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Effect of insecticide residues on the behaviour, mortality and fecundity of the tomato potato psyllid (*Bactericera cockerelli:* TPP)

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Executive summary

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The tomato potato psyllid (*Bactericera cockerelli*: TPP) is a new pest of potatoes in New Zealand that can cause severe economic damage if not adequately controlled. Growers have been forced to increase insecticide inputs into potato crops to manage TPP, but current insecticide practices are not sustainable, either financially or environmentally. As part of a wider programme aimed at developing integrated pest management tools for the potato industry, SFF II/058: Milestone 2 aims to reduce the number of insecticide applications required to control TPP in potato crops. Extending spray intervals is one way of reducing applications, but information on residual activity is required for a number of key products to enable growers to extend spray intervals and still maintain effective TPP control. This study examined the residual activity of six insecticides and found that residues of Cyazypyr™, sulfoxaflor and Sparta™ increased adult mortality up to 14 days after treatment. One-day-old residues of Sparta and sulfoxaflor and Proteus® reduced adult TPP feeding, and increased off-leaf time, suggesting both anti-feeding and repellency effects. In addition, 14-day-old residues of Cyazypyr and sulfoxaflor halved the egg laying rate of female TPP. This study builds on previous studies undertaken by Plant & Food Research, and the results of this and previous studies suggest that there are at least four insecticides with significant residual activity that persists up to 14 days (active ingredients: abamectin, cyantraniliprole, spinetoram, sulfoxaflor). Further research into the anti-feeding and repellency effects of these insecticides is warranted, as they have the potential to reduce pest numbers and disease transmission in potato crops for extended periods.

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1 Introduction

Since its discovery in New Zealand, the tomato potato psyllid (*Bactericera cockerelli*: TPP) has become a serious pest within potato crops in New Zealand. TPP transmits the bacteria *Candidatus* Liberibacter solanacearum (Lso), the causal agent of the potato disease known as Zebra Chip (ZC). Potato growers have been forced to rely heavily on chemical insecticides to protect their crops, but there is strong interest in more sustainable control methods. The overall aim of SFF II/058: Milestone 2 is to reduce the number of insecticide applications required to control TPP in potato crops. Extending spray intervals is one way of reducing applications, but information on residual activity is required for a number of key products to enable growers to extend spray intervals and still maintain effective TPP control. This study examined the residual activity of five insecticides, and also examined the residual activity of Movento® that had been applied at three different spray intervals (Tables 1 & 2). Insecticides used in this trial were chosen by Potatoes New Zealand after consultation with growers and agrichemical companies.

Table 1: Summary of tomato potato psyllid assessments undertaken for SFF II/058: Milestone 2.

Insecticide trade name (active ingredients are given in Table 2)	**Assessments**		
	Mortality (i.e. adult deaths after 3 days exposure to residues)	Egg-laying behaviour (i.e. no. and viability of eggs laid during 3 days of exposure to residues)	Feeding behaviour (i.e. response to residues)
Chess®	√	√	√
DPX-HGW86	√	√	√
Sparta™	√	√	√
Proteus®	√	√	√
GF-2032	√	√	√
Movento®			
One application	√	√	
2 applications 7 days apart	√	√	
2 applications 14 days apart	√	√	

2 Methods

To ensure standard plants that were Lso-free, tissue culture plantlets (‘Russet Burbank’), produced by Peter and Linda Falloon at Aspara Pacific, were used in this trial. Plantlets were planted into standard potting mix in 2.8-L planter bags (PB5s) and grown on in an unheated glasshouse for 6-8 weeks, then transferred outside and sprayed as required for the trials. Three batches of plants were grown, to provide similar aged plants for the three sets of trials carried out (i.e. five-insecticide behavioural assays, five-insecticide mortality assays and Movento mortality assays). All plants had 8-12 leaves when first sprayed. For all trials, spray rates used (Table 2) were based on maximum recommended label rates. Four litres of each treatment were mixed and applied to run-off, using a 5-L hand sprayer. Once sprayed, plants were placed outside (Auckland, between May and June 2012) for the maximum time possible (but not when frosts were expected), allowing natural weathering and degradation of the insecticides.

Table 2: The trade name, active ingredient, Insecticide Resistance Action Committee (IRAC) group, application rate of treatments to tomato potato psyllid.

Trade name	Active ingredient (a.i.)	IRAC group (sub group or exemplifying a.i.)	Application rate used (ml product/L spray)
Proteus®	deltamethrin and thiacloprid	3A (pyrethroid) and 4A (neonicotinoid)	1.3
GF-2032	sulfoxaflor	4C (sulfoximine)	0.6
Sparta™	spinetoram	5 (spinosyn)	1
Chess®	pymetrozine	9B (pymetrozine)	0.4 g
Movento®	spirotetramat	23 (tetronic and tetramic acid derivatives)	1.12
DPX-HGW86	cyantraniliprole (Cyazypyr™)	28 (diamide)	1

2.1 Five-insecticide trial: Behavioural assays

On 24 May 2012, 60 individual potted potato plants were assigned to and sprayed with one of the following treatments: Cyazypyr™, Chess®, Proteus®, Sparta™, sulfoxaflor and untreated control (sprayed with tap water only). There were 10 plants per treatment. The same set of plants was intended to be used for further observation 14 days after treatment (DAT). However, many plants from the first batch of plants died and consequently the 14 DAT behavioural assays were carried out on 25 June 2012, using plants from the second trial that were sprayed on 11 June 2012.

Behavioural assay protocols were modified from Liu & Trumble (2004). The assays were conducted in arenas made by placing a filter paper disc into the base of a 90-mm diameter Petri-dish base. A treated leaf was placed onto the filter paper, then a newly emerged adult TPP was introduced to the leaf and a 35-mm diameter Petri-dish base was inverted over the TPP and leaf to form the observation arena. The arena was placed onto the stage of a binocular microscope (with the overhead microscope light on) and the TPP were allowed to adjust to the arena for a 5-min period before observations began. Observations were made for 15 min and seven behavioural categories were used (Table 3).

Table 3: Categories used to record tomato potato psyllid (TPP) behaviour (modified from Liu & Trumble 2004).

Category	Description
Feeding:	Stylet inserted into leaf tissue OR on leaf with body in feeding position (angled with head close to leaf and abdomen raised, stylet position and mouthparts not visible)
Resting:	Not moving on leaf, not in feeding position, stylet not inserted or not visible
Cleaning:	Using legs to cleanse or wipe antennae, appendages or abdomen
Off Leaf:	Off leaf surface
Walking:	Walking on the leaf surface
Jumping:	Leaping from one point to another on leaf
Probing:	Tapping mouthparts on the leaf surface intermittently

2.2 Five-insecticide trial: Adult mortality, egg-laying and egg viability

On 11 June 2012, another 60 individual potted potato plants were sprayed, using the same spray rates and treatments that had been used in the behavioural assay. There were ten plants per treatment for this trial. On days 1 and 14 after spraying, one leaf on each plant was enclosed in a mesh bag in order to cage the TPP. Thirty-five adult TPP were added to each bag (mixed sex, approximately 1-2 weeks old) and the bags were then tied securely around the stem of the leaf to prevent TPP escape. After three days, the caged leaves were cut from the potato plants and transferred to the laboratory for assessment. In the laboratory, the bags were opened and the status (live or dead) of each TPP was recorded. The sex of each live TPP was also recorded. Each leaf was examined under a binocular microscope and egg numbers recorded. Leaves were then placed onto moistened filter paper within a 90-mm diameter Petri dish. Dishes were sealed with Parafilm® and held at 22° C for 7 days. At the end of this period, unhatched eggs were counted to determine the impact of treatments on egg viability. To ensure plants were dry for handling, plants were brought under cover on days 0 and 13 after treatment, and held under cover while bags were on the plants. Once the caged leaves were excised from the plants, all plants were returned outside to allow weathering and UV degradation of the treatments.

2.3 Movento trial: Adult mortality, egg-laying and egg viability

For the Movento trial, individual potted potato plants were assigned to one of four groups (Movento 1, Movento 2, Movento 3 and control). The plants in the Movento 1 (M1) and control groups received a single spray (of Movento and water respectively) on 2 July 2012. Plants in the Movento 2 group (M2) received two Movento sprays one week apart (25 June 2012 and 2 July 2012), while plants in the Movento 3 group (M3) received two Movento sprays two weeks apart (18 June 2012 and 2 July 2012). On days 1, 7 and 14 after the final spray, one leaf on each plant was enclosed in a mesh bag. Thirty-five adult TPP were added to each bag (mixed sex, approximately 1-2 weeks old) and the bags were then tied securely around the stem of the leaf to prevent TPP escape. Assessments were made after the TPP had been confined to the leaves for three days, as described above. To ensure plants were dry for handling, plants were brought under cover on days 0, 6 and 13 after treatment, and held under cover while bags were on the plants. Once the caged leaves were excised from the plants, all plants were returned outside to allow weathering and UV degradation of the treatments.

