Research on the Development, Biology, and Control of Potato Tuber Moth in the Columbia Basin conducted at OSU's Hermiston Agricultural Research and Extension Center

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Introduction: The potato tuber moth (PTM) *Phthorimaea operculella* (Zeller) (Lepidoptera: Gelechiidae) is one of the most important constraints to potato productivity worldwide. It is a cosmopolitan, oligophagous pest of solanaceous crops commonly found in tropical and subtropical regions. In the U.S., PTM has been found in California, Arizona, New Mexico, Utah, and as far north as Maryland and Virginia. It was first detected in Umatilla County (Hermiston), Oregon, in 2002, with a handful of reports of minor damage. This is apparently the northern most distribution of a reproducing population of PTM in the world (highest latitude north or south).

In 2003, several fields were lost due to PTM resulting in an economic loss of about $2 million USD. Economic losses have increased substantially in 2004 and 2005, due to increased PTM densities in areas already infested, range expansion, tuber damage, and the cost of control measures. In two years, its range has expanded 140 miles north of Hermiston, OR, to the area of Wilbur, WA. A very recent report confirms PTM in Western, Central and Eastern OR, including Klamath Falls, Union County; northeast WA and in at least two counties in Western Idaho. In all sites, distribution and population information is incomplete at this time.

In response to the seriousness of this emerging potato pest in the Northwest, a comprehensive research program aimed at answering basic questions concerning the biology and control of PTM was launched at Oregon State University's Hermiston Agricultural Research and Extension Center (HAREC). This report describes some of the objectives and results of that research effort for the 2005 season.

Objectives:

1. Determine optimal and extreme temperatures for development of PTM eggs, larvae, and pupae.
2. Investigate overwintering biology, including where the moth survives, life stages of survival, and ability to survive in storage.
3. Determine the relationship between percentage green vine cover and tuber damage in early and late potato crops.
4. Examine effective PTM monitoring techniques.
5. Conduct cultural and chemical management trials.Communicate with industry extensively about this new pest.

ACCOMPLISHMENTS:

- A study designed to determine the optimal and extreme temperatures for PTM development, and its ability to survive and develop at temperatures associated with cold storage is nearing completion. Freshly laid eggs are raised in the chambers, each of which is held at a different temperature. Temperatures examined range from 50-93° F. This experiment will produce information on the effect of temperature on the length of time for each stage (egg, larval, pupal, and adult) and on fertility and fecundity of females. Laboratory work is expected to be complete in late spring 2006. Preliminary results are presented.
- A preliminary study of overwintering biology of PTM was conducted in late winter and early spring of 2005. Dozens of emergence traps were built and placed in various fields at HAREC, including fields that were planted with wheat, grass, or potatoes in the previous growing season. Traps were checked daily for adults. Additional studies of overwintering biology are currently in progress, including pheromone trapping, as well as sampling soil, potatoes, and debris in the field.
- A study to determine the relationship between percentage green canopy cover, foliar damage, and tuber damage was conducted at HAREC in the 2005 growing season. A total of 21 untreated plots of Ranger Russets were sampled from July 1, to November 23, 2005.
- A study designed to determine the relationship between number of PTM caught in pheromone traps, foliar damage, and tuber damage was conducted at HAREC. Tuber and foliar damage were estimated in areas where pheromone traps were set, to see if counts obtained from pheromone traps were good indicators of foliar and tuber damage. In addition, several issues related to scouting were also examined, including determining where most foliar damage occurs in the canopy, how long it takes to visually sample whole plants in the field for foliar PTM damage, how accurate those whole plant samples are, and how many plants must be sampled to give a reliable estimate of foliar damage in a given area.
- A total of 47 pesticides or combinations of pesticides were tested in screening trials, including 35 ground application treatments and 12 chemigation treatments.
- A study examining the timing of pesticide application was conducted. This study was designed to address the question of how early a pesticide program must be implemented to control PTM tuber damage. Three pesticides (Asana, Monitor 4, and Lannate LV) were applied beginning at different intervals before vine kill.
- A study examining the effect of desiccant type, with and without a pesticide program, was conducted. Five desiccants, which ranged from acting within hours to weeks, were examined, with and without application of Monitor 4. Two alternative hypotheses have been proposed to explain how desiccants may affect PTM tuber damage. The first suggests that fast acting desiccants may result in direct PTM mortality in the foliage, and thus result in decreased tuber damage, while slow acting desiccants may not kill larvae, and instead provide larvae with time to leave the foliage and enter the tubers, which should result in increased tuber damage. The second, alternative hypothesis suggests the opposite: that slow-acting desiccants decrease tuber damage because some green foliage is left in the field. Since larvae are believed to prefer green foliage over tubers, the presence of some green foliage in the field may actually delay tuber infestation by PTM. All desiccants were examined with and without a pesticide program consisting of Monitor 4 applications (begun 21 days before all chemically defoliated vines were expected to be killed) to see if any potential negative effects of a particular desiccant type could be reduced with a PTM pesticide program. Thus, this design allowed for an investigation of a full range of options that a grower may be interested in implementing.
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- A study was conducted to examine whether green foliage and increased soil moisture decrease PTM tuber damage in early and late season potatoes. The three factors examined were variety type, irrigation practices after vine kill, and senescence type. The two varieties used were an early season variety (Russet Norkotah) and a late season variety (Russet Burbank). Potatoes were either irrigated with 0.10 inches water every day from vine kill until harvest or not irrigated after vine-kill. Half the plots were allowed to naturally senesce and half were chemically defoliated.
- Information on PTM and results of the season's research were disseminated through 19 extension presentations, one scientific presentation, two trade journal articles, and numerous interactions with growers and other members of the potato industry.

RESULTS:

Effect of Temperature on PTM Development

The laboratory experiment examining the effect of temperature on development, mortality, and fecundity in PTM is nearing completion. Freshly laid eggs (< 4 hours old) are raised in environmental chambers, each of which is held at a different temperature (50°F, 61°F, 72°F, 82°F, and 93°F). Twenty eggs are raised in a cage, and there are 10 cages (or replicates) per chamber. The length of time for each stage (egg, larval, pupal, and adult) is recorded, as well as the fertility and fecundity of females raised at each temperature. Data collected and analyzed so far show that the lower developmental threshold is below 50°F; eggs developed into larvae at that temperature in less than six weeks (Table 1). At the warmest temperature tested (93°F), eggs matured into adults in just 16 days. However, cumulative mortality at this temperature to the adult stage is 60%. See Table 1 for detailed preliminary results and estimates and comparisons of egg to adult emergence duration for PTM from HAREC to a population at similar latitude in Australia. Notably, the Oregon population has a developmental threshold below 50° F, while the Australian one does not. Otherwise, the populations appear to be very similar. The exact lower and upper developmental thresholds for the HAREC population will be estimated once the experiment is completed. This work also has important implications for storage. Based on data collected so far, and estimates derived from that data, in storages kept near 50°F, eggs will take approximately seven months to become adults, new larvae will take approximately five months to become adults, and individuals that have just begun pupation will not emerge as adults for over two months.

Overwintering Biology

Observations in 2004/2005 showed that larvae, pupae, and adults could all be found in winter; however, it is not clear which stage is most likely to survive very cold weather and in what type of habitat (e.g., field debris, tubers left in the field, soil). Preliminary studies at HAREC with emergence cages in winter and spring of 2005 indicated that most PTM adult emergence occurred in fields that had been planted in potatoes the year before. However, numbers collected in emergence cages were extremely low, and no statistical analyses were possible. Further research to examine both the location and stage of overwintering is occurring this winter.

Percentage Green Foliar Cover and Tuber Damage Potential
A total of 1,400 potatoes in 21 untreated plots of Ranger Russets were sampled from July 1, to November 23, 2005. Percent green foliar cover on July 1 was 100% and vines on the plots stayed green well into the season, with the first record of a percentage green foliar cover of less than 85% recorded on September 29. Foliar damage associated with PTM was observed as early as July 1, but tubers showed no damage until October 13, when percentage green foliage was reduced to 10%. These data suggest that risk of PTM tuber damage is minimal until green canopy cover is greatly reduced.

Effective PTM Monitoring Techniques
Several issues related to scouting were examined. The first of these issues was determining the position of foliar damage in the canopy. This has important implications not only for scouting (e.g., determining where to focus effort when examining a plant), but also for chemical control. For example, if most mines are located in the upper third of the foliage, aerial pesticide applications may be most effective. However, if damage is spread throughout the foliage, chemigation may be most effective. A total of 1,116 potato plants were examined, and 2,683 foliar mines were found on these plants. Of these, 56% of the mines was found in the upper third of the canopy, 29% was found in the middle third, and 15% was found in the lower third (Figure 1).

Other issues important to scouting include knowing the length of time it takes to visually sample whole plants in the field for PTM foliar damage, the accuracy of those counts, and the number of plants that must be sampled to give a reliable estimate of foliar damage in a given area. A total of 300 Russet Ranger plants were examined in the field for foliar damage, the time needed to examine each plant was recorded, and then the entire plant was brought into the laboratory to be more thoroughly examined. On average, whole plant foliar sampling in the field takes approximately 2 minutes per plant and finds less than 50% of the mines that are found in a thorough examination in the laboratory. The study also showed that reasonably precise estimates of foliar damage for areas of 23 ft x 30 ft can be made by sampling 9 plants (Figure 2).

