# Late Blight Control Alternatives: Resistant Varieties and Organic Fungicides

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**Executive Summary**

Alternatives to copper-based fungicides for the management of late blight for organic potato production remains a challenge and priority for organic vegetable growers in BC. We examined development of foliar and tuber late blight on two potato varieties - Island Sunshine and Krantz - reported to have late blight resistance. Blight-resistant varieties were compared to the susceptible industry standard Russet Norkotah. All three varieties were also treated with one of three fungicide treatments - Parasol, Actinovate or Sonata - in addition to a water Control on a weekly basis for 10 weeks.

For the first six weeks of the trial there was no blight in plots. Comparison of the untreated Control of the three varieties demonstrated that Island Sunshine was the most resistant to foliar late blight, with no difference between Krantz and Norkotah. Examination of fungicide performance on each variety indicated that neither Actinovate or Sonata outperformed the industry standard Parasol. The combination of Parasol and Island Sunshine resulted in the most disease reduction (compared to the maximum severity score among plots per variety). By the end of the trial (Week 10), levels of late blight disease reduction among Parasol treatments were 44% (Island Sunshine), 15% (Krantz) and 5% (Norkotah).

Tuber blight incidence was significantly lower on both Krantz and Island Sunshine tubers at harvest compared to Norkotah. After four weeks of storage tuber blight incidence was still significantly lower for Island Sunshine compared to Norkotah. Although tuber blight incidence was not significantly different between Krantz and Norkotah after storage, overall disease incidence was still lower for Krantz. Future studies should continue to examine alternative fungicides to copper in combination with resistant varieties.

**Introduction**

Potatoes are an important component of the vegetable industry in BC and organic acreage is increasing (ES Cropconsult Ltd. unpublished data). Late blight, *Phytophthora infestans*, is the most devastating potato disease in the world (Chycoski and Punja 1996, Agrios 2005). Due to the cool maritime climate southwestern BC is especially vulnerable to late blight, making it one of the largest production risks to the region's potato growers. Copper hydroxide is the only tool available for late blight control in organic production and is sprayed on average every 5-7 days. There are concerns about the accumulation of copper in the soil and the potential for copper toxicity on plants and soil fauna (Rhoads *et al.* 1989, Daoust *et al.* 2006); the long term status of copper for organic production is uncertain. The main alternative fungicide to copper currently available for organic production, Serenade Max™ (*Bacillus subtilis*), has to date not shown efficacy against late blight in our previous field work (Meberg *et al.* 2008, E.S. Cropconsult Ltd. unpublished data 2006-2007). Therefore there is a need to find alternatives to ensure the long-term viability of organic potato production in BC.

Resistant or tolerant varieties are a cultural tool that could be used to for late blight management for both organic and conventional potatoes (Speiser *et al.* 2006). Defender is a Russet variety that has performed well under blight pressure regardless of whether a spray program was used or not (Stevenson *et al*. 2007). Although, Defender would not have the fresh market appeal of Norkotah (H. Meberg, personal communication) it is still important to determine how this and other potato varieties stand up to blight under our growing conditions and respond to the control tools available for organic production. Several numbered varieties from the University of Minnesota potato breeding program are also promising candidates for late blight resistance (Christian Thill, January 2010, University of Minnesota, personal communication). Several other varieties available in Canada have reports of tolerance to late blight including for example Island Sunshine and Krantz (CFIA 2010).

Actinovate™ (*Streptomyces lydicus*) and Sonata™ (*Bacillus pumilus*) are two OMRI-approved biopesticides registered for potatoes in the US and both have pending or potential registrations in Canada. As reduced-risk products there is limited US efficacy data for both. Actinovate utilizes the bacterium *Streptomyces lydicus* which produces antimicrobial/antifungal compounds that are antagonistic towards several plant pathogens (Trejo-estrada *et al.* 1998). Efficacy has been demonstrated for powdery mildew on pumpkin and *Phytophthora* foliar blight on pepper (Raudales and Gardener 2008). The biopesticide Sonata utilizes the bacterium *Bacillus pumilus* and is used to control rusts and downy and powdery mildews. The US label for Sonata includes late blight on potatoes. In previous work we did not see any efficacy of either product against late blight (Syrovy *et al.* 2009) however these trials were conducted with the late blight-susceptible potato variety (Russet Norkotah). Combining resistant or tolerant potato varieties with either Actinovate or Sonata may provide a more satisfactory level of blight control. Our trial objectives were similar to that used previously by Speiser *et al.* (2006), that is compare commonly grown varieties with potential new varieties, with and without fungicide. In our study we tested Actinovate, Sonata and Parasol in combination with late blight resistant and susceptible potato varieties.

**Materials and Methods**

*Study site and plot description* – The trial was located in Cloverdale BC in an area that is primarily in potato production and had a history of late blight occurrence on both cultivated and volunteer potatoes. The trial was set up along the eastern edge of a field that had been planted with potatoes and harvested prior to the planting of the trial. Adjacent crops included corn, sweet potato, and cabbage. Potatoes were planted on July 13. Each plot was planted with 11 seed potatoes using a two-row planter with 25 cm of spacing between potatoes. At planting fertilizer (8-24-24 at 408 kg/acre) was broadcast over the trial area. Individual plots were 3.5 m long and 0.4 m wide and all plots were in two adjacent rows. The twelve treatments (Table 1) were assigned to plots following a completely randomized design. Plots were irrigated as needed and all were hand weeded once on August 10, 2010. No additional insect or disease control was done in plots. Plants senesced naturally 10 days prior to harvest or were killed by late blight earlier.

