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The phenology of tomato/potato psyllid (TPP) in tamarillos and efficacy of insecticides against TPP

Page-Weir NEM, Chhagan A, Jamieson LE, Poulton J, Davis VA, Griffin M and Connolly PG

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Executive summary

The phenology of tomato/potato psyllid (TPP) in tamarillos and efficacy of insecticides against TPP

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Background

The tomato/potato psyllid (*Bactericera cockerelli:* TPP) is native to North America and was first detected in New Zealand in 2006. The pest primarily attacks plants in the Solanaceae (potato and tomato family) but can also be found feeding on some species of the Convolvulaceae (kumara and bindweed family). Both the adult and nymphal life stages of TPP cause damage to the host plants by feeding on the leaves, resulting in a condition known as 'psyllid yellows'. TPP transmits the bacterial pathogen *Candidatus* Liberibacter solanacearum, which is thought to be the causative agent of 'zebra chip' in potato tubers and stunted growth in fruit and leaves in tomatoes, capsicums and tamarillos. Liberibacter infection not only reduces crop yield and affects the quality of the fruit but ultimately also leads to the decline and death of the infected plant (Sengoda et al. 2010). TPP has also been found carrying the phytoplasma *Ca.* Phytoplasma australiense; however, transmission of this phytoplasma by TPP has not yet been confirmed.

Investigations are underway to understand the phenology of the TPP in various regions of New Zealand, its host range and transmission biology. This information, in conjunction with the development of spray programmes targeted to the susceptible life stages of psyllids, will assist growers in making informed decisions about when to spray to more effectively control TPP in their crops.

This report outlines the progress and results of the following investigations:

- Phenology (seasonal abundance) of TPP in tamarillo orchards
- Susceptibility of different life stages of TPP to insecticides
- Efficacy of insecticide residues against TPP.

Phenology of TPP in Tamarillo orchards

TPP on leaves of 10 branches and 3–5 yellow sticky traps were monitored fortnightly in each of three blocks within each of two tamarillo orchards in Whangarei. Monitoring began in October 2009 in the first orchard and in February 2010 in the second orchard and finished in June 2012. Liberibacter disease symptoms were also monitoring on 10 trees in each block.

Key findings:

- TPP in Northland have multiple overlapping generations
- TPP appears to overwinter as late instar nymphs in tamarillos
- There is low survivorship from young nymphs to old nymph in tamarillos

- There appears to be a constant migration of adult TPP into tamarillo orchards (this is based on monitoring and on grower observation)
- Development of a more effective spray programme from 2009 to 2012 has likely made an impact on the number of TPP found in the tamarillo orchards that were monitored
- Disease symptoms progressed quickly over the summer months, with some trees showing severe symptoms within 6 weeks.

Testing the efficacy of insecticides against TPP nymphs and adults

Potted capsicum plants were infested with TPP eggs and nymphs and sprayed with one of the following 11 insecticides to determine the direct toxicity to these life stages: Avid® + mineral oil, Calypso®, Confidor®, Delegate®, NeemAzal – T/S™, Ovation™50WDG + mineral oil, Talstar®, Pyradym® + mineral oil, Oberon®, DC-Tron®, Movento® + Partner®. Results were compared to TPP survival on untreated control plants.

The numbers of TPP eggs, nymphs and adults on each plant were assessed 1, 2, 4, 6, 8, 10 and 12 weeks after treatment. To determine the efficacy of insecticide residues against adults landing on treated plants, adults were bagged on to leaves once sprays had dried and mortality assessed 3 days later.

Key findings:

- Avid + oil, Talstar, Oberon and Movento gave effective control of TPP nymphs over a 6-week period
- Avid + oil and Talstar had good knockdown effect against TPP nymphs, while Oberon and Movento took a couple of weeks to become effective
- Ovation + oil and the mineral oil treatment controlled TPP nymphs for up to 2 weeks after treatment
- Treatment with Neemazal reduced abundance of TPP nymphs on plants 1, 2 and 6 weeks after application compared with on unsprayed plants
- Confidor treatment did not result in a significant reduction in numbers of TPP nymphs, indicating that the rate applied and therefore taken up by the plant may not have been high enough.

Testing the efficacy of spray residues against TPP nymphs and adults

Potted capsicum plants were treated with one of five insecticides: Avid® Sparta™. NeemAzal – T/S™, Oberon®, Movento® + Partner®. Early instar (1st, 2nd or 3rd) and late instar (4–5th) TPP nymphs were placed on leaves and adult TPP were bagged on treated plants on days 1, 3, 7, 17, 21 and 28 after treatment. Early and late instar nymphal mortality and TPP life stage were assessed 7 days after first exposure to treated plants. Also, adult mortality and the number of eggs laid on the leaf in the enclosed bag were assessed 3 days after adults had been placed on the plants.

Key findings:

- On plants where nymphs were exposed to 1-, 3-, 7-, 17- and 21-day-old residues of Avid or Movento there were significantly fewer TPP than on untreated plants.

- Plants with 3-, 7-, 17- and 21-day-old Oberon residues had significantly fewer TPP than the untreated control plants.

- The numbers of TPP on Sparta-treated plants were variable, with significantly fewer TPP on plants with nymphs that had been exposed to 3-, 17- and 21-day-old residues than TPP on untreated plants.

- There was no significant reduction in the number of TPP on plants where nymphs had been exposed to residues of Neemazal compared with the untreated plants.

- There was no statistically significant reduction in the number of TPP on plants where nymphs had been exposed to 28-day-old residues of any of the products tested.

- The percent mortality of adults exposed to 1-, 3-, 17-, 21- and 28-day-old residues of Sparta on plants was significantly higher than that of adults on untreated control plants.

- Adults exposed to 3-, 7- and17-day-old Avid residues also had significantly higher mortality than adults on untreated control plants. However, adults exposed to 21- and 28-day-old Avid residues showed a similar level of mortality to those on untreated plants.

- There was a higher level of mortality for adults exposed to 1- and 3-day-old residues of Movento, Oberon and Neemazal (41–62% mortality) than adult mortality on untreated control plants (17–21%). However, there was no significant difference in adult mortality when exposed to 7-, 21- and 28-day-old residues of Movento, Oberon and Neemazal compared with adults on untreated plants.

- Fewer eggs were laid by adults exposed to 1- and 3-day-old residues of each of the insecticide treatments than those on unsprayed leaves. This reduction in egg laying persisted for longer with Sparta, with adults exposed to 7-, 17- and 21-day-old Sparta residues laying significantly fewer eggs than those on the other treatments. This was probably due to the high level of adult mortality caused by this product. A reduction in egg laying was not observed for adults exposed to the other insecticide residues older than 7 days.

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1 Introduction

The tomato/potato psyllid (*Bactericera cockerelli:* TPP) was first identified in New Zealand in 2006. Since its discovery, TPP has spread throughout many regions of New Zealand, infesting plants in the Solanaceae and some species of Convolvulaceae. Examples of plants attacked include tomato, potato, capsicum, tamarillo, egg plant, kumara, cape gooseberry and chilli (Liefting et al. 2009; MPI 2012).

Both the adult and nymphal life stages of TPP (Figures 1A & 1B) cause damage to the host plants by feeding on the leaves, which can result in 'psyllid yellows' as seen in tomatoes and potatoes (Sengoda et al. 2010; Brown et al. 2010). TPP transmits the bacterial pathogen *Candidatus* Liberibacter solanacearum, which is thought to be the causative agent of 'zebra chip' in potato tubers (Sengoda et al. 2010), stunted growth in fruit and leaves in tomatoes (Brown et al. 2010), and leaf curling and yellowing in capsicums (MAF 2008b). Tamarillos have tested positive for *Ca*. L. solanacearum (MAF 2008a) with plants exhibiting similar symptoms of yellowing, leaf curling and stunted growth.

A B

Figure 1. (A) TPP adults and eggs; (B) TPP nymphs.

Liberibacter infection not only reduces crop yield and affects the quality of the fruit but ultimately also leads to the decline and death of the infected plant (Sengoda et al. 2010). TPP has also been found carrying the phytoplasma *Ca.* Phytoplasma australiense; however, transmission of this phytoplasma by TPP has not yet been confirmed. Investigations are underway to understand the phenology of the TPP in various regions of New Zealand, its host range and transmission biology. This information, in conjunction with the development of spray programmes targeted to the susceptible life stages of psyllids, will assist growers in making informed decisions about when to spray timings to more effectively control TPP in their crops.

This report outlines the progress and results of the following investigations:

- Phenology (seasonal abundance) of TPP in tamarillo orchards
- Susceptibility of different life stages of TPP to insecticides
- Efficacy of insecticide residues against TPP.

2 Phenology of TPP in tamarillo orchards

2.1 Aim

The aim of this project was to determine the seasonal abundance of the different life stages of TPP on tamarillo trees through field monitoring, and to relate this information to results from potted plant insecticide trials to determine the optimum timing of insecticide applications to control TPP.