The relationship between number of PTM males caught in pheromone traps, foliar damage, and tuber damage was also assessed in Russet Ranger fields at HAREC. Tuber and foliar damage were estimated in areas where pheromone traps were set, to see if counts obtained from pheromone traps were good indicators of foliar and tuber damage. Pheromone trap numbers were not positively correlated with foliar or tuber damage at HAREC (Figure 3). As the season progressed, male counts in pheromone traps decreased as foliar, and eventually tuber damage, increased. This suggests that while pheromone trapping and foliar sampling are extremely important in alerting growers to the potential for tuber damage by PTM, they may not be good predictors of actual tuber damage, even in untreated areas.

Pesticide Screening Trials
Over 47 pesticides or combinations of pesticides were tested in screening trials at HAREC. Of these 35 were ground application treatments. Ground applications treatments were grouped into three general trials. Treatments that were applied at five and seven day intervals formed one trial, and treatments that were applied at 10 day intervals were grouped into two separate trials. Ground treatments that were applied at seven day intervals began 28 days before anticipated desiccation, and ground treatments applied at five and 10 day intervals began 30 days before anticipated desiccation.

See Table 2 for general information about ground treatment trials, including dates of planting, pesticide applications, foliar sampling, desiccation, harvesting, and tuber processing. Chemigation treatments were combined in one trial and included those applied at five, seven, and 10 day intervals, as well as two treatments that were applied at desiccation and one week later (the "kill-down" treatments). See Table 3 for general information about the chemigation trial, including dates of planting, pesticide applications, foliar sampling, desiccation, harvesting, and tuber processing. Plot size for both trials was 30 feet long and eight rows wide.

Ground treatments were applied in 20 gpa with a tractor-mounted boom sprayer with XR 80015 nozzles spaced at 20" at 30 psi at a ground speed of 2.5 mph. Chemigation treatments were applied in 4073 gpa with a research chemigator (orifice size #20) at 25 psi and a ground speed of 0.16 mph. Tables 4, 5, 6, and 7 list the insecticides tested and the rates used. All treatments had 4 replicates. Foliar damage was measured as the number of PTM mines per four randomly selected plants in the center portion of the inner 4 rows in each plot. One hundred tubers in the center portion of the inner two rows were sampled 14 days after desiccation and stored at ambient temperature for 10 days after harvest to increase the likelihood of detecting PTM damage. Tubers were processed with a French fry cutter and damage was measured as the percent PTM damage in 100 potatoes.

Results for Five and Seven Day Ground Treatments:
Almost all treatments (Lannate LV, Asana, Avaunt, Asana+Avaunt, Baythroid, Leverage, Monitor, and an alternating program of Sevin, Monitor, Guthion, and Baythroid) reduced foliar damage significantly as compared to the control (which had an average of 9 mines per plant) (Table 4; Figure 4). Sevin was the only pesticide that did not reduce foliar damage.

In contrast, none of the treatments significantly reduced tuber damage as compared to the control (which had an average of 3% PTM tuber damage). See Table 4 and Figure 4 for more detail. This lack of significance was probably due to high variability in the controls and relatively low PTM tuber damage overall (Figure 10). However, trends for tuber damage for each treatment were significantly correlated ($r=0.76$, $p<0.01$) with those for foliar damage; i.e., treatments that resulted in less foliar damage were more likely to result in less tuber damage as well (Figure 5).

Results for Ten Day Ground Treatments:
All treatment combinations applied in the 10 day treatment for the Group A trial had significantly less foliar damage than the control (which had an average of 5 mines per plant). See Table 5 and Figure 6 for more detail. Of these, the most effective programs with regard to decreasing foliar damage were: Monitor and Leverage; Entrust and Bt; and Asana and Lannate LV.

However, treatment did not significantly affect tuber damage caused by PTM (Table 5; Figure 6). As with the five and seven day trial, high variability in the amount of PTM damage in controls (which had an average of 5% tuber damage) and relatively low overall tuber damage (Figure 10) probably led to the lack of significant results for tuber damage. In this case, however, trends observed for tuber damage for each treatment were not significantly correlated ($r=0.29$, $p>0.05$) with those seen for foliar damage; i.e., treatments that resulted in less foliar damage were not necessarily more likely to show less tuber damage as well (Figure 7).

In the Group B trial, several products were effective at reducing foliar PTM damage significantly as compared to the control (which had an average of 7 mines per plant), including Leverage, Penncap, Provado with TM-472, and Clutch in combination with TM-472, and with TM-472 and TM-465 (Table 6, Figure 8). Foliar damage in treatments with Assail and with Clutch alone did not differ significantly from the control. However, it should be noted that the first application of Assail on 8-18-05 was at a reduced rate (1.7 oz acre instead of 4.0 oz acre).

In contrast, none of the treatments significantly reduced tuber damage as compared to the control at $\alpha = 0.05$. However, at $\alpha = 0.10$, treatments were significantly different, with the same products that provided foliar control also providing tuber control (Table 6 and Figure 8). As a result, average foliar and tuber damage for each treatment were significantly correlated ($r = 0.76$, $p < 0.01$; Figure 9). This ground treatment probably showed the most significant results because of the fairly high overall tuber infestation rate, which may have been a consequence of its proximity to a commercial potato field (Figure 10).

Chemigation Trial:
Rimon, Asana, Lannate LV, Avaunt, and Asana+Avaunt had significantly less foliar damage than the control (which had an average of 10 mines per plant). See Table 7 and Figure 11 for more detail. Note that two Avaunt treatments did not differ significantly in foliar damage from the control, but that these two treatments are "kill-down" applications (i.e., applications are applied on the same day as desiccation and one week after) and therefore no reduction in foliar damage was expected. Foliar damage in the Assail treatment did not differ significantly from the control. However, it should be noted that the first application of Assail on 8-17-05 was at a reduced rate (1.7 oz acre instead of 4.0 oz acre).

There was also a significant effect of chemigation treatment on PTM tuber damage (Table 7; Figure 11). Applications of Asana+Avaunt and of the higher rates of Rimon, Lannate, and Avaunt showed significantly less tuber damage than the control (which had an average of 5% PTM tuber damage). Treatment at kill-down and one-week later with the higher level of Avaunt was also effective at reducing tuber damage. Tuber damage of treatments involving Assail and the lower rates of Rimon, Lannate LV, and Avaunt did not differ significantly from the control. Trends observed for tuber damage for each treatment were not significantly correlated ($r=0.29$, $p>0.05$) with those seen for foliar damage if all data points are examined (Figure 12); however, if the two "kill-down" treatments are eliminated, the correlation between foliar and tuber damage is significant (i.e., treatments that resulted in less foliar damage were more likely to show less tuber damage as well). The fact that the chemigation trial had more significant results compared to the ground trials should not be interpreted to mean that chemigation is a more effective method than ground application; the chemigation trial was located at a different area at HAREC (Figure 13). To examine the relative effectiveness of chemigation versus ground treatments in the future, both treatments will be needed to be incorporated into the same trial.

Pesticide Timing Trial
This study was designed to address the question of how early a PTM program must be implemented to control tuber damage. Three insecticides (Asana, Monitor 4, and Lannate LV) were applied beginning at different intervals before vine kill (see Table 8 for general information including a list of treatments, rates, and dates of applications). Plot size was 30 feet long and eight rows wide. Insecticides were applied in 18 gpa with a tractor-mounted boom sprayer with XR 80015 nozzles spaced at 20" at 30 psi at a ground speed of 2.5 mph.

All treatments had 4 replicates. One hundred tubers in the center portion of the inner two rows were sampled 14 days after desiccation and stored at ambient temperature for 10 days after harvest to increase the likelihood of detecting PTM damage. Tubers were processed with a French fry cutter and damage was measured as the percent PTM damage in 100 potatoes.

All insecticide treatments significantly reduced tuber damage as compared to the control (F=3.9, p=0.004) (Figure 14). However, the data from this trial indicate that there is no apparent advantage in beginning control efforts earlier in the season versus later; there was no trend for PTM tuber damage to increase as the beginning of treatment was delayed (see red lines on Figure 14 to see effect expected if there was an advantage to controlling all season). These data are consistent with other data collected this season; specifically, in the chemigation screening trail, one of the five treatments found effective at controlling PTM tuber damage was a treatment applied only at desiccation and one week later. A top priority in next season's PTM chemical control trials should be continued and expanded trials examining this question.

Desiccant Trial

Five desiccants, which ranged from acting within hours to weeks, were examined, with and without application of Monitor 4 beginning 21 days before vine kill. See Table 9 for general information on the trial, including rates, estimated times for vine kill, and application dates. Plot size was 30 feet long and eight rows wide. Monitor 4 was applied in 18 gpa with a tractor-mounted boom sprayer with XR 80015 nozzles spaced at 20" at 30 psi at a ground speed of 2.5 mph. The desiccants were applied similarly, except that Enquik was applied in 40 gpa and all the other desiccants were applied in 20 gpa. One hundred tubers in the center portion of the inner two rows were sampled 14 days after the last desiccant application. Potatoes were stored at ambient temperature for 10 days after harvest to increase the likelihood of detecting PTM damage. Tubers were processed with a French fry cutter and damage was measured as the percent PTM damage in 100 potatoes.

There was a significant effect of Monitor 4 application (F =11.9, p=0.001), desiccant type (F=2.9, p=0.03) and an interaction between the two main effects (F=5.0, p=0.001) (Figure 15). In almost every case, Monitor 4 decreased PTM damage, as expected. The only exception occurs with the Rely treatment, when an application of Rely and Monitor resulted in increased PTM tuber damage compared to Rely alone. This result is believed to be an anomaly. Regardless, the significant effect of desiccant indicates that the choice of desiccant can affect PTM tuber damage (Figure 15). However, the resulting pattern is ambiguous with regard to the two hypotheses being tested and further research is needed to clarify how different types of desiccants affect PTM tuber damage.

