LATE BLIGHT CONTROL ALTERNATIVES FOR ORGANIC POTATO GROWERS

November 2009

Report to:

Fraserland Organics
Certified Organic Association of British Columbia

November 2009

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SUMMARY

Organic potato production is a flourishing sector of the British Columbia food industry and acreage dedicated to that crop is increasing. Late blight (*Phytophthora infestans* (Mont.) de Bary) is one of the largest production risks of the region's potato growers and has the potential to cause substantial economic losses. Consequently, prevention of foliar epidemics leads to weekly application of an arsenal of fungicides by the conventional growers. On the other hand, only one product, a formulation of copper hydroxide (Parasol WP), provides late blight protection for organic growers. The need for alternatives to copper led to testing of alternative, biological controls for the disease. This study tested two OMRI-listed, natural products, Actinovate SP® and Sonata®, alone or in combinations with each other and/or Parasol WP. The study consisted of six treatments: 1) Parasol sprayed, 2) Actinovate SP sprayed in rotation with Sonata 3) Actinovate SP sprayed 4) Actinovate SP sprayed in rotation with Parasol WP 5) Sonata sprayed 6) Sonata sprayed in rotation with Parasol WP, and 7) untreated (water) Control. Plots were treated weekly and leaves with active late blight lesions were introduced to plots. Late blight incidence and severity was assessed weekly. At harvest, tubers were assessed for yield and infection by *P. infestans.* Disease incidence on the last scoring date reached 29% in the Parasol/Parasol treatment, versus 52% of plants in the untreated Control. Treatments that included Parasol in the rotation tended towards lower late blight incidence than untreated Control, while those that did not had similar or higher incidence than the untreated Control. Treatments that integrated Parasol did better at delaying first infection than treatments that did not. As a result, there was a trend towards a lower accumulation of the disease using the area under disease progress curve (AUDPC). As with disease incidence and severity on plant foliage, late blight incidence on tubers was lowest in treatments that included Parasol alone or in rotation with other products. Treatments did not influence tuber yield. None of the products tested provided sufficient control of the disease to be an effective alternative to copper. Cultural strategies to minimize late blight pressure are discussed.

Introduction

Potatoes are the most important vegetable crop in Canada (Gagnon *et al.,* 2007) and for BC the value of the potato crop is $47 million for 3200 ha of production (Gagnon *et al.,* 2007). The acreage dedicated to organic potato production in BC is increasing (ES Cropconsult Ltd. unpublished data). *Phytophthora infestans* (Mont.) de Bary, also known as late blight, is the most famous and devastating potato disease in the world (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.

Late blight can infect potato plants and tubers at any time during the growing season, harvest and storage. Symptoms initially appear on the lower leaves as water-soaked spots, and develop into chocolate-brown coloured lesions surrounded by a pale green halo (Agrios, 2005). In moist weather, a zone of white, sparse mould on the underside of leaves may appear. Lesions may also be present on petioles and stems, and within a week or two of favorable conditions, total destruction of all plants may occur (Agrios, 2005). Tuber lesions are purplish or brownish, water-soaked tissues that become firm while in storage. The ideal conditions for late blight growth and sporulation is temperatures from 12°C to 24°C, and a relative humidity over 90 percent for eight to ten hours (VanOostrum, 2003).

In southwestern BC, the strains of late blight present are capable of sexual and asexual reproduction (Chycoski and Punja, 1996). Oospores (sexual) can survive in the soil for 3-4 years, acting as a survival structure and also serve as a source of variation via sexual recombination (Fry, 2008). Sexual reproduction enhances late blight's ability to colonize the host plant and adapt to different conditions. However, during the growing season the disease primarily spreads within or between fields through the transportation of more temporary, asexual sporangia or their zoospore contents. Sporangia are extremely mobile and primarily travel via air currents, while zoospores are washed onto the soil or neighbouring plants by rain or irrigation. Infected seed pieces and volunteers in a field may result in an early epidemic. In the region, *P. infestans* has shown an increase in metalaxyl resistance, which enhances the difficulty to manage the fungus (Daayff and Platt, 2000). Preventive and cultural practices such as rotation, control of volunteers and resistant hosts are important tools against late blight but are not sufficient. Consequently, prevention of foliar epidemics leads to frequent fungicides application by potato growers on a 7 to 12 day schedule through the growing season. Conventional growers have an arsenal of preventative fungicides to rotate through their spray programs. In contrast, only one product, a formulation of copper hydroxide (Parasol WP), is approved for organic potato production.

Copper is a naturally occurring element and an effective fungicide with a long history of use in agriculture (Agrios, 2005). However, at high concentrations, and especially in combination with low soil pH, copper has been shown to limit growth of plants including tomatoes (Rhoads et al, 1989) and barley (Daoust et al, 2006). Copper can also accumulate in the soil and has been found in concentrations toxic to animals in plants grown on former organic orchards or vineyards (Moolenaar and Beltrami, 1998). Moreover, the European Union is considering restrictions on the use of copper in organic production (Leifert, 2002). The concern is that copper use could potentially be restricted for organic production in North America. The objective of this study was to test potential alternatives to copper for late blight control on potatoes. In previous studies home-brewed compost teas and the microbial product Serenade Max ® (AgraQuest Inc.) were not able to prevent late blight infection on potatoes as well as copper treatments (Syrovy et al. in prep, ES Cropconsult Ltd. unpublished data).

The products examined in this study were Actinovate SP® and Sonata ®, two biopesticides approved for organic agriculture. Actinovate utilizes the bacterium *Streptomyces lydicus* which produces antimicrobial/antifungal compounds that are antagonistic towards several plant pathogens (Trejo-estrada et al., 1998; Yuan and Crawford, 1995). Actinovate is labeled for a broad range of soil-borne and foliar plant diseases, and the current Canadian label allows application for suppression of Botrytis fruit rot and powdery mildew in field and greenhouse strawberries, powdery mildew in field and greenhouse Gerber Daisy, and suppression of powdery mildew in field and greenhouse peppers. 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. Research has shown that *Bacillus* spp. can reduce plant pathogen’s growth (Jacobson et al. 2004). Antifungal metabolites produced by *Bacillus pumilus*, and their inhibitory activities on fungal mycelial growth and spore germination, were identified in lab bio-assays (Munimbazi and Bullerman, 1998; Edward and Peluso, 2003). The USA label for Sonata includes late blight on potatoes; however Sonata is not currently registered for use in Canada.

