Controlling aphid-vectored viruses for organic seed potato production: Literature and knowledge review

March 2011

Final report to:

Fraserland Organics
Organic Sector Development Program

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Executive Summary

While production of certified organic seed potatoes is a flourishing industry in BC (Anonymous, 2003), it has not grown fast enough to support the increasing demand for organic potatoes. One of the main limitations in the production of organic seed potatoes is the lack of control tools for viruses and their aphid vectors. Potato virus Y (PVY) is one of the most important viruses as it can reduce yield. Soap is the only aphicide currently registered for organic production and it provides insufficient control of aphids to meet seed potato standards. For the purpose of identifying additional management tools for non-persistent viruses and their aphid vectors, this literature review and knowledge review were conducted.

Researchers have found ways to prevent the transmission of non-persistent viruses like PVY through the use of mineral oils as foliar sprays and trap crop borders planted around edges of potato fields. Paraffinic mineral oils sprayed weekly on potato plants act directly on aphid populations through insecticidal activity and by interfering with an aphid's ability to transmit non-persistent viruses. Crop borders, such as soybean, wheat or potato, planted around edges of potato fields act as "virus sinks". The crop border method is based on two facts 1) aphids, attracted to contrast between green (crop) and dark (soil), usually land on field margins and start feeding 2) aphids that arrive carrying a non-persistent virus on their mouthparts will land on the crop border, start feeding, and lose their capacity to transmit non-persistent virus to the main crop.

While mineral oil and crop border plantings have been widely used to control non-persistent potato viruses in organic seed potato production Europe, their use in North America is limited. Some growers in the US have been using these tools with success, and BC seed potato growers could benefit from integrating these tools into their production practices.

Introduction and Objectives

Potatoes are an important vegetable crop for many organic farms in British Columbia. However, potatoes are susceptible to a wide range of diseases which makes organic production a challenge. The use of certified seed potatoes is an important practice for the management of potato diseases, especially those caused by viruses, as viruses have the potential to reduce potato yields. Potato virus Y (PVY) is one of the most important viruses. For each 1% increase in PVY incidence yield can be reduced by 0.1805 t/ha in commonly grown varieties such as Russet Norkotak, Russet Burbank and Shepody (Whitworth *et al.* 2006). PVY like most potato viruses are vectored by aphids, thus virus diseases can spread rapidly to neighbouring fields if aphid vectors are not controlled. Production therefore of seed potatoes, certified to have very low (i.e. below economic impact) virus levels, requires management of both the virus and the aphid vector.

Production of certified organic seed potatoes is a growing industry in BC (Anonymous, 2003). However, production of certified organic seed potatoes has not kept pace with consumer demand for organic potatoes. Because there is an insufficient supply of organic seed potatoes, organic growers are allowed to use conventionally-produced seed tubers. However, certification bodies are increasingly demanding the use of organic propagation material, and seed potato growers would like to supply this market. One of the main limitations for the production of organic seed potatoes is the lack of organic management tools for viruses and their aphid vectors.

Although many insects can vector viruses, aphids are the most important vectors for potatoes. The green peach aphid, *Myzus persicae*, is the most common aphid species in potatoes and the most efficient at transmitting potato viruses (Radcliffe and Ragsdale 2002). Other aphid species such as the potato aphid, *Macrosiphum euphorbiae*, buckthorn aphid, *Aulacorthum solani*, and melon aphid, *Aphis gossypii* are also of concern (Radcliffe and Ragsdale 2002). Viruses can be divided into two groups - persistent and non-persistent viruses. Distinguishing the virus transmission process between persistent and non-persistent viruses is crucial in order to evaluate potential vector controls. When an aphid feeds on a plant infected by a persistent virus (e.g. potato leaf roll virus), it can take hours of probing and incubation before the aphid acquires the virus and has the potential to transmit to another plant. For these viruses, contact insecticides are a good tool to prevent aphids from infecting healthy plants (Radcliffe and Ragsdale 2002). However, in the case of a non-persistent virus (e.g. PVY), an aphid probing an infected plant will instantly acquire the virus; the virus will then remain in the aphid's mouthpart (stylet) until it probes another plant (Fereres and Moreno 2009). Consequently, aphids carrying non-persistent viruses have the potential to infect other plants very quickly. For non-persistent viruses, most insecticides do not prevent virus transmission (Perring *et al.* 1999) because they do not act fast enough to prevent aphids from inserting their mouthparts (i.e. probing) into plants (Loebenstein and Raccah 1980). Control tools that would prevent inoculation and acquisition of virus by aphids are necessary to control non-persistent viruses.

Soap is the only aphicide currently registered for organic production and it provides insufficient control of aphids to meet seed potato standards. Like other insecticides (conventional or organic), soap does not reduce the transmission of non-persistent mosaic viruses (the most common being PVY) since it does not prevent aphids from probing. Researchers have found other ways to prevent the transmission of non-persistent viruses like PVY and these methods include the use of mineral oils as foliar sprays and trap crop borders planted around edges of potato fields. Both of these approaches would be suitable for the production of organic seed potatoes. The objectives of this study are:

1. Review the recent literature with regards to non-persistent virus control using mineral oil and crop border management tools.

2. Interview growers and agricultural experts from the Fraser Valley and other growing regions to determine how extensively these two management approaches are being used.

3. Determine the feasibility of these strategies for use in the Fraser Valley.

Objective 1. Literature Review: Mineral Oil

Mineral oil was first examined for preventing virus transmission by Bradley *et al.* (1962). In their lab experiments, they showed that mineral type oils have the potential to completely inhibit transmission of PVY by aphids to healthy tobacco plants if the plants are coated with the oils. Following the findings of Bradley *et al*. (1962), mineral oil has been used extensively by growers in Europe. Although there are several types of mineral oils, Wijs (1980) demonstrated that the optimum virus transmission inhibition was obtained by paraffinic mineral oil. Since then, research has mostly focused on paraffinic mineral oils, derived from the petroleum industry (e.g. Sunoco 7E, Sunspray Ultrafine 85%, Sunspray 850 EC, etc). Glacial Spray Fluid (Loveland Products Inc), Organic JMS Stylet Oil (JMS Flower Farms Inc) and Purespray/13E (Petro Canada) are paraffinic mineral oils that are currently approved for organic production in the US. There are a number of mineral oils currently registered in Canada, including Purespray/13E (see Appendix I), however none of these products have potato on the current Canadian label. Also many of these oils are registered as adjuvants and only a handful are registered as insecticides. More recently, other types of oil such as rapeseed oil (refined and raw), soya oil (refined and raw) and fish oil have been examined for preventing virus transmission (Martin *et al*. 2004). Refined rapeseed oil was shown to be as effective as paraffinic mineral oil at suppressing transmission of the cucumber mosaic virus on pepper by aphids. However, the oils used in these experiments were formulated for the lab and to our knowledge there are no commercial formulations of these oils in the registration process in Canada.