Irrigation/Senescence Trial

This study was designed to determine whether green foliage and increased soil moisture decrease PTM tuber damage in early and late season potatoes. The three factors examined were variety type, irrigation practices after vine kill, and senescence type. The two varieties used were an early season variety (Russet Norkotah) and a late season variety (Russet Burbank). Potatoes in the irrigated treatment were watered with 0.10 inches by a center pivot every day at 3 PM from vine kill until harvest. Potatoes in the non-irrigated treatment were not irrigated after vine-kill. Half the plots were allowed to naturally senesce and half were chemically defoliated with Enquik. See Table 10 for general information on the trial.

As in all other trials, plots were 8 rows wide and 30 feet long, but each plot was separated from the neighboring plot by 20 feet at the ends and 6 rows on the sides to ensure irrigation was properly applied at the plot level. One hundred tubers in the center portion of the inner two rows were sampled 14 days after Enquik was applied. Potatoes were stored at ambient temperature for 10 days after harvest to increase the likelihood of detecting PTM damage. Tubers were processed with a French fry cutter and damage was measured as the percent PTM damage in 100 potatoes.

Effect of irrigation after vine kill on PTM tuber damage did not differ significantly between Russet Burbank and Norkotah potatoes ($F=0.007$, $p=0.94$) or between chemically defoliated or naturally senesced potatoes ($F=1.5$, $p=0.23$). Although irrigation did not significantly affect percent tuber damage at $\alpha = 0.05$, there was a significant difference at $\alpha = 0.10$ ($F=3.7$, $p=.07$). Potatoes irrigated after desiccation had significantly less PTM tuber damage than those not irrigated after desiccation (Figure 16). There was no significant difference in the percentage of rotten potatoes in irrigated and unirrigated plots, indicating that this level of irrigation does not increase fungal or bacterial infections. These results are promising, and the study should be repeated in the next season.

Communication/Extension

Information on PTM and results of the season's research were disseminated through 19 extension presentations, one scientific presentation, two trade journal articles, and numerous interactions with growers and other members of the potato industry. The details are listed below.

PUBLICATIONS:

Trade Journal Articles

Jensen, A., Hamm, P., Schreiber, A., and S. DeBano. 2005. Prepare for the Tuber Moth in 2005. Potato Country, March. pp. 8 and 22.

Jensen, A. DeBano, S., David, N. Martin, M., and D. Batchelor. 2005. Tuber Moth Survey, April 2005. Potato Progress 5(6): 1-2.

PRESENTATIONS AND REPORTS:

Scientific Presentations

2005 Invasion of the Oregon and Washington Columbia Basin by Potato Tuber Moth. Jensen, A., Hamm, P.B., DeBano, S.J., Landolt, P., and A. Schreiber. Potato Association of America, Scottsbluff Nebraska, August 8.

Extension Presentations

2006 "The Identification and Control of Tuber Moths", Hamm, P., David, N., Jensen, A., DeBano, S. Clough, G., Schreiber, A., and Rondon, S. 2005 Intermountain Pest Management Seminar. Klamath Falls, Oregon, January 20. Audience: 110 participants .

2005 "Potato Tuber Moth Biology in the Columbia Basin". DeBano, S.J., Hamm, P., David, N., Jensen, A. and Wooster, D. Hermiston Farm Fair. Hermiston, Oregon, December 2. Audience: ~150 growers, fieldmen, chemical company representatives, and the general public.

2005 "Impact of Desiccants, Insecticide Timing, and Irrigation on Tuberworm Infection". Clough, G. and DeBano, S.J. Hermiston Farm Fair. Hermiston, Oregon, December 2. Audience: ~150 growers, fieldmen, chemical company representatives, and the general public.

2005 "Potato Tuberworm Management in the Columbia Basin". Schreiber, A., DeBano, S.J., Clough, G., Jensen, A., Hamm, P., and Rondon, S. Hermiston Farm Fair. Hermiston, Oregon, December 2. Audience: ~150 growers, fieldmen, chemical company representatives, and the general public.

2005 "Mechanical Control of Potato Tuber Moth. Hermiston Farm Fair. Hamm, P. David, N., and Jensen, A. Hermiston, Oregon, December 2. Audience: ~150 growers, fieldmen, chemical company representatives, and the general public.

2005 "Host Resistance: Prospects of Incorporating Resistance to Tuber Month in Future Varieties ". Brown, C., Hane, D., DeBano, S.J. and David, N. Hermiston Farm Fair. Hermiston, Oregon, December 2. Audience: ~150 growers, fieldmen, chemical company representatives, and the general public.

2005 "Potato Tuber Moth in the Columbia Basin", DeBano, S.J., Clough, G., David, N., Hamm, P., Schreiber, A., and Jensen, A. Far West Agribusiness Association, Washington Consultants Committee Annual Conference, Yakima, Washington, November 9. Audience, ~75 fieldmen, growers, research scientists, and chemical company and processor representatives.

2005 "Results of Potato Tuber Moth Trials Conducted in Washington". DuPont Working Group. DeBano, S.J., Clough, G., Schreiber, A., and Dobie, C. Pasco, Washington, November 8. Audience: ~30 fieldmen, research scientists, and chemical company and processor representatives.

2005 "Tuber Moth and Beet Leafhopper Populations This Past Summer and How They Compared to Last Year", Hamm, P., David, N., Jensen, A., and DeBano, S. Syngenta Crop Production Seminar, Richland Washington, October 26. Audience: 30 participants.

2005 "The Biology and Recognition of Tuber Moth Damage", Hamm, P., David, N., Jensen, A. and DeBano, S. Idaho Department of Agriculture, Boise, Idaho, August 25. Audience: 20 participants

2005 "Potato Tuber Moth in the Columbia Basin", DeBano, S.J. Hamm, P., Jensen, A., Schreiber, A., Clough, G. and David, N. Lower Columbia Basin Fieldmen and Dealers Association, Pasco, Washington, July 28. Audience: ~15 fieldmen and dealers.

2005 "Potato Tuber Moth: Biology and Potential Control Methods", DeBano, S.J., Schreiber, A., Jensen, A., Clough, G., David, N., and Hamm, P. Washington State University Potato Field Day, Othello, Washington, June 24. Audience: ~ 40 growers, fieldmen, and chemical company representatives.

2005 "Potato Tuber Moth: Biology and Potential Control Methods". Hamm, P., David, D., DeBano, S. J., Jensen, A., and Schreiber, A. Washington State University Potato Field Day, Othello Washington, June 24. Audience: ~ 40 growers, fieldmen, and chemical company representatives.

2005 "Potato Tuber Moth in the Columbia Basin", DeBano, S.J. Regional Growers Meeting, Pasco, Washington, June 2. Audience: ~75 growers, fieldmen, and chemical company representatives.

2005 "Potato Tuber Moth in the Columbia Basin", DeBano, S.J. Regional Growers Meeting, Hermiston, Oregon, June 1. Audience: ~50 growers, fieldmen, and chemical company representatives.

2005"Tuber Moth: Biology and Control", Hamm, P. Phone Conference. May 24. Audience: 100 participants from the Pacific Northwest.

2005 "Tuber Moth: Biology and Control", Hamm, P. Phone Conference. May 26. Audience: 75 participants from the Pacific Northwest.

2005 “The Management of Tuber Moths, Lesion Nematodes, and Pythium Leak in Potatoes”, Hamm, P., David, N., and Jensen, A. AgriNorthwest Winter Meetings, Pasco Washington, February 9, Audience: 30 participants.

2005 “The Biology and Management of Potato Tuber Moths”, Hamm, P., David, N., and Jensen, A. Lamb-Weston Farm Meeting, Baker Oregon, February 8. Audience: 40 participants.

Table 1. Preliminary data from a study examining the effect of temperature on mean development and mortality of PTM. Each replicate is one cage that began with 20 PTM eggs. Mortalities listed are cumulative mortalities.

Temperature	Mean Egg Duration (Mortality)	Mean Larval Duration (Mortality)	Mean Pupal Duration (Mortality)	Time from Egg to Adult Emergence for HAREC Population	Time from Egg to Adult Emergence for Australian Population**
50°F	41.3 days (Mort=62%) (n=7)	90.9 days*	74.3 days*	206.5 days*	BELOW LOWER DEVELOPMENTAL THRESHOLD***
61°F	15.0 days (Mort=28%) (n=10)	33.7 days (Mort=80%) (n=5)	27 days*	75.7 days*	77.3 days
72°F	7.2 days (Mort=20%) (n=10)	15.5 days (Mort=42%) (n=10)	12.5 days (Mort=49%) (n=10)	35.2 days	36.4 days
82°F	4.2 days (Mort=17%) (n=10)	9.0 days (Mort=39%) (n=6)	7.9 days (Mort=43%) (n=6)	21.1 days	20.7 days
93°F	3.2 days (Mort=32%) (n=12)	6.9 days (Mort=52%) (n=10)	5.9 days (Mort=60%) (n=10)	16 days	16 days

*Estimates assume a 1: 2.2: 1.8 egg: larval: pupal duration

**From Briese, 1980 – for a laboratory population that originated in Canberra, Australia (latitude = 35’17”S)

Table 2. General information on five, seven, and 10 day treatments in three ground application trials conducted at HAREC in 2005. The experimental design was a randomized complete block with four replicates. Treatments applied at five and seven day intervals were grouped into one trial, and treatments applied at 10 day intervals were grouped into two separate trials – Group A and Group B.

