Late blight control for organic production: Resistant varieties, reduced copper inputs and sealing soil cracks

Final Report

February 2012

Prepared for

Organic Sector Development Program (Project I-129)
Lower Mainland Horticultural Improvement Association
Fraserland Organics

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Executive Summary

Late blight (*Phytophthora infestans*) is a serious disease of potatoes and organic growers have few control options. In this trial two different approaches for blight management were examined. First, we evaluated the combined effect of resistant varieties with reduced applications of copper-based fungicides. Late blight resistant potato varieties Innovator, Krantz (russet varieties) and Keswick (white variety) and the blight susceptible industry standards Russet Norkotah and Norchip (white variety) were treated with one of four fungicide regimes: 1) copper applied 7 days, 2) copper applied 14 days, 3) water (Control) applied 7 days and 4) water (Control) applied 14 days. Levels of blight on foliage were assessed weekly (for 12 weeks) and on tubers at harvest and after four weeks of storage. Innovator and Krantz had significantly lower late blight levels on foliage compared to Russet Norkotah. Additionally, reducing the amount of copper applied to once every 14 days did not impact late blight control negatively, for any of the varieties. Krantz and Innovator also had low levels of tuber blight both at harvest and after four weeks of storage. For the white varieties, there was no significant difference in late blight levels between the susceptible Norchip and reportedly resistant Keswick. However, Keswick has not been reported to be resistant to the strain of late blight found in the study area (US-23). The second approach to blight management examined in this study was to reduce the amount of late blight infection on tubers by preventing spores from washing down from the soil surface to tubers via soil cracks. This was attempted by sealing soil surface cracks with a roller prior to harvest. Sealing soil cracks did not cause significant reductions in tuber blight incidence. The results of this study indicate that late blight resistant potato varieties should be the foundation of the blight management tool box for organic producers. Additionally our trials demonstrate the importance of testing resistant varieties locally, as strains of late blight vary from region to region.

Introduction

Globally potatoes are one of the most widely grown food crops (Vleeshouwers *et al.* 2011, Haverkort *et al.* 2009). In British Columbia, potatoes account for a large proportion of the organic vegetable acreage grown annually. Although potatoes are susceptible to numerous arthropods and diseases that can reduce yield significantly, late blight is the most serious. Annual yield losses from late blight, caused by the oomycete *Phytophthora infestans*, have been estimated at 16% (Vleeshouwers *et al.* 2011, Haverkort *et al.* 2009). The late blight pathogen can infect stems, leaves and tubers of the potato plant (Vleeshouwers *et al.* 2011, Fry 2008). If late blight is left unmanaged it can destroy entire potato fields in a matter of days. One of the reasons that losses due to late blight can be so severe is that many commonly grown potato varieties (e.g. Russet Norkotah) are highly susceptible to late blight infection. One way to address the problem of severe losses to late blight is to replace susceptible varieties with late blight resistant (or tolerant) varieties. Studies investigating resistance to late blight have concluded that using resistant varieties is the most promising option for managing this disease (Struik 2010).

In addition to relying heavily on a few late blight susceptible varieties, organic potato growers have only one active ingredient for late blight control, copper hydroxide. In southwestern BC, copper-based fungicides are applied on average every 5-7 days for late blight. The European Union is moving toward an exclusion of copper based fungicides, and other organic certification bodies are considering similar restrictions on the use of copper. Thus finding ways to reduce or eliminate copper reliance for organic potato production is imperative (Bouws and Finckh 2008). Growing varieties with late blight resistance can decrease the number of fungicide applications needed and the amount applied each time (Mekonen *et al.* 2011). While resistant varieties may not completely eliminate the need for copper-based fungicides they may require fewer applications to achieve an effective level of blight protection.

While blight infection of foliage can be suppressed sufficiently to keep plants alive, tubers can become infected as spores wash down from the soil surface (Nyankanga *et al.* 2008). Blight infection of tubers is a serious concern for several reasons. Infected tubers do not withstand prolonged storage. Additionally, when tubers are infected with late blight they become more easily infected by other microorganisms such as soft rot bacteria which can also spread rapidly in storage (Mayton *et al.* 2011, Perombelon and Kelman 1980). Finally, spores can over winter in tubers and infected tubers are a common source for early season infections (Cooke and Little 2001). One requirement for high levels of tuber infection in the field is soil surface cracks, which make it possible for spores to reach tubers (Zan 1962). Sealing cracks with a vine roller is recommended as a way to prevent sunlight (Geisel 2003) and late blight spores from contacting tubers (Campbell, 2005; Davidson and Zink, 1999). Currently, a few Fraser Valley growers already employ the practice of rolling their vines to improve the efficacy of vine desiccant sprays and to seal cracks in the hills to prevent the sunlight from greening potatoes that set high in the hill. Sealing, filling or blocking soil surface cracks to prevent spores from washing down to tubers may help to reduce tuber late blight infections (Nyankanga *et al.* 2008).

The objectives of this trial were two-fold:

1) to evaluate the combined efficacy of growing late blight resistant varieties with reduced copper inputs on the development of late blight on foliage and tubers
2) to evaluate the efficacy of sealing soil cracks, in combination with reduced copper inputs, as a method for reducing late blight infection of tubers.

Materials and Methods

Part 1: Resistant varieties and reduced copper applications

Study site, plot description and maintenance – The trial was located in an agricultural field in Cloverdale BC in an area that is used for potato production on a yearly basis and had a history of late blight infection. The trial was located along the southern edge of the field and had been planted with (early-season) potatoes and harvested prior to the planting of the trial. Adjacent crops were grass and squash. For this trial, potatoes were planted by hand on July 15, 2011. Each plot was planted with 12 seed potatoes with 25-cm spacing between potatoes. All plots were 3.5 m long X 0.4 m (single row) wide, for a total plot area of 1.4 m^2. The soil in the trial area was sandy and the area was not fertilized or irrigated during the course of our study.

Trial design, treatment description and application of products– In order to evaluate the efficiency of resistant varieties in combination with a reduced number of copper applications to control late blight, the trial consisted of a three-way design: Variety X Copper treatment X Treatment interval. Five potato varieties were tested including two industry standards (Russet Norkotah and Norchip) and three test varieties with reports of resistance (Krantz, Innovator, and Keswick) (Table 1). The copper product used was the copper-based fungicide Parasol (copper hydroxide) which is the industry standard and was compare to water as the Control (Table 1). Finally, there were two application intervals for foliar sprays: 7-days and 14-days. The full combination of treatments resulted in a total of 20 treatments (Table 1) and each treatment was replicated 8X for a total trial N of 160. Treatments were randomly assigned to plots. Application of copper or water treatments began on August 4, 2011 (all plots treated on this date) and continued until October 12, 2011. The copper and water treatments were applied as foliar sprays using a SOLO backpack sprayer equipped with XR Teejet 8003VS nozzles hand pumped to maintain full pressure. The copper-treatment (Parasol) was applied at the label rate of 2.5 kg/ha or 0.35 g of product/plot (Table 1). The amount of water used for both the Copper and Control plots varied from week to week in order to ensure adequate coverage of the growing plants (Table 2).