2.2 Methods

2.2.1 Monitoring nymphs

Four blocks within two orchards in Whangarei with moderate to high numbers of TPP were located. Within each block, 10 trees infested with TPP were tagged (40 trees in total). The numbers of TPP eggs, early nymphs (first, second and third instars), late nymphs (fourth and fifth instars), and adults on five young and five mature leaves on each of the tagged trees, were examined and recorded fortnightly from October 2009 (orchard 1) and February 2010 (orchard 2) until June 2012. These trees were monitored by two tamarillo growers. Insecticides were applied to these blocks and are summarised in Appendix 1.

2.2.2 Monitoring seasonal flight activity of adults

Within each block, five yellow sticky traps (19 x 18 cm) were also hung in the tamarillo trees and replaced fortnightly. At the time of collection, the traps were covered with a single layer of clear plastic wrap and sent to Plant & Food Research, Auckland, where TPP adults on each sticky board were identified and counted using a microscope. Period of trapping was as above (2.2.1).

2.2.3 Disease monitoring

A rating scale from 1 to 5 was created in conjunction with tamarillo growers to monitor disease symptom development (Figures 1 & 2) on the 40 tagged tamarillo trees, whereby:

1 = Juvenile leaf pinking and cupping. Tree otherwise normal (Figure 2A).
2 = More pronounced pinking and cupping. Change in tree colour – paling.
3 = Juvenile leaves no longer pink – yellow and cupped. Scorching of leaf margins/leaf spotting (Figure 2B).
4 = Juvenile leaves dropped/branch tips scorched (Figure 3A).
5 = Attempted re-growth or total defoliation (Figure 3B).

Once a tree reached a disease score of 5, any further observations were made on a ‘replacement tree’ close by. Period of disease monitoring was as above (2.2.1).

A B

Figure 2. (A) Early leaf pinking and cupping = score 1. (B) Yellowing and cupping of tamarillo leaves = score 3.

A B

Figure 3. (A) Tamarillo branch tip scorching = score 4. (B) Attempted re-growth, small leaves = score 5.

2.2.4 Data analysis

All data recording sheets and sticky traps were sent to Plant & Food Research, Auckland. Data management and calculations were conducted in Microsoft® Office Excel 2007.

Graphs were produced using Origin 7.5 [(PC/Windows XP) Copyright 2004, OriginLab Corporation].

2.3 Results

2.3.1 Monitoring nymphs

The mean number of tomato/potato psyllid eggs, nymphs and adults found per leaf on tamarillo plants each fortnight is shown in Figure 4.

Eggs were predominantly found over the summer months. Early and late instar nymphs were found throughout the year in low numbers apart from a peak in numbers at the start of monitoring when branches already infested with TPP were selected for monitoring. Eggs and nymphs were rarely found during the 2011–12 season.

Adults were intermittently found on monitored branches during the summer months of 2009–10 and 2010–11 but remained at low numbers. Adults were not found on monitored branches over the summer of 2011–12.

Differences in weather patterns may account for the changes in TPP population numbers between the seasons. However, since monitoring began, new sprays that are known to have greater efficacy against TPP have been used, as well as more frequent spray applications. This could explain the ongoing lower numbers of TPP found since the 2010 season.

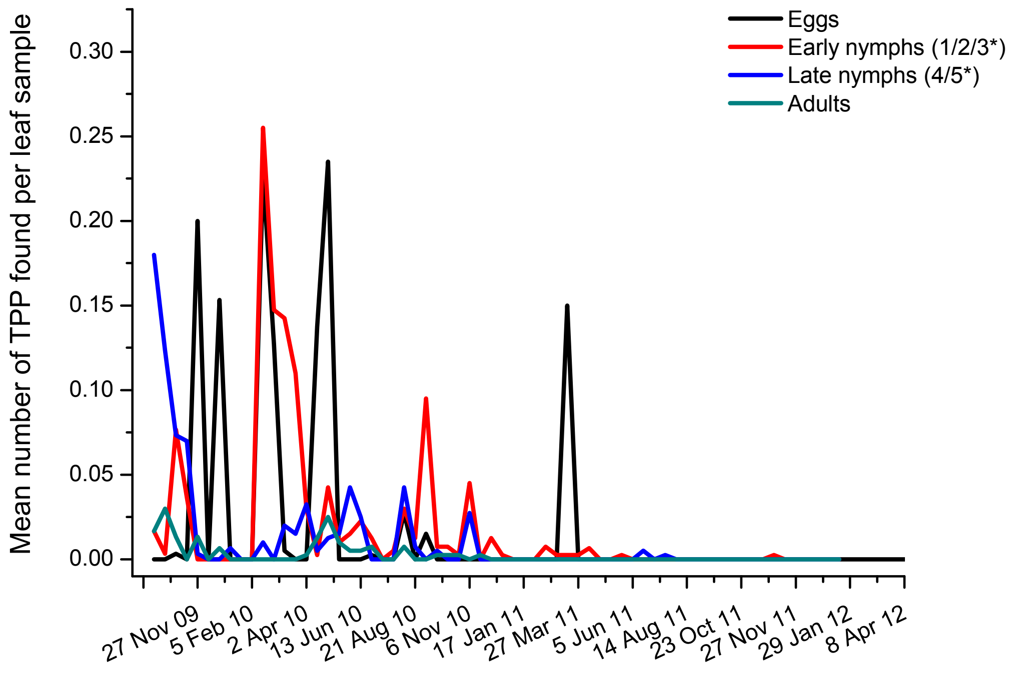

Figure 4. The mean number of tomato/potato psyllid eggs, nymphs and adults found per leaf on tamarillo plants each fortnight.

2.3.2 Monitoring adult flight activity

The mean number of tomato/potato psyllid adults found per sticky trap, per fortnight in tamarillo orchards is shown in Figure 5.

The highest number of adult TPP caught on sticky traps was a mean of six adults per trap, per fortnight, in March 2010. As with the number of nymphs that were found, the number of adults found has also declined. This may also be due to the new spray regime.

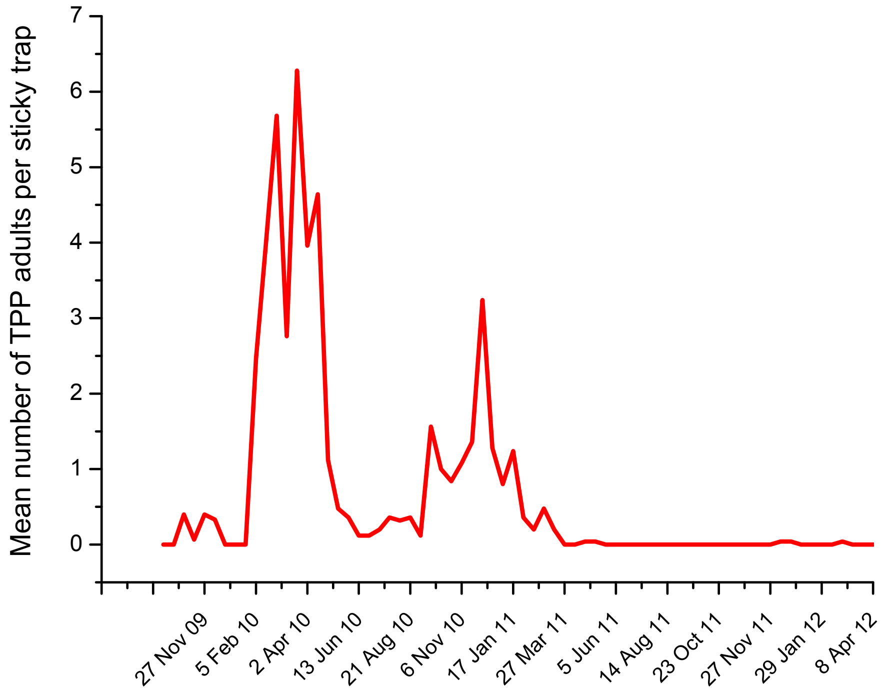

Figure 5. The mean number of tomato/potato psyllid adults found per sticky trap, per fortnight in tamarillo orchards.

2.3.3 Disease symptoms

Eighteen of the initial 40 trees (45%) monitored have since developed disease symptoms and died. Another seven trees which were replacements for dead trees have also died. This gives a total of 25 trees out of 47 (53%) which have died due to Liberibacter infection since October 2009. From the time that infection was first noticed to trees reaching a score of 5 (most severe symptoms) was approximately 2 months, although in some trees disease progression was much faster (4–6 weeks until score of 5).

Early disease symptoms are very similar to drought symptoms and are easily confused. During the summer months, there were several trees that were scored as showing early symptoms (score 1) that did not develop further symptoms, and eased once there was rain.

2.4 Discussion

The main findings of the phenology work are as follows:

- TPP appears to overwinter as nymphs in tamarillo orchards.
- There is low survivorship of TPP from young nymph to older nymph in tamarillos.
- There appears to be a constant migration of adult TPP into the orchards (this is based on monitoring and on grower observation).
- The new spray programme has likely made an impact on the number of TPP found in the tamarillo orchards that were monitored.

These results may be influenced by seasonal difference (e.g. dry summer (drought) vs. wet summer), and as unmanaged solananaceous crops die from TPP burden, there may be less sources of TPP to infest tamarillo orchards.

Disease symptoms progressed quickly over the summer months, with some trees showing severe symptoms within 6 weeks. Early results have indicated that TPP were not found on plants with disease symptoms, indicating a reduced attraction of these plants for feeding or laying eggs. There is significant crop loss due to Liberibacter infection which has a detrimental effect on orchard production.

