector *S. subterranea*) (Nakayama et al. 2010b).
* Foliar symptoms and tuber symptoms may only be loosely related (Tenorio et al. 2006; Carnegie et al. 2010).
* Variable relationships can occur between incidence of daughter plants with foliar symptoms, produced from seed tubers from plants with foliar symptoms (Carnegie et al. 2010).
* Correlation has not been detected between symptoms induced on indicator plants used for PMTV characterization in laboratory/greenhouse experiments and PMTV genotype. Different indicator plants can develop different symptoms of infection, and symptom expression in indicator plants can be affected by environmental factors (Gil et al. 2016).
* PMTV may not be evenly distributed within individual infected plants, or within individual tubers (Germundsson et al. 2002; Santala et al. 2010).

The inconsistent and equivocal nature of symptom expression from PMTV infections make accurate symptomatic diagnoses difficult. For this reason, definitive PMTV diagnoses should not rely on symptom expression in plants (potato or indicator species) or in potato tubers, but should always include appropriate sensitive and specific PMTV detection assays (outlined in Section 8).



**Figure 1.** Symptoms (“spraing”) of *Potato mop-top virus* infection on potato tubers (photo: INRA).



**Figure 2.** Symptoms (“spraing”) *Potato mop-top virus* infection in a potato tuber (photo: INRA).



**Figure 3.** Early symptoms (chlorosis and distortion) of *Potato mop-top virus* infection on potato leaves (photo: INRA).



**Figure 4.** Symptoms (chlorosis and shoot/leaf distortion) of *Potato mop-top virus* infection on a potato plant (photo: INRA).



**Figure 5.** Symptoms (chlorosis and necrosis) of *Potato mop-top virus* infection on a potato leaf (photo: INRA).

Photos credits: Euphytia, INRA, France. <http://ephytia.inra.fr/en/C/21022/Potato-Symptoms>

1. **Survival and perennation of *Potato mop-top virus***

For potato production, survival of PMTV is related (probably directly) to the ability of the *Spongospora* vector to survive, and the ability of PMTV and *S. subterranea* to infect volunteer potato plants and alternative hosts that occur during rotation periods between potato crops.

*Spongospora subterranea* can survive in soils for periods greater than 10 years (Kole 1954; Harrison et al. 1997), and possibly much longer. Anecdotal evidence indicates that the pathogen can survive for several decades (RE Falloon, unpublished). Severe *Spongospora* infection (tuber powdery scab) was recorded in a confined section of a potato crop in Scotland in the mid-1990s. This probably resulted from inoculum from a potato storage pile (“clamp”) established on the field perimeter during World War II (early 1940s). Harrison (1977) suggested that sites of former potato clamps were “particularly infective with potato mop-top virus”, probably because of *S. subterranea* resting spore “accumulation” in these areas.

Long-term survival of *S. subterranea* results from the very extensive proliferation of this pathogen as highly resistant resting spores produced within sporosori, which are the complex survival and dissemination structures. Sporosori contain hundreds to thousands of resting spores (Falloon et al. 2011), and very many sporosori (and, therefore, resting spores) are produced in each root gall and each tuber powdery scab lesion.

*Spongospora subterranea* can also infect several different host plants beside potato (see **Section 9**), including weed and crop species that occur in arable fields and potato crops. These alternative hosts are likely to be important for survival and multiplication of the pathogen in rotation periods between potato crops.

PMTV has been shown to survive within *Spongospora* resting spores for long periods (Jones & Harrison 1969; 1972). For example, soil infested with PMTV and stored in a cold room for 15 years was still able to cause PMTV infections in indicator plants when they were planted into the soil (Kvarnheden & Beuch, cited by Santala et al. 2010).

This information indicates that the PMTV can survive for very long periods (many years) in fields that are infested with PMTV and its vector *S. subterranea*. Long-term survival of both pathogens poses severe problems for efficient management of the diseases they cause (Santala et al. 2010).

1. ***Potato mop-top virus* dissemination in soil, factory effluent, reject potatoes, or composted propagation media**

***4.1 Soil***

Harrison (1997) and Santala et al. (2010) have suggested that wind-blown soil could spread PMTV to uninfested fields in resting spores of *S. subterranea* infected by this virus, and wind dispersal of *S. subterranea* has been implicated for contamination of fields in Israel (L. Tsror, personal communication). It is also very likely that *S. subterranea*-infested soil on tractors and cultivation and potato harvesting machinery can be sources for transmission of *S. subterranea* to non-infested soils, and that these infestations may be sources of vectored PMTV in potato crops. PMTV-infected seed potatoes have been shown to transmit the virus to subsequent crops (Santala et al. 2010), and this could be from soil infested with the pathogens attached to seed tubers and to virus infections within seed tubers.

***4.2 Processing factory waste streams and reject potatoes***

Research is lacking on waste streams from potato processing operations as sources of PMTV for potato crops. However, material from tuber washing and skin removal operations will contain soil and tuber material that may be infested with *S. subterranea*, and the pathogen could be infected with PMTV. Therefore, factory waste materials are potential sources of PMTV infections, where this material is spread on fields before they are used for potato production.