Mineral oils have been shown to affect the ability of aphids to vector non-persistent viruses in three ways: 1) they alter aphid feeding behaviour (Fereres and Moreno 2009), 2) they can have a direct insecticidal effect on aphids, and 3) mineral oils have been shown to alter the virus-aphid interaction such that virus transmission is disrupted (Powell, 1992). Each of these effects are examined below.

Effect on aphid behaviour: Mineral oil can reduce virus transmission by changing aphid feeding behaviour. Stylet penetration on a host plant can be delayed when the plant is sprayed with mineral oil (Powell 1992; Powell *et al.* 1998). Powell (1992) showed that the number of aphids that initiated feeding within the first 30 seconds of exposure to a plant was reduced by 50 % if the plants were treated with mineral oil. In other words, when an aphid lands on a mineral oil-treated plant it will take more time to decide whether or not it will feed compared to an untreated-plant. Further, oils have been shown to have a repulsive effect on aphids, however the repulsive effect only lasts for a short period of time (30 minutes after spraying) (Ameline *et al.* 2010). These changes in aphid behaviour on their own would not be sufficient to reduce virus transmission to the levels acceptable for seed potato production. However, the above studies demonstrate that mineral oil causes an initial negative effect on aphid feeding behaviour, which is then followed by a more long-term effect on population growth and virus transmission (see below).

Direct insecticidal effect on aphids: Several studies show a direct effect of mineral oils on aphid survival (Table 1). Iversen and Harding (2007) observed 75% mortality of woolly beech aphid eggs when they were in contact with mineral oil close to hatching. Mineral oil caused 100% mortality of soybean aphid nymphs and 83.3% mortality in adults treated in lab experiments (Kraiss and Cullen 2008). Najar-Rodriguez *et al.* (2008) showed that mortality of the cotton aphid in laboratory experiments was dependent on the dose of oil-product being tested, lower rates (0.1 µl/ml to 0.25 µl/ml) did not cause and mortality, while at the higher rates (2.5µl/ml to 20 µl/ml) these authors achieved 100% mortality.

As with any insecticide, the efficacy of mineral oil depends on the timing of application. For example, in a lab experiment where oil was sprayed on pepper leaves before green peach aphids were introduced, the mortality rate was 11.7 to 20.8% (Martin *et al.* 2004) while sprays applied after the leaves had been colonised by green peach aphids resulted in a mortality rate of 80% (Martin *et al.* 2006). Oils appear to be most effective when applied when aphid population densities are low. For example, Najar-Rodriguez *et al.*

(2007) observed increased oil-induced mortality of aphids with lower population densities of the melon aphid. Similarly, in field trials conducted with Purespray Green/13E (paraffinic mineral oil), significant reductions in pea aphid, *Acyrthosiphon pisum* and cabbage aphid, *Brevicoryne brassicae* population growth were achieved compared to a water control when treatments started at low aphid densities (i.e. < 30 aphids/plot in peas and < 10 aphids/plot in cole crops) but not when treatments started at higher aphid populations (Dessureault and Prasad 2010). Najar-Rodriguez *et al.* (2008) described the possible modes of action by which mineral oils kill aphids. They showed that the oil rapidly penetrates the aphid cuticle (skin), accumulates in tissues (mostly the lipid-type) and in the cells, where it causes cellular disruptions and death. Interestingly, suffocation is unlikely to be a mode of action of mineral oil as no disruption in the aphid's respiratory system (tracheae) was observed (Najar-Rodriguez *et al.* 2008).

Reduction of virus transmission: Mineral oils have been shown to interfere with virus retention in and on the aphid mouthparts (stylet) (Powell 1992). Normally PVY particles can remain on the green peach aphid stylet for about 17 hrs after feeding on an infected plant (Wrobel 2009). However, treating plants with oil resulted in retention time as short as 2 minutes (Wrobel 2009). Reducing the amount of time that aphids retain non-persistent viruses on their mouthparts reduces the rate of virus transmission to healthy plants. For example, spraying tobacco plants with oil resulted in Etch potyvirus transmission rates of 0 to 1.67% compared to transmission rates of 16.67% to 18.3% in the untreated Control (Wrobel 2009). Complete inhibition of aphid-vectored non-persistent virus transmission by spraying mineral oil have been demonstrated for cucumber mosaic virus transmission to pepper plants (Martin *et al*. 2004), Etch potyvirus transmission on tobacco (Wang and Pirone 1996) and PVY transmission on potatoes (Wrobel 2009). Other studies have achieved reductions in non-persistent virus transmission rates ranging from 50% to 70% compared to the untreated Control (Asjes, 1985; Powell, 1992; Powell *et al.*1998; Martin *et al.* 2006; Boiteau *et al*. 2008) (Table 1). Together these studies demonstrate that there is a consistent effect of mineral oils on both aphid mortality and virus transmission which makes mineral oils one of the most effective tools to control non-persistent virus spread (Loebenstein and Raccah 1980).

Several studies have established that the most effective way to reduce virus transmission using oils is to spray both the infected "source" plant and the uninfected "healthy" plant. Powell (1992) found that spraying the source plant resulted in 8.3% inoculation efficiency, spraying the host plant resulted in 5 % inoculation efficiency, spraying both resulted in 1.7% inoculation efficiency (i.e. the least amount of virus transmission) and spraying neither resulted in a 13.3% inoculation efficiency. Similar transmission results were reported for Etch potyvirus on tobacco plants (Wang and Pirone 1996). Since PVY can also occur on, and be vectored from, volunteer potatoes, tomatoes, peppers and Solanaceous weeds (Difonzo *et al*. 1996) it is unlikely that all potential PVY source plants in an area could be sprayed. However, treating seed potato fields on a regular basis with mineral oils should help to reduce virus transmission regardless of the source of the virus, e.g. neighbouring potato field or infected Solanaceous weeds. Since virus transmission can also occur within a seed potato field, e.g. if a PVY-infected plant is not removed (or rouged) prior to aphids acquiring the virus and transmitting to neighbouring plants, regular spraying of mineral oil will also help reduce within field virus transmission.

Table 1. Summary of the effect of mineral oil sprays on virus transmission and mortality of aphids found by other authors.