3 Testing the efficacy of insecticides against TPP nymphs and adults

3.1 Aim

The aim of this project was to determine the efficacy of various insecticides against TPP nymphs and adults in a potted plant trial.

3.2 Methods

3.2.1 Plants & Insects

For insecticide trials whereby large numbers of TPP need testing capsicum plants were used because earlier preliminary trials showed that there was insufficient egg laying, low nymph establishment and low survival of nymphs on tamarillo plants. Adult TPP of mixed sex were released into a glasshouse unit with capsicum plants (McGregors 'Californian Wonder') to allow egg laying. These eggs were left to hatch so that after 2 weeks there was a mixture of eggs and early instar nymphs on the capsicum plants. This was done in preference to manually infesting plants with eggs and young nymphs as previous work had revealed that these life stages could be damaged when handling. Late instar nymphs, from a laboratory colony, were transferred onto plants using a fine tipped paintbrush so that a minimum of 15 late instar nymphs were on each plant.

3.2.2 Treatments

Plants were assigned treatments (Table 1) and moved to an outdoor spray area to ensure no spray drift between treatments. Treatment rates were based on label rates or those agreed on in consultation with growers.

Table 1. The active ingredient, trade name and rate of treatments.

Treatment (a.i.)	Trade name	Rate (a.i./100 litres)
untreated control		
abamectin+oil	Avid® + mineral oil	70 ml + 500 ml
thiacloprid	Calypso®	60 ml
Imidacloprid[a]	Confidor®	0.1 ml in 100 ml [a]
spinetoram	Delegate®	10 g
azadirachtin	NeemAzal – T/S™	500 ml
buprofezin+oil	Ovation™50WDG + mineral oil	25 g + 500 ml
bifenthrin	Talstar®	40 ml
pyrethrin + oil	Pyradym® + mineral oil	50 ml + 25 ml
spiromesifen	Oberon®	60 ml
mineral oil	DC-Tron®	1000 ml
spirotetramat + oil polymer	Movento® + Partner®	40 ml + 50ml

[a] Applied as a soil drench.

Four litres of each treatment was mixed and applied using a 5 L hand sprayer. On 3 June 2010, treatments were applied starting at the uppermost leaves and working towards the base of the plant, ensuring that the top of each leaf was sprayed but that there was minimal spray run-off. Four replicate plants were treated with each treatment. The control plants received no treatment.

Plants were left outside for approximately 3 h to dry before being moved back into a glasshouse where the temperature was held between 25 and 30°C. Plants were placed into treatment groups and enclosed within a mesh cage. At this time an additional 40 adult TPP of mixed sex were enclosed in a small mesh bag over a leaf on each plant to test residue activity. The numbers of live and dead adults in these bags were counted 3 days after treatment. The numbers of live or dead TPP nymphs on each plant were assessed 1, 2, 4, 6, 8, 10 and 12 weeks after treatment.

On 30 July 2010, spirotetramat treatments were similarly carried out (delayed due to incorrect rate applied on 3 June) and compared with separate controls (control 2) set up at that time. All plants were sprayed and assessed using the methods described above.

By 8 weeks after treatment untreated control plants had significantly deteriorated due to high TPP infestation. Numbers of TPP on controls began to decline as the plants died. All control plants were dead at 12 weeks. Due to this, only data from the first 6 weeks of monitoring are presented when the plants were seen to be healthy.

3.2.3 Statistical analysis

Percentage mortalities of adults exposed to residues were angular transformed and then compared among treatments using analysis of variance (ANOVA). Least significant differences (LSDs) were calculated to separate treatments where the ANOVA demonstrated significant differences ($P < 0.05$). Transformed percentage mortalities of adults exposed to spirotetramat residues were analysed separately and compared to transformed mortalities of adults in untreated plants set up at the same time (control 2). The analysis was performed using GenStat (version 10) ((PC/Windows XP) Copyright 2006, Lawes Agricultural Trust (Rothamsted Experimental Station)).

Differences in populations of early and late nymphs were assumed to be influenced only by the treatment and the number at day zero. It was assumed that differences between the quality of the plant material in the various treatments was negligible during the 6-week period investigated. Numbers of nymphs on the days in question, relative to the number on day zero, were analysed to compare the treatments with the control group. Two proportions were compared:
T_t/T_0 and C_t/C_0 where:
T_t = number of nymphs on treated plants at time t, T_0 = number of nymphs on treated at time 0, C_t = number of nymphs on untreated control plants at time t, and C_0 = number of nymphs on untreated control plants at time 0.

The R version 2.12.1 (R Development Core Team) generalized linear model used the negative binomial model to adjust for the high levels of overdispersion. Because of the necessary approximations made in the assumptions (number of TPP not influenced by plant quality), the Type I error rate was set at 0.01 to lessen the possibility of spurious differences. For the spirotetramat experiment, the numbers of nymphs were compared with those on control plants by a pairwise t-test.

3.3 Results

3.3.1 Adult mortality

Residues of Avid + oil and Talstar resulted in significantly ($P < 0.001$) higher adult mortality than residues from other treatments and controls, with 85−93% of adults dead 3 days after treatment (Figure 6). Adult TPP mortality on leaves with residues of Pyradym + oil, mineral oil, Ovation + oil or Movento was not significantly different ($P \geq 0.05$) from that on untreated leaves (Figure 6).

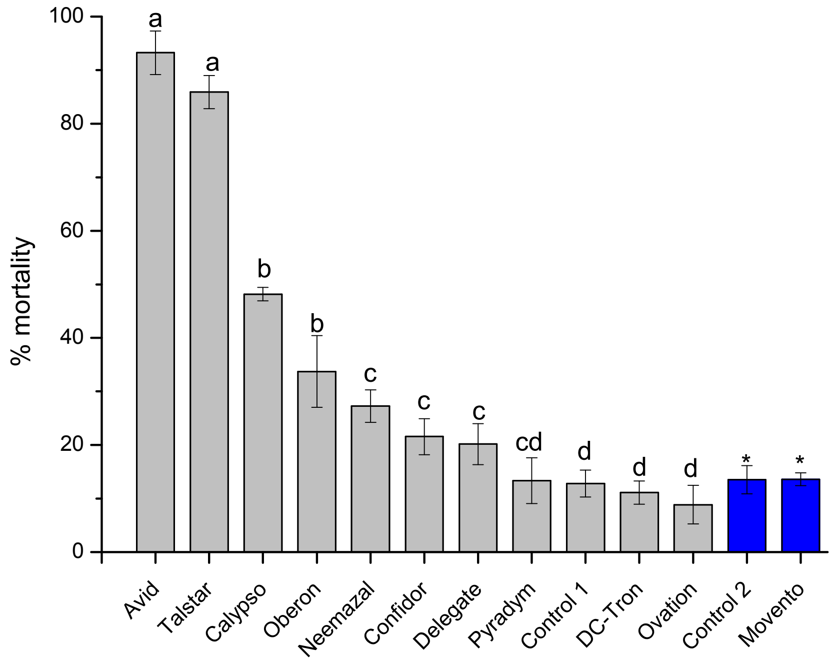

Figure 6. The percentage mortality of tomato/potato psyllid (*Bactericera cockerelli*) adults 3 days after treatment on capsicums. Vertical lines represent the standard errors of the means. Means followed by the same letter are not significantly different at $P = 0.05$. The bars indicated by * are from a later spirotetramat experiment where the control and treatment were not significantly different from each other.

3.3.2 Nymphal mortality

Table 2, Figure 7 and Figure 8 summarise the mean number of nymphs on treated and untreated plants. There were differences in nymph numbers among plants allocated to treatments prior to spray application, therefore the proportion of nymphs on plants compared with day zero is presented in Table 3.

At 1 and 2 weeks after treatment, Ovation+ oil-, mineral oil-, Neemazal-, Talstar-, Avid + oil- and Calypso-treated plants had a lower proportion of live TPP than the untreated control. However, by 4 weeks after treatment the proportion of TPP on Ovation+ oil- and mineral oil-treated plants had begun to increase and there was no longer a significant difference when compared with the controls (Table 3). The Neemazal treated plants still had a significantly lower proportion of TPP than the control at week 6, largely due to the increase in numbers in the control at this time compared with day 0. Calypso had a significantly lower proportion of TPP for up to 4 weeks after treatment.

Table 2. The mean number (± SEM) of live tomato/potato psyllid nymphs before and after treatment.