2.4 Data analysis

2.4.1 Five-insecticide trial: Behavioural assays

Data for the 1 DAT and 14 DAT sets were analysed separately. The number of behaviour phases for each TPP was calculated (e.g. the sequence Cleaning, Resting, Cleaning, Jumping, Resting is five phases; a phase is completed every time there is a change of behaviour) as well as the the total number of each different behaviour type demonstrated by each TPP over the observation period (e.g. the sequence above contains two Cleaning phases, two Resting phases and one Jumping phase). In addition, the duration (in seconds) of each phase was calculated, and the total duration of each behaviour was calculated for each TPP. Counts (i.e. the number of phases and the number of times each behaviour was demonstrated) were analysed with Poisson generalized linear model (GLM; McCullagh & Nelder 1989), with a log link. The analysis included an F-test for the treatment main effect (overall test for differences), and a contrast to compare each insecticide with water (control). The percentage time (out of 15 min) spent on each phase was analysed with a Poisson log-linear model approach for multinomial data (McCullagh & Nelder 1989), adjusting for the continuous rather than discrete nature of the data by using the Pearson dispersion to assess treatments and for the calculation of confidence limits. Each behaviour was then analysed individually, as a binomial GLM with a logit link (using the Pearson dispersion from the multinomial analysis), to provide an assessment of differences between treatments for each behaviour. For the Poisson and binomial analyses, 95% confidence limits for the means were obtained as part of the analysis on the transformed (link) scale, and back-transformed for presentation.

2.4.2 Adult mortality, egg-laying and egg viability

Data for 1 DAT and 14 DAT were analysed separately. The total number of TPP, number of live female TPP, number of eggs, and number of eggs per live female were analysed (‘counts’), as was the percentage of dead TPP and dead/unhatched eggs (‘percentages’). Since some TPP were lost before sexing, results for numbers of females and eggs/ female are less reliable than those for other measurements. Counts were analysed using Poisson generalized linear model (GLM) with a log link (McCullagh & Nelder 1989). The percentage dead TPP and dead/ unhatched eggs were analysed with a binomial GLM with a logit link (McCullagh & Nelder 1989). Each analysis included F-tests of the overall difference between the treatments, done in the analysis of deviance carried out as part of the analysis. Estimated mean counts and 95% confidence limits associated with the means were obtained on the link (log or logit) scale, and back-transformed for presentation. For the analysis of eggs per female, the egg counts were analysed with a Poisson GLM, with a modification. The log(number of females) was included as an ‘offset’ (parameter-less explanatory variable), and the estimated eggs/ female obtained by predicting for numbers of females= 1 (i.e., log(females)=0). The analysis was otherwise as above.

All analyses were carried out with GenStat (GenStat Committee 2011). It should be noted that because of personnel changes and space constraints, pots were not laid out in a randomised design after spraying and assessments were not randomly assigned to personnel. Thus, it is possible that there are some differences between the treatments that relate to the position of the plants during the trials or variations between assessors, rather than just to the treatments.

3 Results

3.1 Five-insecticide trial: Behavioural assays

The initial behaviour for each TPP is summarised in Table 4. For the 1 DAT experiment, 11 (of 60, 18%) individual TPP did not change from the initial behaviour across the 15 min. For 14 DAT, only four TPP did not change from their initial behaviour throughout the 15 min. Of the 60 for 1 DAT TPP, 40 began the 15-min period resting, nine feeding, six walking, three off-leaf, and one each cleaning or probing. At 14 DAT, 30 began the 15-min period resting, 13 feeding, nine walking, and eight were off-leaf.

Table 4: Numbers of tomato potato psyllid (TPP) initially performing each behaviour for each insecticide (number that did not change from that behaviour). No TPP started the experiment with jumping. Abbreviations are as follows: C = cleaning, F = feeding, O = off-leaf, P = probing, R = resting, W = walking, Ch= Chess®, Cy = Cyazypyr™, Pr = Proteus®, Sp = Sparta™, Su= sulfoxaflor, Wa = water (control).

a) 1 Day After Treatment (DAT)

Treatment	C	F	O	P	R	W	Total
Ch	0	2 (0)	0	0	8 (1)	0	10 (1)
Cy	0	0	1 (0)	0	7 (1)	2 (0)	10 (1)
Pr	1 (0)	1 (0)	1 (0)	0	5 (0)	2 (0)	10 (0)
Sp	0	2 (2)	1 (0)	1 (0)	6 (2)	0	10 (4)
Su	0	2 (1)	0	0	6 (2)	2 (0)	10 (3)
W	0	2 (1)	0	0	8 (1)	0	10 (2)
Total	1 (0)	9 (4)	3 (0)	1 (0)	40 (7)	6 (0)	60 (11)

b) 14 DAT

Treatment	C	F	O	P	R	W	Total
Ch	0	4 (0)	1 (0)	0	3 (0)	2 (0)	10 (0)
Cy	0	1 (1)	3 (2)	0	4 (0)	2 (0)	10 (3)
Pr	0	2 (0)	1 (0)	0	5 (0)	2 (0)	10 (0)
Sp	0	2 (1)	2 (0)	0	5 (0)	1 (0)	10 (1)
Su	0	1 (0)	0	0	7 (0)	2 (0)	10 (0)
W	0	3 (0)	1 (0)	0	6 (0)	0	10 (0)
Total	0	13 (2)	8 (2)	0	30 (0)	9 (0)	60 (4)

Figure 1 shows the number of times each type of behaviour was performed by each individual TPP across the whole of the observation period. The total number of phases (i.e. periods of different behaviours, including jumping) varied from 1 to 36 for 1 DAT, and 1 to 28 for 14 DAT. Other than jumping and cleaning, at least one TPP per treatment performed each behaviour, at either 1 or 14 DAT.

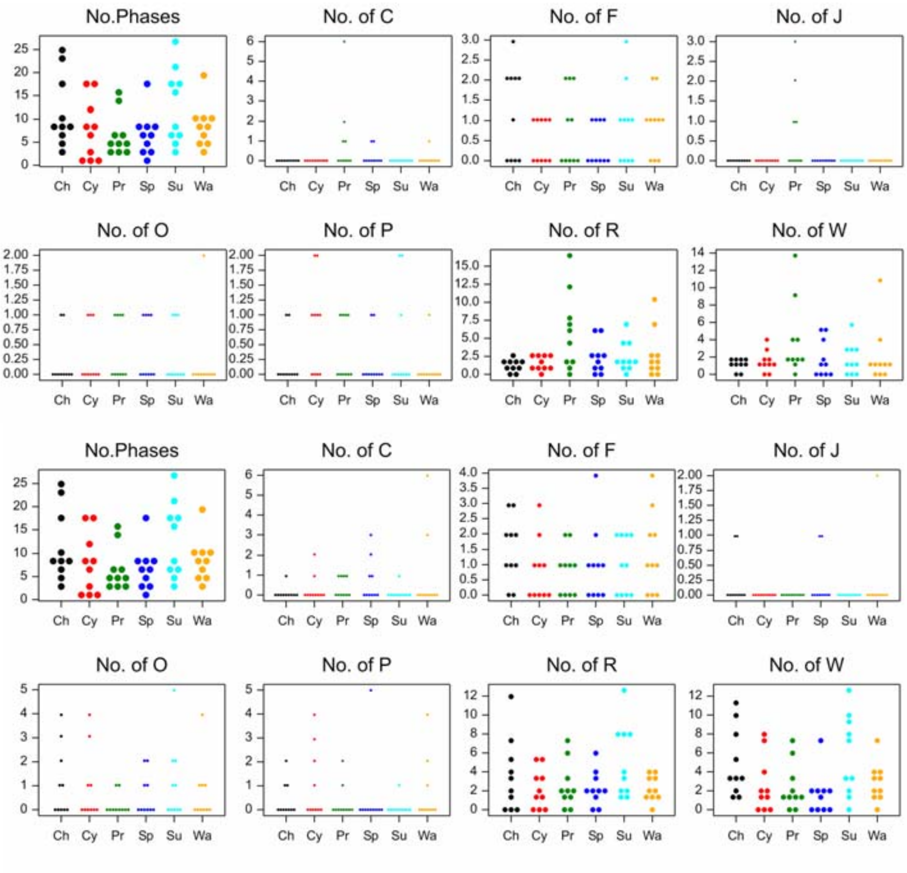

Figure 1: Dot-histograms showing the number of phases (in total and of each behaviour type) for each individual tomato potato psyllid (TPP), for each treatment. Each dot represents an individual TPP. Top two rows: 1 day after treatment (DAT). Bottom two rows: 14 DAT. Abbreviations are as follows: C = cleaning, F = feeding, J = jumping, O = off-leaf, P = probing, R = resting, W = walking, Ch= Chess®, Cy = Cyazypyr™, Pr = Proteus®, Sp = Sparta™, Su= sulfoxaflor, Wa = water (control).

For 1 DAT, the total number of phases (Table 5, Figure 2) shown by each psyllid varied between the treatments (p=0.004). Psyllids underwent the greatest number of behaviour changes (phases) when exposed to the Proteus treatment (mean of 13.2 per TPP), with all others having significantly fewer phases (p<0.05). For 14 DAT (Table 6, Figure 2), the number of phases varied less (p=0.102), with the highest being in the sulfoxaflor treatment (12.9) and the lowest in the Proteus treatment (6.3).

Table 5: One day after treatment: Mean numbers of changes of behaviour (phases) exhibited by tomato potato psyllids (TPP) and mean numbers of phases of each behaviour type per TPP for each treatment (95% confidence limits)† over a 15 minute period. Abbreviations are as follows: C = cleaning, F = feeding, O = off-leaf, P = probing, R = resting, W = walking, Trt = treatment, Ch= Chess®, Cy = Cyazypyr™, Pr = Proteus®, Sp = Sparta™, Su= sulfoxaflor, Wa = water (control).