Materials and Methods

Field, planting, and trial maintenance – A field trial was conducted to compare the efficacy of Sonata and Actinovate against copper for late blight control. The trial was located in Matsqui, BC in an area that is primarily in berry production, thus reducing the risk that our field trial was a source of late blight for surrounding potato fields. Organic (i.e. untreated) seed potatoes (cv. Russet Norkotah), were planted with a two row planter on May 25, 2009 (Table 1). Seed pieces were planted with 25cm in-row spacing, and 91 cm between-row spacing. Plots were hilled once by machine on July 3. Weeds were controlled by hand-weeding every two weeks. Automatic sprinkler irrigation was used to irrigate the trial from two days after planting until emergence.

Table 1 Summary of major trial events

Event	**Date**
Planting	May 25
Hilling	July 3
First treatment and scoring	June 25
1st inoculation of trial	July 10

2nd inoculation of trial	July 23
First appearance of blight in trial	July 31
Final treatment and scoring	September 10
Harvesting	October 9

Description of products, treatments, and experimental design –Three products were tested

1) Actinovate SP (1 x 10^7 cfu/g *Streptomyces lydicus* strain WYEC 108; Natural Industries, Inc., Houston, TX),

2) Sonata (1 x 10^9 cfu/g *Bacillus pumilus* strain QST 2808; AgraQuest Inc., Davis, CA),

3) Parasol WP (copper hydroxide 50%; Nufarm Agriculture Inc., Calgary, AB)

These three products were tested alone or in combination, and a control treatment sprayed with water only was also included in the trial, for a total of seven treatments (Table 1). The seven treatments were applied weekly beginning at about 85-90% plant emergence on June 25th, 2009 (Week 1). Timing of treatment application was consistent with practices of organic potato growers in the Fraser Valley, who follow a weekly preventive spray program due to the aggressiveness of local late blight strains. In total there were 12 sprays during the potato growing season. All plots were sprayed with foliar treatments, using a SOLO backpack sprayer pumped to maintain full pressure. Products were applied at rates consistent with Canadian (Actinovate, Parasol) or USA (Sonata) labels (Table 2), in enough water to give complete and thorough coverage of plant foliage. The volume of water used for each weekly spray was calculated by spraying a plot to runoff with water. The volume of water was increased as plants grew, from 1 liter of water per treatment in week 1, to 6 liters of water per treatment in week 12 (Table 3). This ensured thorough coverage of plants with the spray solutions, as per the label directions of all products tested.

Table 2. Treatments, schedule and rates.

Trt	**Week 1, 3, 5, 7, 9, 11**	**Amount/**	**Week 2, 4, 6, 8, 10, 12**	**Amount/**

	Product and label rate	plot		plot
1	Parasol WP - 2.5 kg/ha	0.75 g/plot	Parasol WP - 2.5 kg/ha	0.75 g/plot
2	Actinovate SP - 425 g/ha	0.13 g/plot	Sonata - 4.67 L/ha	1.4 mL/plot
3	Actinovate SP - 425 g/ha	0.13 g/plot	Actinovate SP - 425 g/ha	0.13 g/plot
4	Actinovate SP - 425 g/ha	0.13 g/plot	Parasol WP - 425 g/ha	0.75 g/plot
5	Sonata - 4.67L/ha	1.4 mL/plot	Sonata - 4.67L/ha	1.4 mL/plot
6	Sonata - 4.67L/ha	1.4 mL/plot	Parasol WP - 2.5 kg/ha	0.75 g/plot
7	Untreated control (water)	N/A	Untreated control (water)	N/A

Table 3: Water volume in weekly treatment solutions.

Week	Volume of H_2O per plot
1	125 mL
2	300 mL
3	500 mL
4	563 mL
5	625 mL
6	625 mL
7-12	750 mL

The seven treatments were replicated eight times (N=56) in a completely randomized design. Each potato plot consisted of a single row 3 m long with an average number of 7 to 11 plants per plot (field plot map including layout of plots is provided in Appendix 1).

Inoculation- Potato leaves and stems infected with late blight were collected from a grower's field in Cloverdale, BC and were stored for 24 hours in plastic bags with moist paper towels to encourage production of sporangia and zoospores. Plant tissue with active late blight lesions were rubbed onto leaves of potato plants in the field plots. To encourage spore survival, inoculation was performed in the evening after dewfall. Plots were inoculated with late blight on July 10th, and again on July 23rd after lesions failed to appear on foliage. The second inoculation was successful and symptoms were apparent the next assessment on July 31.

Assessment- Plots were assessed weekly for incidence and severity, starting from plant emergence and continuing until senescence (Table 1). Incidence was measured by counting the number of plants affected with blight within the plot. Severity was visually measured using a 0-11 grading scale, where 0 represented a 100% healthy plant or 0% diseased plant, and 11 represented a plant with 100% necrotic tissue (Horsfall-Barrat, 1947). At harvest blight incidence on tubers and yield were assessed. All tubers in each plot were hand-dug and sorted in two size classes: <48mm (undersize) and >48mm (marketable). Tubers within each size class were counted and weighed. Fifteen marketable tubers were visually assessed for infection by *P .infestans* by examining the surface, then cutting open the tuber to examine internal tissue for dry, reddish-brown lesions just beneath the skin. Incidence of late blight on tubers was recorded.

Data Analyses - Proportion incidence data on foliage and tubers, and proportion marketable yield (marketable yield/total yield), were arcsine-transformed before analysis. Foliar incidence and severity data were analyzed using repeated measures MANOVA. A separate one-way ANOVA was conducted for each scoring date when significant treatment x time interaction effects were detected using the MANOVA model. 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). Area under disease progress curve (AUDPC) was calculated using the midpoint rule method (Campbell and Madden, 1990). Converted percentages were used in the formula:

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

Where t = time of each reading (in days), y = % of affected foliage at each reading, and n = number of readings. AUDPC was calculated for the period of July 31 (observation of first late blight lesion) to September 10. AUDPC, transformed tuber late blight incidence, yield, and transformed marketable yield data were analyzed using one-way ANOVA, followed by *post-hoc* with either Fisher's LSD test or Tukey Kramer HSD (α=0.05) when treatment effects were significant. All analyses were performed using JMP IN version 4.0.3 (SAS Institute, Inc.).