	Post treatment assessments (weeks)				
Treatment	0	1	2	4	6
Control	215.25 ± 66.24	265 ± 45.08	384.75 ± 54.25	210.25 ± 39.74	343.5 ± 60.11
Ovation	127.75 ± 26.46	68.25 ±5.41	37 ± 4.30	122.25 ± 22.61	216.5 ± 68.33
DC- Tron	94.25 ± 39.78	60.25 ± 17.78	31.25 ± 7.09	55.25 ± 15.55	149.5 ± 25.14
Oberon	93.50 ± 9.72	121.25 ±26.79	15 ± 4.67	3.25 ± 1.97	4.5 ± 4.5
Neemazal	102.25 ± 14.01	54.5 ± 11.76	52.75 ± 10.97	67.75 ± 15.73	67 ± 20.19
Confidor	73.25 ± 15.10	174 ± 32.05	91.5 ± 20.40	46.75 ± 6.47	71.25 ± 20.67
Delegate	93.75 ± 11.24	169.75 ± 28.78	84.5 ± 14.62	46.25 ± 6.71	122 ± 15.04
Talstar	73.75 ± 10.68	7 ± 1.47	4.75 ± 2.13	3.5 ± 2.22	6.25 ± 3.06
Pyradym + oil	99.50 ± 10.74	92.5 ± 14.23	74.25 ± 17.93	42.25 ± 9.63	202.75 ±30.84
Calypso	161.75 ± 25.05	85.5 ± 16.66	57.25 ± 7.88	56.5 ± 3.40	249.75 ± 47.22
Avid + oil	205.75 ± 27.49	17.25 ± 5.22	0.75 ± 0.75	5 ± 4.36	0 ± 0
Control 2	113.75 ± 24.76	149 ± 13.68	358 ± 60.64	122.5 ± 11.82	161.25 ± 52.96
Movento + oil	120 ± 22.15	60.75 ± 18.13	14.25 ± 11.74	25.5 ± 11.75	0 ± 0

Table 3. The relative difference in numbers of live tomato/potato psyllid nymphs on each treatment compared with time 0. Values >1 indicate an increase in number of TPP, while values < 1 indicate a decrease in number of TPP from the start of the experiments.

	Post treatment assessments (weeks)			
Treatment	1	2	4	6
Control	1.23	1.79	0.98	1.60
Ovation	0.53*	0.29*	0.96	1.69
DC-Tron	0.64*	0.33*	0.59	1.59
Oberon	1.30	0.16*	0.03*	0.05*
Neemazal	0.53*	0.52*	0.66	0.66*
Confidor	2.38	1.25	0.64	0.97
Delegate	1.81	0.90*	0.49	1.30
Talstar	0.09*	0.06*	0.05*	0.08*
Pyradym + oil	0.93	0.75*	0.42*	2.04
Calypso	0.53*	0.35*	0.35*	1.54
Avid + oil	0.08*	0.00*	0.02*	0.00[1]
Control 2	1.31	3.15	1.08	1.42
Movento + oil	0.51	0.12*	0.21*	0.00[1]

[a] * indicates a significant difference ($P < 0.01$) between a treatment and the corresponding control.

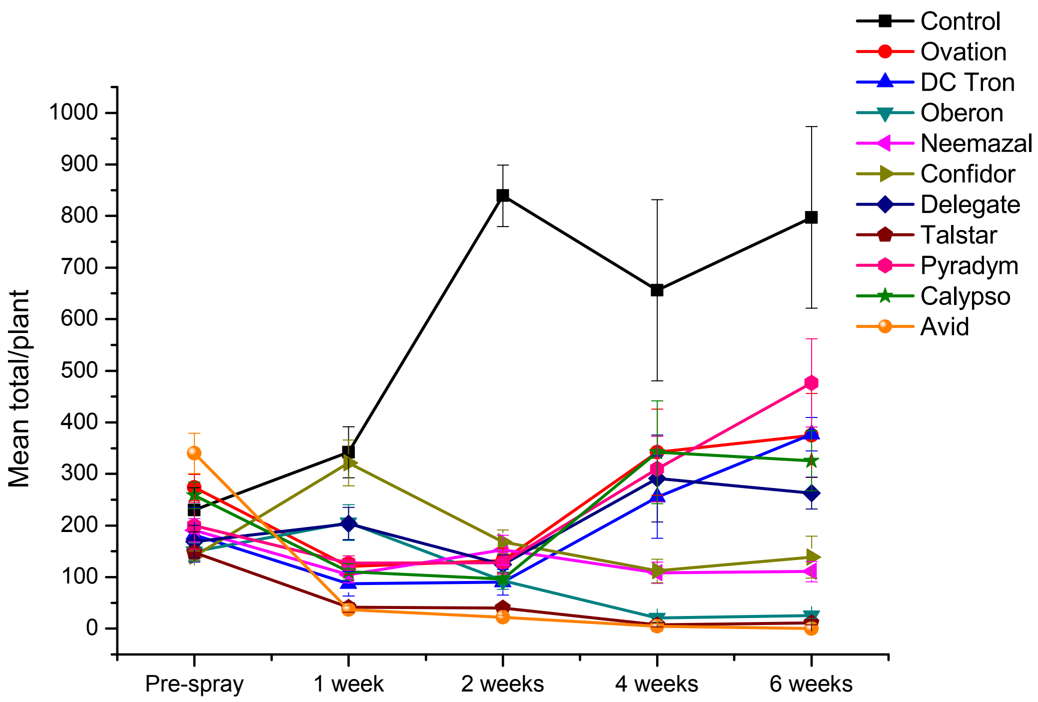

Figure 7. The mean total number (± SEM) of tomato/potato psyllids per plant on each assessment date up to 6 weeks after spraying.

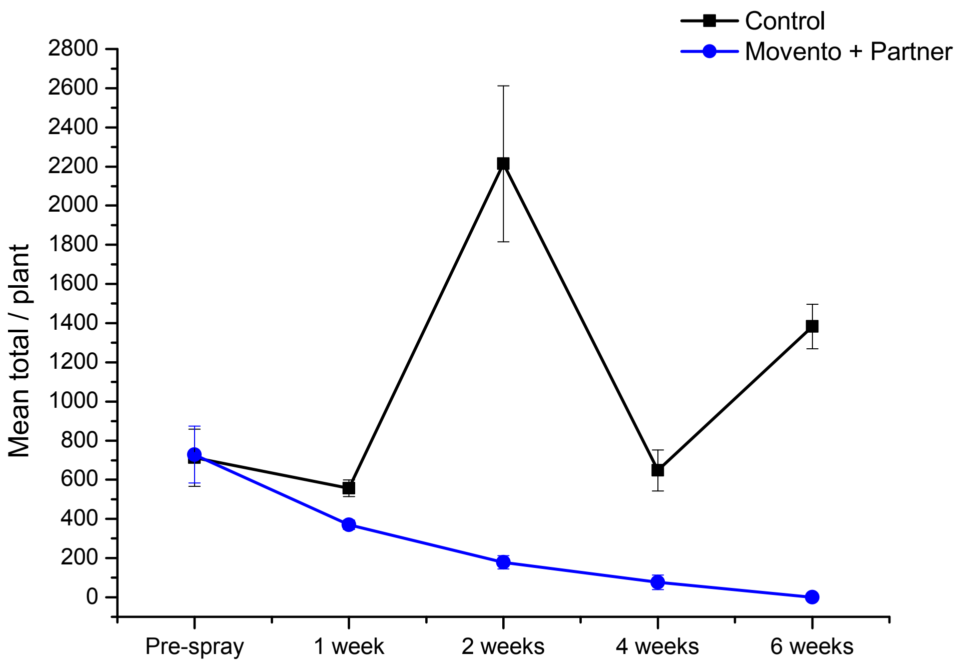

Figure 8. The mean total number (± SEM) of tomato/potato psyllids per plant up to 6 weeks after spraying.

Delegate treatment resulted in a significantly lower proportion of nymphs at week two only. Two weeks after treatment numbers of nymphs on Oberon- and Movento + oil-treated plants had significantly reduced and remained lower than on untreated plants for up to 6 weeks. Pyradym + oil-treated plants showed a significant difference in TPP infestation when compared with untreated controls at 2 and 4 weeks, but by 6 weeks there was no longer a difference between treatments and untreated controls.

After 6 weeks all TPP nymphs were dead on Avid + oil- and Movento+ oil-treated plants and numbers of nymphs on Overon-, Neemazal- and Talstar-treated plants remained significantly lower than on untreated plants.

Numbers of TPP nymphs on Confidor-treated plants were not significantly different from those on untreated controls at any of the assessment times.

3.4 Discussion

The residual activity of insecticides is important against highly mobile pest life stages such as TPP adults which can avoid direct exposure and re-infest plants soon after application. Avid + oil and Talstar residues resulted in high mortality (>80%) of TPP adults. Although the mineral oil treatment in the present study had no significant affect on adult mortality, some mineral oils have been shown to have repellent effect on TPP and reduced oviposition on tomato for up to 3 days after treatment (Yang et al. 2010). The persistence of insecticidal residues against TPP adults and nymphs and their impact on TPP egg laying, feeding and transmission of *Candidatus* Liberibacter solanacearum is currently being investigated (N.E.M. Page-Weir, Plant & Food Research, pers. comm.).

Of the 11 products tested, Avid + oil, Talstar, Oberon, and Movento gave effective control of TPP nymphs over a 6-week period. Avid + oil and Talstar had good knockdown effect against TPP nymphs, while Oberon and Movento took a couple of weeks to become effective. These results support those reported in previous bioassays on TPP nymphs where Avid (Vega-Gutierrez et al. 2008; Berry et al. 2009; Walker & Berry 2009) and Movento (Berry et al. 2009) treatment resulted in effective control of TPP. Effective control of pear psyllids (*Psylla pyri*) using Movento has also been reported (Brück et al. 2009). Previous studies have also shown Oberon to give good control of TPP (Berry et al. 2009; Walker & Berry 2009; Tucuch-Haas et al. 2010).