Table 1. Summary of the 20 treatments and the amount of copper-based product applied to plots for each treatment (plot area $1.4m^2$).

Potato variety (type) and late blight resistance (as per CFIA 2010)	Copper-7day Parasol (copper hydroxide) 2.5kg/ha -	Copper-14day Parasol (copper hydroxide) 2.5 kg/ha -	Control-7 day Water	Control-14 day Water
Russet Norkotah Not resistant	0.35 g	0.35 g	N/A	N/A
Norchip (white) Not resistant	0.35 g	0.35 g	N/A	N/A
Krantz (russet) Resistant	0.35 g	0.35 g	N/A	N/A
Innovator (russet) Resistant	0.35 g	0.35 g	N/A	N/A
Keswick (russet) Resistant	0.35 g	0.35 g	N/A	N/A

Table 2. Summary of water volumes used to apply treatments to test the efficacy of application frequency and resistant varieties on late blight development on potatoes.

Date	Week*	Amount of water applied/Copper plots (mL)	Amount of water applied/Control plots (mL)
August 4, 12, 19	1, 2, 3	128	128
August 26	4	163	154
September 2	5	218	200
September 8	6	250	210
September 15	7	200	190
September 22	8	200	190
September 28	9	137	125
October 6	10	128	95
October 12	11	125	90

* Copper-14day and Control-14day plots were only sprayed on the odd-numbered weeks.

Disease inoculation – Although the trial area had a history of late blight infection trial plots were inoculated with late blight to ensure sufficient and even disease pressure. All plots were inoculated on August 17, 48 hours prior to foliar sprays on August 19. Inoculation consisted of rubbing one active late blight lesion on the middle plant of each plot. One active lesion was used per plot. All plots were inoculated a second time on August 24, using the same protocol as the first inoculation. Late blight lesions were collected from volunteer and cultivated potatoes within in the vicinity of the study field. The strain of late blight in our trial plots was US-23 (Kawchuk, L. AAFC, personal communication, January 2012).

Foliar assessment - Plots were assessed weekly for incidence and severity of late blight infection, starting on August 4, 2011 (pre-treatment) and continuing until October 20, 2011 (1-week post last treatment). Incidence was determined by counting the number of infected plants out of the total number of plants within each plot. A single severity score was assigned to each plot by visually determining the total percentage of infected tissue for all plants infected with late blight in the plot. The percentage of infected tissue was then converted to a severity grade using the Horsfall-Barratt scale where percentages are converted into grades of 0 to 11 (Table 3).

Harvest assessment - Yield and disease incidence on tubers were assessed at harvest on October 25 and 26, 2011. From each plot a 1-m section of row was randomly chosen. The plants (live or dead) in the 1-m section were counted and then all tubers were harvested, counted, and weighed. The surface of each tuber was examined for late blight symptoms and the proportion of tubers with late blight was recorded.

Table 3. Grades used for determining late blight disease severity using the Horsfall-Barratt scale.

Grade	Range of plant tissue infected by late blight lesions
0	0%
1	0-3%
2	3-6%
3	6-12%
4	12-25%
5	25-50%
6	50-75%
7	75-88%
8	88-94%
9	94-97%
10	97-100%
11	100%

Post harvest treatment and assessment - A post-harvest assessment was conducted to determine if any of the treatments had an effect on late blight incidence after a period of storage. After all harvest parameters for tubers were measured, 10 symptom-free tubers from each plot were put into an onion sack (1 sack/plot) which was then placed in a plastic tote. Totes were placed in a cool dry storage area at 1.2 - 10.5^{o}C, 41 - 86% RH and minimal light; conditions similar to local potato storage facilities. Tubers were stored for four weeks (29 days) and then disease incidence on all 10 tubers in each sack was assessed by visually examining each tuber for late blight symptoms.

Analysis - The effect of treatments (Variety X Copper treatment X Treatment interval) on the Area Under Disease Progress Curve (AUDPC) score was analyzed using three-way ANOVA. AUDPC score was calculated as:

$$AUDPC = \Sigma_{i=1}^{n-1} [(t_{i+1} - t_i)(y_i + y_{i+1})/2]$$

Where t = the time interval between assessments (Weeks) and y = severity score (Table 3).

Because of a significant interactions effects on AUDPC score, the effect of Copper treatment X Treatment interval on disease suppression over time was examined separately for each variety using two-way repeated measures MANOVA. Disease suppression was calculated relative to the maximum severity score each week. These scores (weekly maximum severity) always came from a Control plot, and was calculated for each variety. Yield and tuber blight incidence at harvest and four weeks post harvest were examined using three-way ANOVA. All proportion data were arc-sine transformed prior to analyses. All data were analyzed using JMP-In Version 5.1 (SAS Institute, Chicago, IL).

Part 2: Sealing soil cracks to reduce late blight infection of tubers

The second part of the study - sealing soil cracks -was conducted in the same field as Part 1 and all plot maintenance and site features are similar to those described above. These plots were also inoculated with late blight lesions on the same dates and following the same protocol as described above.

Trial design, plot and treatment description –The objective of this trial was to evaluate the impact sealing soil cracks in combination with reduced copper inputs on late blight incidence on tubers. The trial consisted of two sealing treatments (Sealed and Unsealed) and three copper treatments (Copper-7 days, Copper-14 days and a Control (water)-7 days) which were combined together for a total of six treatments (Table 5). The number of replicates/treatment varied for a total trial N of 40 (Table 5). All treatments were randomly assigned to plots which were 9 m long X 0.4 m (one row) wide, for a total plot area of 3.6 m^2. Plots were hand-planted with 34 Russet Norkotah seed potatoes (25-cm spacing) on July 15, 2011. Copper treatments consisted of Parasol (copper hydroxide) applied at the label rate of 2.5 kg/ha (or 0.9 g/plot). The amount of water used to apply treatments varied from week to week in order to ensure adequate coverage of the growing plants (Table 6). Treatments began on August 4, 2011 (all plots treated on this date) and continued until October 6, 2011. Copper and water were applied as foliar sprays using a SOLO backpack sprayer equipped with XR Teejet 8003VS nozzles hand pumped to maintain full pressure. Soil cracks were sealed by rolling potato hills on October 13, 2011. Prior to rolling, all plots in the trial had excess foliage removed by mowing with a hand held mower and with pruning shears. Soil cracks were sealed by pulling a lawn roller (Brinly-Hardy Company model PRC-24R BH) over plots by hand. The lawn roller was 0.6m wide and was filled with 80L of water (approximately 80kg) (Fig. 1).