Oil Type/Brand name	**Field or Lab**	**Crop/virus/ aphid species**	**Virus transmission %/ insecticidal effect**	**Reference**
Mineral oil*/Albolineum and Luxan oil H	Field	Flower bulbs /TBV, IMMV, ISMV,IMYMV, HyMV /	Oil treated plants= a reduction of 52 to 82% of transmission efficiency compared to the Untreated	Asjes, 1985
Paraffin/Suneco 7E	Lab	Tabacco/PVY/ *M. persicae*	Oil treated plants = 6.9% transmission Untreated=35.1% transmission	Powell 1992
Paraffin/JMS Stylet-oil	Lab	Tobacco/Etch potyvirus/ *M. persicae*	Oil treated plants= 0% transmission Untreated= 16.67 transmission	Wang and Pirone 1996
Paraffin/Suneco 7E	Lab	Tabacco/PVY/ *M. persicae*	Oil treated plants = 2.5% transmission Untreated =37 % transmission	Powell *et al.* 1998
Paraffin/Sunspray Ultrafine 85%	Lab	Pepper/ Cucumber mosaic virus/ *M.persicae*	Oil treated plants = 0% transmission Untreated =16% transmission /Mortality rate of aphids feeding on oil treated plants was 11.7 to 20.8 %	Martin *et al.* 2004
Paraffin/Sun oil 7E	Field	Peach orchard/- /*M.persicae*	/9.8 % (year 1) to 81.3 % (year 2) reduction in infestation using oil compared to control	Karagounis *et al.* 2006
Paraffin/Sunspray Ultrafine 85%	Lab + field	Pepper + potatoes/PVY/ *M.persicae*	Oil + Imidacloprid treated plants= 15 % transmission Imidacloprid= 36.9%	Martin *et al.* 2006

			transmission /80 %Mortality rate of aphids feeding on oil (alone) treated plants	
Mineral oil*/Florina Prof (Bayer)	Lab + field	Common Beech/-/*P. Fagi*	/75% mortality of aphid eggs.	Iversen and Harding 2007
Paraffin/nC24 and nC27 Biopest oil	Lab	Cotton plants/-/*A. gossypii*	/>50 % mortality of 1st and 2nd instars nymphs	Najar-Rodriguez *et al.* 2007
Paraffin/nc24 Biopest oil	Lab	Cotton plants/-/*A.gossypii*	/100 % mortality of aphid (adult) at a dose of 2.5 µl/ml	Najar-Rodriguez *et al.* 2008
Paraffin/ Omni supreme spray	Lab	Soybean/-/*A. glycines*	/83.3% (adults)- 100% (nymphs) mortality	Kraiss and Cullen 2008
Paraffin/Superior Oil	Field	Potatoes/PVY/ *M. persicae, A. nasturtii, M. euphorbia.*	Oil treated plants= 88% reduction of transmission in year 1 and 23% reduction of transmission in year 2.	Boiteau *et al.* 2008
Paraffin/Sunspray 85%	Green-house	Potatoes/PVY/ *M.persicae*	Oil treated plants= 0% transmission	Wrobel 2009
Paraffin/ Finavestan Ema	Lab	Potatoes/-/ *M.euphorbiae*	/Nymph survival reduced by about 20%	Ameline 2010

*Unspecified if paraffinic type

Technical considerations-mineral oil

Most of the reviewed studies tested paraffinic mineral oils at concentrations of 0.75 to 1%, which are the recommended label rates. At these concentrations the risk of phytotoxicity is low (Simons and Zitter 1980). However, at higher rates, e.g. concentrations over 3 %, the risk of phytotoxicity increases (Boiteau and Singh 1982). Field studies have demonstrated that mineral oil can last 10-14 days on leaves of crops (Simons *et al.* 1977 in Simons and Zitter 1980). Rain or artificial irrigation (<3cm) does not appear to affect the retention of oil on the foliage regardless of whether rainfall or irrigation occurs right after spraying or a few days later (Boiteau and Wood 1982). However, rainfall or irrigation may impact the efficacy of mineral oils. In a two year field study done in a peach orchard, Karagounis *et al.* (2006) obtained an 81.9% reduction in *M. persicae* infestation when peach trees were sprayed with oil in the first year, but only a 9.8% reduction in infestation in the second year of the experiment and using the same protocol as the first year. The authors suggested that the rainfall was the main factor explaining the difference in efficacy between the two years; rainfall was low in the first year (4.2 mm) while it was considerably higher in the second year (25.2mm). Finally, most authors recommend thorough coverage of plant surfaces in order to achieve maximum efficacy. In particular, weekly sprays are important for protecting new growth (Simons and Zitter 1980; Loebenstein and Raccah 1980; Radcliffe and Ragsdale 2002).

Mineral oils can be mixed with other pesticides (Harrington *et al.* 1989; Martin *et al.* 2006) but attention should be taken when mixing mineral oils with fungicides and inorganic pesticides (e.g. sulfur and copper). There are reports of phytotoxicity when mineral oil has been mixed with fungicides such as chlorothalonil (Bravo) or sulphur-based fungicides (Simons and Zitter 1980). Most mineral oil labels recommend an interval between the oil spray and a sulphur spray. These product labels also advise that spray tanks should be thoroughly cleaned if mineral oils and sulphur-based products are used consecutively. For organic seed potato production, growers would benefit from tank mixes of mineral oil (for aphid/virus control) with copper (for late blight control). Tank mixes of oil and copper would be especially useful as both products would be sprayed at the same frequency (i.e. weekly in most cases). However, information on the compatibility of copper and mineral oil is conflicting. An Australian study conducted on nursery crops showed that mixing oil and copper did not reduce the efficacy of leafminer control by the oil (Rae et al. 1996), and mineral and horticultural oils are often recommended as spreaders for copper-based fungicides (e.g. Bordeaux mixture) (Rae *et al.* 1996). However, in a fact sheet produced by the University of Minnesota on the use of mineral oils, the recommendation is that “mineral oil should not be applied with fungicide containing copper” (Radcliffe 2003). As part of any future investigation on the feasibility of using mineral oil for organic seed potato production in the Fraser Valley, the effect of mixing mineral oil with copper should be investigated.

Objective 1. Literature Review: Crop borders

The concept of crop borders is similar to that of trap cropping and exploits several aspects of aphid behaviour (Fig. 1). First, as aphids move into a field they tend to land more on edges of fields than the middle because they are attracted to the contrast between green (crop) and dark (soil). Thus, as aphid migrate into a field they land more frequently on plants surrounded by gaps than on plants completely surrounded by plants (A’Brook 1968; Smith 1969; A’Brook 1972; Davis and Radcliffe 2009). Second, aphids go through a probing process (insertion of stylet in the plant tissues) in order to evaluate suitability of a plant as a host (Powell *et al.* 2006; Fereres and Moreno 2009) thus aphids carrying non-persistent viruses will deposit the virus in the plants that they first land on in a field. Consistent with these two aphid behaviours, non-persistent virus disease pressure is generally higher in field perimeters than interiors (Difonzo *et al.* 1996; Carroll *et al.* 2009). So, if a field is bordered by a crop, and that crop is where aphids land and probe first, it is into this crop bordering the field that aphids will deposit the virus. By doing so, aphids harbouring a non-persistent virus will become “virus free” and will not infect other plants in the rest of the field (Ragsdale *et al.* 2001). When aphids move from the crop bordering the field (crop border) to the main crop (e.g. seed potatoes) they are no longer carrying the non-persistent viruses like PVY. The crop border acts as trap or "virus-sink" for the virus but not for the aphid (Difonzo *et al.* 1996; Fereres 2000; Hooks and Fereres 2006; Boiteau *et al.* 2008) (Fig. 1).