Ovation + oil and the mineral oil treatment controlled TPP nymphs for up to 2 weeks after treatment. These results support those reported in Berry et al. (2009), where 44% nymphal mortality was recorded at 7 days after treatment with Oberon. Treatment with Neemazal reduced abundance of TPP nymphs as was shown in a laboratory bioassay (Berry et al. 2009). The use of low mammalian toxicity products, such as mineral oil and Neemazal, may be effective when incorporated with other control strategies (e.g. biocontrol, plant resistance, early season harvest window) as part of an IPM programme.

Soil application of Confidor has been found to have a significant impact on immature stages of the Asian citrus psyllid (*Diaphorina citri*) on citrus trees (Sétamou et al. 2010) and has resulted in 53% mortality of TPP nymphs on capsicum seedlings after 7 days. In this study Confidor treatment did not result in a significant reduction in numbers of TPP nymphs indicating that the rate applied and therefore taken up by the plant may not have been high enough.

Very little peer reviewed material on the efficacy of insecticides against psyllids, in particular TPP in New Zealand, is available. Most published research has been undertaken in the United States, Mexico and Central America where growing conditions are different. Therefore, trials testing the efficacy of insecticides used in New Zealand against TPP are an important step towards the establishment of an IPM programme for affected industries and ongoing research is required.

4 Testing the efficacy of spray residues against TPP nymphs and adults

4.1 Aim

The aim of this investigation was to determine the efficacy of various insecticide residues against TPP nymphs and adults in a potted plant trial.

4.2 Methods

4.2.1 Treatments

On 20 June 2011, individual potted capsicum plants (McGregor's 'Californian Wonder') were assigned treatments (Table 4) and moved to an outdoor spray area to ensure no spray drift between treatments. Treatment rates were based on label rates or those agreed on in consultation with growers.

Four litres of each treatment was mixed and applied using a 5-L hand sprayer. Treatments were applied starting at the uppermost leaves and working towards the base of the plant, ensuring that the top of each leaf was sprayed but that there was minimal spray run-off. Four replicate plants were treated with each treatment giving a total of 24 plants per treatment. The control plants were sprayed with tap water only.

Plants were left outside for approximately 3 h to dry before being moved back into a glasshouse where the temperature was held between 25 and 30°C.

Table 4. The active ingredient, trade name and rate of treatments.

Treatment (a.i.)	Trade name	Rate (a.i./100 litres)
Untreated control		Tap water
abamectin	Avid®	70 ml
spinetoram	Sparta™	50 ml
azadirachtin	NeemAzal – T/S™	500 ml
spiromesifen	Oberon®	60 ml
spirotetramat + oil polymer	Movento® + Partner®	40 ml + 100 ml

4.2.2 Insects

On days 1, 3, 7, 17, 21 and 28 after treatment (DAT), four plants from each treatment group were moved to a separate glasshouse cubicle for infestation with TPP. TPP were collected from a glasshouse colony at Plant & Food Research, Mt Albert. Three leaves on each of the four capsicum plants in each treatment group were used – one leaf for early instar (1^{st}, 2^{nd} or 3^{rd}) TPP, one for late instar ($4–5^{th}$) TPP, and another enclosed in a mesh bag with TPP adults.

To transfer TPP onto treated plants, leaves infested with 30 early instar were collected from the colony. Each leaf was then attached to a leaf on the treated capsicum plant using a small amount of Blu-tak. This was done as the early instar nymphs were too delicate to be transferred by paintbrush and left on their original capsicum leaf could move freely to the new leaf without being injured. Thirty late-instar TPP were collected using a fine paint brush and were carefully transferred onto a leaf of the treated capsicum plant. Adult TPP were collected into individual tubes using a mechanical aspirator; each tube contained 30 adults. These were then transferred into small mesh bags, which were subsequently enclosed over a leaf of the capsicum plant using a twist tie.

Treatments were kept on separate trays and covered by large fine mesh bags, to prevent interference by other insects present in the glasshouse. This experiment was conducted in a glasshouse unit where the temperature was held between 25 and 30°C.

Adult mortality and the number of eggs laid on the leaf in the enclosed bag were assessed 3 days after setup. Early and late instar nymphal mortality, and TPP life stage were assessed 7 days after setup.

4.2.3 Statistical analysis

Utilising the MASS (Venables et al. Year?) package with R (R Development Core Team), negative binomial generalized linear models were used to model the numbers of insects and eggs. Analysis of mortality data used a similar model but with an offset to allow for the differences between the number of adults in each treatment. Analysis using a more straightforward Poisson model could not be used because of the degree of overdispersion which is typical of this kind of data. A negative binomial model estimates the overdispersion and gives more realistic estimates of relevant probabilities.

The negative binomial model is one of the log family, a consequence of which is that the standard errors are on the log scale. Those standard errors have been added to and subtracted from the mean (also on the log scale) and the resulting three values back-transformed. Although the untransformed values are presented in the Results section, the transformed values are presented in Tables 9, 10, 11 and 12 within the Appendices. The probabilities listed in the tables relate to the probability of obtaining the corresponding means and standard errors if there was no difference between the treated population and the Control population for the same number of days after treatment.

4.3 Results

4.3.1 Efficacy of residues against nymphs

The mean number of TPP (nymphs + those that survived to adult stage) 7 days after exposure to aged residues is presented in Table 5 and Figure 9. On plants where nymphs were exposed to 1-, 3-, 7-, 17- and 21–day-old residues of Avid or Movento there were significantly fewer TPP than on untreated plants. However, the number of TPP on plants with 28-day-old Avid residues increased substantially. Plants with 3-, 7-, 17- and 21-day-old Oberon residues had significantly fewer TPP than the untreated control plants. However, there was no statistical difference in the number of TPP on plants where nymphs had been exposed to 28-day-old Oberon residues. The number of TPP on Sparta-treated plants was variable, with significantly fewer TPP on plants with nymphs that had been exposed to 3-, 17- and 21-day-old residues compared with numbers of TPP on untreated plants. There was no significant reduction in the number of TPP on plants where nymphs had been exposed to residues of Neemazal compared with the untreated plants.

4.3.2 Efficacy residues against adults

The mean percentage mortality of TPP adults exposed to insecticide residues of different ages is presented in Table 6 and Figure 10. The percent mortality of adults exposed to 1-, 3-, 17-, 21- and 28-day-old residues of Sparta-treated plants was significantly higher (31–72% mortality) than mortality of adults on untreated control plants (12–34% mortality). Adults exposed to 3-, 7- and17-day-old Avid residues also had significantly higher mortality than adults on untreated control plants. However, adults exposed to 21- and 28-day-old Avid residues showed a similar level of mortality as those on untreated plants. There was a higher level of mortality for adults exposed to 1- and 3-day-old residues of Movento, Oberon and Neemazal (41–62% mortality) compared with adult mortality on untreated control plants (17–21%). However, there was no significant difference in adult mortality when exposed to 7-, 21- and 28-day-old residues of Movento, Oberon and Neemazal compared with adults on untreated plants.

The mean number of eggs laid by TPP adults exposed to insecticide residues of various ages is presented in Tables 7 and 8. Overall, egg laying on the untreated plants was variable and ranged between 7.5 and 528 eggs laid over the 3 days that the adults were caged on to the leaf at the different times. This variability was probably due to several factors including the differences in glasshouse temperature over each 3-day period and the variation in age of adults collected. Due to the low numbers of eggs laid on the control and treated leaves for exposures to 1-day-old residues, the data for 1-day-old residues is not presented. Fewer eggs were laid by adults exposed to 1- and 3-day-old residues of all of the insecticide treatments than those on unsprayed leaves. This reduction in egg laying continued for adults exposed to 7-, 17- and 21-day-old Sparta residues, probably due to the high level of adult mortality caused by this product. Reduction in egg laying was not observed for adults exposed to the other insecticide residues older than 7 days.

Table 5. Mean number (± SEM) of tomato/potato psyllids (nymphs and adults) after 7 days' exposure to aged residues.

	Age of residues (days)					
	1	**3**	**7**	**17**	**21**	**28**
Control	24.50 ± 5.17	46.75 ± 16.52	46.50 ± 12.32	68.50 ± 12.56	42.25 ± 5.39	43.75 ± 4.87
Avid	2.25 ± 1.31*	7.00 ± 6.01*	5.50 ± 2.63*	4.75 ± 2.46*	6.25 ± 3.28*	103.00 ± 33.52*
Movento	4.25 ± 1.60*	9.25 ± 3.64*	16.00 ± 2.12*	5.25 ± 1.60*	9.25 ± 2.46*	30.75 ± 8.13
Oberon	13.50 ± 13.50	8.00 ± 1.96*	15.50 ± 4.41*	26.50 ± 9.13*	12.50 ± 3.01*	38.75 ± 11.01
Neemazal	16.50 ± 14.75	32.00 ± 17.02	39.00 ± 10.06	54.25 ± 4.71	39.75 ± 5.94	82.25 ± 14.82*
Sparta	14.75 ± 6.73	3.25 ± 1.65*	27.25 ± 6.54	8.75 ± 2.46*	6.25 ± 2.87*	27.75 ± 6.75

* indicates treatments within the same column that are significantly different from the control (α < 0.05).