Similarly, if the reject potato tubers are used as feeding material for domestic animals (e.g. dairy cattle), then fields where this feed source is spread could become infested with PMTV and/or the virus vector. Anecdotal evidence (R Falloon, unpublished) has indicated that effluent from pig production operations, where reject (probably diseased) potatoes were used to feed the animals, caused severe *Spongospora* infections (powdery scab) in a subsequently grown potato crop. Passage of *S. subterranea* sporosori through the alimentary systems of domestic animals (cattle, goats) has also been shown to have little effect on viability of this pathogen (U Merz, personal communication).

***4.3 Plant and mushroom propagation materials in potato production***

Merz (2017) reported that *S. subterranea* had contaminated peat- and bark-containing growth media used for multiplication of potato lines in plant breeding and “pathogen-free” operations in Europe and the United States of America. He also detected *S. subterranea* (using RT-PCR) in samples obtained in 2013 from a commercial peat production enterprise in Germany, but failed to detect the pathogen from the same site 3 years later. Samples from a Swiss peat-producing location were free of the pathogen.

***Comment***

Used “compost” from commercial mushroom production operations in Canterbury has been applied as organic amendment to fields that were later used for potato production, and the peat component of these composts was imported from Europe (I Kirkwood, personal communication). The recent identifications of PMTV in Canterbury have been from some potato fields where this mushroom compost was used as an organic amendment spread before potato planting. It is well-recognised that *S. subterranea* can withstand temperatures greater than those reached in normal composting operations (U Merz, personal communication), although detailed research on effects of these temperatures on PMTV survival within *Spongospora* resting spores has not been reported.

These results and observations indicate that sporadic *S. subterranea* contamination of growth substrates for plant propagation or mushroom culture substrates (bark- or peat-containing “potting mixes” or “composts”) could have originated from the organic components of these materials.

***Research question***

* What are the effects of elevated temperatures (those used in mushroom compost preparation) on PMTV?

***Industry recommendations***

* That detailed monitoring of peat or tree bark imported to New Zealand is implemented for *S. subterranea* and PMTV infestations, where these materials are to be used in plant and mushroom propagation media.
* That routine spreading of spent mushroom compost or potting mixes is carefully considered for fields that may be used for potato production, that these materials be tested for infestations by *S. subterranea* and PMTV, and that pathogen-positive material not be applied to fields likely to be used for potato production.

1. **Susceptibility of potato cultivars to *Potato mop-top virus***

There is a large body of evidence demonstrating that different potato varieties differ in reaction (susceptibility) to *S. subterranea* (the vector of PMTV), and to PMTV. The reports listed below are examples of studies that have assessed potato varieties and cultivars for relative susceptibility to PMTV.

* Kurppa (1988) assessed proportions of superficial and internal spraing symptoms of PMTV infections in field-grown tubers of 15 potato cultivars. This showed that proportions of tubers with superficial symptoms varied from nil (cv. ‘Pito’) to 63 % (cv. ‘Olympia’), and internal symptoms varied from 18% (cv. ‘Pito’) to 74% (cv. ‘Sieglinde’).
* Sandgren et al. (2002) assessed susceptibility to PMTV and *S. subterranea* for eight field-grown potato germplasm lines (five “breeding lines” and three cultivars). Incidence of PMTV in tubers (indicated by serological detection) ranged from 41 to 91% for the breeding lines and 19 to 91% for the cultivars, but also varied between 2 years (growing seasons) of assessments.
* Tenorio et al. (2006) tested 21 United States potato cultivars for susceptibility to PMTV in field trials in northern South America (Peru), as indicated by serological detection of the virus in tubers. The cultivars were classified as “most susceptible” (20-25% incidence of PMTV in tubers, including cv. ‘Kennebec’) “somewhat less susceptible” (11-16% incidence, including cv. ‘Russet Burbank’) and “least susceptible (less than 9% incidence, including cvs ‘Atlantic’ and ‘Shepody’).
* Carnegie et al. (2009) tested ten potato cultivars for reaction to PMTV in field trials in different locations in the United Kingdom. They planted PMTV-free seed tubers into soils known to be infested with *S. subterranea* and the virus, then assessed harvested tubers for spraing symptoms or PMTV infections (using serolocal detection). Cultivar ‘Hermes’ was the most resistant to PMTV infections in tubers, and cvs ‘Slaney’, ‘Desiree’ and ‘Saturna’ were the most susceptible. However, cvs ‘Maris Piper’, ‘Desiree’ and ‘Winston’ developed the least spraing symptoms, while cvs ‘Rooster’, ‘Saturna’ and ‘Cara’ developed the most tuber symptoms. While these results indicate differences in cultivar reactions to PMTV, they also demonstrate the inconsistencies amongst cultivars for PMTV infection of tubers and expression of spraing symptoms.
* Nakayama et al. (2010b) tested 22 potato cultivars for susceptibility to PMTV in a field evaluation. Only two cultivars developed tuber symptoms of PMTV, and seven developed no symptoms of infection by the virus. However, PMTV was detected in tubers of all of the cultivars (using RT-PCR), and no correlation was found between occurrence spraing in tubers and severity of tuber powdery scab.
* Arif et al. (2016) assessed ten potato cultivars grown commercially in Pakistan for susceptibility to PMTV, in greenhouse and field evaluations. They evaluated tuber symptoms, and measured virus reactions using ELISA and RT-PCR methods. Nine of the cultivars were determined to be “sensitive” to PMTV, while one (cv. ‘Desiree’) was classified as “moderately sensitive”.
* Domfeh et al. (2015) assessed 27 field-grown potato cultivars for susceptibility to PMTV, and *S. subterranea* diseases (tuber powdery scab, root galling). The cultivars varied in sensitivity to PMTV-induced tuber necrosis. Cultivars with russet tuber skins generally had less incidence of necrosis than red-, yellow- or white-skinned cultivars. Statistically significant correlations were determined between numbers of *Spongospora* root galls on plants and incidence and severity of tuber powdery scab, as well as with PMTV-induced tuber necrosis.
* Yellareddygari et al. (2018) assessed 63 potato cultivars for sensitivity to PMTV in field evaluations. They demonstrated that PMTV tuber necrosis and severity were different among the cultivars. Six cultivars were rated as “sensitive”, and 43 as “insensitive”, to PMTV-induced tuber necrosis. Four of the cultivars (‘Bannock Russet’, ‘Gemstar Russet’, ‘Lelah’ and ‘Waneta’) “showed zero PMTV incidence”.