Studies have examined the use of both living crops as well as different kinds of mulches (straw, reflective mulch etc.) to act as the virus sink along the field border. For example, the use of straw mulch in field experiments reduced PVY incidence in the potato crop by as much as 51 % (Saucke and Doring 2004). However, the effectiveness of mulches often degrades as the season progresses (closure of row, degradation of the material, etc) and application of mulches may be impractical on a large scale operation (Ragsdale *et al.* 2001). Thus, living crop borders are better suited for potato production than mulches (Radcliffe and Ragsdale 2002).

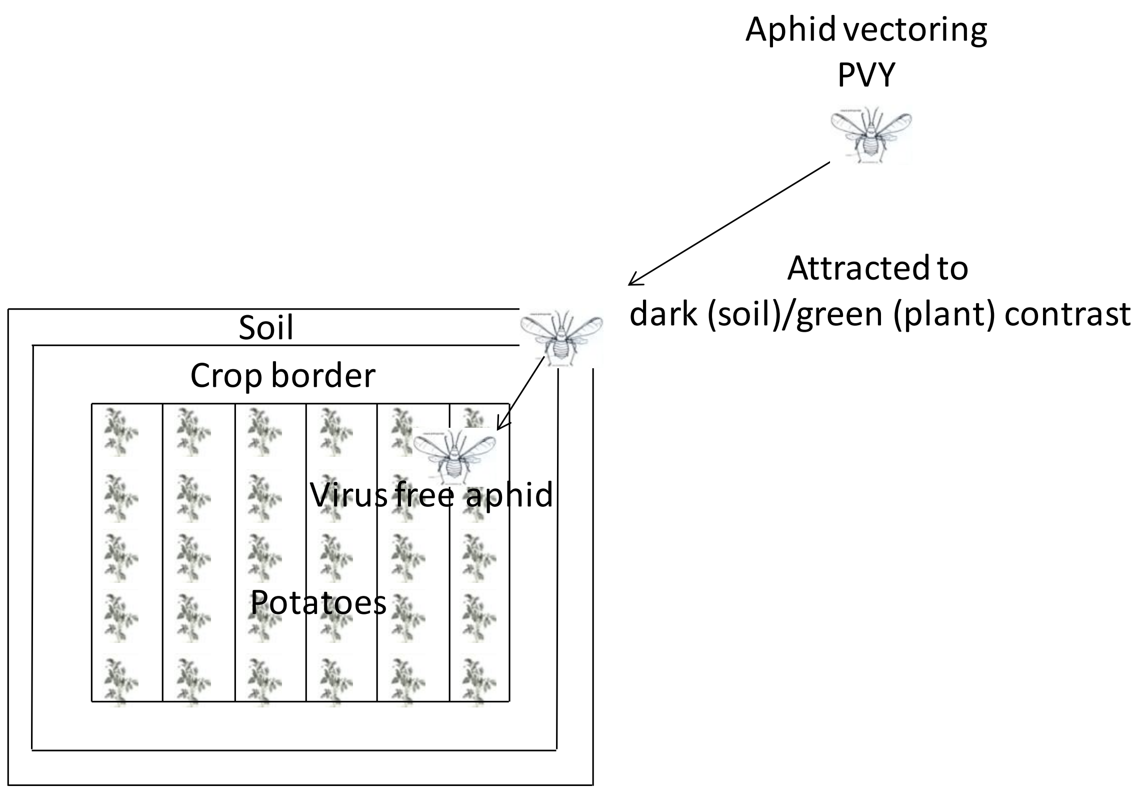

Figure 1. Virus-sink hypothesis for crop border efficacy in reducing the transmission of non-persistent viruses (e.g. potato virus Y) into seed potato fields.

Two studies have examined the use of a crop border in potato production. Difonzo *et al.* (1996) conducted a 3-year field evaluation of crop borders for seed potato production. Initial testing of a 10m wide soybean crop border resulted in a significant reduction in the incidence of PVY on the adjacent potatoes (35 %) compared to PVY incidence on potatoes grown adjacent to the bare-ground border (47.8%). In follow-up trials they tested different crops such as soybean, sorghum and wheat for the crop border. All crop borders performed equally well. The average PVY incidence on potatoes grown adjacent to the crop-bordered plots was 2.7% which was significantly lower than PVY incidence on potatoes grown adjacent to bare-ground borders (6.8%). These authors also compared the efficacy of a potato border to a soybean border. They showed that both crops performed equally well as virus-sinks, with a 65% PVY reduction in plots bordered by soybean and a 61% PVY reduction in plots bordered by potatoes.

A potato crop border would fit in well with the IPM strategies for other potato pests, for example tuber flea beetle which can be controlled very effectively if fields are planted with a headland perimeter of several potato rows. However potato headlands as they are currently used, in the Fraser Valley, would not be fully effective as crop borders because there is a gap between the headland and the main field. This may be something though that could be modified in organic seed potato fields (e.g. reduce the size of the gap between the headland and main field). However, Difonzo *et al.* (1996) mentioned that although potatoes could potentially be used as borders, using a non-PVY host (e.g. soybean) is more desirable to reduce the source of PVY.

The second field experiment examining the use of crop borders for PVY management in potato production looked at a potato crop border alone, mineral oil alone, or a crop border and mineral oil in combination (Boiteau *et al.* 2008). Interestingly, these authors used a potato variety with resistance to PVY (Kennebec) as the crop border while they used a susceptible variety for the rest of the field (Russet Burbank). Results of this three year study demonstrated that using oil in combination with crop borders is twice as effective as using either method alone. The mineral oil and crop borders combined provided 47-59% reduction of PVY incidence in 2004, 57-63% in 2005 and 79-97 % in 2006 when compared to untreated bare-ground bordered plots. Boiteau *et al.* (2008) also found that the efficacy of the mineral oil spray was the same when the mineral oil was sprayed on the borders, the center of the field, or both, and therefore mineral oil costs could be reduced by spraying the borders only.

Selecting PVY resistant potato varieties as crop border (e.g. Kennebec) may be an interesting option to reduce the risk of the crop border been a source of virus. However, most varieties showing resistance to PVY are not fully resistant (Murphy *et al.* 1999). There are different degree and types of resistance; some plants with resistance might not show symptoms but still have the capacity to acquire the virus while other resistant plants may not allow viral establishment in the plant. While the efficacy will depend of the type of resistance of a variety, this approach could potentially be valuable in a crop border system.