Table 6. Mean percentage (± SEM) mortality of adult tomato/potato psyllids per treatment.

	Age of residues (days)					
	1	**3**	**7**	**17**	**21**	**28**
Control	17.04 ± 2.35	20.00 ± 4.76	33.57 ± 13.47	31.71 ± 2.66	12.28 ± 2.26	14.04 ± 1.18
Avid	51.69 ± 10.39*	53.96 ± 3.56*	64.18 ± 7.36*	50.00 ± 5.49*	25.96 ± 10.93	10.77 ± 1.35
Movento	43.22 ± 6.08*	44.09 ± 6.65*	15.79 ± 5.83	15.45 ± 2.08*	12.39 ± 3.15	10.65 ± 4.31
Oberon	49.61 ± 4.05*	42.31 ± 7.43*	22.90 ± 7.83	13.04 ± 1.10*	18.69 ± 4.21	14.68 ± 6.13
Neemazal	51.26 ± 1.04*	61.94 ± 3.09*	23.53 ± 9.23	18.13 ± 2.04*	21.49 ± 5.50	5.04 ± 2.12
Sparta	46.34 ± 4.52*	50.74 ± 10.68*	52.73 ± 8.15	71.54 ± 9.48*	59.48 ± 15.42*	31.01 ± 9.47*

* indicates treatments within the same column that are significantly different from the control (α < 0.05).

Table 7. Mean number (± SEM) of tomato/potato psyllid eggs laid by adults (3 days after placement of adults on treated plants) *(Mean number of adults recovered).*

	Age of residues (days)					
	1	**3**	**7**	**17**	**21**	**28**
Control	7.50 ± 3.92 *(33.75)*	353.75 ± 29.69 (*30.00)*	161.25 ± 49.91 *(35.75)*	528.00 ± 83.78 (*30.75)*	189.75 ± 33.04 *(28.50)*	36.25 ± 14.48 *(28.50)*
Avid	0.50 ± 0.50* *(29.50)*	20.00 ± 5.67* *(34.75)*	56.50 ± 19.29* *(33.50)*	430.25 ± 38.14 *(30.00)*	221.50 ± 54.70 *(26.00)*	34.25 ± 13.83 *(32.50)*
Movento	2.25 ± 1.44 *(29.50)*	6.75 ± 3.90* *(31.75)*	59.0 ± 17.01* *(33.25)*	486.75 ± 114.31 *(30.75)*	169.00 ± 17.17 *(28.25)*	69.75 ±18.01 *(30.50)*
Oberon	0.00 ± 0.00 *(32.25)*	2.75 ± 2.13* (39.00)	84.50 ±23.60 *(32.75)*	568.25 ± 87.99 *(28.75)*	148.00 ± 43.30 *(26.75)*	52.50 ±14.51 *(27.25)*
Neemazal	5.25 ± 1.89 *(29.75)*	10.25 ± 9.59* *(38.75)*	57.75 ± 20.73* (29.75)	486.00 ± 60.30 *(40.00)*	245.00 ± 28.90 *(26.75)*	43.50 ± 16.54 (*29.75)*
Sparta	12.0 ± 7.47 *(30.75)*	74.25 ± 47.84 *(34.00)*	58.75 ±18.40* *(27.50)*	217.50 ± 63.11* (32.50)	83.50 ±19.46* *(29.00)*	26.75 ± 6.56 *(32.25)*

[a] * indicates treatments within the same column that are significantly different from the control ($\alpha < 0.05$**)**.

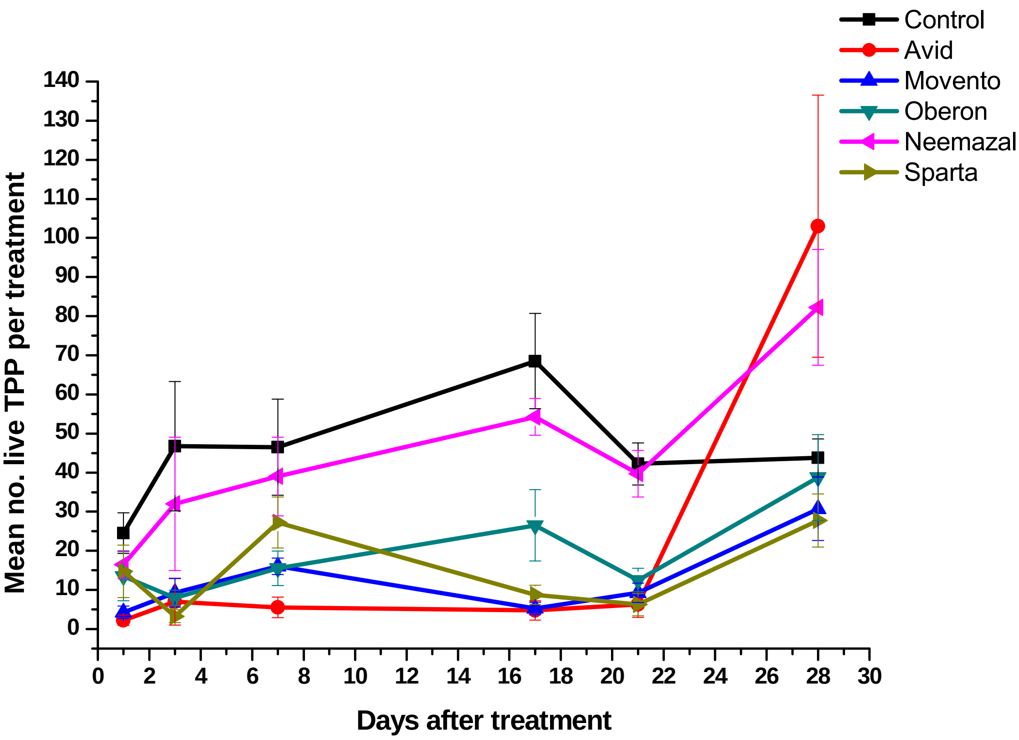

Figure 9. Mean number (± SEM) of tomato/potato psyllids (nymphs and adults) per treatment.

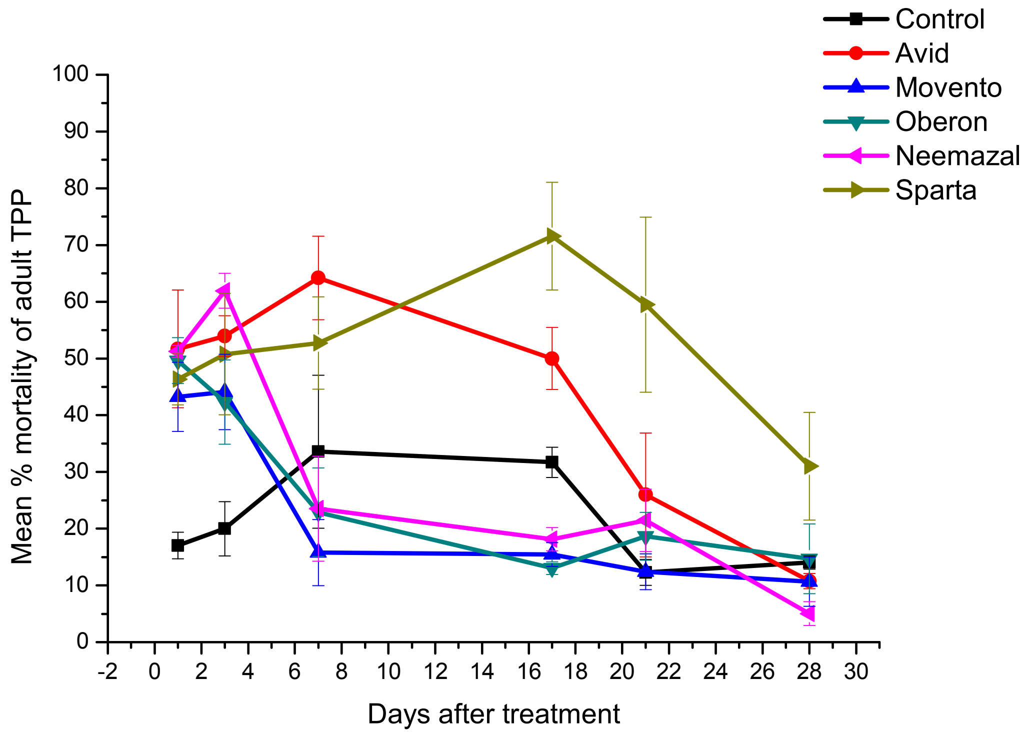

Figure 10. Mean percentage (± SEM) mortality of adult tomato/potato psyllids per treatment.

4.4 Discussion

Plants used in this research were kept in a glasshouse for the entirety of the trial; therefore, residues were not exposed to the natural elements of rainfall and UV light. As a result products can only be compared with each other and extrapolating length of effective residue information out to the field is not recommended.

In this trial, residues of Avid and Movento remained effective against TPP nymphs for up to 21 days. Residues of Oberon and Sparta were also effective against nymphs for this period, although not consistently at all times. Residues of Neemazal were not effective against nymphs.