GROUND TREATMENTS
Variety: Ranger Russets
Plant Date: 4-15-2005
Foliar Sampling Date: 9-13-2005 (Sampled 4 plants per plot)
Kill-Down Date: 9-16-2005
Desiccant Used: Enquik
Harvest Date: 9-27-2005
Processing Dates: 10-9-2005 to 10-11-2005 (Sampled 100 tubers per plot from middle of center 2 rows)
Application Dates:

5 Day Treatments	7 Day Treatments	10 Day Group A Treatments	10 Day Group B Treatments
Aug. 18, 2005	Aug. 17, 2005	Aug. 18, 2005	Aug. 18, 2005
Aug. 22, 2005	Aug. 25, 2005	Aug. 25, 2005	Aug. 27, 2005
Aug. 25, 2005	Sept. 1, 2005	Sept. 5, 2005	Sept. 6, 2005
Aug. 31, 2005	Sept. 8, 2005	Sept. 14, 2005	Sept. 16, 2005
Sept. 5, 2005	Sept. 14, 2005		
Sept. 10, 2005			
Sept. 14, 2005			

Table 3. General information concerning a chemigation trial conducted at HAREC in 2005. The experimental design was a randomized complete block with four replicates. Chemigation treatments included those applied at five, seven, and 10 day intervals, as well as two that were applied at kill-down and one week later.

CHEMIGATION TREATMENTS
Variety: Ranger Russets
Plant Date: 4-15-2005
Foliar Sampling Date: 9-12-2005 (Sampled 4 plants per plot)
Kill-Down Date: 9-16-2005
Desiccant: Enquik
Harvest Date: 9-27-2005
Processing Dates: 10-14 to 10-17-2005 (Sampled 100 tubers per plot from middle of center 2 rows)
Application Dates:

5 Day Treatments	7 Day Treatments	10 Day Treatments	Kill-Down Treatments
Aug. 17, 2005	Aug. 18, 2005	Aug. 17, 2005	Sept. 15, 2005
Aug. 22, 2005	Aug. 25, 2005	Aug. 26, 2005	Sept. 22, 2005
Aug. 26, 2005	Sept. 1, 2005	Sept. 5, 2005	
Aug. 31, 2005	Sept. 8, 2005	Sept. 15, 2005	
Sept. 5, 2005	Sept. 15, 2005		
Sept. 10, 2005			
Sept. 15, 2005			

Table 4. Results of a ground application trial for products applied at five or seven day intervals. Effects on foliar damage were significant ($F = 5.7$, $p < 0.0001$) and treatments with different letters are significantly different at $p \leq 0.05$. Treatments did not significantly affect percent tuber damage ($F = 1.1$, $p = 0.41$).

Pesticide	Rate	Foliar Damage (mean number of mines per plant)	Mean Percent Tuber Damage
Lannate LV	1 pt/acre	0.3 [a]	1.00
Lannate LV	2 pt/acre	0.2 [a]	0.75
Asana	4 fl oz/acre	1.6 [a]	0.75
Asana	8 fl oz/acre	0.7 [a]	1.25
Avaunt	3 fl oz/acre	0.9 [a]	1.25
Avaunt	5 fl oz/acre	0.4 [a]	0.75
Asana+Avaunt	4 + 3 fl oz/acre	1.1 [a]	0.5
Baythroid	2.8 fl oz/acre	0.6 [a]	0.25
Guthion	96 oz/acre	0.9 [a]	0
Leverage	4 fl oz/acre	0.9 [a]	1.00
Monitor	2 pt/acre	0.4 [a]	0.5
Sevin XLR Plus (1st app) Monitor (2nd app) Guthion (3rd app) Baythroid (4th and 5th app)	64 fl oz/acre 2 pt/acre 96 oz/acre 2.8 fl oz/acre	2.7 [a]	0
Sevin XLR Plus	64 fl oz/acre	7.4 [b]	1.75
Untreated Check		9.1 [b]	3

Table 5. Results of a ground application trial for products in Group A applied at 10 day intervals. Four applications were made. Treatment effects on foliar damage were significant ($F = 4.9$, $p = 0.0001$) and treatments with different letters are significantly different at $p \leq 0.05$. Treatment did not significantly affect percent tuber damage ($F = 0.9$, $p = 0.39$).

Pesticide	Rate	Foliar Damage (mean number of mines per plant)	Mean Percent Tuber Damage
Monitor (1st and 3rd app) Leverage (2nd and 4th app)	2 pt/acre 3.75 fl oz/acre	0.1 [a]	1.7
Imidan (1st and 3rd app) Rimon (2nd and 4th app)	2.5 lb/acre 12 fl oz/acre	1.9 [b,c]	1.2
Success (1st and 3rd app) Rimon (2nd and 4th app)	6 fl oz/acre 12 fl oz/acre	1.0 [a,b]	1.2
Avaunt (1st and 3rd app) Rimon (2nd and 4th app)	6 fl oz/acre 12 fl oz/acre	0.5 [a,b]	2.2
Entrust (1st and 3rd app) Bt (2nd and 4th app)	3 oz/acre 1 lb/acre	0.4 [a]	5.7
Asana (1st and 3rd app) Lannate LV (2nd and 4th app)	9 fl oz/acre 3 pt/acre	0.1 [a]	2.7
Monitor (1st and 3rd app) Lannate LV (2nd and 4th app)	2 pt/acre 3 pt/acre	0.7 [a,b]	2.5
Guthion (1st and 3rd app) Lannate LV (2nd and 4th app)	1.5 lb/acre 3 pt/acre	0.6 [a,b]	1.0
Guthion (1st and 3rd app) Sevin XLR(2nd and 4th app)	1.5 lb/acre 64 fl oz/acre	0.9 [a,b]	4.5
Furadan(1st and 3rd app) Monitor (2nd and 4th app)	2 pt/acre 2 pt/acre	0.7 [a,b]	1.0
Monitor (1st and 3rd app) Guthion (2nd and 4th app)	2 pt/acre 1.5 lb/acre	0.9 [a,b]	0.5
Baythroid (1st and 3rd app) Guthion (2nd and 4th app)	2.8 fl oz/acre 2.5 lb/acre	0.4 [a,b]	3.5
Control		4.7 [d]	5

Table 6. Results of a ground application Group B trial for products applied at 10 day intervals. Four applications were made. Treatment effects on foliar damage were significant ($F = 12.8$, $p < 0.0001$) and treatments with different letters are significantly different at $p \leq 0.05$. Treatments did not significantly affect percent tuber damage ($F = 1.8$, $p = 0.09$).

Pesticide	Rate	Foliar Damage (mean number of mines per plant)	Mean Percent Tuber Damage
Clutch	1 oz/acre	10.9 [d]	5.25 [c]
Clutch TM-472	1 oz/acre 1.2 oz/acre	1.7 [a]	4 [a,b]
Clutch TM-472 TM-465	1 oz/acre 1.2 fl oz/acre 8 fl oz/acre	1.9 [a]	3.25 [a,b]
Clutch	1.5 oz/acre	8.2 [c]	8.75 [a,b,c]
Clutch TM-472	1.5 oz/acre 1.8 fl oz/acre	0.9 [a]	2.5 [a]
Clutch TM-472 TM-465	1.5 oz/acre 1.8 fl oz/acre 8 fl oz/acre	2.4 [a]	3 [a,b]
Provado TM-472	3.75 fl oz/acre 1.8 fl oz/acre	1.7 [a]	3 [a]
Leverage	3.75 fl oz/acre	1.7 [a]	3.5 [a,b]
Assail*	4.0 oz/acre	5.6 [b,c]	7 [b,c]
Penncap M	4 pt/acre	3.2 [a,b]	3.5 [a,b]
Control		7.4 [c]	8.25 [c]

* The first application of Assail on 8-18-2005 was applied at a lower rate (1.7 oz/acre instead of 4.0 oz/acre).

Table 7. Results of a chemigation trial for products applied at five, seven, and 10 day intervals and for products applied at kill-down and one-week later. Treatment effects on foliar and tuber damage were significant ($F = 4.3$, $p = 0.003$ and $F = 2.1$, $p = 0.04$, respectively) and treatments with different letters are significantly different at $p \leq 0.05$.

Pesticide	Rate	Foliar Damage (mean number of mines per plant)	Mean Percent Tuber Damage
5 Day Treatments			
Lannate LV	1 pt/acre	0.9 [a]	3.75 [a-e]
Lannate LV	2 pt/acre	0.9 [a]	1.25 [a,b]
7 Day Treatments			
Asana	4 fl oz/acre	4.1 [a]	4.0 [b-e]
Asana	8 fl oz/acre	4.3 [a,b]	2.75 [a-e]
Avaunt	3 oz/acre	4.6 [a,b]	2.25 [a-c]
Avaunt	5 oz/acre	3.1 [a]	1.75 [a,b]
Asana + Avaunt	4 fl oz/acre + 3 oz acre	2.6 [a]	0.75 [a]
10 Day Treatments			
Rimon	9 fl oz/acre	2.8 [a]	5.5 [d,e]
Rimon	12 fl oz/acre	3 [a]	1.25 [a,b]
Assail*	4 oz/acre	11.7 [c]	5.5 [e]
Kill Down Treatments**			
Avaunt	3 oz/acre	13.6 [c]	3 [a-e]
Avaunt	5 oz/acre	12.2 [c]	1.5 [a,b]
Control		10.3 [b,c]	5.25 [c-e]

* The first application of Assail on 8-17-2005 was applied at a lower rate (1.7 oz/acre instead of 4.0 oz/acre).
** Applied at desiccation and one week later.