*Pest inoculation* – Although blight pressure was high overall during the course of the trial (Table 2), in previous trials we have had inconsistent levels of disease pressure in trial plots when relying solely on natural disease inoculation. In order to ensure the occurrence of late blight in the trial all plots were inoculated with active late blight lesions. Lesions were considered active if the white mycelium that gives rise to sporangia and zoospores (Agrios 2005) were visible. Active lesions were collected from potato fields in Abbotsford BC and from the UBC Farm in Vancouver BC. All plots were inoculated twice - Week 3 (Aug. 22) and Week 5 (Sept. 2). Inoculations occurred prior to weekly sprays for those weeks. Protocol for the first inoculation was to lightly mist the plants with water before a single leaf with active late blight lesion was rubbed onto leaves of the middle plants in each plot. The second inoculation was done in a similar manner, however we did not mist plants with water prior to rubbing active lesions on to plants. Once lesions were rubbed onto plants, the inoculum leaf was left in each plot at the base of the middle plants.

*Treatment description* – In order to evaluate the efficacy of organic fungicides and resistant varieties for late blight control, the trial examined three products and three potato varieties along with a control for each variety that received only water for a total of 12 treatments (three varieties X four fungicide treatments - including Control) (Table 1). The number of replicates for each variety varied from seven to nine with a total trial wide N of 89 (Table 2).

The three fungicides tested were Parasol (the copper-based industry standard), Actinovate and Sonata. We were unable to obtain the resistant varieties we had originally hoped to use in this study Defender or the numbered varieties from the University of Minnesota, but we did obtain two other varieties with reports of resistance or tolerance - Island Sunshine and Krantz (CFIA 2010). The varieties used for this trial are described as follows on the CFIA Potato Variety Descriptions website:

- Krantz: a blocky russeted potato with white flesh. Chief markets are french fries, count cartons and the fresh market. A high yielding relatively early mid season russet that stores well with a short dormancy period. Krantz is very resistant to late blight.

- Island Sunshine: a round potato with rough yellow skin and dark yellow flesh. Used chiefly in the fresh market for boiling and baking. Medium to high yield, stores well with a long dormancy period. This variety is highly resistant to late blight.
- Russet Norkotah: a long to oblong heavy russeted variety with white flesh. Medium yielding, attractive potato that stores well and has a medium dormancy period. Russet Norkotah is susceptible to late blight.

Table 1. Summary of 12 treatments and corresponding number of replicates and product rates used for study.

| Variety | Fungicide | # of replicates | Label rate | Plot area ($m^2$) | Amount of product used/plot |
|---|---|---|---|---|---|
| Norkotah | Actinovate SP | 7 | 425g/ha | 1.4 | 0.06g |
| Norkotah | Sonata | 7 | 4.67L/ha | 1.4 | 0.65mL |
| Norkotah | Parasol | 7 | 2.5kg/ha | 1.4 | 0.35g |
| Norkotah | Water (Control) | 8 | - | 1.4 | - |
| Island Sunshine | Actinovate SP | 7 | 425g/ha | 1.4 | 0.06g |
| Island Sunshine | Sonata | 7 | 4.67L/ha | 1.4 | 0.65mL |
| Island Sunshine | Parasol | 7 | 2.5kg/ha | 1.4 | 0.35g |
| Island Sunshine | Water (Control) | 9 | - | 1.4 | - |
| Krantz | Actinovate SP | 7 | 425g/ha | 1.4 | 0.06g |
| Krantz | Sonata | 7 | 4.67L/ha | 1.4 | 0.65mL |
| Krantz | Parasol | 7 | 2.5kg/ha | 1.4 | 0.35g |
| Krantz | Water (Control) | 9 | - | 1.4 | - |

Table 2. Summary of amount of water used to apply fungicides or water (Control plots) and blight pressure during the 10 weeks of the study.

| Date | Week | Amount of water applied/plot (mL) | Overall blight pressure from Abbotsford to Delta[3] |
|---|---|---|---|
| August 6 | 1 | 154 | High |
| August 12 | 2 | 160 | High |
| August 19 | 3 | 200 | High |
| August 26 | 4 | 210 | High |
| September 2 | 5 | 250 | High |
| September 13 | 7[1] | 300 | High |
| September 16 | 7 | 300 | High |
| September 22 | 8 | 300 | High |
| September 29 | 9 | 250 (325/plot for Parasol) [2] | High |
| October 4 | 10 | 250 (325/plot for Parasol) [2] | High |

1. No week 6 application due to weather so two applications were made on week 7.

2. Plant surface area was greater in plots treated with Parasol compared to all other plots.

3. Based on crop monitoring data - active lesions observed in three or more potato fields in each growing regions and weather conditions suitable for blight spread (E.S. Cropconsult Ltd unpublished data).

*Weekly foliar sprays* - Treatments were applied on a weekly schedule for 10 weeks from August 6 to October 4. This schedule is consistent with fungicide application practices of organic potato growers in the Fraser Valley. All products were applied as foliar sprays using a SOLO backpack sprayer equipped with XR Teejet 8003VS nozzles hand pumped to maintain full pressure. The amount of water used to apply the products varied from week to week in order to ensure adequate coverage of the growing plants (Table 2).

