Getting the most out of *Eretmocerus hayati*, an effective natural enemy of silverleaf whitefly

Dr Paul De Barro
CSIRO Entomology

Project Number: VG08051

VG08051

This report is published by Horticulture Australia Ltd to pass on information concerning horticultural research and development undertaken for the vegetables industry.

The research contained in this report was funded by Horticulture Australia Ltd with the financial support of the vegetables industry.

ISBN 0 7341 3013 9

Published and distributed by:
Horticulture Australia Ltd
Level 7
179 Elizabeth Street
Sydney NSW 2000
Telephone: (02) 8295 2300
Fax: (02) 8295 2399

Horticulture Australia

Horticulture Australia Limited
Project VG08051
(31 August 2012)

FINAL REPORT

Getting the most out of *Eretmocerus hayati*, an effective natural enemy of silverleaf whitefly.

Paul De Barro *et al*.
CSIRO Ecosystem Sciences

HAL Project Number: VG08051

Project Leader's Name: Drs Paul De Barro and Nancy Schellhorn

Mailing Address: CSIRO Ecosystem Sciences
GPO Box 2583, Brisbane, QLD 4001
Phone: 07 3833 5720
Fax: 07 3833 5504

This project has been funded by HAL using the vegetable industry levy and matched funds from the Australian Government.

A list of other key personnel

Dr Felix Bianchi, Wageningen University, Netherlands
Dr Juan Villanueva-Jimenez, Colegio de Postgraduados, Mexico
Dr Nadiah Kristensen, formerly CSIRO Sustainable Ecosystems
Ms Lynita Howie, CSIRO Ecosystem Sciences
Ms Rebecca Garrad, CSIRO Ecosystem Sciences
Ms Anna Marcora, CSIRO Ecosystem Sciences
Mr Andrew Hulthen, CSIRO Ecosystem Sciences
Ms Anne Bourne, CSIRO Ecosystem Sciences
Mr Lino Bin, CSIRO Ecosystem Sciences
Mr David Carey, Department of Agriculture, Fisheries and Forestry, Qld

This is the final report for VG08051 titled 'Getting the most out of Eretmocerus hayati, an effective natural enemy of silverleaf whitefly' which summarised the key findings and outlines plans for future research and industry adoption of better capture of pest control provided by this natural enemy.

Date of report: 31 August 2012

Contents

Media Summary

Silverleaf whitefly (SLW) is a considerable pest of vegetable production. It has a borad host range and is able to develop resistance to insecticides rapidly. To reduce reliance on insecticides CSIRO imported and new species of parasitoid, *Eretmocerus hayati*, and began releasing it in November 2004 (HAL final report VG06029). It established well and has since spread to all major vegetable production areas in Australia where SLW occurs. Following post-release evaluation CSIRO identified that while it was highly effective, grower management practices could either assist or hinder the parasitoid's effectiveness. This research focused on how to get more out of the parasitoid, and better silverleaf whitefly (SLW) control by investigating: what management practices and decisions influence the abundance and distribution of the parasitoid; what features of the landscape influence the capacity of the parasitoid to achieve early colonisation of at-risk crops; and why the introduced *E. hayati* provides better control than the native *E. mundus.* Results were used to provide guidelines to growers that help to integrate control options for SLW. These guidelines were summarised in a user guide which identified a set of practical approaches that growers could adopt and integrate into their farming practice. The guide was prepared in consultation with growers so that the content and layout made sense to them.