Residues of Sparta were most effective against TPP adults, causing between 31 and 71% mortality for the 28-day period tested. This was a slightly higher level of adult mortality then reported by Gardener-Gee et al. (2012) where residues of Cyazypyr, sulfoxaflor and Sparta increased adult mortality, whereby at 1 DAT, mortality was 19-30% in these treatments (compared with 9% in the control), while at 14 DAT mortality was 17-29% (compared with 8% in the control).

Residues of Avid were effective against adults for up to 17 days. Residues of Oberon and Neemazal caused between 42 and 50% mortality of TPP adults for up to 3 days and were more effective than untreated adults. Trials conducted by Dohmen-Vereijssen et al. (2012) suggest that a related Neem product, Neem 600 WP, showed some residual effect on egg hatching rates and/or young instar mortality.

5 Acknowledgements

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6 References

Berry NA, Walker MK, Butler RC 2009. Laboratory studies to determine the efficacy of selected insecticides on tomato/potato psyllid. Proceedings of the New Zealand Plant Protection Society's Annual Conference. Otago Museum Conference Centre, Dunedin, New Zealand, 11–13 August 2009. 62: 145–151.

Brown JK, Rehman M, Rogan D, Martin RR, Idris AM 2010. First report of "*Candidatus* Liberibacter psyllaurous" (synonym "Ca. L. solanacearum") associated with 'tomato vein-greening' and 'tomato Psyllid yellows' diseases in commercial greenhouses in Arizona. Plant Disease 94(3): 376.

Dohmen-Vereijssen J, Jorgensen N, Butler RC 2012. SFF11/058: IPM tools for psyllid management – milestone report. Unpublished report.

Gardner-Gee R, Butler RC Griffin M, Puketapu A, MacDonald F, Jamieson LE 2012. Effect of insecticide residues on the behaviour, mortality and fecundity of the Tomato Potato Psyllid (Bactericera cockerelli: TPP): SFF II/058: Milestone 2. Unpublished report.

Liefting LW, Weir BS, Pennycook SR, Clover GRG 2009. "*Candidatus* Liberibacter solanacearum", associated with plants in the family Solanaceae. International Journal of Systematic and Evolutionary Microbiology 59: 2274–2276.

MAF Biosecurity 2008a. Update – *Candidatus* Liberibacter species, 24 July 2008. http://www.biosecurity.govt.nz/pests/surv-mgmt/resp/tom-cap-bacterium/update-24july [Accessed 13 June 2012].

MPI Biosecurity 2012. Potato/Tomato Psyllid. http://www.biosecurity.govt.nz/pests/potato-tomato-psyllid [Accessed 12 June 2010].

R Development Core Team 2012. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org/

Sengoda VG, Munyaneza JE, Crosslin JM, Buchman JL, Pappu HR 2010. Phenotypic and etiological differences between Psyllid yellows and zebra chip diseases of potato. American Journal of Potato Research 87(1): 41–49.

Sétamou M, Rodriguez D, Saldana R, Schwarzlose G, Palrang D, Nelson SD 2010. Efficacy and uptake of soil-applied imidacloprid in the control of Asian citrus psyllid and a citrus leafminer, two foliar-feeding citrus pests. Journal of Economic Entomology 103(5): 1711–1719.

Tucuch-Haas JI, Rodriguez-Maciel JC, Lagunes-Tejeda A, Silva-Aguayo G, Aguilar-Medel S, Robles-Bermudez A, Gonzalez-Camacho JM 2010. Toxicity of spiromesifen to the developmental stages of *Bactericera cockerelli* (Sulc) (Hemiptera: Triozidae). Neotropical Entomology 39(3): 436–440.

Vega-Gutierrez MT, Rodriguez-Maciel JC, Diaz-Gomez O, Bujanos-Muniz R, Mota-Sanchez D, Martinez-Carrillo JL, Lagunes-Tejeda A, Garzon-Tiznado JA 2008. Susceptibility to insecticides in two Mexican populations of tomato-potato psyllid, *Bactericera cockerelli* (Sulc.) (Hemiptera : Triozidae). Agrociencia 42(4): 463–471.

Venables WN, Ripley BD 2002. Modern applied statistics with S. Fourth Edition. New York, Springer. ISBN 0-387-95457-0.

Walker MK, Berry NA 2009, Insecticides have potential for tomato/potato psyllid control. Grower 64(3): 27–28.

Yang XB, Zhang YM, Hua L, Peng LN, Munyaneza JE, Trumble JT, Liu TX 2010. Repellency of selected biorational insecticides to potato psyllid, *Bactericera cockerelli* (Hemiptera: *Psyllidae*). Crop Protection 29(11): 1320–1324.

Appendices

Appendix 1. Insecticides applied in the monitoring blocks.

Grower 1			Grower 2		
Date	Insecticide	Active ingredient	Date	Insecticide	Active ingredient
7/1/2009	Avid	Abamectin			
20/1/2009	Avid	Abamectin			
16/2/2009	Decis	Deltamethrin			
2/3/2009	Decis	Deltamethrin			
18/3/2009	Nuvos Chess	Dichlorvos Pymetrozine			
31/3/2009	Nuvos	Dichlorvos			
28/8/2009	Decis	Deltamethrin			
27/9/2009	Chess Decis	Pymetrozine Deltamethrin			
21/10/2009	Decis	Deltamethrin			
28/10/2009	Decis	Deltamethrin			
6/11/2009	Decis	Deltamethrin	4/11/2009	Calypso Nuvos	Thiacloprid Dichlorvos
16/11/2009	Decis	Deltamethrin			
24/11/2009	Tamaron	Methamidaphos	30/11/2009	Calypso Talstar	Thiacloprid Bifenthrin
9/12/2009	Tamaron	Methamidaphos			
21/12/2009	Movento	Spirotetramat			
27/12/2009	Movento	Spirotetramat			
13/1/2010	Tamaron	Methamidaphos	6/1/2010	Chess Talstar Avid	Pymetrozine Bifenthrin Abamectin
25/1/2010	Talstar	Bifenthrin			
8/2/2010	Decis	Deltamethrin	12/2/2010	Calypso Nuvos	Thiacloprid Dichlorvos
17/2/2010	Tamaron	Methamidaphos			
26/2/2010	Avid	Abamectin			
11/3/2010	Avid	Abamectin			
22/3/2010	Avid	Abamectin			
8/4/2010	Tamaron	Methamidaphos			
25/6/2010	Nuvos	Dichlorvos	10/6/2010	Nuvos	Dichlorvos
9/7/2010	Nuvos	Dichlorvos			
12/8/2010	Nuvos	Dichlorvos			
24/8/2010	Nuvos	Dichlorvos			
10/9/2010	Nuvos	Dichlorvos	10/9/2010	Avid	Abamectin
24/9/2010	Nuvos	Dichlorvos			
28/9/2010	Nuvos	Dichlorvos			
7/10/2010	Decis	Deltamethrin	2/10/2010	Avid	Abamectin
15/10/2010	Talstar Calypso	Bifenthrin Thiacloprid			

26/10/2010	Talstar	Bifenthrin			
3/11/2010	Venom	Bifenthrin			
17/11/2010	Venom	Bifenthrin	2/12/2010	Movento Calypso Talstar	Spirotetramat Thiacloprid Bifenthrin
1/12/2010	Movento Tamaron	Spirotetramat Methamidaphos	5/12/2010	Movento Talstar	Spirotetramat Bifenthrin
15/12/2010	Movento Nuvos	Spirotetramat Dichlorvos	22/12/2010	Movento Talstar	Spirotetramat Bifenthrin
5/1/2011	Lorsban Calypso	Chlorpyifos Thiacloprid			
11/1/2011	Tamaron	Methamidaphos	10/1/2011	Movento Talstar	Spirotetramat Bifenthrin
17/1/2011	Lorsban	Chlorpyifos			
26/1/2011	Tamaron Calypso	Methamidaphos Thiacloprid			
2/2/2011	Lorsban	Chlorpyifos	1/2/2011	Tamaron Calypso	Methamidaphos Thiacloprid
24/2/2011	Calypso	Thiacloprid	28/2/2011	Tamaron	Methamidaphos
28/2/2011					
11/3/2011	Verdex	Abamectin	17/3/2011	Avid	Abamectin
17/3/2011					
29/3/2011	Diazanon Verdex	Diazanon Abamectin			
17/4/2011	Verdex	Abamectin	13/4/2011	Nuvos	Dichlorvos
21/4/2011	Nuvos	Dichlorvos			
21/5/2011	Nuvos	Dichlorvos			
23/5/2011	Verdex	Abamectin			
9/6/2011	Verdex	Abamectin			
5/7/2011	Verdex	Abamectin			
4/8/2011	Verdex	Abamectin			
5/9/2011	Diazanon Verdex	Diazanon Abamectin			
7/10/2011	Verdex	Abamectin	9/10/2011	Avid Calypso	Abamectin Thiacloprid
28/10/2011	Verdex	Abamectin			
17/11/2011	Verdex	Abamectin	3/11/2011	Avid Calypso	Abamectin Thiacloprid
20/11/2011			20/11/2011	Movento	Spirotetramat
8/12/2011	Movento Verdex	Spirotetramat Abamectin			
21/12/2011	Movento Verdex	Spirotetramat Abamectin	21/12/2011	Sparta	Spinetoram
5/1/2012	Sparta	Spinetoram	10/1/2012	Sparta	Spinetoram
19/1/2012	Sparta	Spinetoram	19/1/2012		
2/2/2012	Sparta	Spinetoram	1/2/2012	Tamaron	Methamidaphos
13/2/2012	Diazanon	Diazanon	13/2/2012		
20/2/2012	Sparta	Spinetoram	17/2/2012	Tamaron	Methamidaphos

				Chess	Pymetrozine
2/3/2012	Verdex Chess	Abamectin Pymetrozine	6/3/2012	Avid Chess	Abamectin Pymetrozine
15/3/2012	Verdex Chess	Abamectin Pymetrozine	22/3/2012	Avid	Abamectin
7/4/2012	Verdex	Abamectin			
4/5/2012	Diazanon Nuvos	Diazanon Dichlorvos			
15/5/2012	Diazanon Verdex	Diazanon Abamectin			
29/5/2012	Diazanon Verdex	Diazanon Abamectin			
22/6/2012	Verdex	Abamectin			

Appendix 2. Mean number (± 1 SEM) of tomato/potato psyllids (nymphs and adults) after 7 days' exposure to aged residues.