Trt	Phases	C	F	O	P	R	W
Ch	4.2 (2.3,7.7)	0.0 (0.0,*)	1.2 (0.7,2.2)	0.2 (0.1,0.8)	0.2 (0.1,0.8)	1.4 (0.6,3.2)	1.2 (0.5,3.0)
Cy	4.9 (2.8,8.6)	0.0 (0.0,*)	0.5 (0.2,1.3)	0.3 (0.1,0.9)	0.8 (0.4,1.6)	1.8 (0.9,3.7)	1.5 (0.7,3.4)
Pr	13.2 (9.4,18.6)	1.0 (0.5,1.9)	0.8 (0.4,1.7)	0.4 (0.2,1.1)	0.4 (0.2,1.1)	5.9 (4.0,8.8)	4.0 (2.4,6.6)
Sp	5.5 (3.2,9.4)	0.2 (0.1,0.8)	0.4 (0.1,1.1)	0.4 (0.2,1.1)	0.2 (0.1,0.8)	2.5 (1.4,4.6)	1.8 (0.9,3.8)
Su	6.0 (3.6,10.0)	0.0 (0.0,*)	0.9 (0.4,1.8)	0.3 (0.1,0.9)	0.5 (0.2,1.2)	2.5 (1.4,4.6)	1.8 (0.9,3.8)
Wa	6.2 (3.8,10.2)	0.1 (0.0,0.7)	0.9 (0.4,1.8)	0.2 (0.1,0.8)	0.1 (0.0,0.7)	2.9 (1.6,5.1)	2.0 (1.0,4.0)

* upper Confidence Limit for 0 cannot easily be obtained. †J excluded, 0 for all but Pr which had 0.7 (0.3,1.5).

Table 6: Fourteen days after treatment: Mean numbers of changes of behaviour (phases) exhibited by tomato potato psyllids (TPP) and mean numbers of phases of each behaviour type per TPP for each treatment (95% confidence limits)† over a 15 minute period. Abbreviations are as follows: C = cleaning, F = feeding, O = off-leaf, P = probing, R = resting, W = walking, Trt = treatment, Ch= Chess®, Cy = Cyazypyr™, Pr = Proteus®, Sp = Sparta™, Su= sulfoxaflor, Wa = water (control).

Trt	Phases	C	F	O	P	R	W
Ch	11.4 (7.8,16.7)	0.1 (0.0,1.0)	1.5 (0.8,2.7)	1.1 (0.5,2.4)	0.4 (0.1,1.4)	3.4 (2.0,5.9)	4.7 (2.9,7.7)
Cy	7.5 (4.7,12.0)	0.3 (0.1,1.1)	0.8 (0.4,1.8)	0.9 (0.4,2.1)	1.0 (0.4,2.2)	2.0 (1.0,4.1)	2.5 (1.3,4.9)
Pr	6.3 (3.8,10.6)	0.4 (0.1,1.3)	0.8 (0.4,1.8)	0.2 (0.0,1.3)	0.3 (0.1,1.3)	2.4 (1.3,4.6)	2.2 (1.1,4.5)
Sp	6.8 (4.1,11.2)	0.7 (0.3,1.7)	1.0 (0.5,2.1)	0.6 (0.2,1.7)	0.5 (0.2,1.6)	2.2 (1.1,4.3)	1.6 (0.7,3.7)
Su	12.9 (9.0,18.5)	0.1 (0.0,1.0)	1.0 (0.5,2.1)	1.1 (0.5,2.4)	0.1 (0.0,1.3)	5.0 (3.2,7.8)	5.6 (3.6,8.8)
Wa	8.7 (5.6,13.5)	0.9 (0.4,1.9)	1.4 (0.8,2.6)	0.7 (0.3,1.9)	0.7 (0.3,1.8)	2.1 (1.0,4.2)	2.7 (1.4,5.2)

* upper Confidence Limit for 0 cannot easily be obtained. † J excluded, 0 for all but Ch, Sp, Wa which had 0.2 (0.1,0.8).

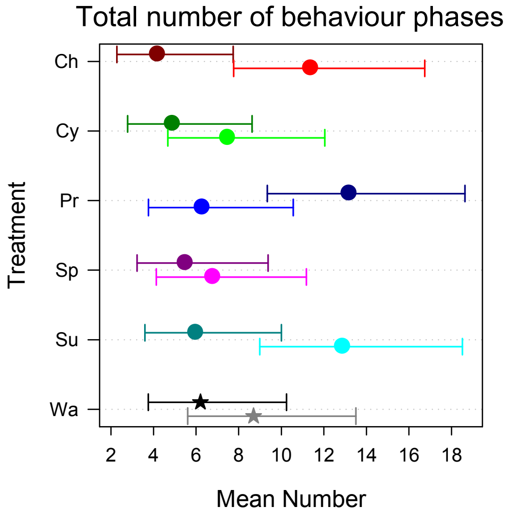

Figure 2: Mean number of behaviour phases per tomato potato psyllid (TPP) over a 15 minute period, ordered by mean number. Error bars show 95% confidence limits for the means. For each treatment, the upper value (darker colour) is for 1 day after treatment (DAT), and the lower for 14 DAT. Abbreviations are as follows: Ch= Chess®, Cy = Cyazypyr™, Pr = Proteus®, Sp = Sparta™, Su= sulfoxaflor, Wa = water (control).

Of the individual behaviours, at 1 DAT (Table 5, Figure 3), the mean number of phases for each per TPP varied between treatments for cleaning ($p<0.001$), jumping ($p<0.001$) and resting ($p=0.005$), with differences between treatments for the other behaviours being less substantial ($0.11<p<0.93$). There was on average less than one cleaning phase per TPP, with the highest number on average in the Proteus treatment (mean=1.0). No TPP cleaned while on the leaves treated with Chess, Cyazypyr or sulfoxaflor. However, on leaves treated with Proteus, a significant number of psyllids exhibited cleaning behaviour ($p<0.001$). Jumping only occurred in the Proteus treatment, with a mean number of jump phases of 0.6 per psyllid on leaves exposed to this insecticide. The number of resting phases was highest in the Proteus treatment (5.9), and this was significantly higher than in the other treatments. The next highest number of resting phases was in the water treatment (2.9), and lowest in the Chess treatment (1.4). The number of off-leaf phases was low, at below 0.5 per TPP. Feeding phases varied from 0.4 (Sparta) to 1.2 (Chess), and walking phases from 1.2 (Chess) to 4 (Proteus). The number of probing phases varied from 0.1 (water) to 0.8 (Cyazypyr).

At 14 DAT (Table 6, Figure 3), there was less variation between the treatments in the number of phases of each type of behaviour. The number of phases ($p=0.102$ for the overall test between treatments) varied from 6.3 (Proteus) to 12.9 (sulfoxaflor). The number of walking behaviours varied most strongly between the treatments ($p=0.025$), from 1.6 on Sparta-treated leaves to 5.6

on sulfoxaflor-treated leaves. Numbers of cleaning phases were quite low, below 1 per TPP, but there were some minor differences (p=0.075), with the lowest number in the sulfoxaflor and Chess treatments (0.1/ TPP), and the highest in the water control (0.9). Variation between the other treatments was lower (0.12<p<0.69).

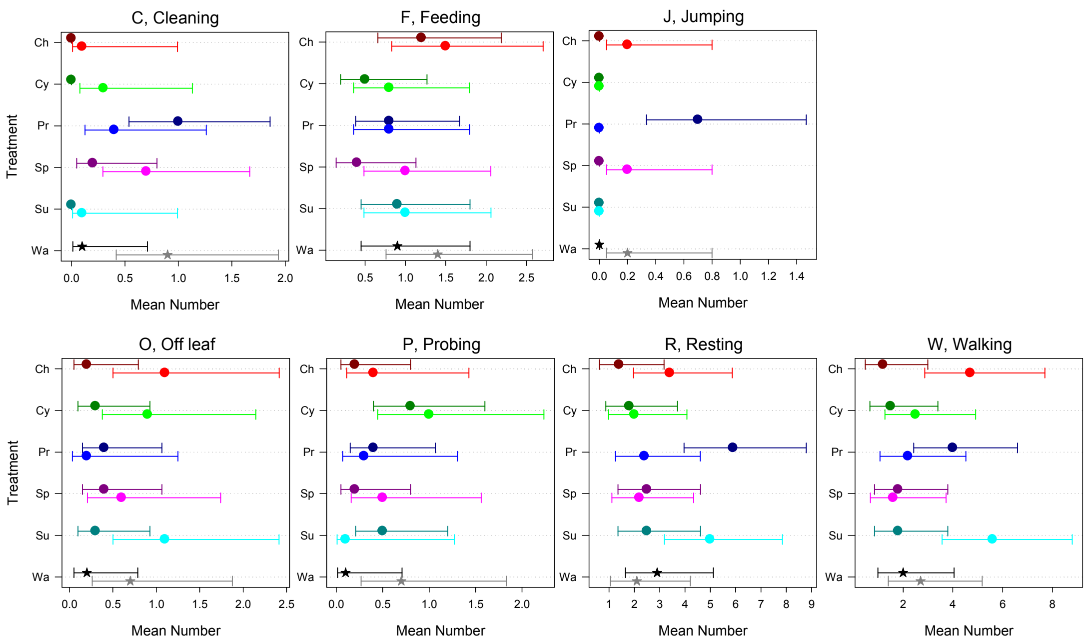

Figure 3. Mean number of each behaviour type per tomato potato psyllid (TPP) over a 15 minute period. For each treatment, the upper value (darker colour) is for one day after treatment (DAT), and the lower for 14 DAT. Error bars show 95% confidence limits for the means (omitted when number=0). Abbreviations are as follows: Ch= Chess®, Cy = Cyazypyr™, Pr = Proteus®, Sp = Sparta™, Su= sulfoxaflor, Wa = water (control).