Genetic transformation has been shown to confer PMTV resistance to host plants, and several reports (some listed below) have demonstrated the potential for transgene technologies to provide effective host resistance to the virus. Valkonen 1012

* Barker et al. (1998) assessed PMTV infections in greenhouse-grown plants of the potato cvs ‘Saturna’ and ‘Pentland Marble’ that were transformed with the PMTV coat protein gene. Incidence of PMTV infections in daughter tubers were 10 to 17% for non-transformed plants, but transformed plants containing the PMTV RNA transcript and coat protein were almost immune to PMTV.
* Melander et al. (2001) obtained similar results with field-grown cv. ‘Hulda’ plants that were transformed to contain a mutated triple gene block protein.
* Germundsson et al. (2002) demonstrated transgenically acquired resistance to PMTV in potato and *Nicotiana benthamiana* plants transformed with the coat protein of PMTV. Field-grown transformed potato lines of cv. ‘Saturna’ containing the PMTV coat protein had reduced incidence of PMTV in their tubers compared with non-transformed ‘Saturna’ plants. Similar transformation of *Nicotiana benthamiana* indicated that the PMTV coat protein restricted accumulation of one of the three virus RNAs in leaves less than in roots. They concluded that coat protein- and RNA-mediated resistance mechanisms may have been involved.
* Chung & Palukaitus (2011) detected resistance to several viruses (including PMTV) in *Nicotiana tabacum* plants transformed with double-stranded RNAs, and their results indicated that resistances to several viruses correlated with levels of RNA accumulation, and was achieved through RNA silencing.

These studies and have also given insights into the potential mechanisms of PMTV resistance in host plants. However, application of these technologies for practical management of PMTV diseases of potato (mop-top and spraing) is dependent on factors beyond this knowledge creation.

***Comment***

Utilisation of cultivar resistance to PMTV (and probably *S. subterranea*) has often been suggested as the most appropriate (and possibly only) strategy for successful management of PMTV infections and spraing in potato tubers and crops (e.g. Yellareddygari et al. 2018) (see **Section 5**). Resistance to PMTV remains a positive characteristic emphasised in release of new potato cultivars (e.g. Stark et al. 2018). However, the complexities of the relationships between potato host plants, PMTV and *S. subterranea* make it very difficult to utilise host resistance for effective management of the diseases they cause (Valkonen 2015).

PMTV causes symptomless tuber infections, so seed tubers of PMTV-“resistant” (symptom-free) cultivars can harbour and proliferate the virus, and contribute to its dissemination and perennation. The situation is similar with *S. subterranea*, where cultivars that are “resistant” to powdery scab on tubers can be very susceptible to *Spongospora* zoosporangium development in roots (Falloon et al., 2003) and root galling (Falloon et al., 2003; 2016). Root infections proliferate the pathogen and release long-surviving virus-infected resting spore inoculum (sporosori) into soils. Potato production regions and fields will then harbour both pathogens (virus and vector) for subsequent potato crops, and these may cause severe diseases if they are established with cultivars that are susceptibile to *S. subterranea* and/or PMTV.

Very few potato cultivars commonly grown in New Zealand feature in reports of cultivar assessments for PMTV resistance. However, cv. ‘Russet Burbank’ has been assessed in several studies, and has been confirmed as “less susceptible” or “insensitive” to PMTV. Similarly, cv. ‘Desiree’ features in several reports, but this cultivar has been shown to develop high levels of incidence of PMTV infections in tubers, but with few spraing symptoms (e.g. Carnegies et al., 2009). The large numbers of other evaluated cultivars have been relevant for the particular regions where assessments have been carried out. The reaction of cv. ‘Innovator’ to PMTV has not been assessed in these studies.

For powdery scab on tubers (caused by *S. subterranea*), many potato cultivars have been assessed in New Zealand. Reactions of 162 cultivars and advanced breeding lines to powdery scab are well-catalogued (Genet et al. 2017), where potato varieties were grouped as “very resistant”, “moderately resistant”, “moderately susceptible” or “very susceptible”, depending on scaled average severity scores derived over multiple growing season evaluations. However, the situation with *S. subterranea* susceptibility is also complex. Recent studies (e.g. Falloon et al. 2016) have shown that individual potato cultivars have different reactions to the three distinct diseases caused by *S. subterranea* (disrupted root function, root galling, tuber powdery scab), and root infections by *S. subterranea* (incidence of zoosporangia in root cells or severity of root galling) may not be related to severity of powdery scab on tubers (Falloon et al. 2016). This complex relationship between *S. subterranea* (the PMTV vector) and different potato cultivars is very likely to be an important confounding factor affecting the susceptibility of different potato cultivars to PMTV.