Results

Incidence - The percentage of plants with late blight symptoms increased over time, with 76% of plants in the trial affected by the disease on the end scoring date, leading to a significant time effect (Fig. 1a; Table 4). There was no significant treatment x time interaction effect when data were analyzed either for all scoring dates, or only dates when late blight was found in test plots (Table 4). Treatments that included Parasol either alone or in combination with Actinovate in the rotation tended towards lower late blight incidence than Actinovate or Sonata on their own, only Parasol on it's own was significantly different from the control (Fig 1b; Table 5). These treatment differences were observed when data were analyzed for all scoring dates and for the last seven (from July 31).

Table 4. Statistical results for analysis of treatment and time effects on late blight incidence on potatoes. Data were analyzed using repeated measure MANOVA.

Effect	F value	Degrees of Freedom	p-value
All scoring dates:			
Treatment	2.4335	6, 49	**0.0388**
Time	54.4637	11, 39	**<0.0001**
Treatment x Time	0.7175	66, 214	0.9428
After blight occurrence (July 31-end):			
Treatment	2.4335	6, 49	**0.0388**
Time	104.5913	6, 44	**<0.0001**
Treatment x Time	1.2926	36, 196	0.1386

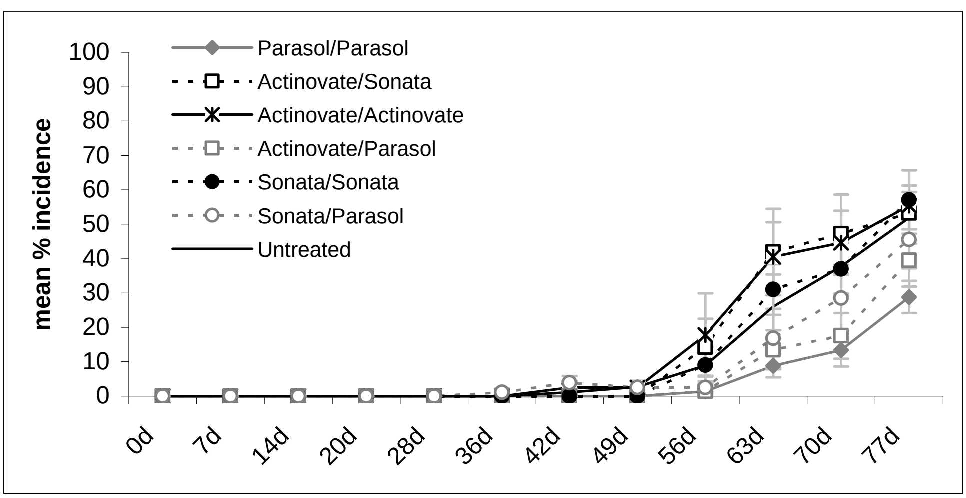

Fig 1a: Mean percentage of plants affected by late blight on each scoring date. Bars represent the standard error for 7 replicates/treatment/date.

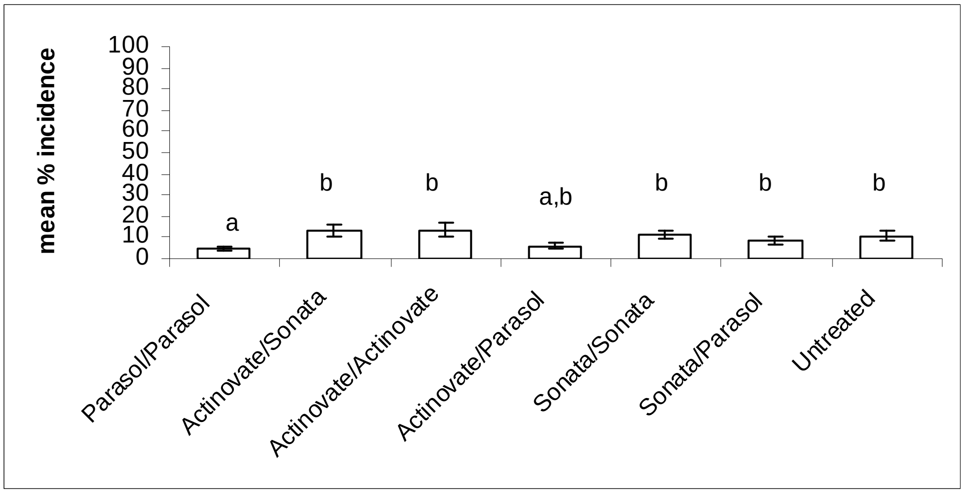

Fig 1b: Mean (± standard error) percentage of plants affected by late blight over the duration of the trial. Bars with different letters are significantly different from each other (Fisher's LSD).

Table 5: Mean percentage of plants (± standard error mean) affected by late blight on the last six scoring dates.

Treatment	42 d	49 d	56 d	63 d	70 d	77 d
Parasol / Parasol	0.00 ± 0.00	0.00 ± 0.00	1.39 ± 1.39	8.87 ± 3.38	13.36 ± 4.76	28.85 ± 4.72
Actinovate / Sonata	0.00 ± 0.00	0.00 ± 0.00	14.24 ± 7.56	41.91 ± 12.5	47.19 ± 11.5	53.30 ± 7.91
Actinovate / Actinovate	2.50 ± 1.64	2.50 ± 1.64	17.78 ± 9.79	40.56 ± 1.00	44.58 ± 9.34	55.42 ± 10.3
Actinovate / Parasol	0.00 ± 0.00	0.00 ± 0.00	1.39 ± 1.39	13.51 ± 5.66	17.53 ± 6.66	39.54 ± 7.65
Sonata / Sonata	0.00 ± 0.00	0.00 ± 0.00	9.03 ± 5.25	31.01 ± 7.40	36.94 ± 7.66	57.10 ± 8.58
Sonata / Parasol	3.91 ± 1.92	2.53 ± 1.66	2.53 ± 1.66	16.83 ± 8.53	28.55 ± 9.61	45.54 ± 8.32
Untreated	1.14 ± 1.14	2.70 ± 1.80	8.95 ± 7.73	26.04 ± 9.34	37.73 ± 7.91	51.83 ± 7.53

Severity & AUDPC - The disease progress curves for this trial show that disease severity increased in all treatments over time (Fig. 2). The effect of time on late blight severity was significant; however effect of treatment was not significant when data for all scoring dates, or only dates when late blight was found, were analyzed (Table 6). There was a significant treatment x time interaction when data from first appearance of blight to last scoring date were analyzed (Table 6), however further analysis showed that no treatments differed significantly from each other on any scoring dates ($p > 0.05$). Although there was a trend towards lower AUDPC in treatments including Parasol (Fig. 3) there were no significant treatment effects on AUDPC ($F (6, 49) = 1.13$; $p = 0.36$).