*Foliar blight and yield (tuber) assessments* - Plots were assessed weekly for incidence and severity of late blight infection, starting on August 6 (pre-treatment) and continuing until October 13 (1-week post last treatment). Incidence was determined by counting the proportion of infected plants versus total 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). Severity data recorded using the Horsfall-Barratt scale were converted to estimated mean percentages using a conversion table prepared by Redman, King, and Brown of Eli Lilly and Company (Elanco Division). Yield and disease incidence on tubers were assessed at harvest October 20. From each plot a 1 m section was randomly chosen. The number of plants (live or dead) in the 1 m section was counted and then all tubers were harvested, counted, and weighed. The surface of each tuber was examined for any signs or symptoms of the following diseases: late blight, rhizoctonia, soft rot, dry rot and common scab. Proportion of tubers with presence of each disease was recorded.

*Analysis* - Disease severity data were analyzed by calculating the AUDPC (Area Under Disease Progress Curve) using the following formula:

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

Where t= the time interval between assessments (Weeks) and y = severity score. Severity (AUDPC) data were first analyzed for the Control of each variety tested to determine the relative susceptibility to blight for each variety. AUDPC was calculated for the entire duration of the trial (Week 1 to 10). AUDPC scores were analyzed using one-way ANOVA. Then the impact of fungicide treatments on disease suppression was analyzed separately for each variety. The amount of disease suppression (%) was calculated relative to the maximum severity score each week. These scores always came from a Control plot. Because blight pressure varied from week to week, disease suppression data were analyzed with one-way ANOVA for each date, similar to the analysis of severity data in Stevenson *et al*. (2007). All *post-hoc* means comparisons were done using Tukey-Kramer HSD ($\alpha = 0.05$). Impact of treatments on yield parameters and proportion of tubers with each disease were analyzed using two-way (Variety X Fungicide) ANOVA. All proportion data were arc-sine transformed prior to analysis. *Post-hoc* means comparisons, when needed, were done with Tukey Kramer HSD. All data were analyzed using Jmp-In Version 5.1 (SAS Institute, Chicago, IL).

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 assessment* - We conducted an additional assessment in order to determine if any of our Variety X Fungicide treatment combinations resulted in better performance post-harvest. After all harvest parameters for tubers were measured, five harvested tubers from each plot were randomly selected, put into an onion sack which were then placed in totes (Fig. 1). Totes were placed in a cool dry storage area with minimal light where they were stored for 27 days. The temperature in the storage area ranged from 5.9-12.2$^{o}$C and the relative humidity ranged from 64-88%. These conditions were similar to local potato storage facilities. At the end of the 27 days each tuber was visually examined for late blight symptoms. The impact of treatments on the proportion of tubers infected with late blight (i.e. blight incidence) was analyzed using two-way (Variety X Fungicide) ANOVA. All proportion data were arc-sine transformed prior to analysis. *Post-hoc* means comparisons, when needed, were done with Tukey Kramer HSD. All data were analyzed using Jmp-In Version 5.1 (SAS Institute, Chicago, IL).


Figure 1. Post-harvest assessment of late blight development on tubers. Randomly selected tubers from each field plot were placed in onion sacks and then into plastic totes in order to maintain humidity at levels similar to potato storage facilities.

**Results and Discussion**

Susceptibility of Varieties to Late Blight - Based on a comparison of the AUDPC scores for the untreated Controls of each variety, Island Sunshine is the least susceptible to the late blight strains present in our trial plots (Fig. 2; $F(2,86) = 15.49$, $p < 0.001$). There was no significant difference in blight susceptibility between Krantz and Norkotah (Fig. 2). Because of the different degrees of susceptibility to late blight for each variety, treatment effects were examined separately for each variety.