Table 4. Number of replicates for the six combinations of sealing soil cracks and reduced copper input treatments

Treatment	Copper-7day Parasol (copper hydroxide) 2.5kg/ha	Copper-14day Parasol (copper hydroxide) 2.5 kg/ha	Control-7 day Water
Sealed	6	6	8
Unsealed	7	7	6

Table 5. Summary of water volumes used to apply treatments to foliage to test the combined efficacy of reduced copper inputs and sealing soil cracks on late blight development.

Date	Week*	Amount of water applied/copper plot (mL)	Amount of water applied/control plot (mL)
August 4, 12, 19	1, 2, 3	250	250
August 26	4	307	279
September 2	5	384	357
September 8	6	468	425
September 15	7	396	384
September 22	8	338	320
September 28	9	231	214
October 6	10	196	136

* Copper-14day plots were only sprayed on the odd-numbered weeks.

Figure 1. Roller used to roll potato hills to seal soil cracks for the control of late blight infection of tubers.

Assessment - Plots were assessed weekly for incidence and severity of late blight infection, starting on August 4, 2011 (pre-treatment) and continuing until October 12, 2011 (1-week post last treatment). Incidence and severity were assessed in the same manner described above for Part 1. Yield and disease incidence on tubers were assessed at harvest on October 25, 2011. From each plot a 2.2-m section of row was randomly chosen. Plants in the 2.2-m section were counted and then all tubers were harvested, counted, and weighed. The surface of each tuber was examined for symptoms of late blight and the proportion of tubers with late blight was recorded. As in Part 1, a post-harvest assessment was also conducted. After all harvest parameters for tubers were measured, 20 blight-free tubers from each plot were put into an onion sack and stored for four weeks (29 days) under the same conditions described above for Part 1. After storage tubers were assessed for late blight.

Analysis - The AUDPC score (calculated using the same formula as in Part 1) for foliar blight and tuber blight incidence at harvest and following storage were analyzed using two-way ANOVA (Sealing treatment X Copper treatment). All proportion data were arc-sine transformed prior to analyses. All data were analyzed using JMP-In Version 5.1 (SAS Institute, Chicago, IL).

Results

Part 1. Resistant varieties and reduced copper applications

AUDPC Score - The combined effect of Variety, Copper treatment (copper or no copper) and Treatment interval (7 or 14 days) on the final AUDPC score was examined first. Of these three main effects and their possible interactions Variety, Copper treatment and the interaction of the two had significant effects on the final AUDPC score (Table 6). In terms of varieties, the AUDPC score was significantly lower for Krantz and Innovator than for the other three varieties. Further, all plots treated with copper had 3X less blight than the water Control plots (Fig. 2). Interestingly, there was no significant difference between the 7 and 14-day intervals. To further understand the significant interaction of Copper treatment X Variety on blight development - we examined how foliar treatments affected blight control separately for each variety.

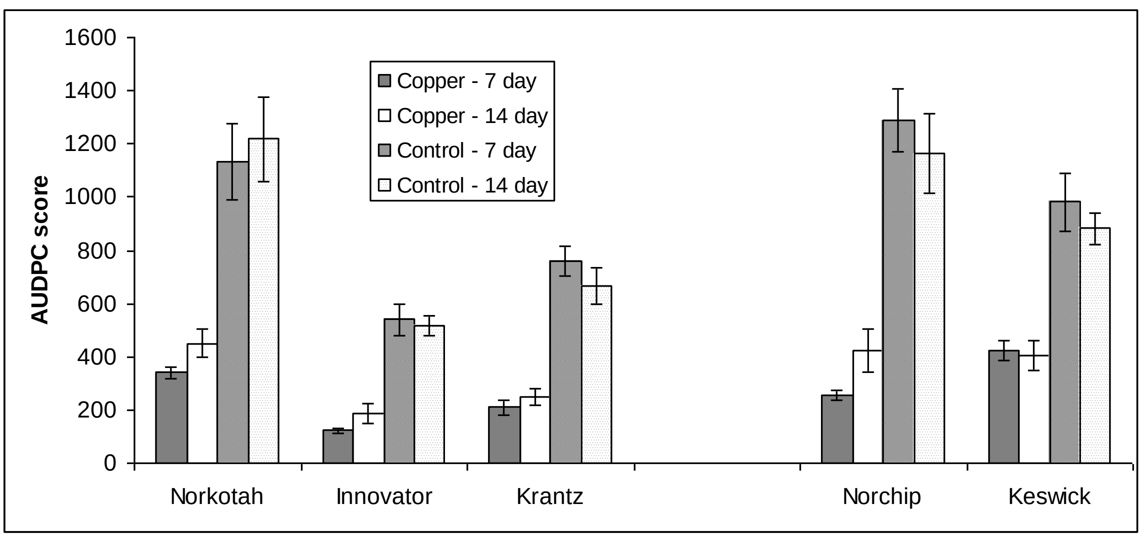

Figure 2. Effect of potato variety, copper treatment and treatment interval on the AUDPC (area under disease progress curve) score for late blight. Bars represent the mean ± s.e. for eight replicates/treatment.

Table 6. Statistical results for analysis of main trial effects (variety, copper treatment, and treatment interval) and their interactions on the AUDPC score.

Effect or Interaction	F-value	Degrees of Freedom	*p-value*
Variety	24.19	4, 149	*<0.0001*
Copper Treatment	287.30	1, 149	*<0.0001*
Treatment Interval	0.09	1, 149	*0.76*
Variety X Treatment	7.28	4, 149	*<0.0001*
Variety X Interval	0.55	4, 149	*0.70*
Treatment X Interval	3.01	1, 149	*0.08*
Variety X Treatment X Interval	*0.39*	*4, 149*	*0.81*

Disease reduction over time by variety

Russet Norkotah is the current industry standard russet variety. As expected applications of copper resulted in significant reductions in blight severity compared to no copper treatment. Copper applications provided good disease control until the last two weeks of the trial, by which time all plants had blight (no reduction in disease severity). There was no significant difference between the 7 or 14-day spray interval (Fig. 3, Table 7).