Table 6: Statistical results for analysis of treatment and time effects on late blight severity on potatoes. Data were analyzed using repeated measure MANOVA.

Effect	F value	Degrees of Freedom	p-value
All scoring dates:			
Treatment	0.1726	6, 49	0.9830
Time	5.7013	11, 39	<0.0001
Treatment x Time	0.9292	66, 214.14	0.6295
After blight occurrence (July 31-end):			
Treatment	0.1726	6, 49	0.9830
Time	11.7717	6, 44	<0.0001
Treatment x Time	1.6772	36, 195.98	0.0143

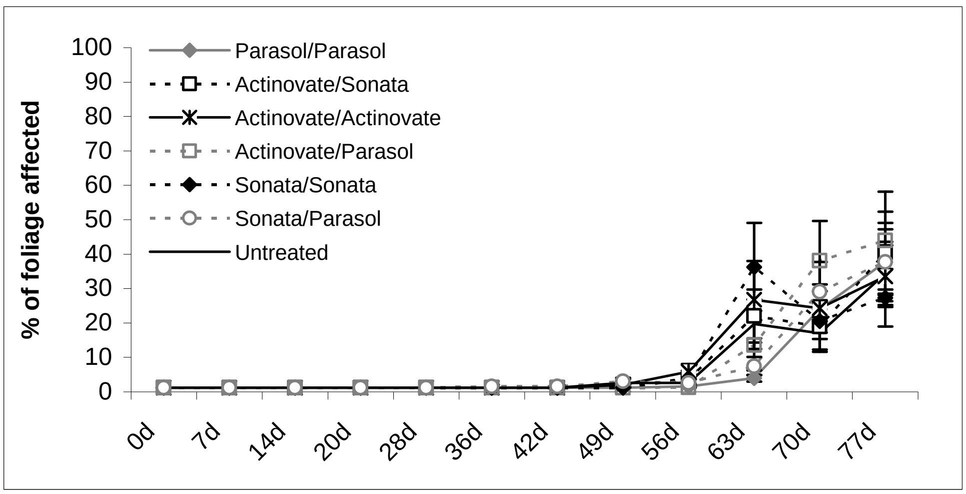

Fig 2: Disease progress curves showing changes in severity of late blight infection on foliage over time. Bars represent standard error for N=7 replicates/treatment/date.

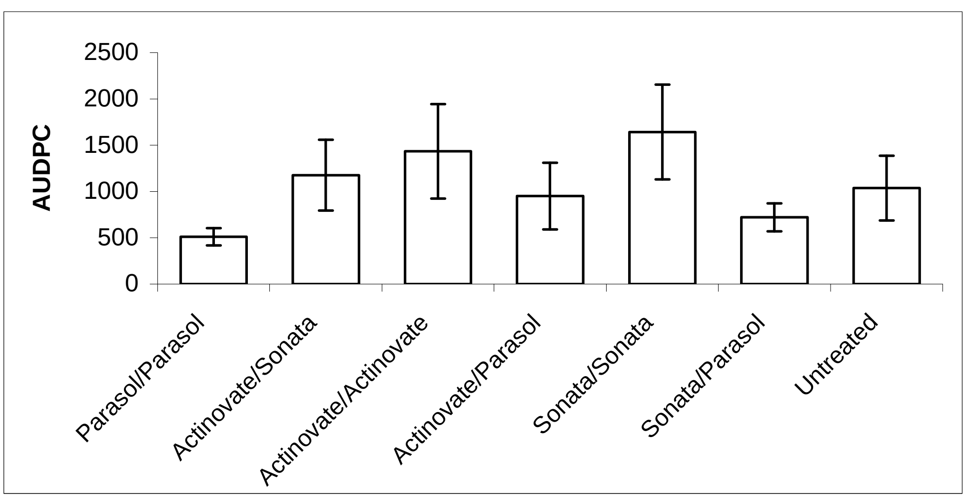

Fig 3: Mean (± standard error) area under disease progress curve, summarizing the accumulation of daily percentage late blight infection between observation of first lesion on July 31 and final assessment on September 10, for each treatment.

Tuber infection - Late blight infection on tubers at harvest followed a similar pattern to disease severity on foliage. Effect of treatments on late blight infection on tubers at harvest was significant (F (6,49) = 5.53; p=0.0002). Treatments with Sonata alone or in rotation with Actinovate had higher tuber infection than tubers treated with copper only (Fig. 4). However, none of the treatments differed significantly from the Control.

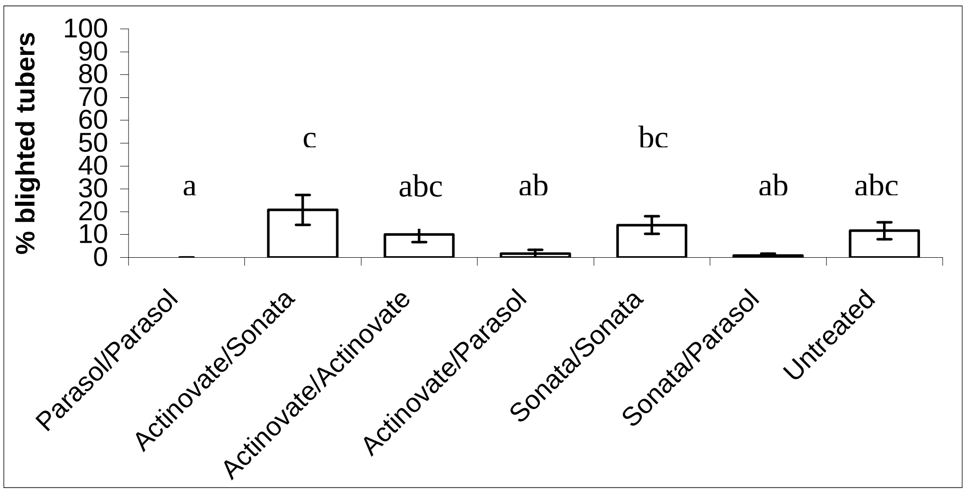

Fig 4: Mean (± standard error) percentage of tubers in each treatment showing blight symptoms at harvest. Bars with different letters are significantly different from each other (Tukey Kramer HSD).