***Research questions***

* What are the relative susceptibilities of the predominant New Zealand-grown potato cultivars to PMTV infections and to spraing symptoms in tubers?
* Can potato cultivar resistance to PMTV be utilised to effectively manage PMTV diseases in New Zealand, taking cognisance of the cultivars grown in this country?

1. **Effects of *Potato mop-top virus* on potato yields**

Many reports of PMTV infection of potato indicate that the dominant consequences of these infections result from spraing symptoms in tubers, which reduce tuber quality (e.g. Santala et al. 2010), and from PMTV infections in seed tubers as sources of virus transmission. For example, Nielsen & Mølgaard (1997) measured tuber yields during three growing seasons in Denmark. Field-grown potatoes (cv. ‘Saturna’) with severe spraing symptoms were compared with crops with slight or no symptoms. No statistically significant correlations were detected, either between severity of spraing and yields, or between spraing severity and tuber dry matter. Yellareddygari *et al.* (2018) stated that “Although PMTV has no direct impact on yield loss, it may incur quality loss, which can lead to rejection of tubers intended for the fresh market and processing industry.” Other reports often discount, or do not consider, direct effects of PMTV virus on plant or crop productivity (number of tubers, weight/tuber or crop yields) (see reviews listed in **Section 1**).

There are some reports, however, where reductions in tuber yields have been linked to PMTV infections. Kurppa (1998) tested six cultivars grown in field trials in Finland, from either healthy or PMTV-infected seed tubers. Numbers of tubers per plant were reduced for infected plants of one cultivar (‘Saturna’) by 20%. Weight of tubers per plant were reduced by 9 to 37% for four cultivars (‘Ostara’, ’Olympia’, ‘Sabina’, ‘Saturna’). Numbers of tubers and weight of tubers per plant for ‘Bintje’ and ‘Matilda’ were not affected (*P* > 0.05) by PMTV infections in their seed tubers. Carnegie et al. (2010a), in Scotland, assessed field-grown potato plants with or without foliar mop-top symptoms. Tuber yields from cv. ‘Hermes’ plants with severe symptoms were 67% and 57% less (in two growing seasons) than plants without symptoms, and numbers of tubers from symptomatic plants were 57% and 46% less (in the two seasons) than those from plants without symptoms.

While results of these studies are equivocal, they indicate that a complex and confounded situation probably exists for PMTV and *S. subterranea*. Studies have not considered that *S. subterranea* may have been a cause of yield reductions where PMTV occurred. Recent research in New Zealand (Falloon et al., 2016), where *S. subterranea* was assumed to be acting alone, has provided evidence that this pathogen can reduce plant growth and productivity through root infections, with the magnitude of these effects being cultivar dependent. Similar experimental evidence has been obtained from study of *S. subterranea* infection of tomato roots (Balendres et al. 2018).

Santala et al. (2010) noted that “The spraing disease constitutes a severe quality problem in staple potatoes and potatoes grown for the food industry and is a major obstacle to economically profitable potato production in [the Nordic countries Norway, Sweden, Denmark and Finland]. Affected tubers are unsuitable for the French fry and chip (crisp) industries and are rejected by supermarkets and the food industry.” This emphasises the effects of PMTV infection on quality of tubers, rather than on their quantity and weight (yield).

***Research questions***

* What are the effects of PMTV on growth and tuber production of potato plants?
* Do PMTV and *S. subterranea* infections of potato have separate (possibly additive) or synergistic effects on potato plant and crop productivity (plant growth, tuber size and weight, tuber yields from crops)?

1. **Temperature and soil moisture effects on *Potato mop-top virus***

There is general consensus that optimum temperatures for PMTV infections of potato, and infections by *S. subterranea*, are 15 to 20°C, and that these infections can occur, but at less incidence and intensity, at as low as 5 to 8°C, and up to 22 to 25°C. *Spongospora subterranea* causes severe powdery scab in potato crops in regions where air temperatures are much higher than this optimum and range. This is most probably because intensive irrigation is used for production of potatoes in regions where high temperature are experienced (e.g. Australia and South Africa). The frequent (sometimes daily) applications of water used for potato crops in these regions are likely to maintain soil temperatures close to the optimum range for *S. subterranea*. Intensive irrigation will also provide moist soil conditions that are known to support *S. subterranea* zoospore infection of potato roots and tubers. It is also possible, however, that severe diseases caused by *S. subterranea* in high temperature regions may be due to strains of the pathogen adapted to high soil temperatures.

Cooper & Harrison (1973) suggested that occurrence of PMTV in potato crops in Scotland was “unrelated” to accumulated temperature. However, they reported that occurrence of the virus was “strongly related” to annual rainfall, with “little” PMTV-related disease where annual rainfall was less than 760 mm, “increased prevalence” where rainfall was from 760 to 1,140 mm, and “great probability of infection” where rainfall was more than 1,140 mm each year.

Carnegie et al. (2010b) assessed effects of different temperatures on PMTV and *S. subterranea*, in controlled temperature greenhouse conditions. Incidence of foliar symptoms of PMTV infection was greatest on plants grown at 12°C, less at 16°C, there were few symptoms at 20°C and symptoms were absent at 24°C. Transmission from PMTV-infected seed tubers was not affected by temperatures between 12 and 24°C, but when the virus was transmitted by *S. subterranea*, “minimal” PMTV tuber infection occurred at 24°C, and no differences were recorded between 12 and 20°C. Incidence of powdery scab on tubers was greatest at 12 and 16°C, and very low at 20 and 24°C. Incidence and severity of *Spongospora* root galling were greatest at 20°C and very low at 24°C. Carnegie et al. (2010b) concluded that PMTV infection of potato roots can occur at higher temperatures than those for powdery scab on tubers, and that root infection can enable transmission of PMTV into potato plants.