An alternative hypothesis to the virus-sink hypothesis for crop borders is that a living crop along the edge or border of a field acts as a physical barrier, preventing aphids from getting to the main crop by disturbing their flight and physically trapping them (Hooks and Fereres 2006). In order for the crop border to act as a physical barrier it must be taller than the main crop. However, a crop border designed to reduce PVY transmission does not need to be taller than the main crop (Difonzo *et al.* 1996). Difonzo *et al.* (2006), tested different crop borders of different height (potato, soybean, sorghum, wheat and crop-free border) and did not see a difference in the number of aphids present in the main crop. Other studies have also found that the average catch of aphids on potatoes grown adjacent to the bare-ground border plots is similar to the aphid catch on potatoes grown adjacent to cropped border, regardless of the height of the crop border (Fereres 2000; Boiteau *et al.* 2008). These studies have also found that aphids land in higher numbers in the perimeters of a field than in the middle, regardless of the type of border (bare-ground or cropped). These findings suggest that the virus-sink hypothesis is the stronger explanation of crop border effectiveness for managing PVY than the physical barrier hypothesis. This is good news for seed potato growers as it means they do not have to select crops that grow taller than potatoes for their crop borders.

Technical considerations-crop border

Compared to mineral oil, implementing crop borders for non-persistent virus control requires more technical considerations (Table 2). The biggest challenge for seed potato growers in BC in regards to crop border is land availability and the selecting a crop for the border that would fit in their production practices. The Fraser Valley is not a growing area favourable for soybeans because of insufficient heat. Although as a crop border, soybean plants would not have to grow to maturity, they would need to have a certain level of biomass and be established when the potatoes start to grow. Wheat and potato appear to be the two crops suitable for crop borders in the Fraser Valley, because growers are familiar with these crops, and both grow well here.

Table 2. Summary of technical considerations for the use of crop border.

Technical consideration	**Author**
Crop borders for protecting fields from outside source of non-persistent viruses won’t control in-field spread when the virus is coming from the seed pieces.	Hooks and Fereres 2006
Crop borders might be more useful when seed potato production is close to commercial (table stock) fields areas as the virus will mainly come externally.	Difonzo *et al.* 1996
Crop borders are better suited for small fields as there is a tendency to lose the effect as the field gets bigger. For a large field, inter-planted barrier may be more suitable.	Hooks and Fereres 2006
The crop border should be established before or at the same time as the main crop, but not after in order to be effective.	Fereres 2000
The effectiveness of the crop border will depend on the	Fereres 2000

timing of aphid infestation. If the infestation happens early in the season and the crop is still small, the effect of the borders isn't maximal.	
Choosing a border that cannot be infected by PVY is better than a susceptible one, especially for early generation seeds (low tolerance for PVY incidence).	Difonzo *et al.* 1996
Preferably the crop border should not harbour any other main potato pest or disease.	Fereres *et al.* 2000
It is recommended to create a fallow area around the crop border (on the outside) to increase the effectiveness.	Difonzo *et al.* 1996
Avoid gap between the crop border and the main crop.	Davis and Radcliffe 2009
The common practice of leaving a bare row between seed lots is not recommended as it attracts aphids. If it is required (CFIA requires the practice) it is recommended to plant a crop border on the buffer area. Gaps as small as 3 consecutive plants favour PVY spread.	Radcliffe and Ragsdale 2000 Davis and Radcliffe 2009
A crop border does not have to be much bigger than just a few meters.	Radcliffe and Ragsdale 2002

Objective 2: Knowledge Review

The objective of the knowledge review is to determine the extent to which either method (mineral oil or crop borders) are used for seed potato production across North America and to understand the challenges and limitations of these approaches as encountered by the growers, researchers, and practitioners (e.g. extension agents, seed potato inspectors, consultants, etc.) using these methods. For the purpose of this review, we interviewed researchers, practitioners and growers from Canada and the United States. A separate questionnaire was used for researchers and practitioners (Appendix II) and growers (Appendix III)

Canada

British Columbia

Two CFIA seed potato inspectors (Kate Schoen and Ryan Dear) working in the Fraser Valley and Pemberton area were interviewed to evaluate if there were any seed potato growers using mineral oil or crop borders in BC. To their knowledge, these methods are not being used by BC seed potato growers. Four seed potato growers were interviewed in BC (two conventional and two organic) out of approximately 20 seed potato growers in BC. None of the growers interviewed are using mineral oil or crop borders. The methods used by these growers to control mosaic viruses include: using virus-free and insecticide-treated seed (conventional production) potatoes, hand rouging (removal of plants with virus symptoms), and foliar insecticide treatments (conventional production). All growers said they would be interested in field testing mineral oil. For the crop border, it appears that land availability might be an issue, i.e. setting land aside for crop borders means less land for production of main seed potato crop. However, the organic growers interviewed expressed interest in integrating crop borders in their management practices. Again, Fraser Valley growers are already used to the concept of planting headland rows to trap other insect pests. The configuration of headlands could be modified (e.g. potato headlands planted right by the main crop (no gap) or planting wheat between the headland and the main crop) (see Objective 3).

Alberta

One CFIA seed potato inspector (Danny McArthur) and one practitioner involved in the seed potato industry in Alberta (Deb Hart, Seed Co-ordinator for Potato Growers of Alberta) were interviewed. They mentioned that to their knowledge mineral oil and crop borders were not commonly used tools. A total of 5 seed potato growers were interviewed out of approximately 30 seed potato growers in Alberta. One grower had tried mineral oil in the past (Farm A), but is no longer using it. This owner was from Europe and was familiar with the use of mineral oil from his farming experience there. He stopped using oil because aphids are not generally a big issue in his area of production in Alberta. He has seen good results with oil but has also observed that potato plants sometimes grow slower when oil is used (see Table 3 for interview summary). The main methods to control non-persistent virus used by Alberta growers are similar to ones used by BC growers: clean seeds, visual inspection, rouging, keeping aphids under control, systemic insecticides and early harvest.

Manitoba

One CFIA seed potato inspector (Gabriel Lambert) was interviewed to see if there are any seed potato growers using mineral oil or crop borders in Manitoba. To his knowledge, two growers are using oil and one is using crop border, out of about 10 seed potato growers in Manitoba. We were able to interview one of the seed potato growers (Farm B). This farm uses mineral oil on the conventional seed potato fields. They use Superior 70 mineral oil as adjuvant tank-mixed with fungicide sprayed every 5-10 days and starting when aphids are above threshold. They would use mineral oil for their organic seed potato if there was a registered product (Table 3).

Table 3. Summary of interviews with two Canadian growers that have used mineral oil.