Conducting surveys of grower practices, laboratory and field experiments on growers' properties we show that several years post-release of *E. hayati*:

- SLW has significantly decreased in all areas with the worst year being 2006 for Lockyer, 2004 for Bundaberg, and 2008 for Burdekin.
- Growers that improved their farm hygiene had a significant reduction in SLW problems.
- Broad spectrum insecticide to manage insect pests on whitefly host crops is still very prevalent and these insecticides are deadly to the parasitoid. The more that they are used the worse the grower ranked their whitefly problem.
- There are limited chemical options to control SLW that are also soft on *E. hayati*. The extensive use of imidacloprid should be an indication to look for alternatives.
- *E. hayati* lives longer and is more fecund than the native *E. mundus*.
- *E. hayati* has the potential, when not disrupted by broad-spectrum insecticide, to cause a 100 fold decrease in silverleaf whitefly numbers.
- *E. hayati* disperses by flying at distances of tens of metres, flying and wind at distances of hundreds of metres, and primarily wind at distances of kilometres.
- Seasonal crop rotations have the potential to get *E. hayati* into crops faster and keep silverleaf whitefly populations lower for longer

These findings show that *E. hayati* has had a significant impact on SLW populations. With *E. hayati* now available for inundative release, future R&D should focus on assisting growers with its integration into the full complement of pest management decisions for SLW susceptible crops. We also found that *E. hayati* adults survived 4.5 days longer and produced three times as many progeny as *E. mundus* and so may help explain why *E. hayati* performs better in the field in Australia, than *E. mundus*.

Technical Summary

The Problem. Certain silverleaf whitefly pest management practices were disrupting the parasitoid, *Eretmocerus hayati*, and so were impeding the achievement of long-term sustainable silverleaf whitefly control.

The Project Science. Building on the findings from the previous HAL project, *Release, post-release evaluation and habitat management of the silverleaf whitefly parasitoid* Eretmocerus hayati (VG06029), we investigated how to get more out of the parasitoid, and better SLW control by determining: what management practices and decisions influence the abundance and distribution of the parasitoid; what features of the landscape influence the capacity of the parasitoid to achieve early colonisation of at-risk crops; and why the introduced *E. hayati* provides better control than the native *E. mundus.* The findings were summarised in a grower guide.

The Key Research Findings

Survey of Growers and Crop Agronomist on Pest Management for SLW:

- Broad spectrum insecticide is still the predominant means of controlling insects on whitefly host crops in all three major vegetable producing regions (Lockyer Valley, Bundaberg, Burdekin area). These insecticides are highly disruptive to *E. hayati*. The more growers said they used these chemicals the worse they rated their SLW problem.
- SLW has significantly decreased in all areas since releases of *E. hayati* began in November 2004, with the worst year being 2006 for Lockyer, 2004 for Bundaberg, and 2008 for Burdekin.
- Growers that improved their farm hygiene had a significant reduction in SLW problems.
- To reduce SLW numbers the most effective actions are to (1) avoid using broad spectrum insecticides, (2) control broad-leaf weeds, (3) plant near a refuge for the parasitoid (orchards and food plants for beneficial insects are good), and (4) when possible plant strategically to avoid peak SLW times.

Spatially-explicit modelling combined with an on-farm trial – a) dispersal of *E. hayati* – rate and mechanisms; and b) Crop rotations to support early colonization of *E. hayati* into newly planted SLW susceptible crops:

- *E. hayati* disperses by: flying at distances of tens of metres, flying and wind at distances of hundreds of metres, and primarily wind at distances of kilometres.
- *E. hayati* has the potential, when not disrupted by broad-spectrum insecticide, to cause a 100 fold decrease in silverleaf whitefly numbers.
- *E. hayati* can provide the best SLW control when a low-medium suitable crop is planted prior to high-suitable SLW crops.

Laboratory experiment – Why is the introduced parasitoid – *E. hayati* more effective than the native, *E. mundus*?:

- *E. hayati* lives longer and is more fecund than the native *E. mundus*, which may be the key mechanisms explaining the superior SLW control by *E. hayati*.

Extension Highlights. Sixty-eight growers and twenty-two consultants were surveyed; results were communicated at six grower workshops, with ten face-to-face grower collaborators, one University lecture, two grower magazine articles (1 in prep), and two scientific peer-reviewed manuscripts (in press, and in review). The grower guide which summarised the key findings of this study was also produced with the aid of grower input in terms of content and design.