3.1.1 Percentage time spent exhibiting each behaviour

Figure 4 shows the percentage time spent by each TPP on each activity. Variation between TPP in the time spent feeding or resting was particularly high, varying from 0 to 100% for most treatments for both 1 and 14 DAT.

The pattern of percentage times spent on each behaviour did not vary substantially between the treatments for either 1 or 14 DAT (p>0.2; Table 7 & 8, Figures 5 & 6). For individual behaviours, at 1 DAT, the greatest variation in the percentage of time was for feeding (p=0.005) and for the time off-leaf (p=0.047). For cleaning, probing, walking or resting, the differences between the treatments were much smaller (0.14<p≤1). At 14 DAT, the percentage time only varied substantially between treatments for time off-leaf (p=0.002), with much less variation in the other treatments (0.14<p<1).

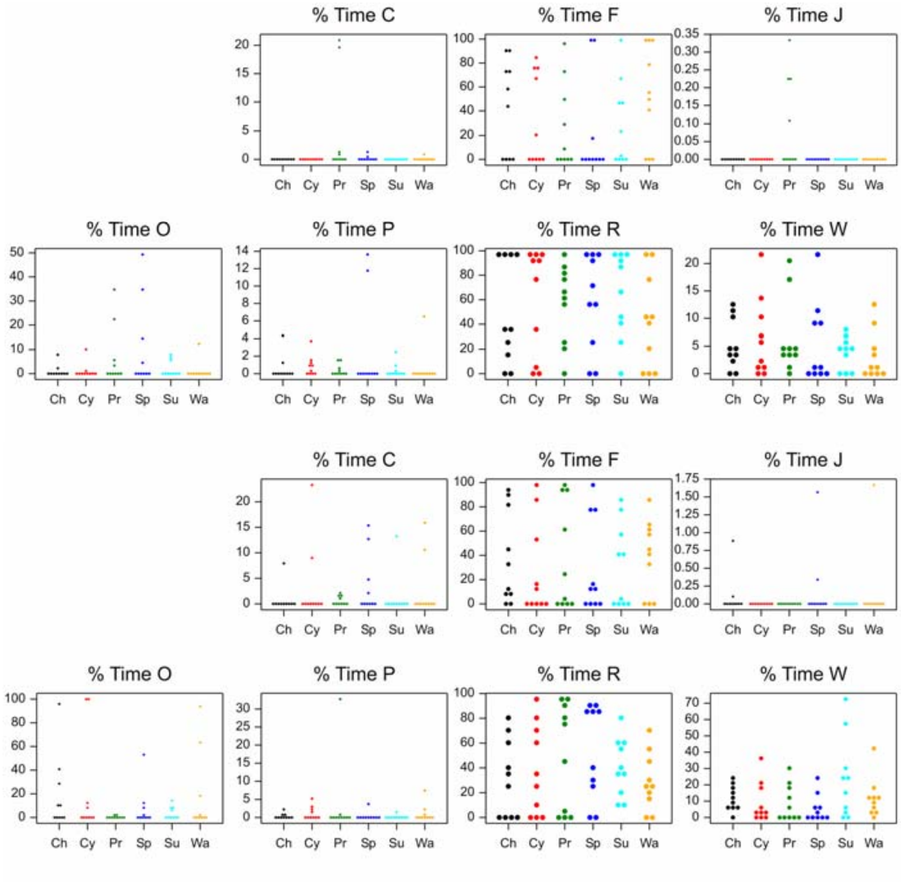

Figure 4. Dot-histograms of the percentage time spent by individual tomato potato psyllid (TPP) on each activity (recorded over a 15 minute period). Top two rows: One day after treatment (DAT). Bottom two rows: 14 DAT. Abbreviations are as follows: C = cleaning, F = feeding, O = off-leaf, J= Jumping, P = probing, R = resting, W = walking, Ch= Chess®, Cy = Cyazypyr™, Pr = Proteus®, Sp = Sparta™, Su= sulfoxaflor, Wa = water (control).

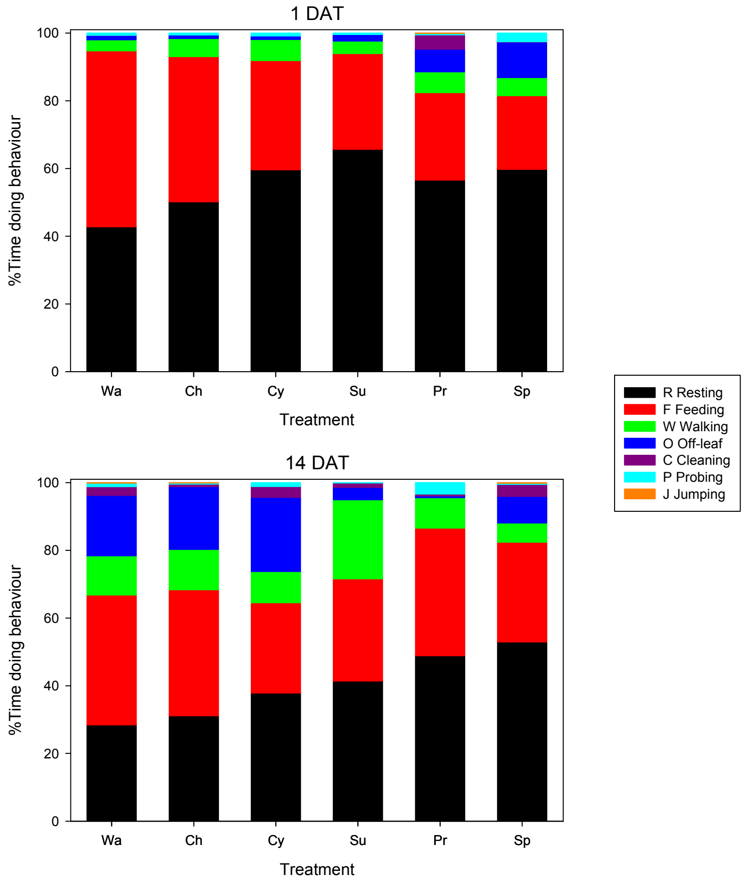

Figure 5. Percentage time spent on each activity for tomato potato psyllid (TPP) on each insecticide treatment. Activity was recorded one day after treatment (DAT) or 14 DAT. Note that activities are ordered by the percentage time over all insecticides for each activity. Abbreviations are as follows: Ch= Chess®, Cy = Cyazypyr™, Pr = Proteus®, Sp = Sparta™, Su= sulfoxaflor, Wa = water (control).

Table 7. One day after treatment: Percentage time spent by tomato potato psyllid (TPP) on each behaviour type for each insecticide (activity recorded over a 15 minute period). Abbreviations are as follows: C = cleaning, F = feeding, O = off-leaf, P = probing, R = resting, W = walking, Trt = treatment, Ch= Chess®, Cy = Cyazypyr™, Pr = Proteus®, Sp = Sparta™, Su= sulfoxaflor, Wa = water (control).

Trt	%C	%F	%O	%P	%R	%W
Ch	0.0 (0.0,1.6)	42.9 (30.8,55.9)	1.1 (0.1,11.6)	0.6 (0.0,15.0)	50.2 (0.0,100.0)	5.3 (1.7,15.1)
Cy	0.0 (0.0,1.6)	32.2 (21.5,45.3)	1.1 (0.1,11.6)	0.9 (0.1,12.5)	59.6 (0.0,100.0)	6.2 (2.2,16.2)
Pr	4.3 (1.2,13.8)	25.8 (16.2,38.5)	6.7 (2.5,16.7)	0.4 (0.0,19.2)	56.6 (0.0,100.0)	6.2 (2.2,16.2)
Sp	0.2 (0.0,48.4)	21.8 (12.9,34.2)	10.4 (4.8,21.3)	2.5 (0.5,11.9)	59.8 (0.0,100.0)	5.3 (1.8,15.1)
Su	0.0 (0.0,1.6)	28.3 (18.2,41.1)	2.0 (0.3,11.4)	0.4 (0.0,19.2)	65.7 (0.0,100.0)	3.7 (1.0,13.1)
Wa	0.1 (0.0,93.6)	52.0 (39.2,64.5)	1.2 (0.1,11.4)	0.7 (0.0,13.9)	42.8 (0.0,100.0)	3.3 (0.8,12.6)

Table 8. Fourteen days after treatment: Percentage time spent by tomato potato psyllid (TPP) on each behaviour type for each insecticide (activity recorded over a 15 minute period). Abbreviations are as follows: C = cleaning, F = feeding, O = off-leaf, P = probing, R = resting, W = walking, Trt = treatment, Ch= Chess®, Cy = Cyazypyr™, Pr = Proteus®, Sp = Sparta™, Su= sulfoxaflor, Wa = water (control).