Domfeh & Gudmestad (2016) carried out a detailed greenhouse experiment to measure effects of different soil moisture regimes on *S. subterranea* root gall development, tuber powdery scab and PMTV-induced tuber necrosis in two potato cultivars. Incidence of powdery scab was greater in moist soil than dry soil, and incidence and severity of PMTV-induced necrosis were also greater in moist soil than dry soil. The cv. ‘Ivory Crisp’ developed more root galls than cv. ‘Dakota Crisp’, and powdery scab incidence on tubers was related to incidence of PMTV-induced tuber necrosis.

Symptoms of PMTV in potato tubers can be enhanced after harvest by alternating storage temperatures (e.g. from 8°C to 18-20°C) at short intervals (1 to 2 weeks) (Harrison & Jones 1971; Sandgren 1995; Mølgaard & Nielsen 1996;).

***Comment***

There is general recognition in Scandinavian countries that disease caused by PMTV (spraing in tubers) causes greater problems for potato production than those caused by *S. subterranea* (root galls and tuber powdery scab) (e.g. Santala et al. 2010). This indicates that PMTV thrives to a greater extent in the cool climates of northern Europe than the vector of the virus, *S. subterranea*. It is also very generally accepted that *S. subterranea* requires moist soil conditions for infection of host plants, because moist soils are necessary for movement of the infective motile zoospores of the pathogen.

These observations indicate that PMTV may cause greatest problems for New Zealand potato production in southern (cooler) areas of the country (e.g Southland, Otago, Canterbury), rather than in more northern regions (e.g. Waikato, Pukekohe).

1. **Methods for detection of *Potato mop-top virus***

Santala et al. (2010) reviewed methods for detection of PMTV, and these have since continued to be developed and compared. PMTV detection methods are of four general types, listed below, Most of these methods require considerable technical skills for their application. Examples of protocols that have been used for sampling of tubers and field soils for detection of PMTV infestations are also documented. Protocols for detection *S. subterranea* in soil are likely to provide valuable tools for investigating epidemiology and control of PMTV, as well as for similar research on diseases caused by *S. subterranea* (van der Graaf et al. (2003)

***8.1 Disease symptoms***

The use of visual symptoms of PMTV infections (cracking and spraing in potato tubers, “mop-top” and leaf distortions in shoots) have been widely used for detection of PMTV infections, particularly in field- or greenhouse-grown plants. However, PMTV symptoms can be ephemeral (see above), and tuber symptoms may not be apparent in PMTV-infected tubers, so symptom detection is very likely to unreliable for detecting this virus. For example, Latvala-Kilby et al. (2009) assessed PMTV infections in field-grown tubers of five potato cultivars using spraing symptom assessments and RT-PCR detection of the virus (see below). RT-PCR showed that, depending on cultivar, between 2 and 100% of tubers without spraing symptoms were infected with PMTV. Other studies have confirmed this conclusion (e.g. Sokmen et al. 1998; Nakayama et al. 2010b; Beuch et al. 2014).

***8.2 Bait tests and virus indicator plants***

Growing potato or specific virus indicator plants in soil infested with *S. subterranea* and PMTV, or in field soil-amended growth media, has been used in several studies to detect PMTV (e.g. Sandgren 1995; Arif et al. 2014;). Beside potato, *Chenopodium amaranticolor,* *Nicotiana benthamiana*, *N. clevelandii*, *N. debneyi*, *N. rustica*, *N. tabacum* and *Solanum lycopersicum* (tomato) have all been used as PMTV indicator plants (Nakayama et al. 2010a; Latvala-Kilby et al. 2009; Santala et al. 2010; Gil et al. 2016). Indicator plants can also be inoculated with sap extracted from candidate (suspect) host plants, using standard virus inoculation procedures. Symptoms of PMTV infections in these plants may vary considerably for different PMTV strains (“isolates”; Gil et al. 2016).

***8.3 Enzyme-linked immunosorbent assays (ELISA and DAS-ELISA)***

ELISA techniques have been commonly used for detection of PMTV in host plants. Examples are in the studies of: Roberts & Harrison (1979); Arif et al. (1994; 2013; 2014); Nielsen & Mølgaard (1997); Sokmen et al. (1998); Nicolaisen et al. (1999); Čeřovská et al. (2003; 2006); Sokmen et al. (1998); Latvala-Kilby et al. (2009); and Arif et al. 2014). Some of these reports include comparisons of efficiency of ELISA with other methods for detecting the virus.

***8.4 Reverse transcription polymerase chain reaction (RT-PCR) methods***

Numerous studies have employed RT-PCR technologies for PMTV detection, and these methods are widely accepted as the most sensitive and precise for PMTV detection. Example studies are those of: Arif et al. (1994), Sokmen et al. (1998), Nicolaisen et al. 1999; Sandgren et al. (2001), Germundsson et al. (2002), van der Graaf et al. (2003), Latvala-Kilby et al. (2009), Ryazantsev & Zavriev (2009), Nakayama et al. (2010a), Maoka et al. (2013), Arif et al. (2014), Gil et al. (2016), Lee et al. (2017) and Nikitin et al. 2018). Various RT-PCR protocols and modifications have been detailed in these papers, and some studies have compared this technology with other methods for PMTV detection.