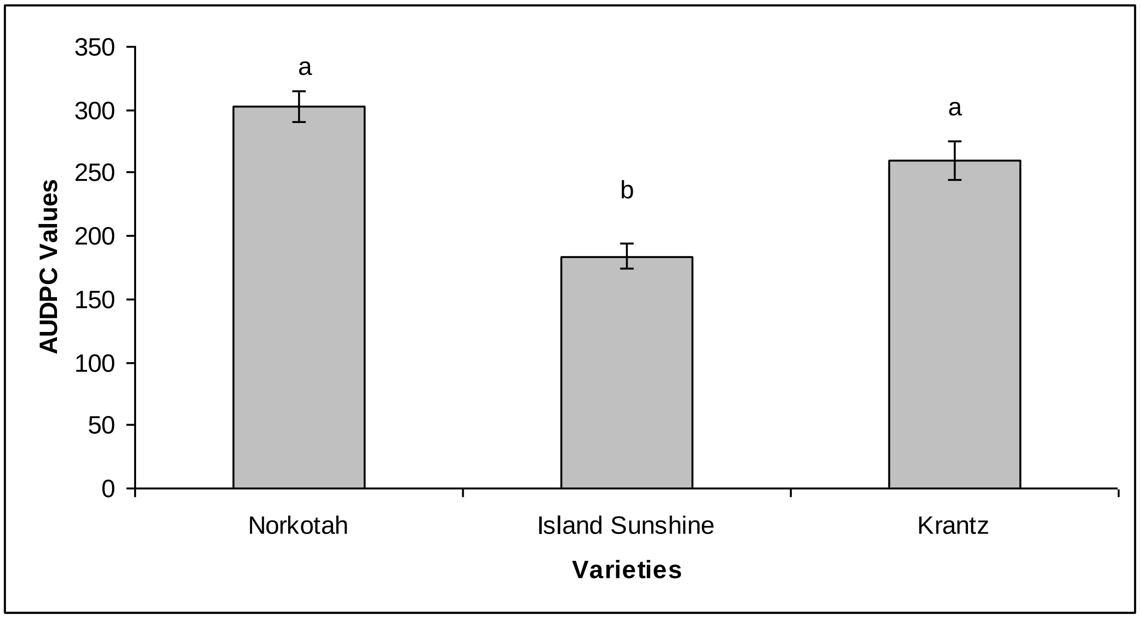


Figure 2. Area under disease progress curve (AUDPC) for the untreated Controls of three potato varieties against late blight. Each bar represents the mean ± s.e. AUDPC score for each variety. Bars with different letters are significantly different from each other (Tukey-Kramer HSD).

Efficacy of fungicide treatments (Norkotah) - The performance of the three fungicides was first examined on Norkotah (the industry standard). Blight occurred on Norkotah in Weeks 4 and 5 - however only on one Control plot, thus we did not begin the analysis of the data until Week 6 when blight was observed in the majority of plots. Neither Actinovate or Sonata were as effective as Parasol in reducing blight severity on Norkotah foliage (Table 4, Fig. 3). By the end of the trial however, even Parasol was ineffective against blight, a result consistent with what growers usually experience under conditions of heavy disease pressure. Naturally occurring variation among Control plots gives the illusion of disease control in Control plots (e.g. in Week 6 *averag*e late blight severity in Control plots was 55% less than the maximum disease severity score in *one* of the Control plots).

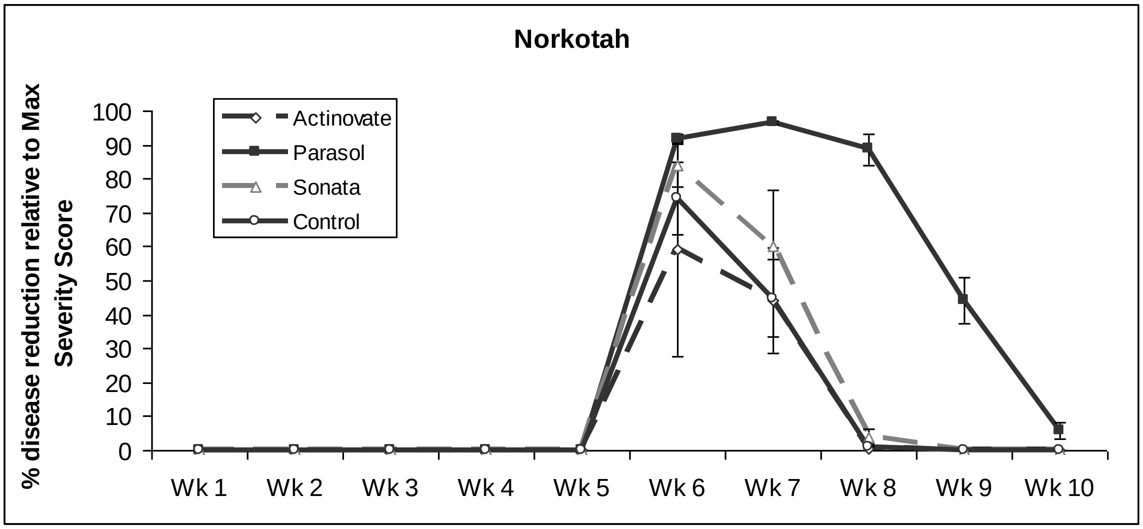


Figure 3. Effect of three fungicides on late blight disease reduction (%) on potato plants var. Island Sunshine. From Weeks 1 to 5 there was no disease in plots. Disease reduction was calculated relative to the maximum disease severity score among Control plots. However, there was naturally occurring variation in disease severity among Control plots in Weeks 6, 7, 8 and 9, and the line for Control plots should be interpreted as such.

Table 4. Statistical results for disease reduction by fungicides in Norkotah plots

| % Reduction | F | Degrees of Freedom | P-value | Means comparison |
|---|---|---|---|---|
| Week 6 | 0.78 | 3,24 | 0.51 | N/A |
| Week 7 | 4.00 | 3,24 | 0.02 | Parasol > Control & Actinovate<br>Parasol = Sonata<br>Control = Sonata & Actinovate<br>Sonata = Actinovate |
| Week 8 | 275.04 | 3,24 | <0.0001 | Parasol > Control & Sonata & Actinovate<br>Control = Actinovate = Sonata |
| Week 9 | 44.16 | 3,24 | <0.0001 | Parasol > Control & Sonata & Actinovate<br>Control = Actinovate = Sonata |
| Week 10 | 6.54 | 3,24 | 0.002 | Parasol > Control & Sonata & Actinovate<br>Control = Actinovate = Sonata |

Efficacy of fungicide treatments (Island Sunshine) - There was no late blight on Island Sunshine plots until Week 6. The most effective treatment for suppressing late blight on Island Sunshine plants was Parasol (Table 5), even by Week 10 - Parasol on Island Sunshine was providing 44% disease reduction (Fig. 4). In Week 8 Sonata also caused a significant reduction in disease severity (71%) compared to the water only Control (Fig. 4); for the remaining weeks, however, there was no difference between Sonata and the Control. There was no difference between Actinovate and the Control and neither Actinovate or Sonata outperformed Parasol.