	1 DAT	3 DAT	7 DAT	14 DAT	21 DAT	28 DAT
Control	24.50 (17.30, 34.70)	46.75 (31.60, 69.10)	46.50 (37.40, 57.80)	68.50 (54.60, 85.90)	42.25 (34.50, 51.70)	43.75 (35.10, 54.50)
Avid	2.25* (1.40, 3.60) 0.000	7.00* (4.60, 10.70) 0.001	5.50* (4.10, 7.40) 0.000	4.75* (3.50, 6.50) 0.000	6.25* (4.80, 8.20) 0.000	103.00* (83.30, 127.30) 0.005
Movento	4.25* (2.80, 6.40) 0.001	9.25* (6.10, 14.0) 0.005	16.00* (12.60, 20.40) 0.001	5.25* (3.90, 7.10) 0.000	9.25* (7.20, 11.90) 0.000	30.75 (24.60, 38.50) 0.262
Oberon	13.50 (9.40, 19.30) 0.233	8.00* (5.20, 12.20) 0.002	15.50* (12.20, 19.70) 0.001	26.50* (20.90, 33.70) 0.004	12.50* (9.90, 15.80) 0.000	38.75* (31.10, 48.30) 0.697
Neemazal	16.50 (11.60, 23.50) 0.426	32.00 (21.60, 47.40) 0.494	39.00 (31.30, 48.60) 0.571	54.25 (43.20, 68.20) 0.469	39.75 (32.40, 48.70) 0.832	82.25* (66.50, 101.80) 0.039
Sparta	14.75* (10.30, 21.10) 0.309	3.25* (2.0, 5.20) 0.000	27.25 (21.70, 34.20) 0.090	8.75* (6.60, 11.50) 0.000	6.25* (4.80, 8.20) 0.000	27.75 (22.10, 34.80) 0.149

[a] * indicates treatments within the same column that are significantly different from the control (α < 0.05**).**

[b] (MeanLse, Mean Pse)

[c] *P* value

Table 10. Mean percentage (± 1 SEM) mortality of adult tomato/potato psyllid per treatment.

	1 DAT	3 DAT	7 DAT	17 DAT	21 DAT	28 DAT
Control	17.04 (13.80, 21.00)	20.00 (16.30, 24.50)	33.57 (23.10, 39.60)	31.71 (27.00, 37.10)	12.28 (9.00, 16.70)	14.04 (10.40, 18.80)
Avid	51.69* (45.50, 58.80) 0.000	53.96* (48.00, 60.60) 0.000	64.18* (51.00, 83.50) 0.036	50.00* (43.90, 56.90) 0.027	25.96 (20.50, 33.50) 0.055	10.77 (8.00, 14.80) 0.550
Movento	43.22* (37.60, 49.70) 0.000	44.09* (38.60, 50.40) 0.001	15.79 (11.50, 21.40) 0.111	15.45* (12.30, 19.40) 0.010	12.39 (9.10, 16.90) 0.982	10.65 (7.80, 14.80) 0.543
Oberon	49.61* (43.80, 56.20) 0.000	42.31* (37.40, 47.90) 0.002	22.90 (17.20, 30.50) 0.481	13.04* (10.10, 16.90) 0.003	18.69 (14.50, 24.90) 0.287	14.68 (11.10, 20.00) 0.879
Neemazal	51.26* (45.10, 58.30) 0.000	61.94* (55.90, 68.60) 0.000	23.53 (18.00, 32.20) 0.566	18.13* (15.10, 21.80) 0.023	21.49 (16.60, 27.80) 0.164	5.04 (3.20, 7.80) 0.052
Sparta	46.34* (40.60, 52.90) 0.000	50.74 * (44.90, 57.20) 0.000	52.73 (40.90, 68.60) 0.134	71.54* (64.50, 79.40) 0.000	59.48* (48.60, 71.80) 0.000	31.01* (24.70, 38.70) 0.033

[a] * indicates treatments within the same column that are significantly different from the control (α < 0.05**).**

[b] (MeanLse, Mean Pse)

[c] *P* value

Table 11. Mean number (± 1 SEM) of tomato/potato psyllid eggs laid by adults bagged on to plants (3 days after placement on plants).

	1 DAT	3 DAT	7 DAT	17 DAT	21 DAT	28 DAT
Control	7.50 (4.50, 12.50)	353.75 (201.10, 622.30)	161.25 (117.40, 221.50)	528.00 (446.90, 623.80)	189.75 (155.60, 231.40)	36.25 (24.90, 52.90)
Avid	0.50* (0.20, 1.20) 0.006	20.00* (11.30, 35.50) 0.000	56.50* (41.00, 77.90) 0.020	430.25 (364.00, 508.50) 0.386	221.50 (181.70, 270.00) 0.581	34.25 (23.50, 50.00) 0.915
Movento	2.25 (1.30, 4.00) 0.119	6.75* (3.70, 12.30) 0.000	59.00* (42.80, 81.40) 0.026	486.75 (411.90, 575.20) 0.730	169.00 (138.50, 206.20) 0.680	69.75 (48.00, 101.30) 0.217
Oberon	0.00 (0.00, Inf) 0.996	2.75* (1.50, 5.20) 0.000	84.50 (61.40, 116.30) 0.151	568.25 (481.00, 671.30) 0.755	148.00 (121.20, 180.70) 0.377	52.50 (36.10, 76.30) 0.486
Neemazal	5.25 (31.0, 8.90) 0.625	10.25* (5.70, 18.40) 0.000	57.75* (41.90, 79.70) 0.023	486.00 (411.30, 574.30) 0.725	245.00 (201.00, 298.60) 0.362	43.50 (29.90, 63.30) 0.732
Sparta	12.0 (7.30, 19.70) 0.509	74.25 (42.10, 130.90) 0.051	58.75* (42.60, 81.00) 0.025	217.50* (183.70, 257.50) 0.000	83.50* (68.20, 102.30) 0.004	26.75 (18.30, 39.10) 0.570

[a] * indicates treatments within the same column that are significantly different from the control (α < 0.05**).**
[b] (MeanLse, Mean Pse)
[c] *P* value

Table 12. Mean number (± 1 SEM) of tomato/potato psyllid eggs laid by adults emerged from nymphs placed on plants (7 days after placement on plants).

	1 DAT	3 DAT	7 DAT	17 DAT	21 DAT	28 DAT
Control	30.00 (15.60, 57.80)	115.75 (81.10, 165.30)	51.25 (34.50, 76.20)	91.75 (48.50, 173.50)	74.25 (48.10, 114.60)	16.25 (7.70, 34.10)
Avid	2.00* (1.00, 4.20) 0.006	1.00* (0.50, 1.80) 0.000	19.25 (12.80, 28.90) 0.085	17.50 (9.20, 33.40) 0.068	22.50 (14.40 35.00) 0.054	13.50 (6.40, 28.40) 0.860
Movento	2.00* (1.00, 4.20) 0.006	6.75* (4.50, 10.10) 0.000	20.25 (13.50, 30.40) 0.102	27.25 (14.30, 51.80) 0.180	86.75 (56.20, 133.90) 0.800	0.00 (0.00, Inf) 0.996
Oberon	0.00 (0.00, Inf) 0.998	27.75* (19.30, 40.00) 0.005	24.25 (16.20, 36.30) 0.186	77.75 (41.10, 147.10) 0.854	55.00 (35.60, 85.00) 0.626	13.75 (6.50, 28.90) 0.874
Neemazal	2.75 (6.60, 24.80) 0.359	29.25* (20.30, 42.10) 0.007	53.25 (35.80, 79.20) 0.946	42.25 (22.30, 80.10) 0.390	53.75 (34.80, 83.10) 0.600	16.75 (8.00, 35.10) 0.977
Sparta	0.00 (0.00, Inf) 0.998	3.50* (2.20, 5.40) 0.000	12.50* (8.30, 18.90) 0.014	12.75* (6.70, 24.40) 0.030	9.50* (6.00, 15.00) 0.001	2.75 (1.20, 6.10) 0.101

[a] * indicates treatments within the same column that are significantly different from the control (α < 0.05**).**
[b] (MeanLse, Mean Pse)
[c] *P* value