Farm/ Province/ Acreage of Seed potatoes	Method currently used to control PVY on your farm	Do you use mineral oil on your farm?	Do you use crop border on your farm?
Farm A Alberta 500 acres	Monitoring and rouging Will spray an insecticide only about once per season	Use to spray mineral oil every two weeks on the high class seed (EII). He stopped using it because aphids are rarely a problem. He also mentioned that potato sometimes grow slower when oil was sprayed	No
Farm B Manitoba 800 acres conventional And 30 acres organic	Clean seeds and mineral oil Seed piece treatment	Yes, started a few years ago. Uses "Superior 70" Starts when aphids are above threshold and then sprays every 5-10 days, tank-mixed with the fungicide. Would use it on organic too but there isn't any registered product yet.	No Concerned about increasing weed pressure if the border of the field isn't keep cultivated. Also is concerned about increasing pest pressure by using crop border that would attract them.

New Brunswick

Gilles Boiteau (Agriculture and Agri-Food Canada) was interviewed to obtain information on seed potato grower practices in NB. Dr. Boiteau has conducted extensive research on mineral oil and crop borders for control of non-persistent viruses in potato production (Boiteau and Singh 1982, Boiteau and Woods 1982 and Boiteau *et al.* 2008). The summary of his interview is presented in Table 4. Boiteau recommends that using clean virus-free seed potatoes as the first and most important control tool available to seed potato growers to control viruses. Then tools such as mineral oil or crop borders can be included in the integrated pest management tool box. Although neither method is 100% effective using mineral oil and crop borders can make a difference in the overall control of non--persistent viruses in seed potato production. For mineral oil, he mentioned that sprays of oil should start at crop emergence, and be repeated weekly in order to cover the new growth. To Dr. Boiteau's knowledge, about 10-15 % of the 125 seed potato growers in NB use mineral oil (mostly Superior oil). He mentioned that one of the limitations for mineral oil use is that it is currently registered as adjuvant and not as an insecticide in potatoes. Registrants consider the seed potato market too small to justify a label expansion. As for crop borders, while this method has great potential for non-persistent virus control, its utilisation is limited in NB because growers are unable to afford the extra land needed for the crop border. Dr. Boiteau does not foresee crop borders being widely used in the near future in that province.

Table 4. Summary of New-Brunswick researcher interview.

Contact person/ Affiliation	**Method currently used to control PVY**	**Do growers use mineral oil?**	**Do grower use crop border**
Dr. Gilles Boiteau, Agriculture and Agri-Food Canada	Clean seeds, isolation and mineral oil	Yes, about 10-15 % of seed potato growers use mineral oil, mainly "Superior oil" on the earlier generations. Mineral oil is not specifically registered for insect control but it is registered as an adjuvant and growers will apply the oil tank-mixed with fungicide	Just a few growers are using it. He thinks main limitation of this method is the use of extra land and the cost associated to it

Other jurisdictions

Europe

Foliar sprays of mineral oil to control non-persistent viruses is a common practice in France (Sigvald and Hulle 2004 Ameline *et al.* 2010), the UK (Harrington et al. 1989) and Spain (Martin et al. 2006). Potato/PVY is one example of a crop/virus combination where mineral oil is used in Europe but mineral oil is also used on other crop such as pepper, lilies and cucumber for the control of non-persistent viruses (Simons and Zitter, 1980).

United States

In order to evaluate the importance or mineral oil and crop borders in US production practices, two practitioners working in the seed potato industry in Minnesota and Montana, were interviewed (Table 5). While using mineral oil and crop borders are not common practices in Minnesota and Montana, some growers have implemented these tools, and in recent years more are experimenting and adopting these methods, especially mineral oil. We interviewed three growers, one from Montana and two from Minnesota who are using both mineral oil and crop borders for seed potato production (Table 6). All three growers measured the success of these methods by the consistently low incidence of PVY in seed potatoes harvested from fields treated with mineral oil sprays or planted with crop borders. Two of the growers interviewed (Farms C and D) included mineral oil and crop borders into their practices a few years ago. Anecdotal evidence from both farms indicates considerable reduction the incidence of PVY. One of the growers (Farm C) had considered giving up growing Russet Norkotah seed because the incidence of PVY was too high. However, since using mineral oil, the incidence of PVY is very low and this grower now continues to produce Norkotah seed. All three growers begin applying mineral oil early in the growing season and continue to apply at least once per week to cover the new growth. For the crop borders, one of the growers is using a soybean border and the other two use the most resistant potato varieties as crop borders.

Table 5. Summary of the US researchers and practitioners interviews

Contact person/ Affiliation	Method currently used to control PVY	Do growers use mineral oil?	Do grower use crop border
Eileen Carpenter/ Montana Seed Potato Certification	Clean seeds, systemic insecticides, isolation, mineral oil.	A few	Yes, many will grow their early generation seeds in the middle of their later generations
Michael Horken/ Minnesota Department of Agriculture	Clean seeds, insecticide sprays, in furrow insecticide at planting, spray mineral oil early and frequently, top-kill early, plant low generation material first and top-kill first, hand rouging	Yes, a few growers are using mineral oil but it is not a standard practice	Yes, some growers use soybean and winter wheat. He believes that wheat is better because soybean seems to attract aphids

Table 6. Summary of the US growers interviews

Farms/ State/ Acreage of Seed potatoes	Method currently used to control PVY on your farm	Do you use mineral oil on your farm?	Do you use crop border on your farm?
Farm C Montana 600 acres	Clean seeds, rouging and mineral oil for PVY control. Also will try to plant early generation far from other grower's potato fields. For persistent virus, uses Admire in-furrow at planting and will generally spray insecticide once or twice per season depending on the aphid levels.	Yes, started a few years ago. Uses "Glacial Spay Fluid" (OMRI approved). Generally for earlier generations (Nuclear and G1) but will sometimes spray the perimeter of later generation (ex.G3). Once/week starting very soon after emergence (6-8 inches tall) and will apply until top-kill. The cost	He used to plant soybean and wheat as a crop border. He found it challenging to manage the herbicides applications so that it would not interfere with other crops in the rotation or with the border. What he does now is plant the less susceptible varieties around the more susceptible

		is 3$/ acre	ones
Farm D Minnesota 450 acres	Clean seeds and mineral oil for PVY control. For persistent virus, uses insecticide in-furrow at planting and when aphids are above threshold will apply Fulfill at the border of the fields only. Usually 2 sprays are required	Yes, started a few years ago. Uses "Stylet oil" which is a paraffinic mineral oil. Use it for earlier generations. Once or twice/week. Sometime apply aerially. But otherwise tank mix the oil with fungicide	Yes, plant older generations around earlier ones. Otherwise, will separate the 16 outside rows from the rest of the field (harvested and stored separately)
Farm E Minnesota 1000 acres	Clean seeds and mineral oil For persistent virus, uses insecticide in-furrow at planting and when aphids are above threshold will spray insecticides.	Yes, have been using mineral oil since the beginning (have been growing seed for 5 years). Uses "Aphoil" a paraffinic mineral oil. Once/week starting at 80% row closure	Yes. He was using borders of grain but the herbicide used for potatoes would kill the grain. Now he uses a 20-30 feet wide soybean border around the edges of the seed fields (all generations). He does not harvest the soybean. He makes sure there is no gap between the soybean and the potatoes. Does not leave a gap on the outside either

Objective 3. Determine the feasibility of these strategies for the Fraser Valley.