Table 8. General information for the pesticide timing trial. The experimental design was a randomized complete block with 4 replicates. Lannate LV was applied at 5 day intervals, and Monitor 4 and Asana were applied at 7 day intervals.

PESTICIDE TIMING TREATMENTS
Variety: Ranger Russets
Plant Date: 3-31-05
Kill Down Date: 9-21-2005
Desiccant Used: Enquik
Harvest Date: 10-6-05
Processing Dates: 10-17-05 to 10-19-05
(Sampled 100 tubers per plot from middle of center 2 rows)

Treatments	**Rate**	**Date Applied**
Lannate LV – 6 applications	2.25 pt/acre	8-27-05; 9-1-05; 9-6-05; 9-11-05; 9-16-05; 9-21-05
Lannate LV – 5 applications	2.25 pt/acre	9-1-05; 9-6-05; 9-11-05; 9-16-05; 9-21-05
Lannate LV – 4 applications	2.25 pt/acre	9-6-05; 9-11-05; 9-16-05; 9-21-05
Lannate LV – 3 applications	2.25 pt/acre	9-11-05; 9-16-05; 9-21-05
Lannate LV – 2 applications	2.25 pt/acre	9-16-05; 9-21-05
Monitor 4 – 5 applications	1.75 pt/acre	8-24-05; 8-31-05; 9-7-05; 9-14-05; 9-21-05
Monitor 4 – 4 applications	1.75 pt/acre	8-31-05; 9-7-05; 9-14-05; 9-21-05
Monitor 4 – 3 applications	1.75 pt/acre	9-7-05; 9-14-05; 9-21-05
Monitor 4 – 2 applications	1.75 pt/acre	9-14-05; 9-21-05
Asana – 5 applications	7.5 oz/acre	8-24-05; 8-31-05; 9-7-05; 9-14-05; 9-21-05
Asana – 4 applications	7.5 oz/acre	8-31-05; 9-7-05; 9-14-05; 9-21-05
Asana – 3 applications	7.5 oz/acre	9-7-05; 9-14-05; 9-21-05
Asana – 2 applications	7.5 oz/acre	9-14-05; 9-21-05
Control		

Table 9. General information for the desiccant trial. The experimental design was a randomized complete block with 4 replicates. Desiccants were either applied without a pesticide program or with Monitor 4 (1.75 pt/acre at 18 gal/acre) applied 4 times weekly beginning 21 days before vine kill. All desiccants were applied at 20 gal/acre except for Enquik, which was applied at 40 gal/acre.

DESICCANT TREATMENTS
Variety: Ranger Russets
Plant Date: 4-20-2005
Monitor Application Dates: 8-31-05; 9-7-05; 9-14-05; 9-20-05
Harvest Date: 10-7-05
Processing Dates: 10-19 to 10-21-05
(Sampled 100 tubers per plot from middle of center 2 rows)

Treatments	Rate	Time Needed for Vine kill*	Date Applied
Enquik (monocarbamide dihydrogen sulfate)	20 gal/acre	1 day	9-20-05
Reglone (diquat)	2 pt/acre	1-2 days	9-19-05
ET (pyraflufen ethyl)	5.5 oz/acre	7 days	9-14-05
Aim (carfentrazone)	3.6 oz/acre	10-14 days	9-11-05
Rely (glufosinate-ammonium)	3 pt/acre	14 days	9-7-05
Control			

*Estimates provided by manufacturer's representatives.

Table 10. General information for the irrigation/senescence trial. The experimental design was a randomized complete block with 4 replicates. As in all other trials, plots were 8 rows wide and 30 feet long, but each plot was separated from neighboring plots by 20 feet at the ends and 6 rows on the sides to ensure irrigation was properly applied at the plot level.

IRRIGATION/SENESCENCE TREATMENTS
Variety: Russet Norkotah and Russet Burbank
Plant Date: 4-20-2005
Desiccant Used: Enquik
Kill-Down Date: 9-22-05
Irrigation Dates and Times: 9-23-05 to 10-05-05 applied at 3 PM
Harvest Date: 10-6-05
Processing Dates: 10-21-05 to 10-24-05
(Sampled 100 tubers per plot from middle of center 2 rows)

Treatments:

- Natural Senescence without Irrigation
- Natural Senescence with Irrigation
- Chemical Defoliation without Irrigation
- Chemical Defoliation with Irrigation

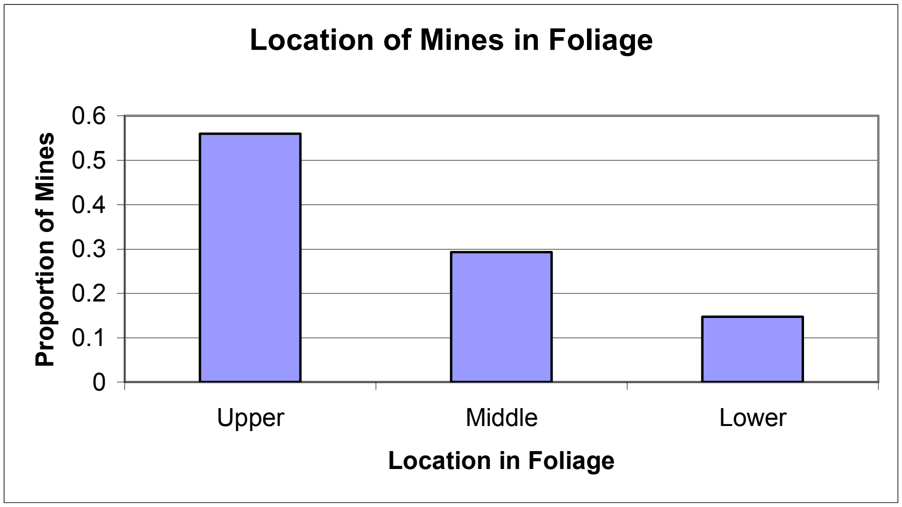

Figure 1. Location of PTM mining damage in foliage of Russet Ranger potatoes.

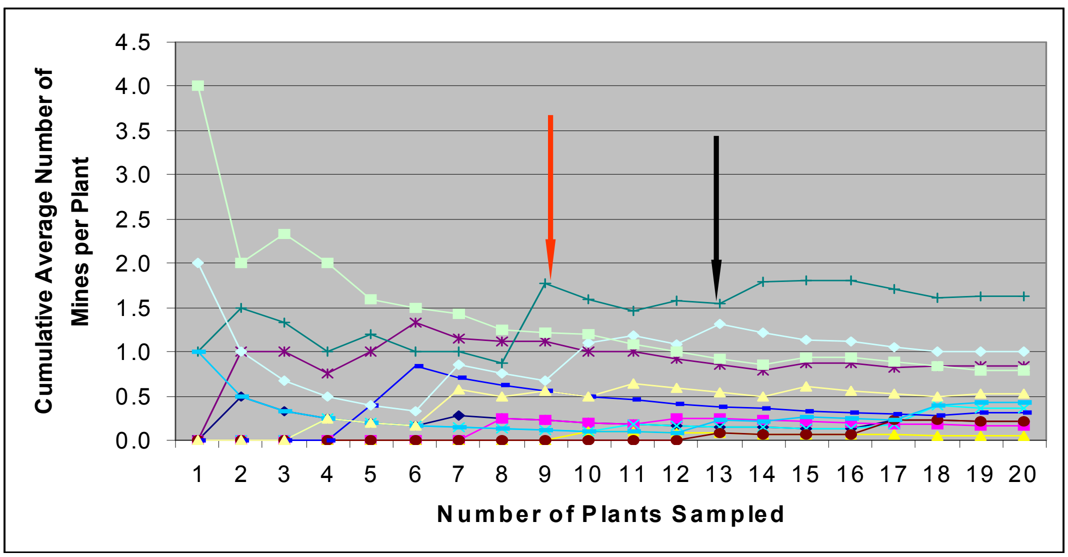

Figure 2. The cumulative average number of mines detected with increased sampling efforts. Each line represents a different plot (12 plots of 15 plots sampled showed some foliar damage). The red arrow indicates the number of plants that must be sampled to have a reasonably precise estimate of foliar damage – when nine plants are sampled all plot averages stay within 0.5 mines per plant with increasing sampling effort. The black arrow indicates the number of plants that must be sampled to detect low levels of PTM foliar damage; all plots found to have any damage displayed it by the time 13 plants were sampled.

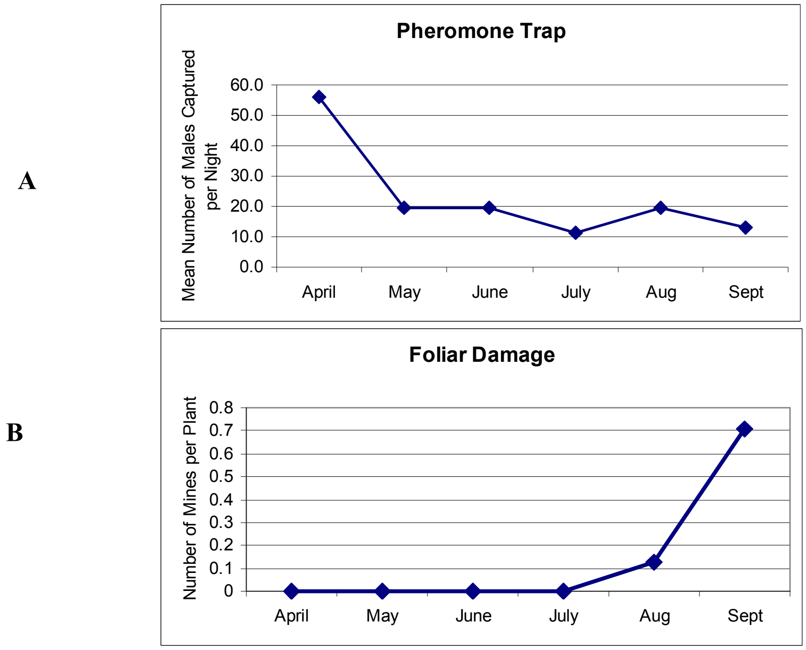

Figure 3. The relationship between pheromone trap captures (A) and foliar damage (B) in an untreated area at HAREC. No tuber damage was observed until September.