Tuber yield – There were no significant effects of treatments on both total yield (Fig. 5; F (6,49) = 0.85; p=0.54) and marketable yield (F(6,49) = 1.21; p=0.32).

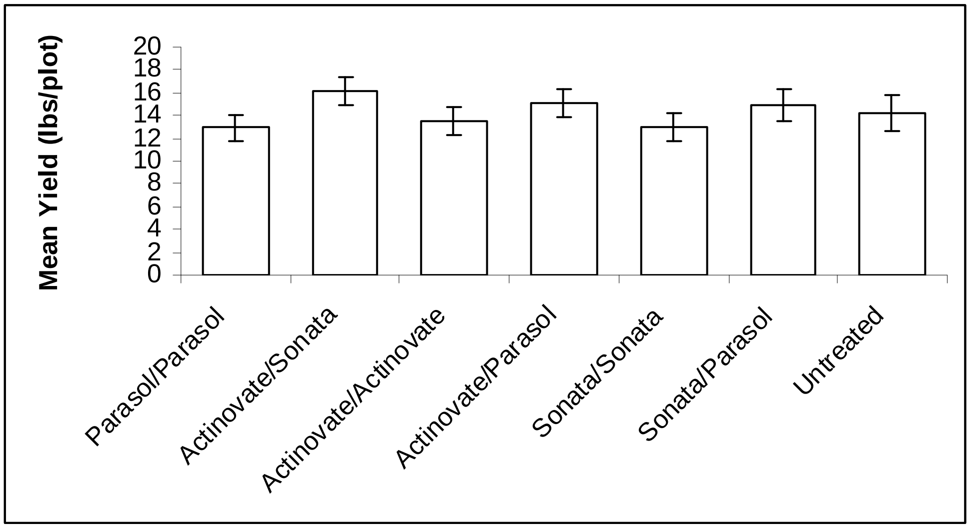

Fig 5: Mean (± standard error) total tuber yield at harvest (lbs/plot) for each treatment.

Discussion

Blight pressure in 2009 was similar to previous years when this work has been conducted. In 2009 late blight epidemic began on July 31, slightly later than 2005 (July 15) and 2008 (July 25). Assessment continued for seven weeks after first observation of infection, two weeks longer than both previous years. Final incidence was more similar to 2005 than 2008 (65% incidence in control in 2005 vs. 100% in 2008), however severity reached higher levels in this year's study compared with 2005.

Our research this year found only the copper industry standard, significantly lowered late blight incidence but not severity compared with the untreated Control. However, treatments where copper was rotated with another product did not have a reduction in blight incidence. This is in contrast to our previous work that showed that all treatments that included copper sprayed either weekly *or* bi-weekly, reduced late blight incidence (2005, E. S. Cropconsult Ltd., unpublished data) or severity (2008, E. S. Cropconsult Ltd., unpublished data). Perhaps more importantly in all three years of this work (2005, 2008, and 2009) none of the alternative treatments (Serenade, Actinovate or Sonata) provided sufficient blight control when used on their own or in rotation with each other.

Previous field trials have identified copper as the most effective preventive organic treatment for late blight (Stone, 2007; Dorn et al, 2007; E. S. Cropconsult Ltd., unpublished data). These trials compared copper sprays with a variety of alternatives including hydrogen dioxide and peroxyacetic acid (BioSafe) and compost teas (Stone, 2007), sulfuric clays and plant extracts (Dorn et al, 2007), and commercial biological treatments including Sonata (Stone, 2007; Dorn et al, 2007), Serenade, and Trichodex (Dorn et al, 2007). Compost tea gave a much smaller, but significant reduction in AUDPC compared with the control (Stone, 2007), however two years of our previous work have not demonstrated efficacy with composts from two different sources (E. S. Cropconsult Ltd., unpublished data). Instability of organic preparations has been implicated as a cause for lowered efficacy in the field (Dorn et al, 2007).

Foliar treatment options for organic late blight management are dwindling and perhaps this is what's leading researchers to pursue more cultural methods of late blight management. There is some work demonstrating that allicin, a volatile in garlic extract, can reduce infection of tuber tissue by *P. infestans* when applied either via fumigation or directly to the tuber tissue (Curtis et al, 2004), or foliar infection when applied to excised leaves (Portz et al, 2008). Efficacy has not been demonstrated in the field so far, however seed disinfection with allicin-containing preparations has been suggested as a practical application (Slusarenko et al, 2008).

A completely different strategy that is being tested is nitrogen management. Studies in Germany found that foliar loss due to late blight often did not reach yield-limiting levels until after tuber growth had naturally slowed (Möller et al, 2007). Our studies support this finding, as we did not observe any yield increase despite lowered foliar late blight incidence in 2005 (no yield data in 2008). Similarly, the study in Oregon noted that yield differences might have been seen had the epidemic occurred earlier in the season (Stone, 2007). The authors found a much stronger correlation between available nitrogen and the length of tuber bulking period; tubers bulked longer if higher nitrogen levels were made available by pre-cropping with clover and adding manure (Möller et al, 2007). This prolonged bulking period under high nitrogen fertility lead to greater susceptibility of high-nitrogen potatoes to yield loss due to late blight. Unsprayed potatoes with high nitrogen fertility produced similar yields to sprayed potatoes with low nitrogen fertility in one trial, but yielded less in another (Möller et al, 2007). However the yield loss relationship was nonexistent to weak if *P. infestans* infection occurred after late July. Although some authors have observed a substantial tuber yield increase when foliar late blight severity was lowered by copper applications (Speiser et al, 2006), perhaps the late onset of blight in most years in the Pacific Northwest warrants exploring yield compensation with nitrogen management instead of routine spraying.

Other strategies that have been explored to cope with yield loss due to late blight are presprouting (chitting) and early planting in order to bulk tubers before foliar loss becomes limiting (Hospers-Brands et al, 2008). The authors found that planting earlier significantly increased yields when a late blight epidemic was severe in both the UK and Netherlands (Hospers-Brands et al, 2008), but the extent of the increase depended on the variety being tested. Although early planting was effective in those areas, planting in coastal BC is often delayed due to wet weather, making this an unreliable tool.