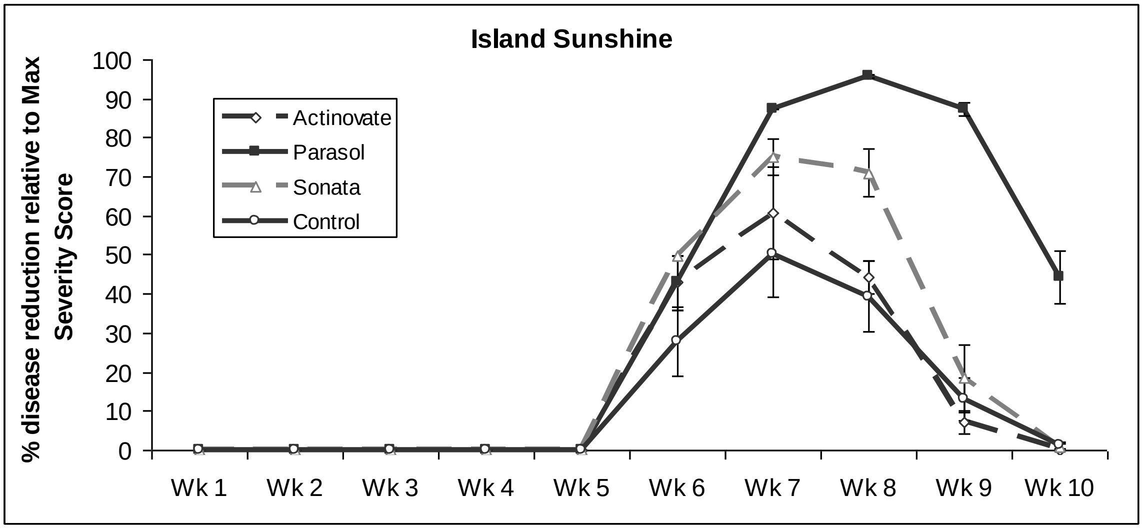


Figure 4. Effect of three fungicides on late blight disease reduction (%) on potato plants var. Island Sunshine. From Weeks 1 to 5 there was no disease in plots. Disease reduction was calculated relative to the maximum disease severity score among Control plots. However, there was naturally occurring variation in disease severity among Control plots in Weeks 6, 7, 8 and 9, and the line for Control plots should be interpreted as such.

Table 5. Statistical results for disease reduction by fungicides in Island Sunshine plots

| % Reduction | F | Degrees of Freedom | P-value | Means comparison |
|---|---|---|---|---|
| Week 6 | 1.90 | 3,26 | 0.15 | N/A |
| Week 7 | 3.58 | 3,26 | 0.03 | Parasol > Control<br>Parasol = Sonata & Actinovate<br>Control = Sonata & Actinovate<br>Sonata = Actinovate |
| Week 8 | 15.53 | 3,26 | <0.0001 | Parasol > Control & Actinovate<br>Sonata > Control& Actinovate<br>Control = Actinovate |
| Week 9 | 47.80 | 3,26 | <0.0001 | Parasol > Control & Sonata & Actinovate<br>Control = Sonata & Actinovate<br>Sonata = Actinovate |
| Week 10 | 45.10 | 3,26 | <0.0001 | Parasol > Control & Sonata & Actinovate<br>Control = Sonata & Actinovate<br>Sonata = Actinovate |

Efficacy of fungicide treatments (Krantz) - Blight did not appear on any Krantz plants until week 6. However, significant treatment effects did not occur until Week 7 (Table 6) when Parasol caused a significant reduction in disease severity compared to the Control (Fig. 5). Sonata did not cause levels of disease reduction that were different from the natural variation in disease severity that occurred among Control plots (Fig. 5). Neither of the alternatives - Actinovate or Sonata - were as effective as Parasol.

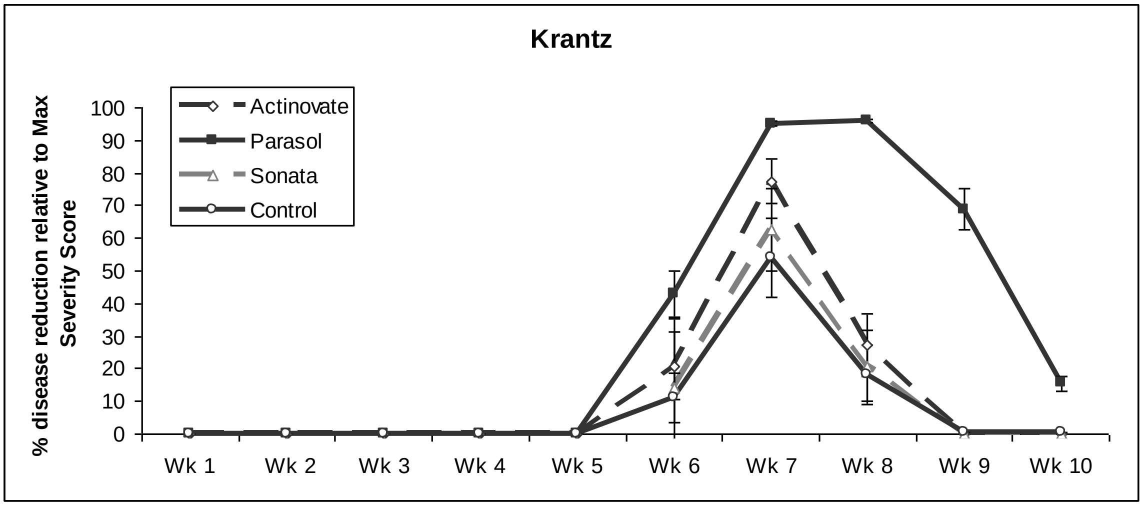


Figure 5. Effect of three fungicides on late blight disease reduction (%) on potato plants var. Krantz. From Weeks 1 to 5 there was no disease in plots. Disease reduction was calculated relative to the maximum disease severity score among Control plots. However, there was naturally occurring variation in disease severity among Control plots in Weeks 6, 7, 8 and 9, and the line for Control plots should be interpreted as such.