Trt	%C	%F	%O	%P	%R	%W
Ch	0.8 (0.0,19.9)	37.3 (24.1,52.7)	18.5 (9.4,33.2)	0.3 (0.0,39.3)	31.1 (19.0,46.5)	11.9 (5.0,25.6)
Cy	3.2 (0.6,15.7)	26.7 (15.5,41.9)	21.9 (11.9,36.9)	1.1 (0.1,16.8)	37.9 (24.6,53.2)	9.2 (3.4,22.5)
Pr	0.6 (0.0,23.7)	37.7 (24.4,53.1)	0.5 (0.0,22.0)	3.4 (0.6,15.8)	48.9 (34.2,63.7)	9.0 (3.3,22.2)
Sp	3.5 (0.7,15.9)	29.4 (17.6,44.8)	7.9 (2.7,20.9)	0.4 (0.0,36.9)	53.0 (38.0,67.4)	5.7 (1.6,18.1)
Su	1.3 (0.1,16.1)	30.2 (18.3,45.6)	3.6 (0.7,16.0)	0.1 (0.0,86.4)	41.4 (27.6,56.7)	23.4 (13.0,38.4)
Wa	2.6 (0.4,15.2)	38.3 (25.0,53.7)	17.8 (8.9,32.4)	1.0 (0.1,17.4)	28.5 (16.9,43.8)	11.6 (4.8,25.3)

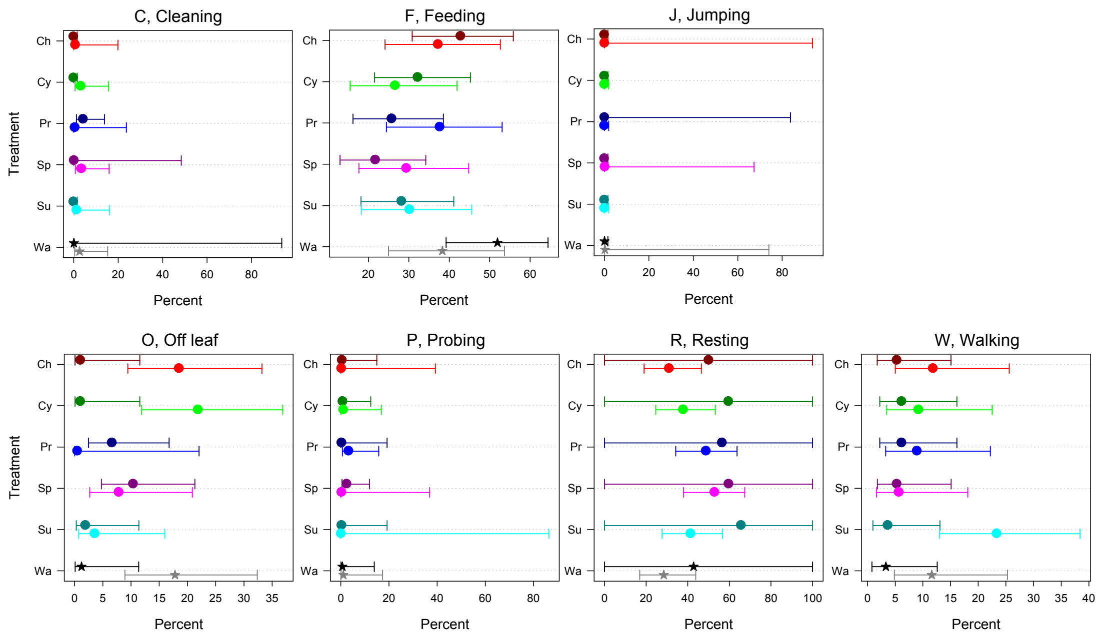

Figure 6. Percentage time spent by tomato potato psyllid (TPP) on each behaviour type for each insecticide treatment (activity recorded over a 15 minute period). For each treatment, the upper value (darker colour) is for one day after treatment (DAT), and the lower for 14 DAT. Error bars show 95% confidence limits for the means (omitted when number=0). Abbreviations are as follows: Ch= Chess®, Cy = Cyazypyr™, Pr = Proteus®, Sp = Sparta™, Su= sulfoxaflor, Wa = water (control).

3.2 Five-insecticide trial: Adult mortality, egg-laying and egg hatching

At 1 DAT neither total numbers of TPP nor number of female TPP varied significantly between the treatments (p=0.887, 0.965 respectively, Table 9 & Figure 7). There was an average of 33.8 TPP per cage, with an average of 16.4 females. However, the total number of eggs per caged leaf and the number of eggs per female varied between the treatments (p<0.001, Table 9 & Figure 7). The number of eggs and eggs per female was significantly lower with all the chemicals than in the control (varying from p = 0.035 to p<0.001). Numbers of eggs were reduced least by Chess and Sparta (~30 eggs/ leaf and 1.7 eggs/ female), and most by Proteus (1.8 eggs/ leaf and 0.1 eggs/ female).

Table 9. One day after treatment: Mean total tomato potato psyllid (TPP), total female TPP, eggs per cage and eggs per female (95% confidence limits).

Treatment	Total TPP	Total females	No eggs	Eggs/female
Control	34.1 (30.6,38.0)	16.3 (13.8,19.3)	57.6 (40.8,81.4)	3.8 (2.7,5.4)
Chess®	34.1 (30.6,38.0)	16.6 (14.2,19.4)	30.2 (18.8,48.5)	1.6 (1.0,2.7)
Cyazypyr™	33.1 (29.6,37.0)	17.0 (14.6,19.8)	9.7 (4.2,22.5)	0.6 (0.3,1.4)
Sparta™	35.5 (31.9,39.5)	16.7 (14.3,19.5)	30.6 (19.1,49.1)	1.8 (1.1,2.9)
Proteus®	32.3 (28.9,36.1)	16.1 (13.7,18.9)	1.8 (0.3,12.7)	0.1 (0.0,0.7)
sulfoxaflor	33.7 (30.2,37.6)	15.4 (13.1,18.1)	13.3 (6.5,27.3)	0.9 (0.4,1.7)

At 14 DAT, neither total numbers of TPP nor numbers of female TPP varied significantly between the treatments (p=0.845, 0.567 respectively, Table 10 & Figure 7). There was an average of 36.2 TPP per cage, with an average of 17.6 females. However, the total number of eggs and the number of eggs per female varied between the treatments (p=0.006, p<0.001 respectively, Table 10 & Figure 7). The number of eggs and eggs per female was lower with all the chemicals than in the control, although not significantly so in all cases (p>0.8 for Chess and Sparta treatments; p=0.065 and 0.062 for eggs and eggs/female for Proteus treatment; p=0.029 and 0.003 for Cyazypyr treatment, and p=0.005 and p=0.001 for sulfoxaflor treatment).

Numbers of eggs were reduced least by Sparta (53 eggs/ leaf and 1.8 eggs/ female). Total eggs were reduced most by sulfoxaflor (24 eggs/ leaf and 1.3 eggs/ female).

Table 10. Fourteen days after treatment: Mean total tomato potato psyllid (TPP), total female TPP, eggs per cage and eggs per female (95% confidence limits).

Treatment	Total TPP	Total females	No eggs	Eggs/female
Control	35.9 (32.3,39.9)	17.0 (14.6,19.8)	51.8 (38.4,69.9)	3.0 (2.3,4.0)
Chess®	37.5 (33.8,41.6)	17.3 (14.9,20.1)	50.8 (37.5,68.7)	2.9 (2.2,3.9)
Cyazypyr™	37.1 (33.4,41.2)	19.7 (17.1,22.7)	29.8 (20.1,44.2)	1.5 (1.1,2.2)
Sparta™	36.7 (33.1,40.7)	16.8 (14.4,19.6)	53.0 (39.4,71.3)	3.2 (2.4,4.1)
Proteus®	34.1 (30.6,38.0)	16.5 (14.1,19.3)	33.0 (22.7,48.0)	2.0 (1.4,2.8)
sulfoxaflor	36.0 (32.4,40.0)	18.1 (15.6,21.0)	23.8 (15.3,37.0)	1.3 (0.9,2.0)