Allowing infection to develop in the field, even without yield loss, could present new challenges in storage due to tuber blight infection. There has been some work with mulches and hilling to reduce spread of *P. infestans* inoculum to tubers. One study found that a black polyethylene film significantly reduced tuber blight compared with the control, however it did not eliminate tuber infection completely. Hilling to a depth greater than 15 cm lowered tuber infection in one year, but not the other (Glass et al, 2001). A second study found that straw mulch was ineffective at lowering tuber blight incidence, but hilling to a depth greater than 7 cm significantly reduced tuber blight (Nyankanga et al, 2008). These results viewed together suggest that soil type might be an important factor in the efficacy deep hilling to reduce tuber blight incidence.

A final possible strategy to manage late blight is growing of resistant varieties, either alone or in combination with more susceptible varieties. There are now several registered russet varieties in Canada that boast some level of resistance to either foliar or tuber late blight infection, including Umatilla Russet, Butte, Alta Crown, and Nooksack (Canadian Potato Varieties Descriptions, CFIA). Defender is a russet developed by the tri-states breeding program between Washington, Oregon, and Idaho, for which similar yields have been recorded after a blight epidemic, regardless of whether the variety was under a spray program or not (Stevenson et al, 2007). It is yet to be explored whether incorporating any of these varieties into a field with a more susceptible variety can slow progress of infection. However, given that the OMRI-approved foliar fungicides tested to date have shown little impact on late blight of potatoes, alternative practices such as resistant varieties and nitrogen management should be explored further as they may be an organic grower's best route towards an integrated blight management program.

ACKNOWLEDGEMENTS
We thank Fraserland Organics for donation of organic seed potatoes and for providing financial contributions. Dr. Janice Elmhirst (Elmhirst Diagnostics and Research) helped with plant inoculation. This study was partly supported by COABC's OSDP fund. E. S. Cropconsult staff made various contributions to this trial. We thank Todd Kabaluk and staff at AAFC Agassiz for lending us potato planting equipment.

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Appendix I – Field Plot Map

→ N

Parasol / Parasol (1)	Actinovate / Sonata (1)	Actinovate / Parasol (1)	Actinovate / Actinovate (1)
Sonata / Sonata (1)	Sonata / Parasol (1)	Parasol / Parasol (2)	Untreated (1)
Untreated (2)	Actinovate / Parasol (2)	Actinovate / Actinovate (2)	Sonata / Sonata (2)
Actinovate / Sonata (2)	Parasol / Parasol (3)	Sonata / Parasol (2)	Actinovate / Parasol (3)
Untreated (3)	Actinovate / Actinovate (3)	Sonata / Sonata (3)	Actinovate / Sonata (3)
Sonata / Parasol (3)	Untreated (4)	Actinovate / Sonata (4)	Actinovate / Actinovate (4)
Sonata / Sonata (4)	Actinovate / Sonata (5)	Actinovate / Parasol (4)	Untreated (5)
Actinovate / Actinovate (5)	Sonata / Sonata (5)	Actinovate / Actinovate (6)	Sonata / Parasol (4)
Sonata / Parasol (5)	Untreated (6)	Actinovate / Sonata (6)	Actinovate / Parasol (5)
Actinovate / Parasol (6)	Parasol / Parasol (5)	Parasol / Parasol (4)	Sonata / Sonata (6)
Untreated (7)	Actinovate / Actinovate (7)	Sonata / Parasol (6)	Actinovate / Parasol (7)
Parasol / Parasol (6)	Sonata / Parasol (7)	Actinovate / Sonata (7)	Untreated (8)
Sonata / Sonata (7)	Actinovate / Sonata (8)	Actinovate / Parasol (8)	Parasol / Parasol (7)
Actinovate / Actinovate (8)	Parasol / Parasol (8)	Sonata / Parasol (8)	Sonata / Sonata (8)

Appendix II – Raw Foliar Incidence Data

Treatment	Rep	Plants per Plot (#)	# of plants with foliar infection 06/25/09	7/2/2009	07/09/09	07/15/09	07/23/09	07/31/09	08/06/09	08/13/09	08/20/09	08/27/09	09/03/09	09/10/09
Parasol/Parasol	1	8	0	0	0	0	0	0	0	0	0	0	0	1
Parasol/Parasol	2	7	0	0	0	0	0	0	0	0	0	2	3	4
Parasol/Parasol	3	9	0	0	0	0	0	0	0	0	0	1	1	2
Parasol/Parasol	4	9	0	0	0	0	0	0	0	0	1	1	1	3
Parasol/Parasol	5	11	0	0	0	0	0	0	0	0	0	1	2	3
Parasol/Parasol	6	8	0	0	0	0	0	0	0	0	0	0	1	2
Parasol/Parasol	7	10	0	0	0	0	0	0	0	0	0	0	0	2
Parasol/Parasol	8	9	0	0	0	0	0	0	0	0	0	1	1	3
Actinovate/Sonata	1	8	0	0	0	0	0	0	0	0	2	7	7	7
Actinovate/Sonata	2	10	0	0	0	0	0	0	0	0	0	1	1	2
Actinovate/Sonata	3	10	0	0	0	0	0	0	0	0	0	4	4	4
Actinovate/Sonata	4	10	0	0	0	0	0	0	0	0	0	0	2	5
Actinovate/Sonata	5	10	0	0	0	0	0	0	0	0	0	2	2	4
Actinovate/Sonata	6	9	0	0	0	0	0	0	0	0	0	4	4	4
Actinovate/Sonata	7	9	0	0	0	0	0	0	0	0	3	3	5	6
Actinovate/Sonata	8	9	0	0	0	0	0	0	0	0	5	9	9	7
Actinovate/Actinovate	1	10	0	0	0	0	0	0	0	0	8	10	10	10
Actinovate/Actinovate	2	10	0	0	0	0	0	0	1	1	3	5	5	6
Actinovate/Actinovate	3	9	0	0	0	0	0	0	0	0	0	3	3	3
Actinovate/Actinovate	4	10	0	0	0	0	0	0	0	0	0	1	1	1
Actinovate/Actinovate	5	9	0	0	0	0	0	0	0	0	2	2	4	7
Actinovate/Actinovate	6	10	0	0	0	0	0	0	1	1	1	2	3	4
Actinovate/Actinovate	7	9	0	0	0	0	0	0	0	0	0	3	3	4
Actinovate/Actinovate	8	9	0	0	0	0	0	0	0	0	0	5	5	7
Actinovate/Parasol	1	9	0	0	0	0	0	0	0	0	1	4	4	7
Actinovate/Parasol	2	8	0	0	0	0	0	0	0	0	0	0	0	1
Actinovate/Parasol	3	10	0	0	0	0	0	0	0	0	0	0	0	2
Actinovate/Parasol	4	8	0	0	0	0	0	0	0	0	0	1	1	2
Actinovate/Parasol	5	10	0	0	0	0	0	0	0	0	0	1	1	3
Actinovate/Parasol	6	9	0	0	0	0	0	0	0	0	0	1	3	5