Table 6. Statistical results for disease reduction by fungicides in Krantz plots

| % Reduction | F | Degrees of Freedom | P-value | Means comparison |
|---|---|---|---|---|
| Week 6 | 1.35 | 3,26 | 0.28 | N/A |
| Week 7 | 3.41 | 3,26 | 0.03 | Parasol > Control<br>Parasol = Sonata & Actinovate<br>Control = Sonata & Actinovate<br>Sonata = Actinovate |
| Week 8 | 17.59 | 3,26 | <0.0001 | Parasol > Control & Sonata & Actinovate<br>Control = Actinovate = Sonata |
| Week 9 | 125.10 | 3,26 | <0.0001 | Parasol > Control & Sonata & Actinovate<br>Control = Actinovate = Sonata |
| Week 10 | 45.29 | 3,26 | <0.0001 | Parasol > Control & Sonata & Actinovate<br>Control = Actinovate = Sonata |

Summary of fungicide and variety effects on disease severity - Overall, Island Sunshine was the most resistant to late blight (Fig. 2 and 6). Unfortunately, neither Actinovate or Sonata were as effective as Parasol, although Sonata did cause significant levels of disease reduction (71%) on Island Sunshine for 1 week of the trial. On all three varieties

Parasol was the most effective fungicide at reducing late blight severity, although the efficacy of Parasol declined over the course of the trial. By the end of the trial Parasol was most effective on Island Sunshine (44% disease suppression), followed by Krantz (15% disease suppression) and finally Norkotah (only 6% disease suppression by Week 10). Thus there is an interactive effect of variety and fungicide, combining Parasol with Island Sunshine resulted in the most effective reduction in foliar late blight.

Figure 6. Control plots for Island Sunshine (far left), Krantz (middle) and Russet Norkotah (far right) at Week 8. Foliage still present on Island Sunshine vines, vines still upright but foliage largely diseased on Krantz vines, and vines and foliage severely reduced on Russet Norkotah.

*Weekly foliar sprays*: *Yield* - Even though Norkotah was the most susceptible to blight, it still had significantly greater yield - in terms of number of plants at harvest, number of tubers harvested from plots and final weight of these tubers (Fig. 7 a-c). Parasol-treated plots also had significantly higher tuber yield (total tuber weight/plot) than the other fungicide treatments; fungicide treatments did not impact the other yield parameters, including weight/tuber. Finally, the interaction of Variety X Fungicide did not have a significant impact on any of the yield measurements (Table 7). As plants were growing during the trial we observed overall slow emergence of plants in Island Sunshine plots and very low stand overall for this variety. So although Island Sunshine appears to be more tolerant to blight (at least in term of the damage to foliage) in terms of yield it does not perform as well as the more susceptible Norkotah. In contrast, the yield of Krantz was similar to Norkotah (Fig. 5c).

Table 7. Statistical results for two-way (Variety X Fungicide) repeated measures ANOVA for analysis of harvest parameters.

| | Variety | Fungicide | Variety X Fungicide |
|---|---|---|---|
| # plants at harvest | $F(2, 88) = 11.56$<br>$P < 0.001$ | $F(3, 88) = 0.76$<br>$P = 0.52$ | $F(6, 88) = 2.07$<br>$P = 0.07$ |
| # of tubers harvest | $F(2, 88) = 6.54$<br>$P = 0.002$ | $F(3, 88) = 0.28$<br>$P = 0.84$ | $F(6, 88) = 1.75$<br>$P = 0.12$ |
| Tuber weight/plot | $F(2, 88) = 48.27$<br>$P < 0.001$ | $F(3, 88) = 6.42$<br>$P = 0.0006$ | $F(6, 88) = 1.39$<br>$P = 0.23$ |
| Weight/tuber | $F(2, 88) = 31.62$<br>$P < 0.001$ | $F(3, 88) = 3.92$<br>$P = 0.01$ | $F(6, 88) = 0.40$<br>$P = 0.88$ |

*Weekly foliar sprays*: *Disease incidence at harvest* - Late blight incidence on tubers at harvest was significantly lower on both Island Sunshine and Krantz than the Norkotah

Control (Table 8). However, the only treatment that had lower blight incidence on tubers at harvest than the Norkotah Parasol treatment was the Krantz Control (Table 8; Variety: $F(2, 88) = 14.89$, $P < 0.001$, Fungicide: $F(3, 88) = 2.25$, $P = 0.09$, Variety X Fungicide: $F(6, 88) = 2.95$, $P = 0.01$). Parasol caused a significant reduction in rhizoctonia incidence on tubers at harvest, however there was no effect of potato variety (Table 8; Variety: $F(2, 88) = 3.18$, $P = 0.05$, Fungicide: $F(3, 88) = 4.85$, $P = 0.004$, Variety X Fungicide: $F(6, 88) = 1.58$, $P = 0.16$). As with late blight, all of the Krantz and Island Sunshine treatments had lower incidence of soft rot than the Norkotah Control but not the industry standard Norkotah Parasol treatment (Table 8; Variety: $F(2, 88) = 23.54$, $P < 0.001$, Fungicide: $F(3, 88) = 2.66$, $P = 0.05$, Variety X Fungicide: $F(6, 88) = 3.18$, $P = 0.007$). Finally, the overall occurrence of dry rot and common scab in this trial was too low to warrant analysis (S. Sabaratnam, BCAGRI, personal communication).