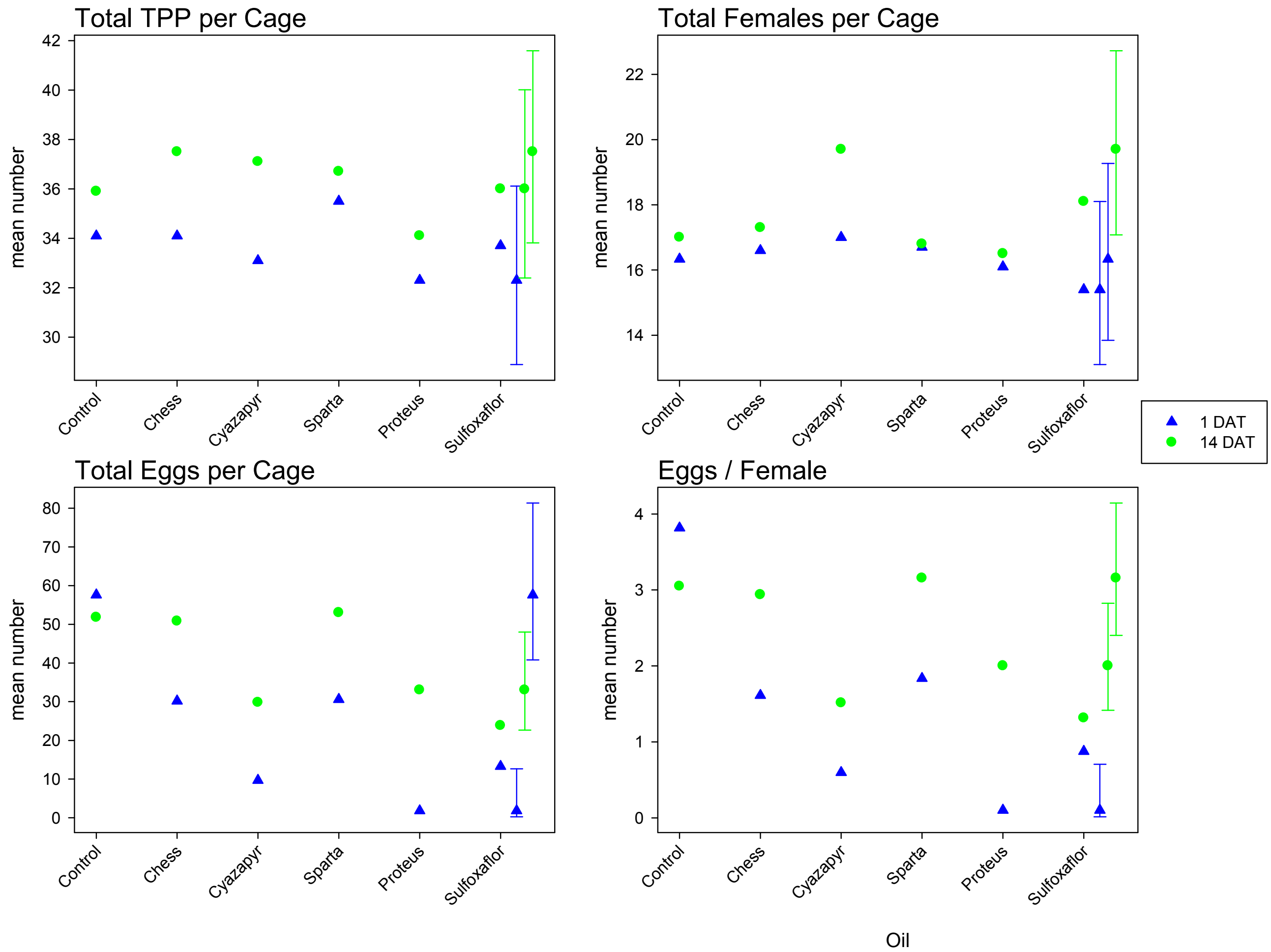

Figure 7. Mean total tomato potato psyllid (TPP), female TPP and eggs per cage and eggs per female, for 1 (blue) and 14 days after treatment (DAT) (green). Error bars show 95% confidence limits for the highest, a mid range, and the smallest mean in each plot.

The percentage of dead TPP varied significantly between the treatments at both 1 DAT ($p<0.001$) and 14 DAT ($p=0.002$) (Table 11 & Figure 8). However, the percentage of unhatched eggs did not vary significantly between the treatments for either 1 or 14 DAT ($p=0.717$ and $p=0.453$ respectively). For both 1 and 14 DAT, the percentage of dead TPP was higher with all five insecticides than in the water control, but not significantly so for all chemicals. ($p= 0.315$, 0.146 for the Chess treatment for 1 and 14 DAT respectively; $p=0.030$ and $p=0.041$ for Sparta treatment; $p=0.023$ and $p=0.025$ for sulfoxaflor treatment; $p<0.001$ and $p=0.078$ for Proteus treatment; and $p<0.001$ for 1 and 14 DAT for Cyazypyr treatment). The percentage of dead

TPP, over and above the controls, was lowest for the Chess treatment (less than 2x the control) and highest for the Proteus (54% mortality, 1 DAT) and Cyazypyr treatments (29% mortality, 14 DAT).

Table 11. Mean percentage of tomato potato psyllid (TPP) dead and mean percentage of unhatched eggs (95% confidence limits). Mortality was assessed after 72 h exposure to treatment residues for exposure periods beginning one day after treatment (DAT) or 14 DAT. Eggs laid during exposure periods were incubated and the percentage of unhatched eggs was recorded after seven days incubation.

Treatment	% TPP dead		% eggs unhatched	
	1 DAT	14 DAT	1 DAT	14 DAT
Control	9.4 (5.3,16.1)	8.1 (4.4,14.4)	18.6 (12.4,26.8)	9.3 (5.4,15.5)
Chess®	13.5 (8.4,20.9)	13.9 (8.9,21.0)	21.9 (13.1,34.1)	9.8 (5.8,16.3)
Cyazypyr™	30.8 (23.1,39.8)	29.1 (21.8,37.6)	21.6 (8.5,45.1)	17.4 (10.5,27.7)
Sparta™	19.4 (13.4,27.3)	16.9 (11.3,24.5)	16.0 (8.8,27.5)	14.2 (9.2,21.1)
Proteus®	53.6 (44.3,62.5)	15.5 (10.0,23.3)	33.3 (5.3,81.8)	14.8 (8.7,24.1)
sulfoxaflor	20.2 (13.9,28.4)	18.1 (12.2,25.9)	30.1 (15.7,49.8)	13.4 (6.9,24.5)

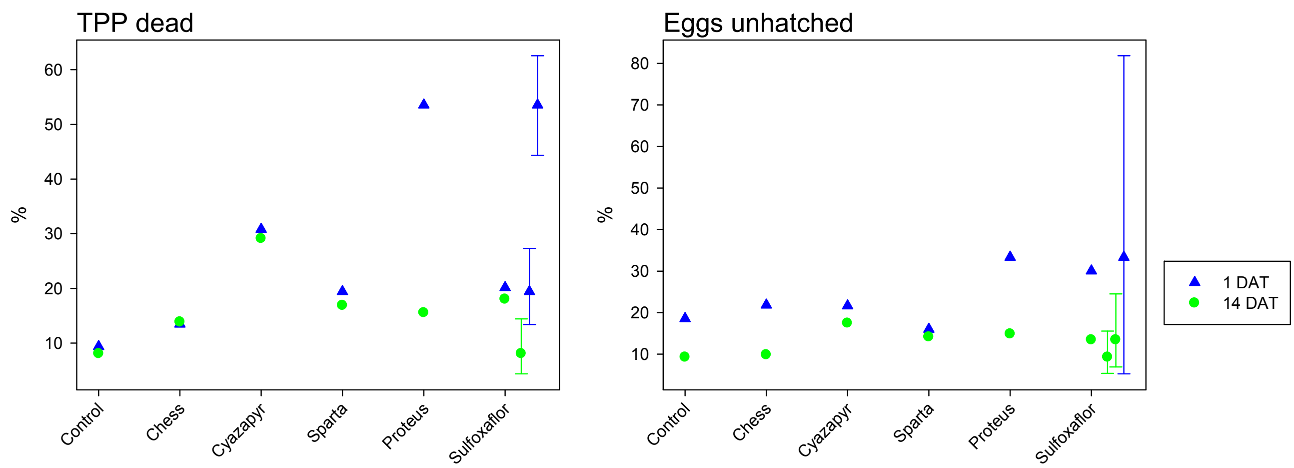

Figure 8. Mean percentage of tomato potato psyllid (TPP) dead and mean percentage of unhatched eggs (95% confidence limits). Mortality was assessed after 72 h exposure to treatment residues for exposure periods beginning one day after treatment (DAT) (blue) or 14 DAT (green). Eggs laid during exposure periods were incubated and the percentage of unhatched eggs was recorded after seven days incubation.

3.3 Movento trial: Adult mortality, egg-laying and egg hatching

Table 12 summarises the measurements made. Eggs were present in all cages of psyllids exposed to leaves 7 DAT, but no eggs were found in three out of the 40 cages set up in the 1 DAT assessment, or in two of the 40 cages set up for the 14 DAT assessment.

Table 12. Summary of data for tomato potato psyllid (TPP) Movento® trial (DAT = days after treatment with insecticide).

DAT	Count	No. of 0s (of 40 cages)	%0s	Max number / cage	Total
1	Total TPP in cage	0	0.0	43	1318
	Total females	0	0.0	23	617
	Eggs	3	7.5	74	394
	Eggs/ female	3	7.5	4	27
7	Total TPP in cage	0	0.0	55	1375
	Total females	0	0.0	24	676
	Eggs	0	0.0	237	3542
	Eggs/ female	0	0.0	13	209
14	Total TPP in cage	0	0.0	39	1281
	Total females	0	0.0	27	602
	Eggs	2	5.0	62	586
	Eggs/ female	2	5.0	3	38

3.3.1 Egg laying

One day after treatment, neither total numbers of TPP nor numbers of female TPP varied significantly between the treatments (p=0.349, 0.141 respectively, Table 13). There was an average of 32.3 TPP per cage, with an average of 15.4 females. The total numbers of eggs per caged leaf and the number of eggs per female also did not vary significantly between the treatments (0.293, 0.229 respectively), although numbers were highest for the controls and lowest for the M2 treatment. There was an average of 9.9 eggs per cage, equivalent to 0.7 eggs per female.

Table 13. One day after treatment: Mean total tomato potato psyllid (TPP) per cage, total female TPP per cage, eggs per cage and eggs per female (95% confidence limits). M1 and control plants received a single spray (of Movento® and water respectively) , M2 plants received two Movento sprays one week apart and M3 plants received two Movento sprays two weeks apart.