Treatment	Rep	Plants per Plot (#)	# of plants with foliar infection 06/25/09	7/2/2009	07/09/09	07/15/09	07/23/09	07/31/09	08/06/09	08/13/09	08/20/09	08/27/09	09/03/09	09/10/09
Actinovate/Parasol	7	11	0	0	0	0	0	0	0	0	0	0	0	5
Actinovate/Parasol	8	10	0	0	0	0	0	0	0	0	0	3	4	5
Sonata/Sonata	1	9	0	0	0	0	0	0	0	0	2	2	2	4
Sonata/Sonata	2	10	0	0	0	0	0	0	0	0	1	6	6	6
Sonata/Sonata	3	9	0	0	0	0	0	0	0	0	0	3	3	6
Sonata/Sonata	4	8	0	0	0	0	0	0	0	0	0	1	4	7
Sonata/Sonata	5	10	0	0	0	0	0	0	0	0	0	2	2	4
Sonata/Sonata	6	11	0	0	0	0	0	0	0	0	0	0	0	2
Sonata/Sonata	7	10	0	0	0	0	0	0	0	0	4	5	6	9
Sonata/Sonata	8	10	0	0	0	0	0	0	0	0	0	5	5	5
Sonata/Parasol	1	10	0	0	0	0	0	0	0	0	0	0	0	2
Sonata/Parasol	2	9	0	0	0	0	0	0	1	0	0	0	1	3
Sonata/Parasol	3	9	0	0	0	0	0	0	0	0	1	1	3	4
Sonata/Parasol	4	10	0	0	0	0	0	0	0	0	0	0	1	2
Sonata/Parasol	5	10	0	0	0	0	0	0	0	0	0	7	8	9
Sonata/Parasol	6	9	0	0	0	0	0	0	0	0	0	1	1	4
Sonata/Parasol	7	11	0	0	0	0	0	1	1	1	1	1	3	5
Sonata/Parasol	8	9	0	0	0	0	0	0	1	1	0	3	5	6
Untreated control	1	8	0	0	0	0	0	0	0	1	5	7	7	7
Untreated control	2	10	0	0	0	0	0	0	0	0	0	3	4	6
Untreated control	3	9	0	0	0	0	0	0	0	0	0	0	4	7
Untreated control	4	10	0	0	0	0	0	0	0	0	0	1	4	5
Untreated control	5	11	0	0	0	0	0	0	0	0	0	2	3	4
Untreated control	6	9	0	0	0	0	0	0	0	0	0	2	2	3
Untreated control	7	9	0	0	0	0	0	0	0	0	0	2	2	3
Untreated control	8	11	0	0	0	0	0	0	1	1	1	2	2	4

Appendix III – Raw Foliar Severity Data

		Late Blight Severity Score (0-11)											
Treatment	Rep	06/25/09	07/02/09	07/09/09	07/15/09	07/23/09	07/31/09	08/06/09	08/13/09	08/20/09	08/27/09	09/03/09	09/10/09
Parasol/Parasol	1	0	0	0	0	0	0	0	0	0	0	2	2
Parasol/Parasol	2	0	0	0	0	0	0	0	0	0	2	5	6
Parasol/Parasol	3	0	0	0	0	0	0	0	0	0	2	5	6
Parasol/Parasol	4	0	0	0	0	0	0	0	0	2	3	4	4
Parasol/Parasol	5	0	0	0	0	0	0	0	0	0	2	5	6
Parasol/Parasol	6	0	0	0	0	0	0	0	0	0	0	3	3
Parasol/Parasol	7	0	0	0	0	0	0	0	0	0	0	3	4
Parasol/Parasol	8	0	0	0	0	0	0	0	0	0	2	5	6
Actinovate/Sonata	1	0	0	0	0	0	0	0	0	2	5	3	5
Actinovate/Sonata	2	0	0	0	0	0	0	0	0	0	2	2	2
Actinovate/Sonata	3	0	0	0	0	0	0	0	0	0	3	2	4
Actinovate/Sonata	4	0	0	0	0	0	0	0	0	0	0	2	4
Actinovate/Sonata	5	0	0	0	0	0	0	0	0	0	2	3	3
Actinovate/Sonata	6	0	0	0	0	0	0	0	0	0	4	4	6
Actinovate/Sonata	7	0	0	0	0	0	0	0	0	3	6	5	7
Actinovate/Sonata	8	0	0	0	0	0	0	0	0	3	5	6	8
Actinovate/Actinovate	1	0	0	0	0	0	0	0	0	4	8	6	8
Actinovate/Actinovate	2	0	0	0	0	0	0	0	2	2	4	5	5
Actinovate/Actinovate	3	0	0	0	0	0	0	0	0	0	3	3	3
Actinovate/Actinovate	4	0	0	0	0	0	0	0	0	0	2	3	4
Actinovate/Actinovate	5	0	0	0	0	0	0	0	0	3	3	3	4
Actinovate/Actinovate	6	0	0	0	0	0	0	0	2	3	3	4	5
Actinovate/Actinovate	7	0	0	0	0	0	0	0	0	0	3	3	4
Actinovate/Actinovate	8	0	0	0	0	0	0	0	0	0	6	5	5
Actinovate/Parasol	1	0	0	0	0	0	0	0	0	1	6	7	9
Actinovate/Parasol	2	0	0	0	0	0	0	0	0	0	0	2	2
Actinovate/Parasol	3	0	0	0	0	0	0	0	0	0	0	3	3
Actinovate/Parasol	4	0	0	0	0	0	0	0	0	0	2	4	4
Actinovate/Parasol	5	0	0	0	0	0	0	0	0	0	3	5	5