Recommendations. Growers and crop agronomists should follow the recommendations provided in the 'field' guide, including when required, select an insecticide less harmful to *E. hayati*, practice good farm hygiene, control broad-leaf weeds, provide a refuge and/or early-season low-medium suitable crop as part of the rotation prior to planting highly suitable SLW crops. Future R&D should focus on assisting growers to transition from a purely chemical control of their pest management problem, to a more integrated one. Many growers express strong interest in wanting to achieve better SLW control and include *E. hayati* as a main option. However, there are many pests of a single crop, so integrating pest control is a significant barrier to long-term sustainable control of SLW. This is particularly important now that *E. hayati* is available commercially through Bugs For Bugs (www.bugsforbugs.com.au).

Introduction

VG06029 ‘Release, post-release evaluation and habitat management of the silverleaf whitefly parasitoid’ has succeeded in establishing the parasitoid of silverleaf whitefly (SLW), *Eretmocerus hayati*, widely across Australia (De Barro & Coombs 2009). Data gathered has confirmed that *E. hayati* is capable of delivering a high level of control, but that this can be patchy. The observed levels of parasitism of SLW prior to release of E. hayati averaged 3.6±19.2%. Since the release parasitism has increased to an average of 23±5.1%. Given that the post-release period is less than 3 years, the shift in levels of parasitism is remarkable. However, weather events such as drought and inappropriate use of pesticides can disrupt efficacy. Additional releases will not improve this, rather the major gains in achieving effective levels of parasitism will be through knowing how to manipulate the parasitoid in the field. How sustainable the long term control of SLW by *E. hayati* proves to be will depend on knowing how it functions across large regions of agriculture. Research undertaken as part of VG06029 has identified the role of the distance between sources of parasitoids and the time taken to colonise crops. Time to colonization is a key feature in determining the potential for success of the parasitoid and knowing how to manipulate this is likely to be a key feature in managing the pest successfully. The pest, SLW, was influenced by processes at scales greater than 4 kms (the limits of our landscape study). Therefore, our results suggest that one of the best ways to manage SLW is to aid early colonisation of the parasitoid into new plantings, in other words, getting the parasitoid into the crop soon after SLW has first colonised the crop is likely to be one of the critical success factors.

We combined on-farm management decisions with our knowledge of landscape features such as farm layout, provision of refuges and cropping composition to understand the circumstances which increase or decrease the capacity for the parasitoid to effectively control silverleaf whitefly numbers. The objectives include:

1. Determine what management practices and decisions influence the abundance and distribution of the parasitoid.
2. Determine what features of the landscape influence the capacity of the parasitoid to achieve early colonisation of at-risk crops.
3. Produce a grower management guide to how best to encourage the parasitoid to colonise crops and deliver high level of control.

To achieve these outcomes, the research took on three aspects. Firstly, to conduct a survey of grower and consultant behaviours and surrounding land use to determine the ability of *E. hayati* to survive in the landscape. Secondly, to develop a model of crop rotations that would favour survival of *E. hayati* and minimise the outbreak of silverleaf whitefly, and to test the model in the field. Thirdly, to conduct laboratory experiments to evaluate the relative performance of the introduced *E. hayati* compared to the native *E. mundus*. Introductions specific to each section are provided.

This research will then see the final chapter in the current 12 years of research into the control of SLW. The research began in 1995 and focused on gathering and assessing background information. It then progressed into measuring and reducing impact through the use of effective pesticides. This allowed the stabilisation of problem and created a platform on which to move to the introduction of effective natural enemies. Based on releases in the USA, an effective parasitoid was identified, introduced into quarantine in Australia, tested for biosafety and then released. This final stage focuses on how to get the best out *E. hayati* and it is anticipated that this will be the final research activity on SLW for CSIRO.