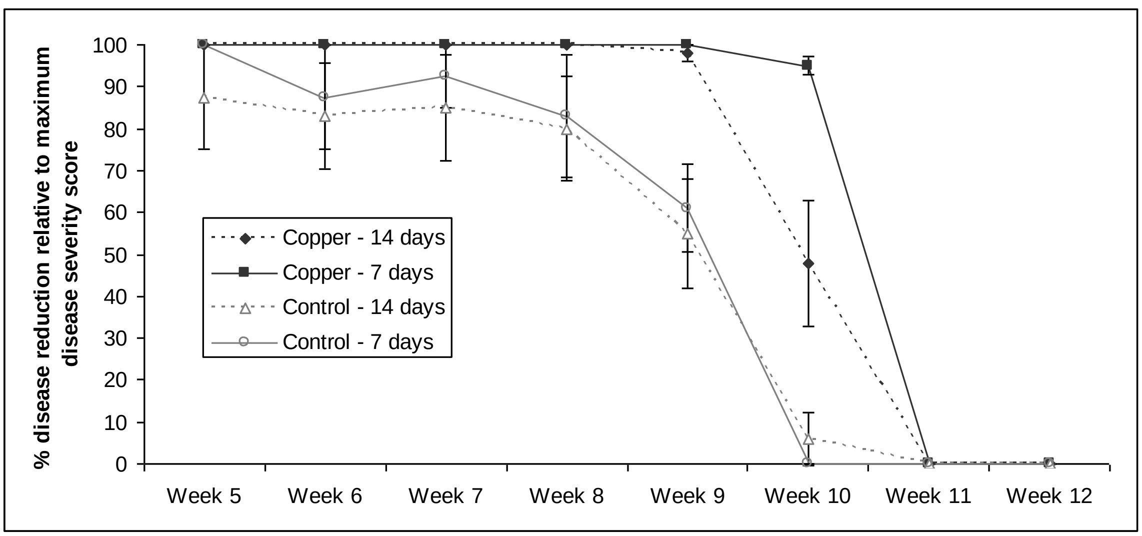

Figure 3. Effect of copper treatment intervals on late blight disease reduction (mean ± s.e. disease severity score) on potato plants var. Russet Norkotah. From Weeks 1 to 4 there was no disease in plots. Disease reduction was calculated relative to the maximum disease severity score among the Control plots.

Table 7. Repeated-measures MANOVA table for % disease reduction (based on severity score) in Russet Norkotah

	F-value	Degrees of Freedom	*p-value*
Copper Treatment	17.17	1,28	***0.0003***
Treatment Interval	0.97	1,28	*0.33*
Copper X Interval	0.073	1,28	*0.79*
Time	116.36	7,22	***<0.0001***
Copper Treatment X Time	9.17	7,22	***<0.0001***
Interval X Time	0.79	7,22	*0.60*
Copper Treatment X Interval X Time	*1.46*	*7,22*	*0.23*

Innovator is an alternative russet variety that has been shown to have blight resistance (CFIA 2010). Application of copper kept Innovator plots disease free for several additional weeks compared to the untreated Innovator plots (Fig. 4). Interestingly, there was no difference in disease control between the 7-day and 14-day copper spray intervals except in week 11 - when blight increased dramatically in the 14-day plots. However, a week later the amount of disease control across all Innovator plots was less than 10%. These week to week differences, in the later part of the trial, account for the significant interactions of the Copper treatment and Treatment interval with time (Table 9).

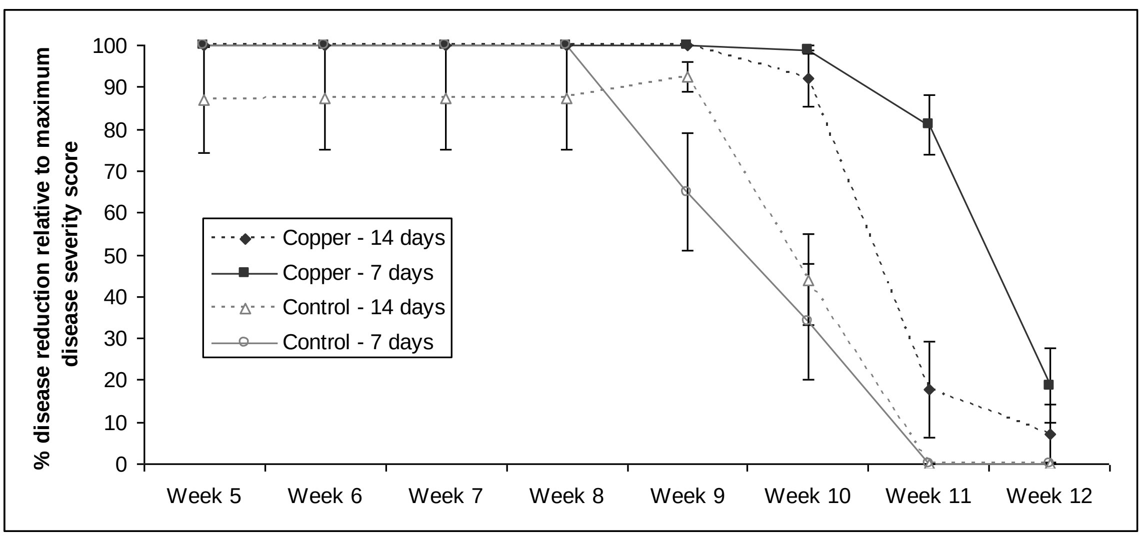

Figure 4. Effect of copper treatment intervals on % late blight disease reduction (mean ± s.e. disease severity score) on potato plants var. Innovator. From Weeks 1 to 4 there was no disease in plots. Disease reduction was calculated relative to the maximum disease severity score among the Control plots.

Table 8. Repeated-measures MANOVA table for % disease reduction in Innovator plots

	F-value	Degrees of Freedom	*p-value*
Copper Treatment	22.66	1,28	***<0.0001***
Treatment Interval	1.85	1,28	*0.18*
Copper X Interval	0.97	1,28	*0.33*
Time	65.26	7,22	***<0.0001***
Copper Treatment X Time	8.28	7,22	***<0.0001***
Interval X Time	3.41	7,22	***0.01***
Copper Treatment X Interval X Time	*3.13*	*7,22*	***0.02***

Krantz is another russet variety that has also shown to have blight resistance (CFIA 2010) and performed well in previous trials conducted locally (Glover *et al*. 2010). Although Krantz treated plots developed blight by Week 9, the combination of varietal resistance and copper kept the amount of blight in plots significantly lower than in the untreated plots for two additional weeks (Fig. 5, Table 9). By week 12 the amount of disease reduction in all plots was 0, i.e. all plants had high levels of blight. For Krantz, there was no effect of the spray interval.