Treatment	Rep	Late Blight 06/25/09	Severity Score (0-11) 07/02/09	07/09/09	07/15/09	07/23/09	07/31/09	08/06/09	08/13/09	08/20/09	08/27/09	09/03/09	09/10/09
Actinovate/Parasol	6	0	0	0	0	0	0	0	0	0	3	7	9
Actinovate/Parasol	7	0	0	0	0	0	0	0	0	0	0	3	3
Actinovate/Parasol	8	0	0	0	0	0	0	0	0	0	4	6	7
Sonata/Sonata	1	0	0	0	0	0	0	0	0	2	3	3	3
Sonata/Sonata	2	0	0	0	0	0	0	0	0	1	4	5	5
Sonata/Sonata	3	0	0	0	0	0	0	0	0	0	5	4	4
Sonata/Sonata	4	0	0	0	0	0	0	0	0	0	8	2	3
Sonata/Sonata	5	0	0	0	0	0	0	0	0	0	2	3	3
Sonata/Sonata	6	0	0	0	0	0	0	0	0	0	0	3	3
Sonata/Sonata	7	0	0	0	0	0	0	0	0	4	8	5	6
Sonata/Sonata	8	0	0	0	0	0	0	0	0	0	5	5	6
Sonata/Parasol	1	0	0	0	0	0	0	0	0	0	0	3	3
Sonata/Parasol	2	0	0	0	0	0	0	0	3	0	0	3	3
Sonata/Parasol	3	0	0	0	0	0	0	0	0	3	4	2	2
Sonata/Parasol	4	0	0	0	0	0	0	0	0	0	0	3	3
Sonata/Parasol	5	0	0	0	0	0	0	0	0	0	3	6	7
Sonata/Parasol	6	0	0	0	0	0	0	0	0	0	2	6	6
Sonata/Parasol	7	0	0	0	0	0	2	2	2	2	2	5	6
Sonata/Parasol	8	0	0	0	0	0	0	0	2	0	4	5	6
Untreated control	1	0	0	0	0	0	0	0	2	2	5	5	6
Untreated control	2	0	0	0	0	0	0	0	0	0	3	2	3
Untreated control	3	0	0	0	0	0	0	0	0	0	0	4	5
Untreated control	4	0	0	0	0	0	0	0	0	0	4	3	5
Untreated control	5	0	0	0	0	0	0	0	0	0	3	3	4
Untreated control	6	0	0	0	0	0	0	0	0	0	3	3	4
Untreated control	7	0	0	0	0	0	0	0	0	0	3	3	3
Untreated control	8	0	0	0	0	0	0	0	3	3	6	5	7

Appendix IV – Raw Tuber Yield and Tuber Late Blight Infection Incidence Data

Treatment	Rep	# of Tubers Undersize (<48mm)	Marketable (>48mm)	Tuber Yield (lbs/plot) Undersize (<48mm)	Marketable (>48mm)	# of marketable size tubers with late blight (/15)
Parasol/Parasol	1	20	15	6.75	2.00	0
Parasol/Parasol	2	17	19	6.95	2.20	0
Parasol/Parasol	3	29	21	10.50	2.40	0
Parasol/Parasol	4	31	54	13.10	3.40	0
Parasol/Parasol	5	25	33	9.00	2.40	0
Parasol/Parasol	6	28	36	9.60	2.15	0
Parasol/Parasol	7	34	51	13.35	4.65	0
Parasol/Parasol	8	30	37	12.30	2.75	0
Actinovate/Sonata	1	25	16	9.95	2.15	5
Actinovate/Sonata	2	22	12	8.95	1.15	3
Actinovate/Sonata	3	36	32	16.40	3.05	8
Actinovate/Sonata	4	35	20	14.95	1.75	5
Actinovate/Sonata	5	34	33	13.20	2.85	0
Actinovate/Sonata	6	39	42	15.75	3.50	1
Actinovate/Sonata	7	41	47	16.00	3.50	0
Actinovate/Sonata	8	37	43	12.05	4.25	3
Actinovate/Actinovate	1	19	20	6.75	2.15	3
Actinovate/Actinovate	2	31	19	11.70	2.15	3
Actinovate/Actinovate	3	33	28	12.15	2.70	2
Actinovate/Actinovate	4	27	19	11.15	2.25	3
Actinovate/Actinovate	5	25	45	7.65	2.90	0
Actinovate/Actinovate	6	36	49	16.10	4.05	0
Actinovate/Actinovate	7	31	43	10.90	4.50	1
Actinovate/Actinovate	8	24	52	7.15	3.60	0
Actinovate/Parasol	1	22	27	9.10	3.25	2
Actinovate/Parasol	2	33	25	11.50	2.05	0
Actinovate/Parasol	3	38	16	16.00	2.00	0
Actinovate/Parasol	4	28	50	13.05	3.45	0
Actinovate/Parasol	5	38	45	16.35	3.55	0

		# of Tubers		Tuber Yield (lbs/plot)		
Treatment	Rep	Undersize (<48mm)	Marketable (>48mm)	Undersize (<48mm)	Marketable (>48mm)	# of marketable size tubers with late blight (/15)
Actinovate/Parasol	6	21	33	6.90	2.45	0
Actinovate/Parasol	7	31	31	12.35	1.55	0
Actinovate/Parasol	8	36	46	13.35	3.55	0
Sonata/Sonata	1	21	17	7.55	2.35	4
Sonata/Sonata	2	23	22	8.65	3.00	3
Sonata/Sonata	3	32	24	12.30	1.80	4
Sonata/Sonata	4	21	29	8.65	1.55	0
Sonata/Sonata	5	35	34	13.00	2.15	0
Sonata/Sonata	6	29	48	13.00	3.90	2
Sonata/Sonata	7	19	18	6.95	1.45	1
Sonata/Sonata	8	38	42	14.90	2.75	3
Sonata/Parasol	1	32	25	13.25	2.30	0
Sonata/Parasol	2	31	28	11.75	2.90	0
Sonata/Parasol	3	28	18	8.90	1.50	0
Sonata/Parasol	4	32	19	12.85	2.05	0
Sonata/Parasol	5	19	35	6.15	3.10	0
Sonata/Parasol	6	31	33	11.80	2.60	1
Sonata/Parasol	7	45	45	13.90	4.40	0
Sonata/Parasol	8	43	41	18.40	3.40	0
Untreated control	1	23	24	8.55	2.50	2
Untreated control	2	27	21	9.65	2.00	3
Untreated control	3	21	18	7.45	1.45	2
Untreated control	4	35	24	14.90	2.00	0
Untreated control	5	42	26	17.60	3.25	4
Untreated control	6	31	47	11.85	3.75	0
Untreated control	7	23	32	7.25	2.40	0
Untreated control	8	43	33	16.90	1.90	3