Section 1

Survey of on-farm activities that influence survival of *E. hayati* in the field

1. Survey of on-farm activities that influence survival of *E. hayati* in the field

Introduction

Silverleaf whitefly (*Bemisia tabaci* biotype B) arrived in Australia in 1994. It is one of the world's most invasive insects (Invasive Species Specialist Group 2012) with a reputation for quickly developing resistance to insecticides (Palumbo *et al*. 2001). Shortly after the arrival of silverleaf whitefly, entomologists at CSIRO started looking for a biocontrol solution. T he experiences with biocontrol agents elsewhere and available CLIMEX models pointed to *E. hayati* as a potential solution (De Barro and Schellhorn 2008). After much specificity testing, *E. hayati* was released and successfully became established in Australia between 2004 and 2008 (De Barro and Schellhorn 2008). However, anecdotal evidence from the Lockyer Valley suggests that *E. hayati* numbers can drop between seasons to levels that are too low to provide significant pest control.

Given that *E. hayati* has become established, and can be highly effective, a better understanding of grower silverleaf whitefly control practices, which could be impacting on *E. hayati* survival, was needed. Therefore, a survey of grower practices and consultant recommendations was conducted as a logical way to gather this information. Two previous surveys provided some understanding of grower attitudes and beliefs toward biological control and *E. hayati* (Heisswolf and Kay 2007; Schellhorn 2007). Both previous surveys, however, focused on f inding out what growers and consultants knew about whitefly and *E. hayati*, where they gained that information and whether that information had caused them to make a practice change. Both surveys did report that Confidor (imidacloprid) was the main insecticide used by growers to control whitefly and Heisswolf and Kay (2007) also noted that there was some change towards using softer insecticides to protect parasitoids, with increased monitoring and improved farm hygiene. However neither of these surveys provided a clear picture of the environment in which *E. hayati* needed to survive. Furthermore, neither survey used a grower 'self-assessment score' to relate practices with the severity of their silverleaf whitefly problem. The survey was developed after: 1) extensive consultation with DPI staff, 2) characterisation of the different landscapes in terms of the various crops and non-crop habitat grown in the different regions, and 3) discussion and refinement with the independent consulting company.

The types of questions asked included: 'What is it about the landscape, what is going on in that landscape, and on-farm practice that is impacting on silverleaf whitefly populations and survival of *E. hayati*?' In addition, growers were asked to self assess their whitefly problem and whether the problem was improving, including how they diagnosed their whitefly problem; the information used to decide to actively manage whitefly; and what they did to manage whitefly. Consultants were asked about their spray recommendations and their experiences with silverleaf whitefly.

This information allowed the comparison of growers' perceived whitefly problem against their whitefly management practices and surrounding land-uses. Consequently, an the survey provided an indication of the challenges to *E. hayati* survival, thus what changes to improve *E. hayati* survival could be made, and shared, with growers.

Method

Survey design

The survey was designed to capture the decision process of growers and consultants for managing silverleaf whitefly (*Bemisia tabaci* (biotype B)) (SLW). In particular, how those decisions impacted on the survival or *Eretmocerus hayati* and the drivers behind those decisions. To understand their answers, several questions were included to capture the respondents' demography and crops they grew or provided pest management support, and the scale of their SLW problem. Through several iterations, the spatial ecology team developed and reviewed survey questions for the purpose of gaining information about on-farm practices and pest control decision-making.

Two surveys were conducted in three major growing regions; one survey of growers and the other of consultants that make recommendations to growers in the Lockyer Valley, Bundaberg and Burdekin region.

Conducting the survey

We contracted J&R Coutts, a company specialising in rural surveys, to conduct the surveys by telephone. The contacts for growers and consultants were sourced DPI grower lists, crop consultants and previous grower collaborators. Telephone interviews occurred between November 2009 and February 2010.