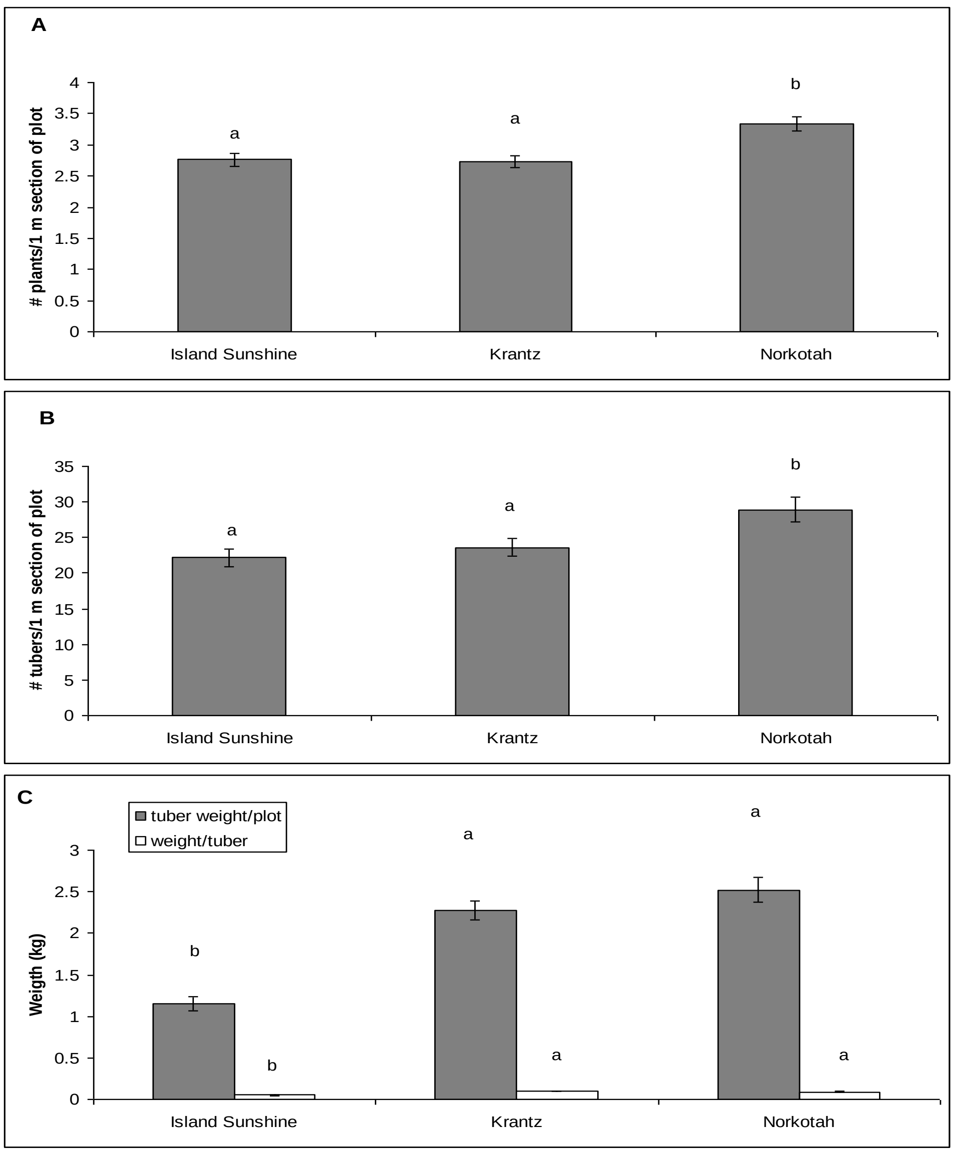


Figure 7. Effect of potato variety on the harvest parameters of a) number of plants, b) tubers and c) tuber yield (total weight of tubers/plot and weight/tuber). Each bar

represents the mean ± s.e. of 30 replicates for Island Sunshine and Krantz and 29 replicates for Russet Norkotah. Yield parameters (same colour bars) with the same letter are not significantly different from each other.

*Post-harvest assessment: Tuber blight* - Tuber blight incidence was significantly lower on Island Sunshine and Krantz tubers than Norkotah, four weeks after storage (Fig. 8; Variety: $F(2, 88) = 5.16$, $P = 0.008$, Fungicide: $F(3, 88) = 1.29$, $P = 0.28$, Variety X Fungicide: $F(6, 88) = 0.34$, $P = 0.91$). Island Sunshine had the best overall performance with significantly lower incidence of blight compared to Norkotah both at harvest and after storage. Krantz had lower incidence of blight on tubers at harvest compared to Norkotah, but not after four weeks of storage (Fig. 8). So while more tubers were harvested from Norkotah plots than Island Sunshine (Fig. 7C), a greater proportion of Island Sunshine tubers would still be infection free and therefore available for market than Norkotah (Fig. 8).