Treatment	Total TPP	Total Females	No. Eggs	Eggs/Female
Control	34.0 (30.5,38.0)	14.8 (12.5,17.5)	14.7 (8.5,25.3)	1.0 (0.6,1.7)
M1	30.8 (27.4,34.6)	13.7 (11.5,16.3)	9.6 (4.9,18.8)	0.7 (0.4,1.4)
M2	32.0 (28.6,35.8)	15.5 (13.2,18.2)	5.8 (2.4,13.8)	0.4 (0.2,0.9)
M3	35.0 (31.4,39.0)	17.7 (15.2,20.6)	9.3 (4.7,18.4)	0.5 (0.3,1.1)

Seven days after treatment, neither total numbers of TPP nor numbers of female TPP varied significantly between the treatments (p=0.970, 0.940 respectively, Table 14). There was an average of 34.4 TPP per cage, with an average of 16.9 females. However, the total number of eggs and the number of eggs per female varied between the treatments (p<0.001). The numbers of eggs per cage and eggs per female were significantly lower in all the chemical treatments than in the control (varying from p=0.003 to p<0.001). Numbers of eggs were reduced least by M2 treatment (84 eggs/ cage and 5.0 eggs/ female), and most by M1 (42 eggs/ cage and 2.4 eggs/ female).

Table 14. Seven days after treatment: Mean total tomato potato psyllid (TPP), total female TPP, eggs per cage and eggs per female (95% confidence limits). M1 and control plants received a single spray (of Movento® and water respectively) , M2 plants received two Movento sprays one week apart and M3 plants received two Movento sprays two weeks apart.

Treatment	Total TPP	Total females	No eggs	Eggs/female
Control	34.6 (30.0,39.9)	17.2 (14.7,20.1)	156.5 (124.2,197.1)	9.1 (7.4,11.1)
M1	35.2 (30.6,40.5)	17.4 (14.9,20.3)	42.1 (27.0,65.7)	2.4 (1.6,3.6)
M2	34.1 (29.6,39.3)	16.6 (14.2,19.4)	83.7 (61.0,114.8)	5.0 (3.8,6.6)
M3	33.6 (29.1,38.8)	16.4 (14.0,19.2)	71.9 (51.1,101.1)	4.4 (3.3,5.9)

Fourteen days after treatment, neither total numbers of TPP nor the numbers of female TPP varied significantly between the treatments (p=0.823, 0.741 respectively, Table 15, Figure 9). There was an average of 32.0 TPP per cage, with an average of 15.1 females. The total number of eggs and the number of eggs per female did not vary significantly between the treatments (p=0.102, 0.117 respectively). The number of eggs per cage and eggs per female was lower in the M1 and M3 treatments than in the control, and higher in M3, but not significantly so in any case ($0.18<p<0.91$).

Table 15. Fourteen days after treatment: Mean total tomato potato psyllid (TPP), total female TPP, eggs per cage and eggs per female (95% confidence limits). M1 and control plants received a single spray (of Movento® and water respectively) , M2 plants received two Movento sprays one week apart and M3 plants received two Movento sprays two weeks apart.

Treatment	Total TPP	Total females	No eggs	Eggs/female
Control	31.7 (28.3,35.5)	14.5 (12.3,17.2)	14.5 (8.1,26.1)	1.0 (0.6,1.7)
M1	31.4 (28.0,35.2)	14.3 (12.1,16.9)	10.7 (5.4,21.2)	0.7 (0.4,1.4)
M2	33.5 (30.0,37.4)	15.4 (13.1,18.1)	9.5 (4.6,19.6)	0.6 (0.3,1.2)
M3	31.5 (28.1,35.3)	16.0 (13.6,18.8)	23.9 (15.1,37.8)	1.5 (1.0,2.3)

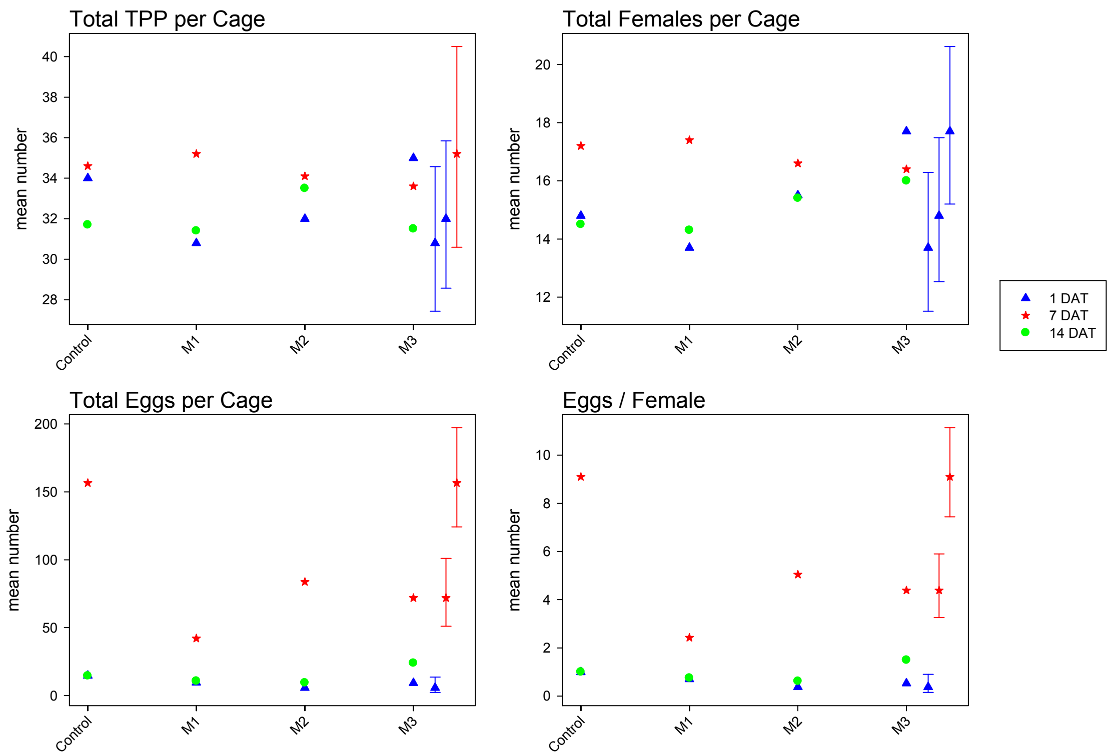

Figure 9. Mean total tomato potato psyllid (TPP), female TPP and eggs per cage and eggs per female, for 1 (blue) 7 (Red), and 14 days after treatment (DAT) (green). Error bars show 95% confidence limits for the highest, a mid range, and the smallest mean in each plot. M1 and control plants received a single spray (of Movento® and water respectively) , M2 plants received two Movento sprays one week apart and M3 plants received two Movento sprays two weeks apart.

3.3.2 Mortality and egg hatching

The percentage of dead TPP did not vary strongly between the treatments at any of the assessments (p=0.567, 0.108, 0.892 for 1, 7 and 14 DAT for the overall difference between treatments, Table 16 & Figure 10). However, at 7 DAT, mortality was higher with the M3 treatment (p=0.022) than in the control.

Table 16. Percentage tomato potato psyllid (TPP) dead (95% confidence limits). M1 and control plants received a single spray (of Movento® and water respectively), M2 plants received two Movento sprays one week apart and M3 plants received two Movento sprays two weeks apart. Mortality was assessed after 72 h exposure to treatment residues for exposure periods beginning one day after treatment (DAT), 7 DAT or 14 DAT.

Treatment	1 DAT	7 DAT	14 DAT
Control	13.8 (9.0,20.6)	9.8 (4.7,19.3)	19.6 (13.7,27.1)
M1	11.7 (7.1,18.6)	18.5 (11.1,29.2)	16.2 (10.9,23.5)
M2	17.2 (11.6,24.7)	15.5 (8.8,26.1)	17.3 (11.9,24.4)
M3	16.3 (11.1,23.3)	25.3 (16.4,36.9)	16.8 (11.4,24.1)

The percentage of unhatched eggs varied between the treatments for all three assessments (p=0.001, 0.002, 0.013 for 1, 7 and 14 DAT, Table 17). Egg mortality was higher than in the control with all three treatments at each of the assessments, although not strongly significantly so in all cases (0.0001<p<0.08).

Table 17. Percentage unhatched tomato potato psyllid (TPP) eggs (95% confidence limits). M1 and control plants received a single spray (of Movento® and water respectively) , M2 plants received two Movento sprays one week apart and M3 plants received two Movento sprays two weeks apart. Assessments were made 1, 7 and 14 days after treatment (DAT).