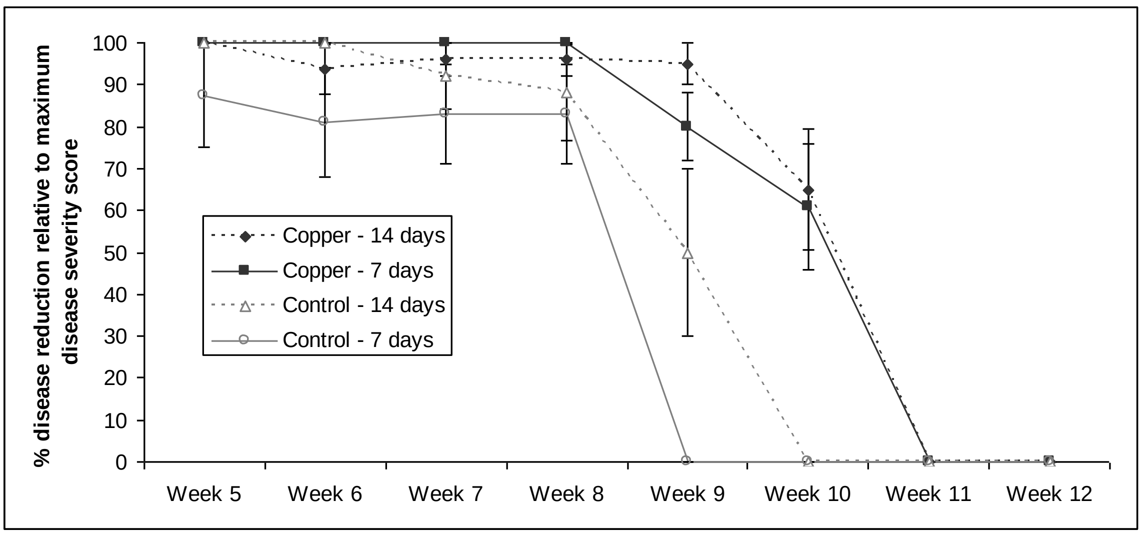

Figure 5. Effect of copper treatment intervals on % late blight disease reduction (mean ± s.e. disease severity score) on potato plants var. Krantz. From Weeks 1 to 4 there was no disease in plots. Disease reduction was calculated relative to the maximum disease severity score among the Control plots.

Table 9. Repeated-measures MANOVA table for % disease reduction in Krantz plots

	F-value	Degrees of Freedom	*p-value*
Copper Treatment	11.44	1,28	***0.002***
Treatment Interval	1.32	1,28	*0.26*
Copper X Interval	1.13	1,28	*0.30*
Time	439.58	7,22	***<0.0001***
Copper Treatment X Time	5.91	7,22	***0.0006***
Interval X Time	1.47	7,22	*0.29*
Copper Treatment X Interval X Time	*0.67*	*7,22*	*0.69*

Norchip is the current industry standard white variety. Applications of copper significantly reduced blight development until week 11 when all plants had developed the disease (Fig. 6, Table 10). There was no difference in disease control between the 7 and 14-day spray intervals.

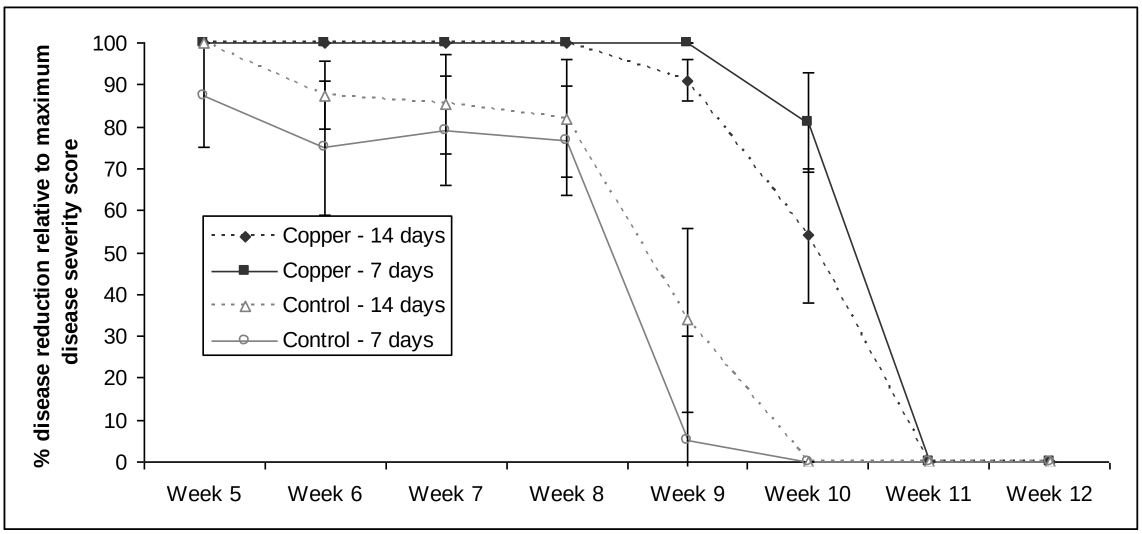

Figure 6. Effect of copper treatment intervals on % late blight disease reduction (mean ± s.e. disease severity score) on potato plants var. Norchip. From Weeks 1 to 4 there was no disease in plots. Disease reduction was calculated relative to the maximum disease severity score among the Control plots.

Table 10. Repeated-measures MANOVA table for % disease reduction in Norchip plots

	F-value	Degrees of Freedom	*p-value*
Copper Treatment	20.28	1,28	***0.0001***
Treatment Interval	0.10	1,28	*0.76*
Copper X Interval	1.23	1,28	*0.28*
Time	119.73	7,22	***<0.0001***
Copper Treatment X Time	6.99	7,22	***0.0002***
Interval X Time	0.46	7,22	*0.86*
Copper Treatment X Interval X Time	*0.53*	*7,22*	*0.80*

Keswick is the alternative white variety tested in this trial, with reports of resistance to late blight (CFIA 2010). However, based on AUDPC score (Fig. 2) it did not perform better than the blight-susceptible Norchip. Examination of disease reduction over the course of the trial showed that Keswick responded to copper treatments in a similar manner as all other varieties: application of copper improved blight control and the 14-day interval performed as well as the 7-day spray interval (Fig. 7, Table 11). Interestingly, blight did not develop in any of the Keswick plots (including the water Control) until week 7.