PCR technology is currently at an advanced stage of development, where it can be applied for field detection of PMTV and *S. subterranea*. Nikitin et al. (2018) outlined a multi-pathogen real-time PCR system for detection of potato pathogens. This system was described as “accurate, rapid and user-friendly”, and likely to “significantly contribute to pathogen screening and phytopathological studies”. DeShields et al. (2018) described real time PCR protocols and equipment for “on-site” detection of soilborne potato pathogens, potentially for field use. Their system was validated for detection of infestations and infections of *S. subterranea*, PMTV and *Rhizoctonia solani* in field soils and in host plant tissues.

***Comparison of PMTV detection methods***

Several papers report the use of multiple PMTV detection methods, and have determined their relative sensitivity.

* Arif et al. (1994) demonstrated that ELISA and RT-PCR were more sensitive than bait tests and sap inoculations of indicator plants for diagnosis of PMTV infestations in soil and infections in potato tubers. RT-PCR detected PMTV in roots and leaves of *Nicotiana debneyi* bait plants after 3 weeks growth in viruliferous soil, and this detection was 3 weeks prior to development of plant symptoms and 2 weeks before detection of PMTV with ELISA.
* Sokmen et al. (1998) compared ELISA and RT-PCR for PMTV detection in potato tubers, and found that more infected tubers were detected using ELISA than with their PCR protocol. They suggested that this may have resulted from uneven distribution of the virus within individual tubers. They also demonstrated that treatment of tubers at 20°C for 4 weeks prior to virus testing “nearly doubled” the number of sampled sites in tubers at which PMTV was detected by ELISA.
* Latvala-Kilby et al. (2009) used visual symptom assessments, bait plant assays, ELISA and RT-PCR in various experiments, as methods for detection of PMTV in large numbers of potato tubers and sprouts. Visual assessment did not detect many of the infections in tubers, even after low temperature storage. RT-PCR was considered to be the most sensitive technology for PMTV detection.
* Maoka et al. (2013) compared ELISA with modified RT-PCR for detecting potato viruses (including PMTV). They found that the molecular method was more sensitive for virus detection than ELISA, although they did not record PMTV in any of 35 landraces they assayed.
* Arif et al. (2014) reported that spraing symptoms (browning) within tubers were positively related to ELISA-detected PMTV infections, but these detected virus infections were not related to external tuber symptoms of the virus or powdery scab (*S. subterranea*).
* Arif et al. (2014) used bait plants, ELISA and RT-PCR in their survey of potato growing regions and commonly grown cultivars in Pakistan. They concluded that both methods “readily detected” PMTV in tubers with external (brown arc) and internal (browning) symptoms.

***Field sampling to detect PMTV infestations***

Some studies have used small numbers of tuber, plant or soil samples for testing of pathogen detection protocols. Examples are:

* Maoka et al. (2013) collected stems, leaves and tubers from field grown plants of Japanese potato “landraces”, and propagated cuttings and plants from these plants in a greenhouse prior to indexing for several viruses.
* Muhammad et al. (2014) broadly assayed PMTV infestations in Pakistan across several regions of this country and from several potato fields within each region. From each field, a 500 g soil sample and tubers from a 4 m2 plot were used in the study.
* Nikitin et al. (2018) used three to five plants for validating real-time PCR detection of multiple potato pathogens, including PMTV.
* Arif et al. (2013), for PMTV detection in individual fields, sampled plants from approx. 4 m2 in each field, and collected three soil samples of approx. 500 g at 20-25 m spacing at the field boundary.

Other protocols for PMTV detection have used systematic and detailed field sampling approaches. Examples are:

* Latvala-Kilby et al. (2009) sampled large numbers of tubers from different potato cultivars (342 to 512 tubers depending on cultivar) from one multi-cultivar field trial in a known PMTV infested field.
* Nakayama et al. (2010) used tomato bait plants grown in nutrient solution suspensions of natural field soils, followed by modified RT-PCR of their tissues, to detect PMTV soil infestations, with the protocol relying on *S. subterranea* infection of tomato for PMTV detection. They carried out detailed sampling of a total of 224 fields in Hokkaido, Japan. From each field, 50-100 g of soil was taken from approx. 12 sites per hectare, at approx. 35 m spacings across the field. They showed that a microplate hybridization modification of RT-PCR gave “much improved detection of PMTV in soil”.

***Tuber sampling for detection of spraing symptoms or PMTV infections***

* Latvala-Kilby et al. (2009) (see above) sampled large numbers of tubers (several hundred) for assays of cultivar reaction to PMTV.
* Carnegie et al. (2012) surveyed seed potato crops in Scotland for PMTV infections in tubers. They obtained a 200 tuber sample from each assessed crop, from up to ten crops of each of four commonly-grown cultivars. However, the numbers of tubers from each crop that were assayed for PMTV infections (using ELISA) were not specified.

***Industry recommendations***

* That modern RT-PCR technologies be evaluated for detection of PMTV in multiple substrates (soil, plants, different potato plant organs (tubers, roots, shoots)), and that an appropriate method be adopted for routine detection and assessments of the virus in New Zealand.
* That standard protocols be adopted for sampling of potato tubers, plants and fields (soils) for PMTV detection.