Treatment	1 DAT	7 DAT	14 DAT
Control	6.8 (2.9,15.2)	5.7 (3.5,9.2)	4.1 (1.5,10.9)
M1	18.7 (10.1,32.1)	12.1 (6.4,21.9)	19.6 (11.7,31.0)
M2	44.8 (28.2,62.7)	12.9 (8.3,19.5)	17.9 (10.0,29.9)
M3	22.6 (12.9,36.6)	18.8 (12.8,26.7)	10.9 (6.8,17.1)

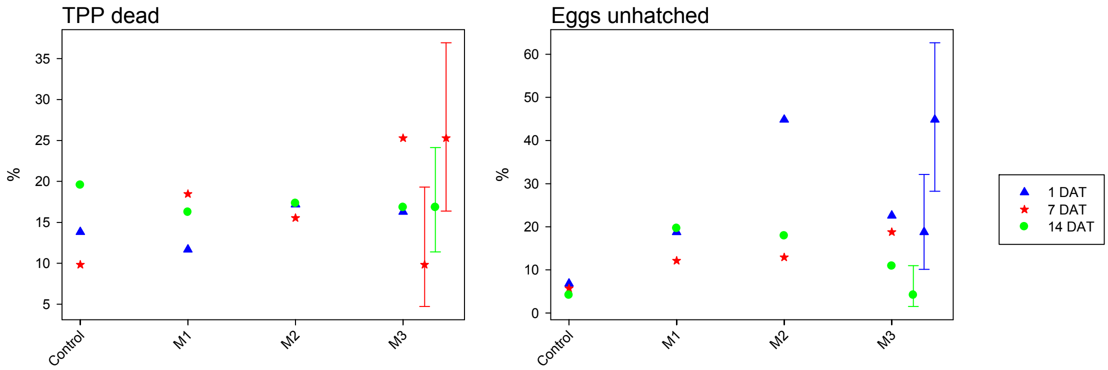

Figure 10. Mean percentage of dead tomato potato psyllids (TPP) and percentage of eggs unhatched for 1 (blue), 7 (red) and 14 days after treatment (DAT) (green). Error bars show 95% confidence limits for the highest, a mid range, and the smallest mean in each plot. M1 and control plants received a single spray (of Movento® and water respectively) , M2 plants received two Movento sprays one week apart and M3 plants received two Movento sprays two weeks apart. Assessments were made 1, 7 and 14 DAT.

4 Discussion

Understanding the actions of insecticide residues is crucial to achieve optimal application intervals and effective crop protection. The present study has demonstrated that some insecticides tested are capable of reducing egg-laying and increasing mortality of adult TPP for at least 14 days. Specifically, residues of Cyazypyr, sulfoxaflor and Sparta increased adult mortality. 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). In addition, 14-day-old residues of Sparta and Cyazypyr and sulfoxaflor halved the egg laying rate of female TPP, even under the no-choice situation created in the present trials. One-day-old residues of sulfoxaflor and Proteus reduced feeding, and increased off-leaf time, suggesting both anti-feeding and repellency effects. Significant differences in feeding activity were not detected in the behavioural assay at 14 DAT, but the sensitivity of the assay may have been reduced by methodological issues (see Sections 2.1 & 2.4).

Three of these insecticides (Cyazypyr, sulfoxaflor and Sparta) are relatively new chemistries. Cyazypyr is a registered trade name of the active ingredient cyantraniliprole, developed by Dupont (DuPont Code: DPX-HGW86). Cyantraniliprole is a second generation ryanodine receptor insecticide with cross-spectrum activity (i.e. active against Lepidoptera, Hemiptera and other sucking or chewing insects) with both foliar and systemic activity (Cornwell 2012). Importantly, unpublished studies suggest cyantraniliprole stops targeted pests from feeding within minutes (Cornwell 2012) and may therefore prevent the transmission of pathogens such as Lso. Cyantraniliprole is pending registration in New Zealand for use on potato, tomato and onion crops. The specific product that has been proposed for use in New Zealand is DuPont Benevia®, a 10% oil dispersion formulation. To date there is little published information available on this product.

Sulfoxaflor is the first active ingredient to be developed from the sulfoximine class of insecticides, a novel class of nicotinic acetylcholine receptor agonists that has been discovered by Dow AgroSciences (Babcock et al. 2011). Laboratory studies indicate that activity of sulfoxaflor is equivalent or superior to the neonicotinoid insecticides for control of several important sap-sucking pests (Babcock et al. 2011). In addition, field studies suggest sulfoxaflor has residual activity up to 16 days after application and that the degree of residual activity is equivalent to or better than neonicotinoid residual activity against aphids and other sap-sucking insects (Babcock et al. 2011). Research trials with TPP are underway elsewhere, but to date there is little published information on the use of this insecticide to control TPP. In 2011, an application was made for the importation of a Dow product (GF-2032, a.i. sulfoxaflor) into New Zealand.

Sparta was registered in New Zealand for use on potatoes by Dow AgroSciences in 2010. The active ingredient of Sparta is spinetoram, which works by both contact and ingestion activity. Sparta belongs to the spinosyn group of insecticides. To our knowledge, there are no published studies on the behavioural response of TPP to Sparta. However, Sparta was included in a previous SFF-funded glasshouse study (Page-Weir et al. 2012). This previous work showed that Sparta had residual activity against TPP for up to 28 days. Percent mortality of psyllid adults was significantly higher than in the control for all time points assessed (except 7 DAT) through the four-week study (46% adult mortality 1 DAT, 51% 3 DAT, 53% 7 DAT, 72% 17 DAT, 59% 21 DAT and 31% 28 DAT). Psyllids laid significantly fewer eggs on Sparta-treated leaves than on control leaves and this effect persisted for 21 days after treatment (100% reduction in egg-laying compared with control 1 DAT, 97% 3 DAT, 75% 7 DAT, 86% 17 DAT, 86% 21 DAT). The present study confirms that Sparta has appreciable residual activity even when exposed to weathering and UV degradation. Spinosad is a related insecticide, and behavioural assays have shown that spinosad reduces feeding activity of TPP on tomato varieties 1 DAT (Liu & Trumble 2004).

Proteus is another relatively new option for psyllid control in New Zealand and is a co-formulation of a neonicotinoid (thiacloprid) and a pyrethroid (deltamethrin). It is a contact and systemic insecticide, providing both knockdown and residual action. In the present study Proteus had a pronounced effect one day after treatment, increasing cleaning and jumping behaviour, increasing adult mortality, reducing the duration of feeding episodes, and reducing numbers of eggs laid. The effects of the insecticide were not as pronounced at 14 DAT: adults exposed to 14-day-old residues of Proteus continued to show higher mortality and lay fewer eggs than those on untreated leaves, but the results were not statistically significant.

Chess is an older chemistry, included in this trial because of its potential anti-feeding action. The active ingredient of Chess is pymetrozine, and behavioural assays have shown that pymetrozine can decrease TPP feeding activity on potatoes for up to 14 days (Butler et al. 2011). However, transmission assays indicated that the degree of feeding disruption was not sufficient to reduce Lso transmission at 1 DAT (Butler et al. 2011). In the present study, Chess did not have any significant effect on TPP behaviour or adult mortality 14 DAT. It should be noted that Chess is a slow-acting insecticide, and the mortality rates measured here (after three days of exposure to residues) may have underestimated potential mortality effects.

A separate trial was undertaken to examine the effect of Movento application frequencies. Plants sprayed with a single Movento application were compared with plants sprayed twice with Movento (sprays either 1 week apart or 2 weeks apart). All the Movento treatments significantly reduced egg-laying at 7 DAT compared with the control and reduced egg-hatching at 1 DAT, 7 DAT and 14 DAT. However, there were no significant differences overall in adult mortality and there were no clear differences between the three Movento treatments at any time point assessed. This pattern of results suggests that the additional sprays applied in the M2 and M3 treatments had little effect on residual activity. The previous SFF study (Page-Weir et al. 2012) found that a single application of Movento had no significant impact on adult mortality beyond 3 DAT and no significant effect on egg-laying beyond 7 DAT.

The results of this and previous studies suggest that there are at least four insecticides with residual activity that persists up to 14 days (Table 18). Further research into the anti-feeding and repellency effects of these insecticides are warranted, as they may have the potential to reduce Lso transmission in crops for extended periods. Work at PFR is currently underway to develop additional behavioural bioassays that could be used to improve understanding of TPP responses to insecticide residues. This work is particularly important for the TPP/Lso complex, as TPP readily transmits Lso during feeding and hence conventional control approaches may not be sufficient to prevent Lso disease development within the crop. A recent review suggests that the most valuable and effective strategies to manage Lso are likely to be those that discourage TPP feeding, and that products with substantial TPP deterrence and repellency are likely to be important tools within integrated pest management programmes for the TPP/Lso complex (Munyaneza & Henne 2012).

Table 18. Comparison between this study and previous studies of residue activity (DAT = days after treatment).

Product name	**IRAC group (a.i.)**	**This study**	**Previous SFF study (Page-Weir et al. 2012)**	**Selected behavioural & transmission assays (Butler et al. 2011)**
Proteus®	3A (deltamethrin) and 4A (thiacloprid)	Reduced egg-lay 1 DAT only, reduced feeding 1 DAT only, increased adult mortality 1 DAT only	-	-
GF-2032	4C (sulfoxaflor)	Reduced egg-lay 1+14 DAT, increased adult mortality 1+14 DAT	-	-
Sparta™	5 (spinetoram)	Reduced egg-lay 1 DAT only, reduced feeding 1 DAT only, increased adult mortality 1+14 DAT	Reduced egg lay up to 21 DAT, increased adult mortality up to 28 DAT	-
Avid®	6 (abamectin)	-	Reduced egg-lay up to 7 DAT, increased adult mortality up to 17 DAT	Reduced feeding up to 14 DAT, repellency up to 14 DAT, reduced Lso transmission 1 DAT
Chess®	9B (pymetrozine)	Reduced egg-lay 1 DAT only	-	Reduced feeding up to 14 DAT, repellency up to 14 DAT, no reduction in Lso transmission 1 DAT
DPX-HGW86	28 (cyantraniliprole, Cyazypyr™)	Reduced egg-lay 1+14 DAT, increased adult mortality 1+14 DAT	-	-

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