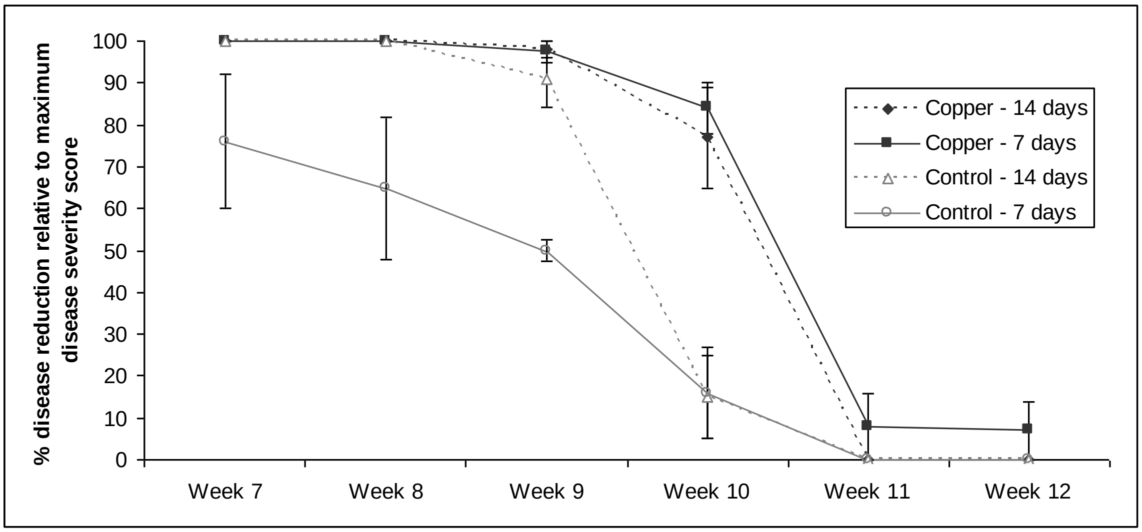

Figure 7. Effect of copper treatment intervals on % late blight disease reduction (mean ± s.e. disease severity score) on potato plants var. Keswick. From Weeks 1 to 6 there was no disease in plots. Disease reduction was calculated relative to the maximum disease severity score among the Control plots.

Table 11. Repeated-measures MANOVA table for % disease reduction in Keswick plots

	F-value	Degrees of Freedom	*p-value*
Copper Treatment	14.65	1,28	***0.0007***
Treatment Interval	1.30	1,28	*0.27*
Copper X Interval	3.22	1,28	*0.08*
Time	141.01	5,24	***<0.0001***
Copper Treatment X Time	7.48	5,24	***0.0002***
Interval X Time	1.02	5,24	*0.43*
Copper Treatment X Interval X Time	*0.93*	*5,24*	*0.48*

Harvest and Post-Harvest Assessments (Yield and Blight Incidence on Tubers)

There was a significant effect of both Variety and Copper treatment on yield of tubers (weight/tuber) at harvest - plots treated with copper yielded heavier tubers than the water Control plots (Table 12). All of the russet type potatoes (Innovator, Krantz and Norkotah) were equal in weight to each other but weighed more than the white potatoes (Keswick and Norchip) (Fig. 8). In terms of blight incidence on tubers at harvest, the least amount of blight was found on Innovator, Krantz (copper or water treated plots) Norchip (copper treated plots only) and on Russet Norkotah (Copper 7-days only) (Fig. 9, Table 12). Innovator and Krantz tubers continued to have significantly lower levels of blight following storage than Russet Norkotah (Fig. 10). There was no difference in the blight incidence on Keswick and Norchip, either at harvest or post-storage (Fig. 10). As expected, copper treatment during crop growth had no effect of blight incidence following storage (Table 12) - as only blight free tubers were placed into storage, following harvest.

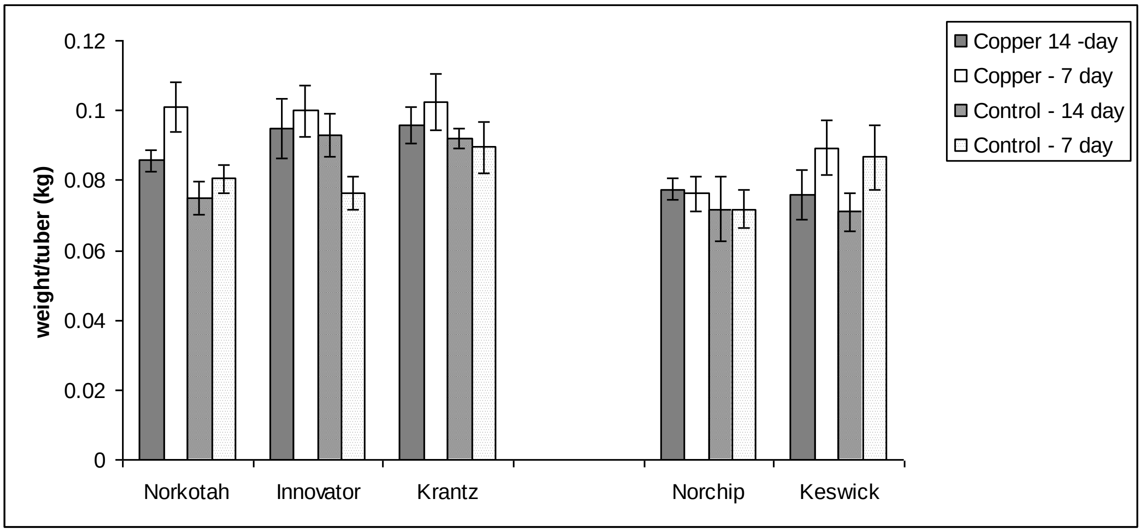

Figure 8. Harvest weights (mean ± s.e.) of tubers from five different potato varieties and grown under four different foliar spray programs.

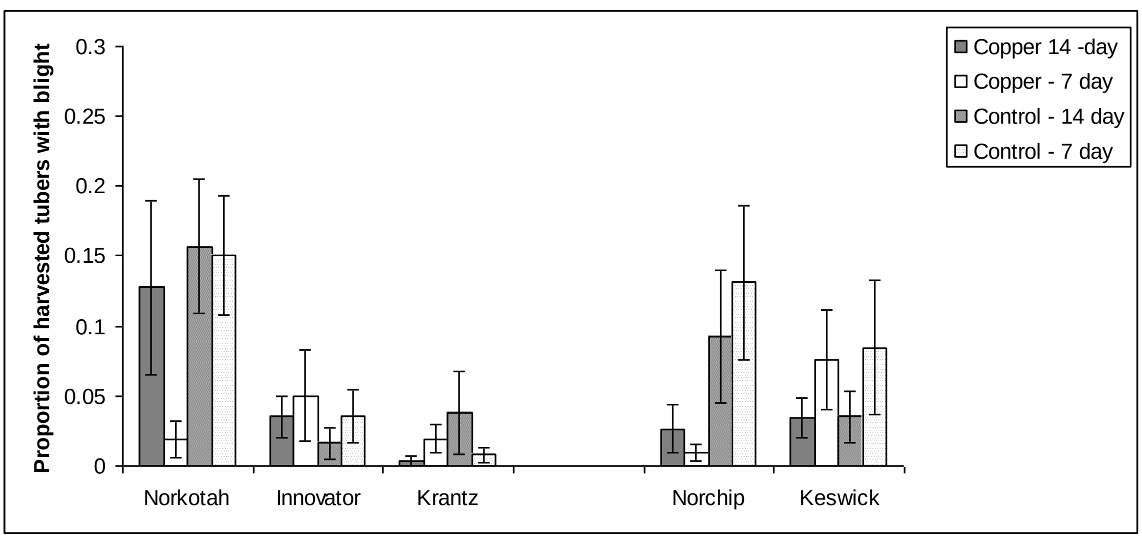

Figure 9. Effect of potato variety and copper treatment and treatment interval on the proportion (mean ± s.e.) of tubers with blight at harvest.