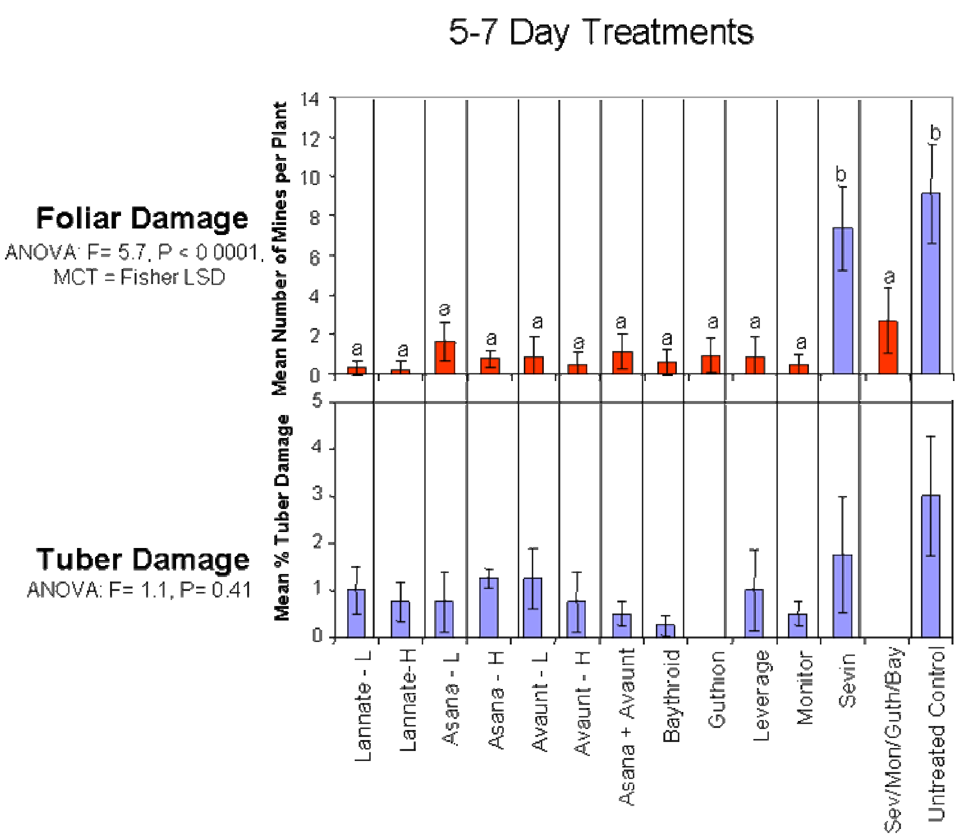

Figure 4. Results of a ground application trial for products applied at five and seven day intervals. Treatment effects on foliar damage were significant ($F = 5.7$; $p < 0.0001$) and treatments with different letters are significantly different at $p \leq 0.05$. Those treatments that differed significantly from the control are shown in red. Treatment did not significantly affect percent tuber damage ($F = 1.1$, $p = 0.41$).

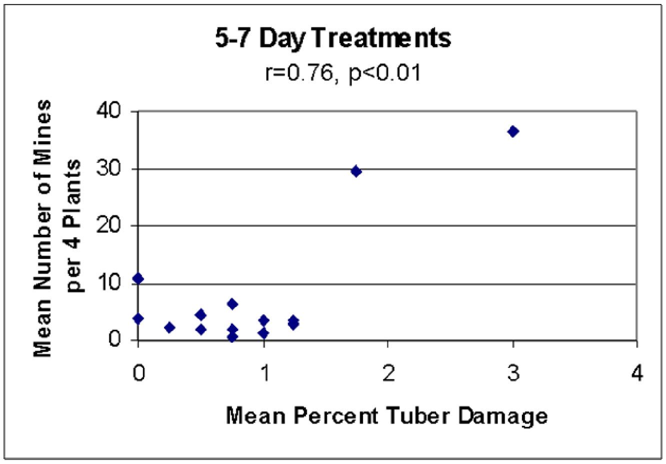

Figure 5. Correlation between amount of tuber damage and foliar damage in five and seven day treatments.

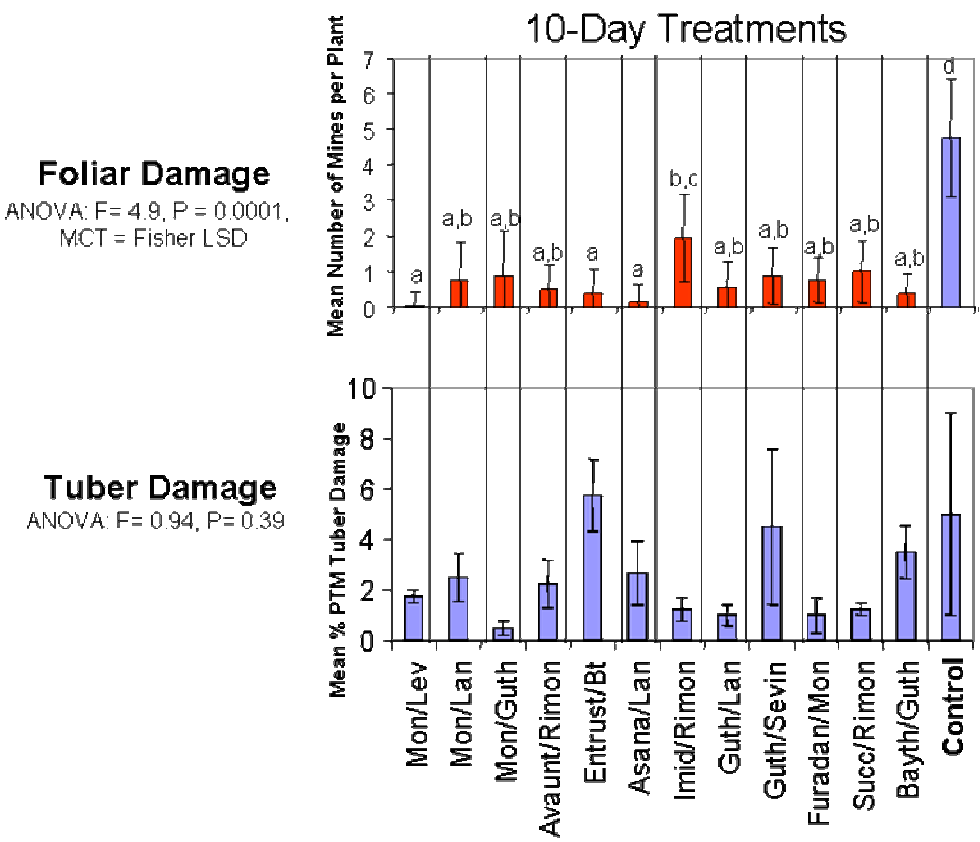

Figure 6. Results of a ground application trial for products in Group A applied at 10 day intervals. Treatment effects on foliar damager were significant (F = 4.9, p = 0.0001) and treatments with different letters are significantly different at p≤ 0.05. Those treatments that differed significantly from the control are shown in red. Treatment did not significantly affect percent tuber damage (F = 0.9, p = 0.39). Error bars indicate standard errors.

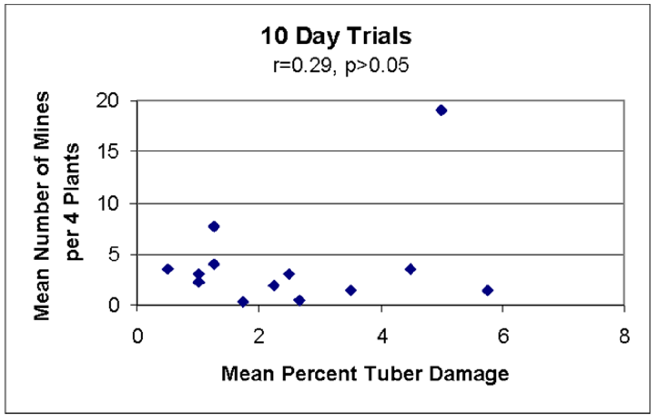

Figure 7. Correlation between amount of tuber damage and foliar damage in 10 day treatments in Group A.