Mineral oil has been shown to provide a considerable level of control of non-persistent viruses. In order to be effective, a 1% solution of paraffinic mineral oil should be applied early in the growing season and should be applied weekly. This tool might be well suited to areas where seed potato production is close to conventional production as is the case in the Fraser Valley (e.g. Delta and Richmond). Several studies have demonstrated that spraying healthy uninfected plants will provide significant control even if the virus source is not sprayed. For organic seed potato growers this could represent the only viable product to control aphids and curtail the spread of non-persistent viruses.

The use of crop borders is a perfect example of the potential of manipulating the environment, in an environmentally sound way, based on observations of insect behaviour. Crop borders could be very well suited for organic production and growers from Montana and Minnesota are using this tool with success. Growers have mainly used soybean, wheat and potato. Potatoes and grain crops such as wheat are feasible options for crop borders in the Fraser Valley. Potatoes would have the advantage of not requiring additional management compared to the main seed potato crop. However, using potatoes as border eliminates the advantage of using a border that does not get infected with the virus (PVY). However, land availability might be the bigger issue for using crop borders in the Fraser Valley, and was the main reason growers in other parts of Canada did not use crop borders (Table 3 and 6). The crop border approach for the Fraser Valley should be developed to focus on minimal use of production space.

Currently a considerable numbers of Fraser Valley potato growers use headlands as a method for managing tuber flea beetles. Potato headlands could be modified to reduce the gap between the headland and the main crop so that they could also be used to trap PVY-infected aphids, i.e. used as virus sink. However, by reducing the gap between headland and main field, the potato headland will be damaged by the machinery going into the field. Another option for growers would be to plant a wheat crop between the headland and the main crop, so that the headland still acts on other pest (flea beetle) and as a crop border for aphids (no soil/plant contrast between the headland and the main crop) (Fig 2). Wheat could handle the physical damage from machinery better than potatoes. For growers that have not been using headlands in the past, they could plant wheat adjacent to row ends (instead of all around) so that there is a crop border effect, but less land is used. Grower could also consider discarding the outside few rows of seed potatoes as they are likely to have higher percentage of virus. Another option would be to include a resistant variety in this system, to be planted in the headlands and the field margins. CFIA would require that the resistant variety be separated by a buffer row, however wheat could be used as the buffer.

It is important to reinforce that for crop borders to work, no gap should be left between the crop border and the main crop. The current practice required by CFIA of bare rows between two varieties or two generations of seed potatoes planted in the same field does not appear to be a good practice for virus transmission (Radcliffe and Ragsdale 2000; Davis and Radcliffe 2009). The practice of leaving a bare row between varieties should be further investigated for its effect on virus spread and the alternative of planting a crop (e.g. wheat) on that buffer row should be evaluated as an alternative method for separating varieties and generations of seed potatoes in fields but also minimizing virus transmission.

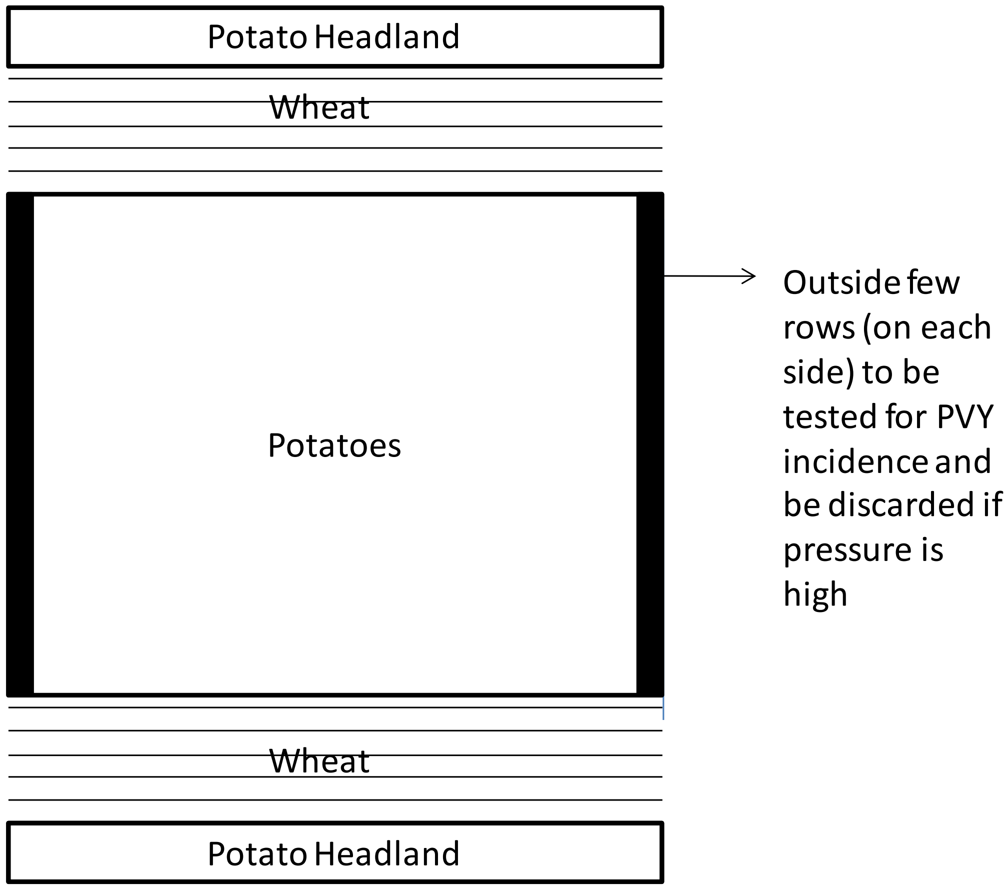

Figure 2. Potential approach that includes the effect of "virus sinks" in our current practice of using potato headland.