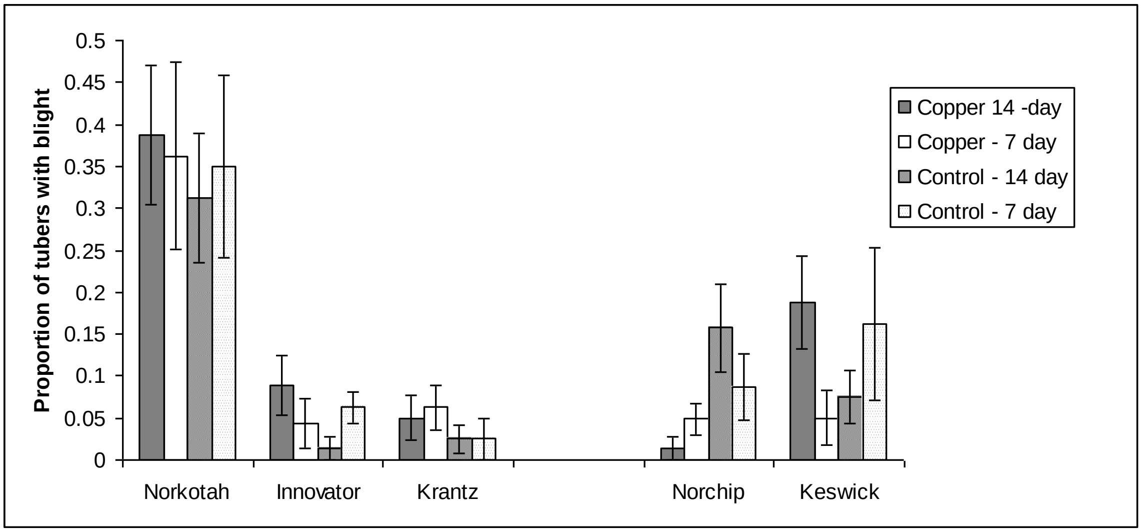

Figure 10. Effect of potato variety and copper treatment and treatment interval on the proportion (mean ± s.e.) of tubers with blight after 4-weeks in storage under conditions similar to commercial potato storage facilities.

Table 12. Analyses results for effect of reduced copper spray interval and resistant varieties on harvest and post-harvest parameters of yield and tuber blight incidence.

Main and interaction effects	Harvest - Yield (Weight/tuber)	Harvest - Blight incidence on tubers	*Post-harvest - Blight incidence on tubers*
Variety	F(4,135) = 6.58 **P<0.0001**	F(4,135) = 5.17 **P = 0.007**	*F(4,135) = 21.60* ***P<0.0001***
Treatment	F(1, 135) = 10.34 **P = 0.002**	F(1, 135) = 5.75 **P = 0.02**	*F(1, 135) = 0.01* *P = 0.92*
Treatment Interval	F (1, 135) = 2.07 P = 0.15	F (1, 135) = 0.02 P = 0.90	*F (1, 135) = 0.06* *P = 0.82*
Variety X Treatment	F(4, 135) = 0.62 P = 0.65	F(4, 135) = 2.27 P = 0.07	*F(4, 135) = 0.92* *P = 0.46*
Variety X Interval	F(4, 135) = 1.65 P = 0.16	F(4, 135) = 1.43 P = 0.23	*F(4, 135) = 0.07* *P = 0.99*
Treatment X Interval	F(1, 135) = 1.68 P = 0.20	F(1, 135) = 0.76 P = 0.38	*F(1, 135) = 1.10* *P = 0.30*
Variety X Interval X Treatment	*F(4, 135) = 0.57* *P = 0.69*	*F(4, 135) = 0.78* *P = 0.54*	*F(4, 135) = 1.19* *P = 0.32*

Part 2. Sealing soil cracks

As expected there was no effect of pre-harvest sealing of soil cracks on foliar blight on potatoes in the weeks prior to harvest (Table 13). Treatment had a significant effect on AUDPC scores, with copper treatment resulting lower disease score compared to the water Control. The sealing of soil cracks two weeks prior to harvest did not result in a reduction in blight incidence on tubers either at harvest (Fig. 11) or after 4-weeks of storage (Fig. 12, Table 13). Application of copper did result in significant reductions in the tuber blight incidence at harvest (Fig. 11) and after storage (Fig. 12).

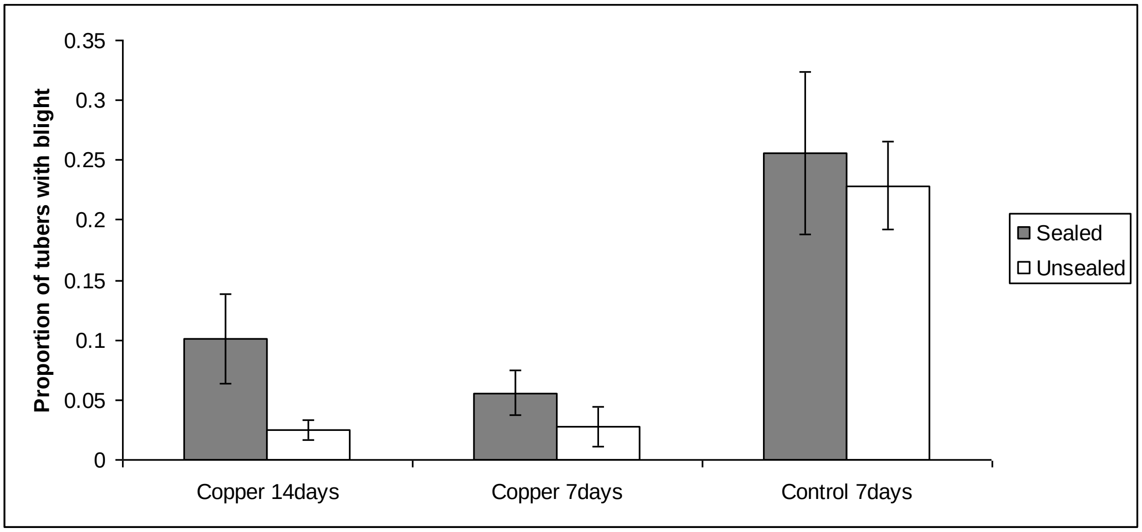

Figure 11. Effect of sealing soil cracks and copper treatments on proportion (mean ± s.e.) of tubers with blight at harvest.