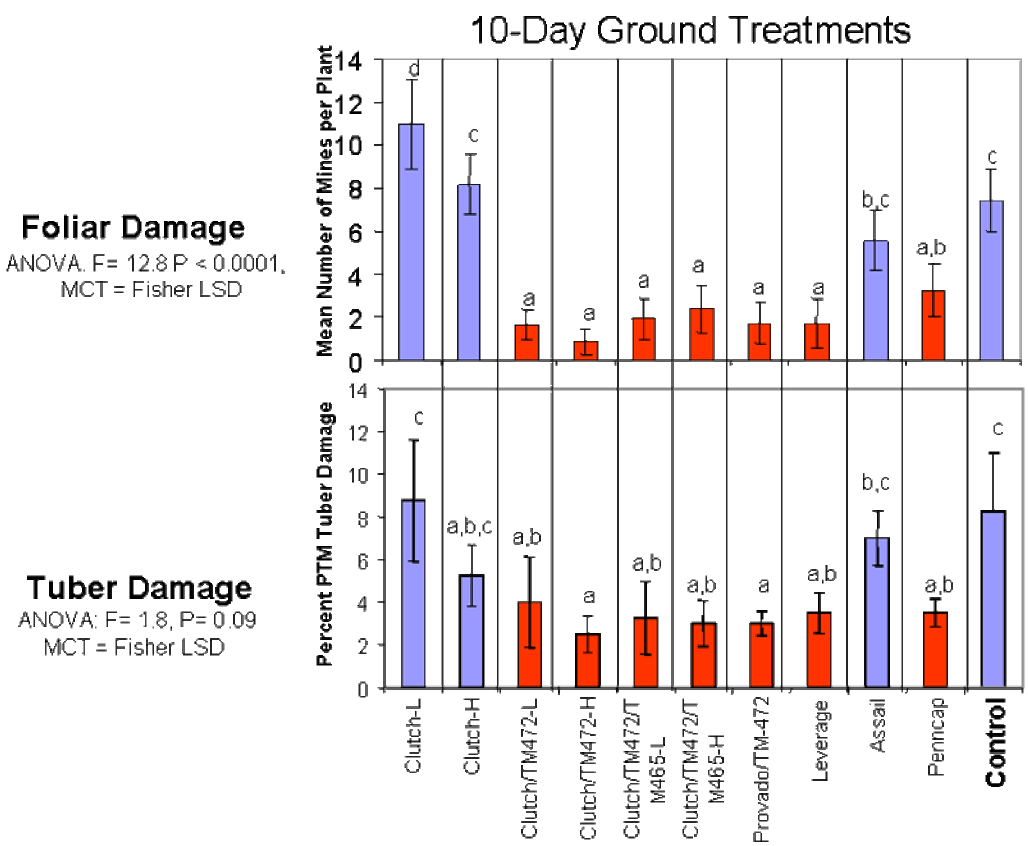

Figure 8. Results of a ground application trial for products in Group B applied at 10 day intervals. Treatment effect on foliar damage was significant ($F = 12.8$, $p < 0.0001$) and treatments with different letters are significantly different at $p \leq 0.05$. Those treatments that differed significantly from the control are shown in red. Although treatments did not significantly affect percent tuber damage at $\alpha = 0.05$, there was a significant difference at $\alpha = 0.10$ ($F = 1.8$, $p = 0.09$) and treatments with different letters are significantly different at $p \leq 0.10$. Error bars indicate standard errors.

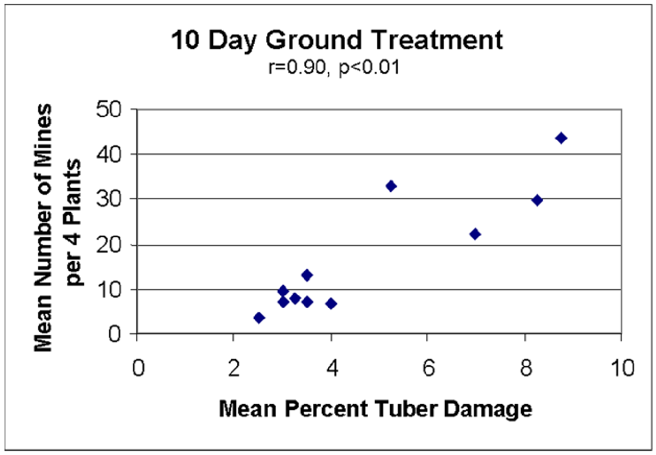

Figure 9. Correlation between amount of tuber damage and foliar damage in 10 day ground treatments for Group B.

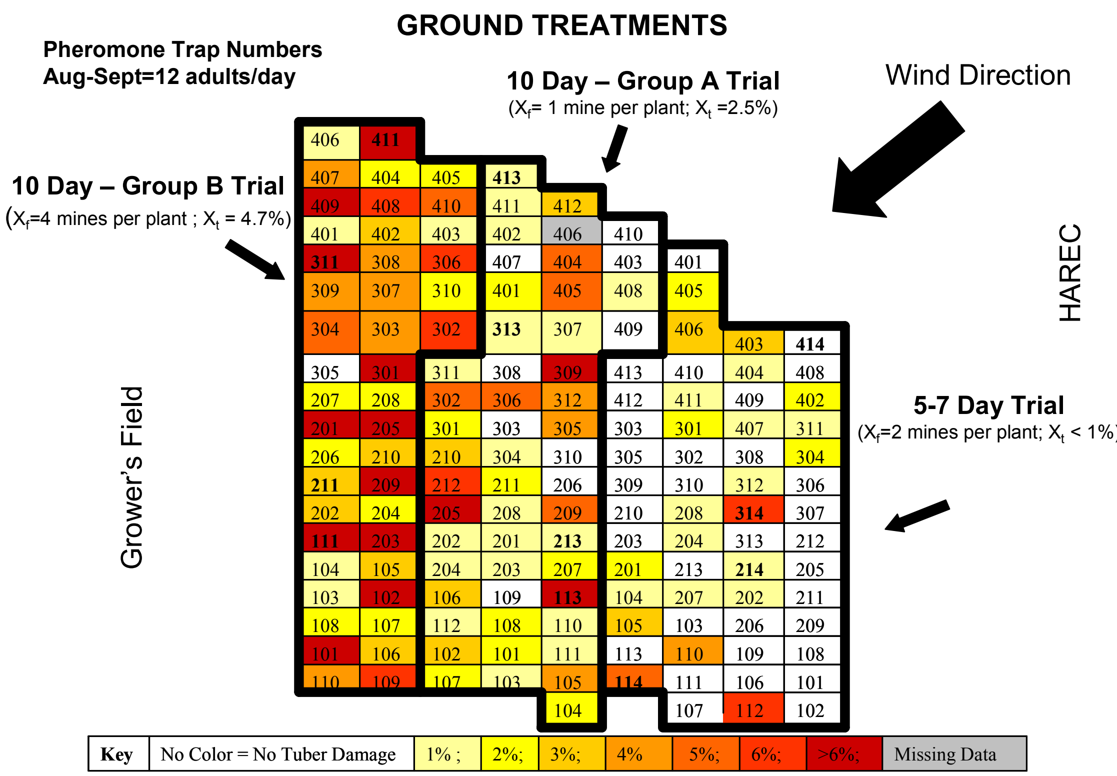

Figure 10. Map of PTM tuber damage intensity in an area at HAREC where all screening of pesticides applied as a ground application took place. Numbers of control plots are in bold face type. X_f indicates the mean number of PTM mines per plant and X_t indicates the mean percent of PTM tuber damage per plot.

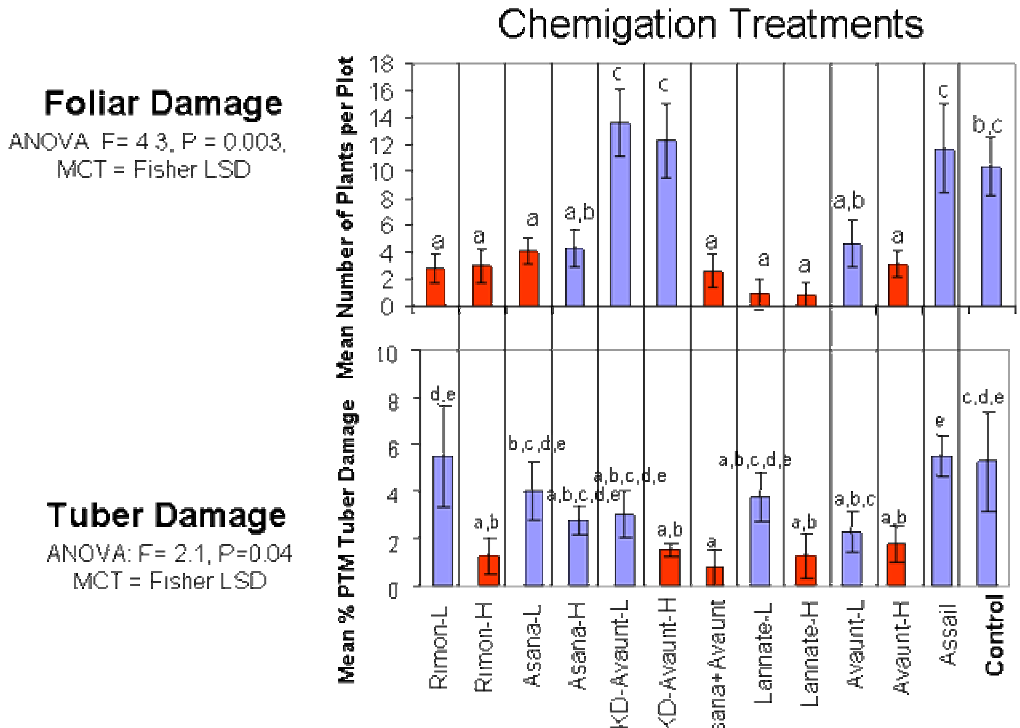

Figure 11. Results of a chemigation trial for products applied at five, seven, and 10 day intervals. Treatment effects on foliar and tuber damage were significant (F = 4.3, p = 0.003 and F = 2.1, p = 0.04, respectively) and treatments with different letters are significantly different at p ≤ 0.05. Those treatments that differed significantly from the control are shown in red. Error bars indicate standard errors.