Table 8. Proportion (mean ± s.e.) of tubers with five common tuber diseases at harvest. Post-hoc analysis were done for diseases for which there were significant Variety X Fungicide interaction affects.

| Variety | Fungicide | Late blight[1] | Rhizoctonia | Soft rot[2] | Dry rot | Common scab |
|---|---|---|---|---|---|---|
| Norkotah | Actinovate | 0.18±0.05 a,b | 0.36±0.18 | 0.18±0.05 a,b | 0 | 0.005±0.005 |
| Norkotah | Sonata | 0.06±0.02 b,c | 0.47±0.02 | 0.06±0.02 b,c | 0 | 0.005±0.005 |
| Norkotah | Parasol | 0.08±0.04 b,c | 0.14±0.08 | 0.08±0.04 b,c | 0 | 0 |
| Norkotah | Control | 0.28±0.08 a | 0.44±0.10 | 0.28±0.08 a | 0 | 0 |
| Island Sunshine | Actinovate | 0.02±0.01 b,c | 0.60±0.11 | 0 c | 0.01±0.01 | 0.008±0.008 |
| Island Sunshine | Sonata | 0.04±0.02 b,c | 0.27±0.18 | 0 c | 0 | 0 |
| Island Sunshine | Parasol | 0.06±0.03 b,c | 0.04±0.04 | 0 c | 0 | 0.02±0.02 |
| Island Sunshine | Control | 0.05±0.01 b,c | 0.44±0.08 | 0 c | 0 | 0 |
| Krantz | Actinovate | 0.04±0.03 b,c | 0.18±0.09 | 0.04±0.03 b,c | 0 | 0 |
| Krantz | Sonata | 0.03±0.02 b,c | 0.31±0.09 | 0.03±0.02 b,c | 0 | 0 |
| Krantz | Parasol | 0.02±0.02 b,c | 0.10±0.09 | 0.02±0.02 b,c | 0 | 0.01±0.001 |
| Krantz | Control | 0.01±0.006 c | 0.15±0.12 | 0.01±0.007 c | 0.006±0 | 0 |

1,2. Values in the same column followed by the same letter are not significantly different from each other based on Tukey Kramer HSD *post-hoc* test.

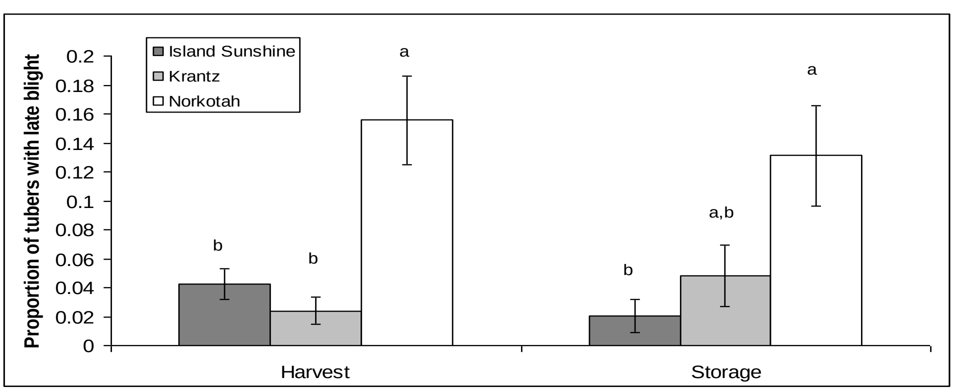

Figure 8. Effect of potato variety on tuber blight incidence at harvest and four weeks after storage. Harvest and storage data were analyzed separately and bars with the same letters are not significantly different from each other. Each bar represents the mean ± s.e. of 30 replicates for Island Sunshine and Krantz and 29 replicates for Russet Norkotah.

Finding control tools for late blight that are suitable alternatives to copper for organic production remains a challenge. For a second year in a row we have found that the label rate of the biofungicides Actinovate and Sonata do not perform as well as Parasol against late blight. Future studies should focus on higher rates of these two products and the role played by application timing, water volume and possibly the efficacy of including adjuvants, provided these would be acceptable to registrants and Canadian pesticide registration bodies.

Overall, Island Sunshine had significantly lower levels of blight development (AUDPC) than Norkotah or Krantz. Further, we found that disease suppression was the most effective in Parasol-treated Island Sunshine potatoes. Future work should continue to screen fungicides on Island Sunshine, which would not be a replacement for Norkotah-type potatoes but could be an alternative nevertheless. Despite, being more susceptible to late blight during the growing season, Norkotah had significantly higher tuber yield than Island Sunshine. However, more of the Norkotah tubers had blight both at harvest and after four weeks in storage than Island Sunshine. Krantz had yields similar to Norkotah and less tuber blight at harvest than Norkotah. After four weeks of storage tuber blight on Krantz tubers was not significantly different than Norkotah, but was still lower overall. Unlike Island Sunshine, Krantz is a potential replacement for Norkotah (similar type of tuber). Therefore work should continue on Krantz and screening fungicides (at different rates) on this variety.

Future work should continue to test additional potato varieties for late blight resistance or tolerance. Speiser *et al.* (2006) identified several varieties in their trials that were blight resistant to European strains of late blight - however they point out that market requirements ultimately determine which potato varieties are grown. Future trials for OMRI-approved fungicides should also continue to test products on blight resistant or tolerant potato varieties.

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