Summary

Both mineral oil and crop borders have potential as management tools for non-persistent viruses in seed potato production. Both the scientific literature and grower's experiences have demonstrated the important role that these methods could play in an integrated pest management program for non-persistent viruses. Combining both methods has the potential to be the most effective strategy for non-persistent virus control in organic seed potato production. Future research focused on the following aspects would benefit the longer term goal of increasing organic seed potato production in BC:

- Field trials to evaluate the potential of OMRI-approved mineral oils (e.g. Purespray/13E) at controlling aphids and PVY spread in the Fraser Valley.
- The potential to tank mix mineral oil and copper
- The potential to modify headlands so that they can be used for PVY management as well as tuber flea beetle control

- The optimal field size for crop border methods to be effective

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Appendix I. List of mineral oils registered in Canada (PMRA list)

Product Name	Registrant	Type of oil	Registered Use
Assist	BASF Canada Inc.	Paraffinic base 83% + surfactant blend	Herbicide adjuvant
Bartlett Superior "70" Oil	N.M. Bartlett Inc.	Unspecified mineral oil	Insecticide
Baseline Adjuvant	Dow AgroSciences Canada Inc.	Unspecified: mineral oil 50% + surfactant blend	Herbicide adjuvant
C-6104 Adjuvant	BASF Canada Inc	Blend of paraffin oil and methylated seed oil 64.9%	Herbicide adjuvant
Challenger Adjuvant	Dow AgroSciences Canada Inc.	Unspecified: mineral oil 50% + surfactant blend	Herbicide adjuvant
Chem Spray	AgraCity Crop and Nutrition Ltd.	Paraffinic base 83% + surfactant blend	Herbicide adjuvant
Civitas	Petro-Canada Lubricants Inc.	Unspecified mineral oil	Herbicide for Turf
Green Earth Horticultural Oil Insect Spray	Sure-Gro IP Inc.	Unspecified mineral oil	Insecticide
Guardsman Dormant Spray Oil	Univar Canada Ltd.	Unspecified mineral oil	Insecticide
Landscape Oil	Plant Products Co. Ltd	Unspecified mineral oil	Insecticide
Liquid Insecticide oil spray for Dormant Tree	Superior Control Products Inc	Unspecified mineral oil	Insecticide
Mana 8317	Makhetshim Agan of North America, Inc	Paraffinic base 83% + surfactant blend	Herbicide adjuvant
Mohawk 150	Newalta	Unspecified mineral oil	Unspecified

base oil	Corporation		
Mohawk Dormant Spray Oil	Newalta Corporation	Unspecified mineral oil	Insecticide
Prevail Adjuvant	Dow AgroSciences Canada Inc	Unspecified: mineral oil 50% + surfactant blend	Herbicide adjuvant
Pro Superior oil	Agrium Advanced Technologies RP Inc.	Unspecified mineral oil	Insecticide
Shell Canada Kornoil Concentrate	Shell Canada Products	Unspecified: mineral oil 83% + surfactant blend	Adjuvant
Shell Canada Superior 70 Spray oil	Shell Canada Products	Unspecified mineral oil	Insecticide
Shell Canada Emulsible Spray Oil	Shell Canada Products	Unspecified mineral oil	Insecticide
Spray Oil 13	Petro-Canada Lubricants Inc.	Severely Hydrotreated Paraffinic Oil	Unspecified
Spray Oil 13E	Petro-Canada Lubricants Inc.	Unspecified mineral oil	Insecticide
Spray Oil 10	Petro-Canada Lubricants Inc.	Severely Hydrotreated Paraffinic Oil	Fungicide/ insecticide
Spray Oil 15	Petro-Canada Lubricants Inc.	Severely Hydrotreated Paraffinic Oil	Unspecified
Spray Oil 22	Petro-Canada Lubricants Inc.	Severely Hydrotreated Paraffinic Oil	Unspecified
Sunspray 6E	Agent for Sunoco, Inc.	Paraffinic base	Insecticide
Superior 70 Oil	United Agri Product Canada Inc.	Unspecified mineral oil	Insecticide
Turbocharge Adjuvant	Syngenta Crop protection Canada, Inc	Unspecified: mineral oil 50% + surfactant blend	Herbicide adjuvant
Turbocharge 2	Syngenta Crop	Unspecified: mineral oil	Herbicide adjuvant

Adjuvant	protection Canada, Inc	50% + surfactant blend	
Turbocharge B Adjuvant	Dow AgroSciences Canada Inc.	Unspecified: mineral oil 50% + surfactant blend	Herbicide adjuvant
Turbocharge D Adjuvant	Dow AgroSciences Canada Inc.	Unspecified: mineral oil 50% + surfactant blend	Herbicide adjuvant
Turbocharge EST Adjuvant	Syngenta Crop protection Canada, Inc	Unspecified: mineral oil 50% + surfactant blend	Herbicide adjuvant
Wilson	Sure-Gro IP Inc.	Unspecified mineral oil	Insecticide
XA Oil Concentrate	United Agri Product Canada Inc.	Unspecified: mineral oil 83% + surfactant blend	Herbicide adjuvant

Appendix II. Researchers and Practitioners questionnaire

Researchers and practitioners questionnaire: Control of non-persistent virus (e.g. PVY) in seed potato production.

Name_____________________________

Company/affiliation_____________________________

General

1- To your knowledge what are the most effective ways of controlling non-persistent viruses?

2- What are the more intensively used control methods to control non-persistent viruses in seed potato production in your area?

Mineral oil; It has been shown that virus acquisition and transmission of non-persistent virus by aphids can be significantly reduced if the plants are covered by mineral oil.

3- Have you heard of mineral oil (sprayed on the foliage) to control non-persistent viruses?

4- Is this a practice used by seed potato growers in your production area? -if yes describe protocol and if possible provide grower's contact info.

Crop borders; Also called barrier plants or catch crops, this management tool is thought to reduce non- persistent virus transmission from field to field by "cleaning" the aphid mouthpart before entering a seed potato field.

5- Have you heard of crop border (could be a different crop or what we call potato headland) to control non-persistent virus?

6- Is this practice used by seed potato growers in your production area? If yes, for what reason and give details? If possible provide grower's contact info.

Appendix III. Growers questionnaire

Grower's questionnaire: Control of non-persistent virus (e.g. mosaic virus) in seed potato production.

Name/Farm name

____

General

1- How many acres/hectares of seed potatoes are grown on your farm?

2- How long have you been growing seed potatoes?

3- Which classes of seed potatoes are grown on your farm?

4- What methods are implemented on your farm to control mosaic virus?

Mineral oil; It has been shown that virus acquisition and transmission of non-persistent virus by aphids can be significantly reduced if the plants are covered by mineral oil.

5- Have you heard of mineral oil (sprayed on the foliage) to control mosaic virus?

6- Have you used or are you using mineral oil to control mosaic virus on your farm? If yes when do you start applying, how regularly, which seed class, what type of oil, what are the results, etc.?

7- If not, would you be interested in using mineral oil in your practices if it was shown to be effective at controlling mosaic virus?

Crop Borders; Also called barrier plants or catch crops, this management tool is thought to reduce non- persistent virus transmission from field to field by "cleaning" the aphid mouthpart before entering a seed potato field.

8- Have you heard of crop borders (could be a different crop or what we call potato headland) to control mosaic virus

9- Do you use this practice in you seed potato fields? If yes, describe what crop, in which seed class and for what reason, and what are the results, etc?

10- If not, would you be interested in including crop borders in your practices if it was shown to help control mosaic virus?