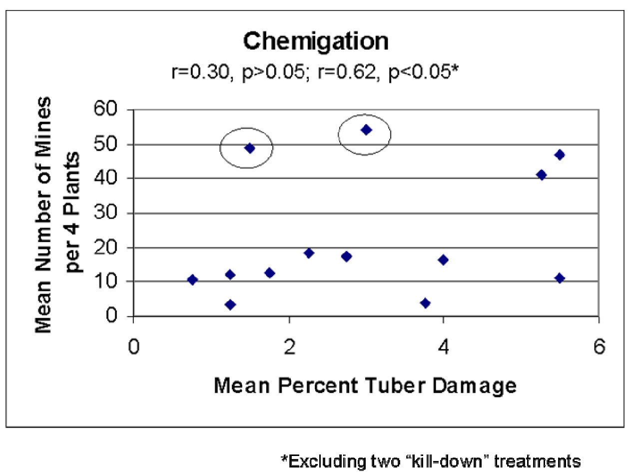

Figure 12. Correlation between amount of tuber damage and foliar damage in chemigation treatments. The correlation is statistically insignificant (r=0.30, p>0.05) if all treatments are included. However, if the two "kill-down" treatments are excluded (the points circled), the relationship between tuber and foliar damage becomes statistically significant (r=0.62, p<0.05)

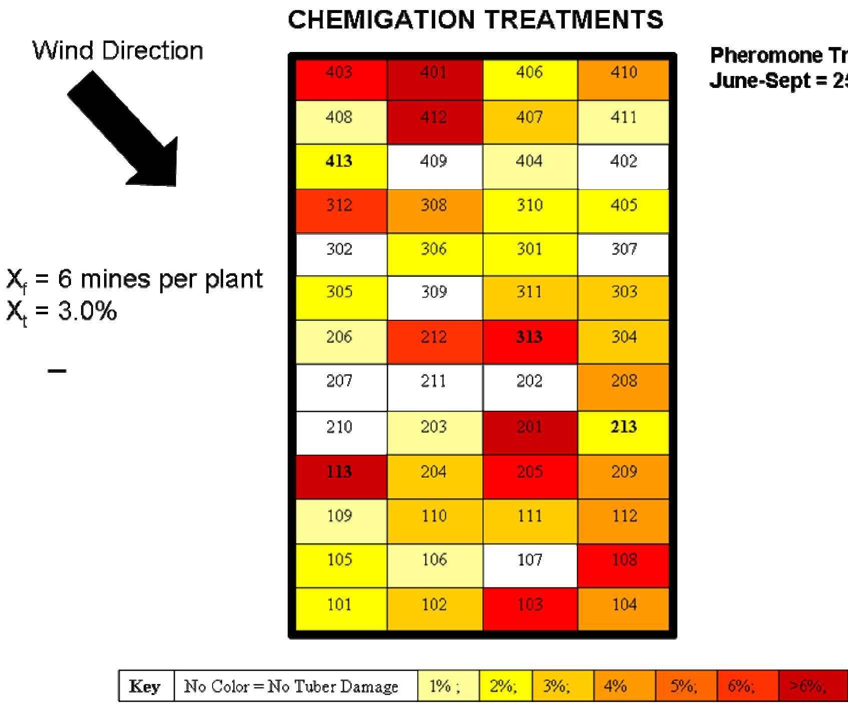

Figure 13. Map of intensity of PTM infestation in a chemigation trial at HAREC in 2005. Numbers of control plots are in bold face type. X_f indicates the mean number of PTM mines per plant and X_t indicates the mean percent of PTM tuber damage per plot.

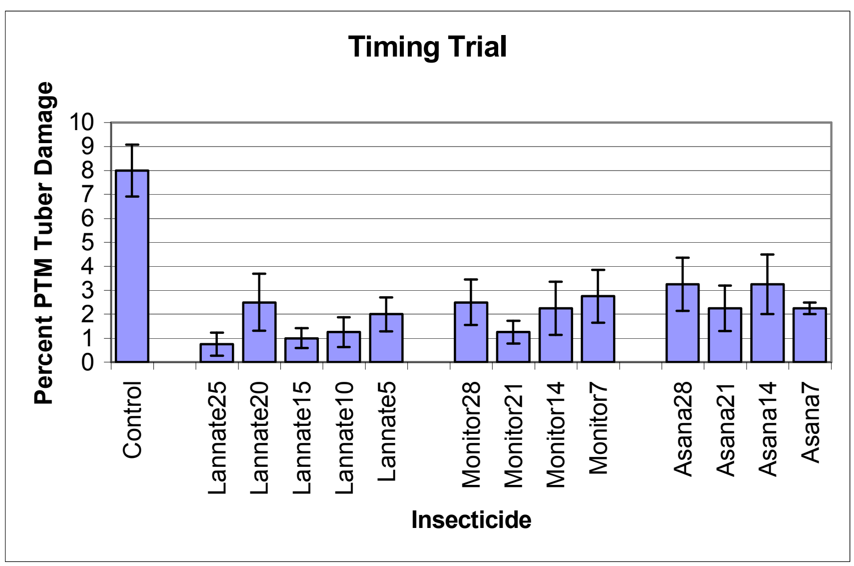

Figure 14. Effect of timing of pesticide application on PTM tuber damage. The number after the pesticide name indicates the number of days before vine kill in which a regular control program began. For example, Lannate25 indicates that Lannate was applied 6 times, starting 25 days before vine kill. Lannate5 indicates that Lannate was applied 2 times, starting 5 days before vine kill. (See Table 8 for details). Error bars indicate standard errors. Red lines indicate the direction of effect expected if there was an advantage to controlling all season.

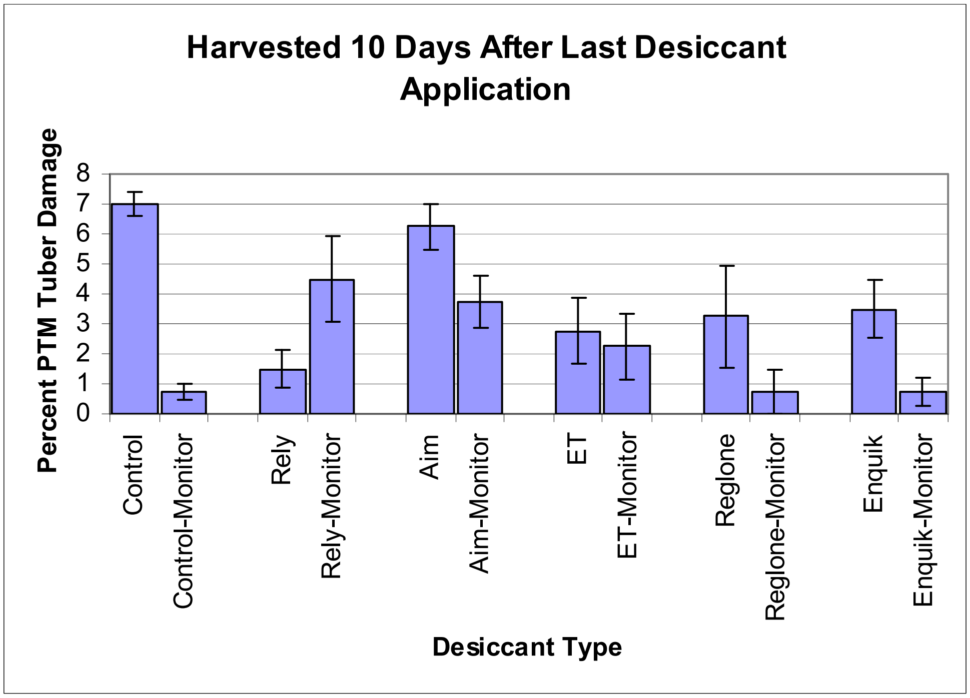

Figure 15. Effect of desiccant type with and without Monitor application on PTM tuber damage in Russet Rangers. There was a significant effect of Monitor application ($F = 11.9$, $p=0.001$), desiccant type ($F=2.9$, $p=0.03$) and an interaction between the two main effects ($F=5.0$, $p=0.001$). Error bars indicate standard errors.

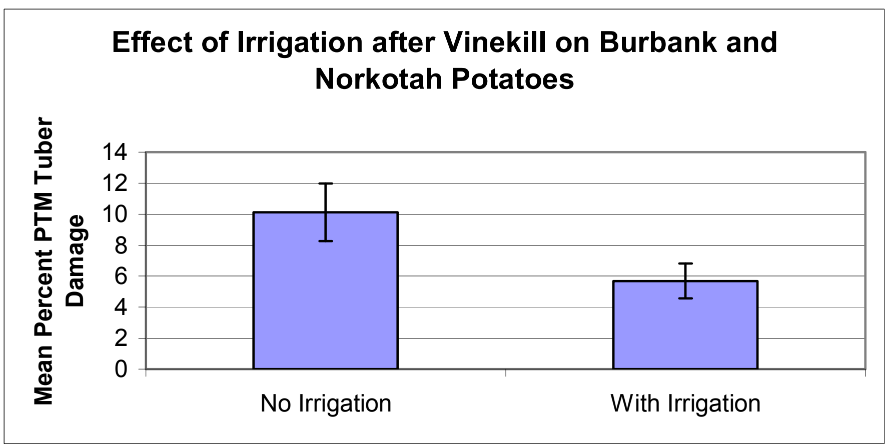

Figure 16. Effect of irrigation after vine kill on PTM tuber damage in Russet Burbank and Norkotah potatoes. Although irrigation did not significantly affect percent tuber damage at $\alpha = 0.05$, there was a significant difference at $\alpha = 0.10$ ($F=3.7$, $p=.07$). There was no significant difference in PTM between varieties ($F=0.007$, $p=0.94$) or between senescence type (chemical defoliation or natural senescence; $F=1.5$, $p=0.23$).