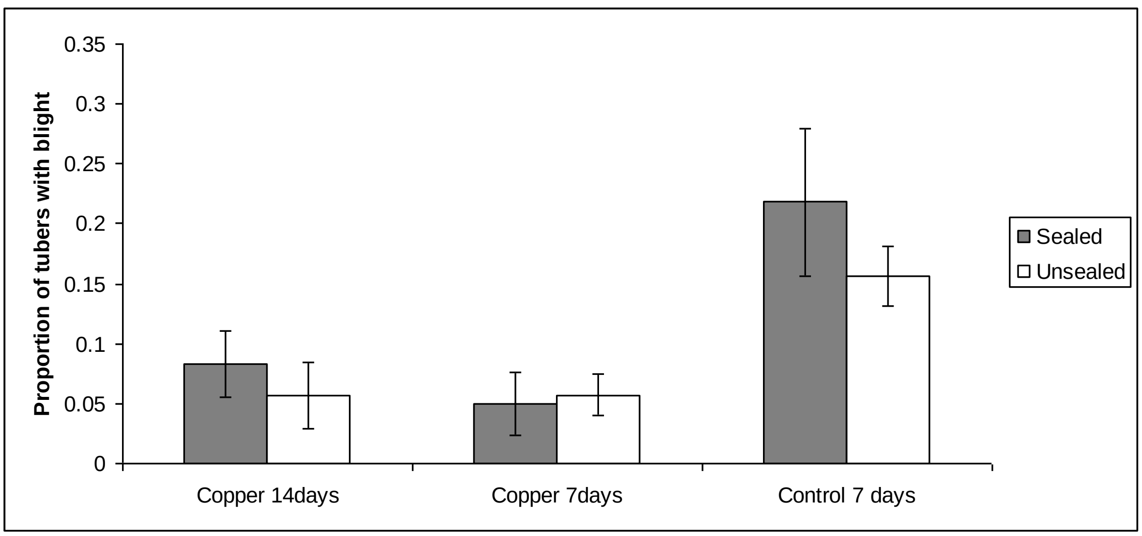

Figure 12. Effect of sealing soil cracks and copper treatments on proportion (mean ± s.e.) of tubers with blight after 4-weeks in storage under conditions similar to commercial potato storage facilities..

Table 13. Analyses results for effect of reduced copper treatments and sealing of soil cracks on foliar AUDPC scores, and blight incidence on tubers at harvest and post-harvest.

Main and interaction effects	Foliar AUDPC	Harvest - Blight incidence on tubers	*Post-harvest - Blight incidence on tubers*
Copper Treatment	F(2,39) = 12.41 **P<0.0001**	F(2,39) = 15.29 **P <0.0001**	*F(2,39) = 7.53* ***P=0.002***
Sealing Treatment	F(1, 39) = 0.0005 P = 0.98	F(1, 39) = 1.80 P = 0.19	*F(1, 39) = 0.76* *P = 0.39*
Copper Treatment X Sealing Treatment	*F (2,39) = 0.19* *P = 0.83*	*F (2,39) = 0.24* *P = 0.79*	*F (2,39) = 0.42* *P = 0.66*

Discussion and Recommendations for Further Study

The findings of this study demonstrate that resistant varieties should be the foundation of the blight management tool box for organic potato production in southwestern BC. The two resistant russet varieties (Innovator and Krantz) tested demonstrated good levels of tolerance to our dominant local strain of late blight (US-23). Levels of foliar late blight on these two varieties on their own, were higher than on Russet Norkotah plants treated with copper every 7-days (see Fig. 2). However, treating the resistant varieties with copper every 14 days resulted in very good levels of disease suppression on foliage (Fig. 4 and 5). Similarly, when the late blight resistant varieties (Jalenie and Gudenie) were treated with one or two fungicide applications disease levels were similar to the susceptible variety treated with fungicide four to five times (Mekonen *et al.* 2011). More importantly, Innovator and Krantz tubers had very low level of blight both at harvest and following 4-weeks of storage. Andreu *et al.* (2010) also reported that Innovator tubers have high levels of late blight resistance. Finally our results continue to show that Krantz and Innovator are potential replacements for Norkotah, since the size of individual tubers is similar among all three but blight incidence was lower on the two resistant varieties. Another objective of this work was to find ways to reduce copper reliance for organic potato production. Reducing the copper spray interval to 14-days does not appear to have any negative consequences for blight control for either Innovator or Krantz. Thus combining resistant varieties with a longer copper spray interval is one way organic potato growers can reduce their reliance on copper and achieve effective blight control.

While the alternatives to the industry standard russet look promising, we did not find a good candidate to replace the current standard white potato variety - Norchip. The resistant white variety tested - Keswick - had equal levels of blight on foliage and tubers as Norchip. This is most likely because Keswick is not resistant to the blight strain found in our trial plots US-23 (CFIA 2010). These findings underscore the importance of doing trials for disease control strategies at the local level - pathogens have many strains and control tools (whether chemical, biological or cultural in the case of resistant varieties) may not target all strains of a pathogen equally.

Our trial also demonstrated that sealing soil cracks at harvest was ineffective for reducing tuber blight incidence. This is most likely because soil cracks appear while plants are still growing, thus spores are washing down from the soil to tubers in the weeks prior to top-kill of vines. While the roller used in this trial did result in an effective and long-lasting seal, such an instrument would not be practical to use while the potato plant is still growing. Since physically sealing soil cracks during crop growth is unlikely to be practical or cost-effective other approaches to create a barrier to fill or reduce spore entry via soil cracks could be explored. Re-hilling, mulching or assorted row covers, at the soil level, could be used protect tubers. For example, Nyankanga *et al.* (2008) found that combining a potato variety (Allegany) with some late blight resistance with hilling showed a trend (though not statistically significant) towards a reduced incidence of late blight on tubers from larger hills. Finally, it is important to note that our study field had sandy soil and was not irrigated thus soil cracks form easily under these conditions. Fields with more organic matter and clay may have less cracking during crop growth, in which case sealing cracks after top-kill and prior to harvest maybe effective.

Recommendations for Further Study

- Continued testing of blight resistant varieties as alternatives to susceptible industry standards
- Testing of resistant varieties in combination with a reduced copper spray interval or alternatives to copper. Based on previous tests (e.g. Glover *et al*. 2010) it appears that most of the commercially available biofungicides have very limited efficacy against the local strains of late blight. However, recent work by the Institute of Sustainable Horticulture has identified local strains of the fungus *Trichoderma* spp. which may have activity against late blight.
- Explore re-hilling (Nyankanga *et al.* 2008) as another approach to protect tubers from spores washing down via soil cracks
- Investigate organic methods to protect tubers from blight development in storage

Acknowledgements

This project received financial support from the Organic Sector Development Program, Fraserland Organics and the Lower Mainland Horticultural Improvement Association. We would like to thank Wes Heppell and Peter Schouten from Heppell's Potato Corporation for kindly providing us with equipment and access to the field for this trial. Thanks to Kiara Jack and Kristine Ferris of E.S. Cropconsult Ltd. for help in harvesting the trial.

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