1. **Alternative hosts of *Potato mop-top virus***

The susceptibility of plants other than potato to PMTV has been assessed in several studies.

‘Natural’ (field) transmission of PMTV to potato (and other hosts) is dependent on *S. subterranea* as the virus vector, and it is well-recognised that several Solanaceous and other plants are hosts, both of *S. subterranea* and PMTV (Jones & Harrison 1969; Harrison & Jones 1970; Andersen et al. 2002; Qu & Christ 2006, Nitzan et al. 2009; Shah et al. 2010; Tsror et al. 2017).

Alternative hosts of *S. subterranea* include commonly occurring crop weeds and some cultivated plants (e.g barley and wheat; Tsror et al. 2017). Some reports suggest that PMTV has a narrower host range than *S. subterranea*. For example, Andersen et al. (2002) evaluated 17 weed species common in potato fields in Denmark for infection with PMTV and *S. subterranea*, as demonstrated in a hydroponic plant growth system using PMTV-containing zoospores of *S. subterranea*. Only *Chenopodium album* (fathen) and *Solanum nigrum* (black nightshade) became infected with PMTV, whereas 13 of the tested weeds became infected with *S. subterranea*.

***Comment***

Different extents of the reported alternative host spectra for PMTV and *S. subterranea* may be due to differences in specific testing for susceptibility in plants (weeds) commonly associated with potato crops and rotations, rather than to differences in host range between the two pathogens.

***Research question***

Are weeds and other hosts growing in association with New Zealand potato crops (including in crop rotations) infected with the PMTV?

1. ***Potato mop-top virus* and indigenous or unique relict Māori potatoes**

No information is available on the relative susceptibility of Māori potato varieties to PMTV.

Harris (2001) described 18 different “cultivars” of Māori potato occurring and cultivated in New Zealand. These are likely to be *Solanum tuberosum* sub sp. *tuberosum*, but some have characteristics similar to *S. tuberosum* sub sp. *andigena*.

Four of these cultivars (‘Huakaroro’, ‘Karupārera’, ‘Moemoe’ and ‘Urenika’) have been assessed for effects resulting from S. *subterranea* inoculation, in a detailed greenhouse experiment (Falloon, et al. 2007). This showed that all four cultivars, when inoculated with the pathogen, developed *Spongospora* root galls, but cvs ‘Karupārera’ and ‘Moemoe’ developed far fewer root galls than cvs ‘Huakaroro’ or ‘Urenika’. Water uptake (root function) was also diminished in the inoculated plants relative to uninoculated plants, with different amounts of disrupted root function in the four cultivars. Inoculation resulted in reduced plant growth (shoot and/or root dry weights) for all four cultivars. Field observations (RA Gent unpublished, cited in Falloon et al. 2007) have indicated that cv. ‘Urenika’ is susceptible to tuber powdery scab and cv. ‘Moemoe’ is resistant, reflecting their respective reactions to *Spongospora* root galling.

***Comment***

These results and observations indicate that Māori potatoes, generally, are likely to be susceptible to infection the *S. subterranea*, in ways similar to more the broadly cultivated locally and internationally bred cultivars. It is also probable that Māori potatoes are susceptible to PMTV vectored by *S. subterranea*. As with conventional potato cultivars, it is also likely that Māori varieties will show differing susceptibilities to PMTV (as to *S. subterranea*), through differing innate resistance to the virus and/or to the PMTV vector.

***Research question***

What are the reactions of Māori potato varieties (“cultivars”) to PMTV?

1. **Disease management strategies for *Potato mop-top virus***

Papers addressing control of *S. subterranea* diseases (Falloon 2008; Merz & Falloon 2009) and PMTV (Santala et al. 2010) in potatoes have recommended integrated management strategies, where multiple disease control methods are recommended. This is because no method alone is completely effective for preventing either disease. Factors making it difficult to manage these diseases include the long-term survival of *S. subterranea* harbouring PMTV, intensive crop production practices with short periods between potato crops, and common weeds as alternative hosts of both pathogens. Variability of soil environments, requirements for regular irrigation and lack of acceptable pesticide strategies are also factors preventing efficient control of the diseases they cause.

Potential integrated management for diseases caused by *S. subterranea* is likely to include (Merz & Falloon 2009):

***Avoidance and field choice*** Use of pathogen-free seed tubers and plant crops into pathogen-free soils;

***Treatments of seed tubers and soils*** Where infested seed tubers and soils are unavoidable, pesticide chemicals (seed tuber and/or soil treatments), biofumigation, trap crops or biocontrol may reduce initial inoculum.

***Cultivar resistance*** Plant resistant cultivars.

***Crop management practices*** Employ long rotation periods between potato crops, use cultivation and irrigation management to avoid compacted and waterlogged soils, control alternative hosts (weeds and volunteer potato plants), use appropriate crop hygiene (clean machinery between potato crops).

The 3rd International Powdery Scab Workshop (Merz & Falloon 2017) promulgated “grower decisions” for management of powdery scab (caused by *S. subterranea*) in their potato crops. These stemmed from consideration of “cultivar choice”, “field choice” or “seed tubers”

***For cultivars***, reactions (resistant or susceptible) to tuber or root diseases caused by the pathogen were the criteria upon which cultivar choice could be based.

***For fields***, period between potato crops (more or less than 6 years) and potato cropping history indicated choice of cultivar, as susceptible (no preceding potato) or resistant (previous potato crops). For short terms between potato crops, decisions could be based on *Spongospora* detection in soil, field and soil management (avoiding compaction and excessive irrigation, use of biofumigation/trap crops, use of soil-applied pesticides or nutrients), or use of alternative fields. For longer periods between potato crops, decisions could consider relative cultivar susceptibility.

***For seed tubers***, decisions would be based on choice of lines certified as below statutory powdery scab incidence levels, and/or use of appropriate seed tuber treatments.

Agricultural extension service publications from the USA have recommended methods for management of PMYV.

* The North Dakota State University Extension service (Robinson et al. 2018) recommended:
* Abandon infested fields and never plant potatoes in them again.
* Remove all soil from implements that move from infested fields to non-infested fields (maintain the same practice for equipment used in producing rotational crops and any tillage implements).
* Do not re-spread harvest soil into non-infested fields.
* Ensure see tuber sources are produced in fields free of powdery scab and/or PMTV through PCR testing and/or bioassay.
* Plant potato cultivars that are tolerant of PMTV tuber necrosis.
* Similar recommendations have been made by the Wisconsin Department of Agriculture, Trade and Consumer Protection (Leisso & Phibbs 2019), and these also include recommendations for appropriate management of *S. subterranea* as the PMTV vector.

Valkonen (2015) concluded that there was “no efficient or possible strategy to prevent [PMTV] infections” in potato crops, nor was control of the PMTV vector (*S. subterranea*) “an efficient or possible strategy to prevent [virus] infections.” However, he concluded that “resistance of potato cultivars to PMTV remains the only option for control of PMTV”, and that effective resistance to the virus would depend on deployment of genetic transformation for incorporation of effective resistance genes from *Solanum tuberosum* sources, or utilising transgenetic technologies to incorporate foreign resistance genes into potato cultivars.

***Industry recommendations***

That robust and appropriate PMTV and *S. subterranea* testing regimes be routinely used for seed potato lines, and for soils from fields to be used for potato production.

That seed tuber lines infected with PMTV and *S. subterranea* be avoided for establishment of potato crops.

That fields infested by PMTV and *S. subterranea* be avoided for potato production.

That spreading of potato processing factory effluent for animal feed be avoided for fields that may be used for potato production.

That composts proposed for field disposal be tested for *S. subterranea*/PMTV, and where positive results indicate, that these materials are not used for potential potato fields.

That periods between potato crops, for seed tuber, processing or fresh production, are maximised (greater than 10 years) to reduce the likelihood of *S. subterranea*/PMTV infections.

That appropriate management strategies for diseases caused by PMTV and *S. subterranea* are appropriately publicised for all sectors of the New Zealand potato industry.

1. **Research questions:**

* What are the genetic (molecular) characteristics and variability of PMTV in New Zealand, and are New Zealand strains of the virus different from those elsewhere in the world?
* Can genetic characteristics of New Zealand PMTV strains indicate their international geographical origin(s), or date of introduction into New Zealand?
* What are the effects of elevated temperatures on PMTV?
* What are the effects of PMTV on growth and tuber production of potato plants?
* Do PMTV and *S. subterranea* infections of potato have separate (possibly additive) or synergistic effects on potato plant and crop productivity (plant growth, tuber size and weight, tuber yields from crops)?
* What are the relative susceptibilities of the predominant New Zealand-grown potato cultivars to PMTV infections and to spraing symptoms in tubers?
* Can potato cultivar resistance to PMTV be utilised to effectively manage PMTV diseases in New Zealand, taking cognisance of the cultivars grown in this country?
* What are the reactions of Māori potato varieties (“cultivars”) to PMTV?
* Are weeds and other hosts growing in associations with New Zealand potato crops (including in rotations) infected with the PMTV?

1. **Industry recommendations:**

* That detailed monitoring of peat or tree bark imported to New Zealand is implemented for *S. subterranea* and PMTV infestations, where these materials are to be used in plant and mushroom propagation media.
* That routine spreading of spent mushroom compost or potting mixes be carefully considered for fields that may be used for potato production, that these materials be tested for infestations by *S. subterranea* and PMTV, and that pathogen-positive material not be applied to fields likely to be used for potato production.
* That modern RT-PCR technologies be evaluated for detection of PMTV in multiple substrates (soil, plants, different potato plant organs (tubers, roots, shoots)), and that an appropriate method be adopted for routine detection and assessments of the virus in New Zealand.
* That standard protocols be adopted for sampling of potato tubers, plants and fields (soils) for PMTV detection.
* That robust and appropriate PMTV and *S. subterranea* testing regimes be routinely used for seed potato lines, and for soils from fields to be used for potato production.
* That seed tuber lines infected with PMTV and *S. subterranea* be avoided for establishment of potato crops.
* That fields infested by PMTV and *S. subterranea* be avoided for potato production.
* That spreading of potato processing factory effluent for animal feed be avoided for fields that may be used for potato production.
* That composts proposed for field disposal be tested for *S. subterranea*/PMTV, and where positive results indicate, that these materials are not used for potential potato fields.
* That periods between potato crops, for seed tuber, processing or fresh production, are maximised (greater than 10 years) to reduce the likelihood of *S. subterranea*/PMTV infections.
* That appropriate management strategies for diseases caused by PMTV and *S. subterranea* are appropriately publicised for all sectors of the New Zealand potato industry.

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