Analysing the results

Nancy Schellhorn, Anne Bourne and Lynita Howie analysed the results of the survey. Responses were considered as a whole and grouped into the three growing regions. The survey questions (shown in grey), results, and interpretation follow.

Results and Discussion

Grower Survey

1. What is your role in the farming industry? (please tick all that apply)

☐ Farm owner
☐ Farm manager
☐ Farm worker
☐ Other ___________________________

The majority of respondents were farm owners (92%). T hree respondents each identified as farm workers or managers while one respondent identified as a grower and one was a nursery director (Figure 1).

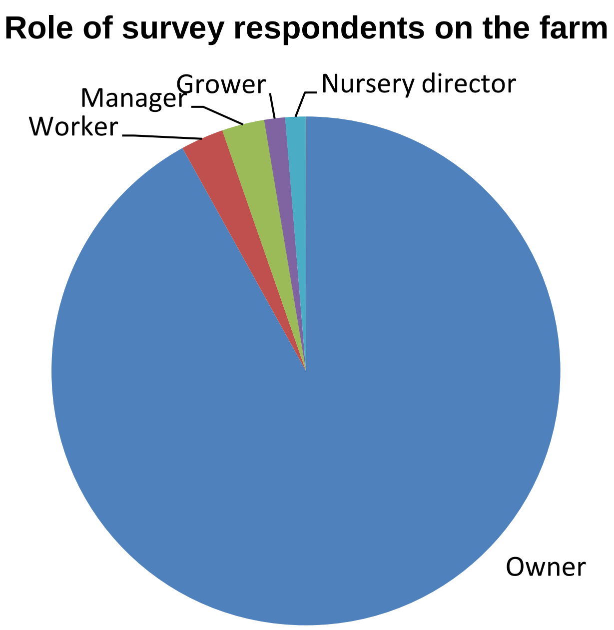


Figure 1. The role of survey respondents on the farm

2. How long have you been farming for? _______ Years

On average, growers from the Lockyer Valley had been farming slightly longer (31 years) than those from Bundaberg (25 years) or the Ayr/Burdekin/Bowen region (22 years). The length of time respondents had been farming was not significantly different in the three regions (Figure 2).

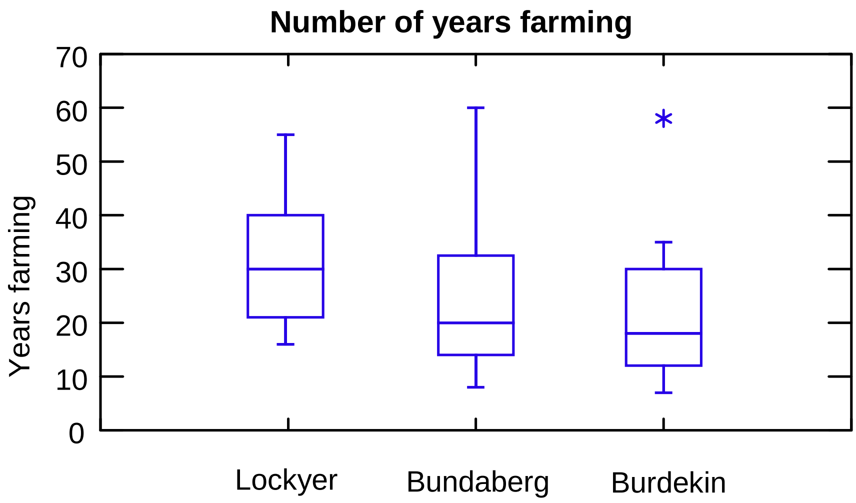


Figure 2. The numbers of years that growers had been farming by location.

3. Which district is closest to you?

☐ Burdekin Region
☐ Bundaberg
☐ Lockyer

A total of 68 growers completed the survey by telephone interview from the three Queensland growing regions. More than half were from the Lockyer (Figure 3). The Burdekin region encompasses the region between Ayr and Bowen, including Gumlu and Home Hill, referred to as the Burdekin region.

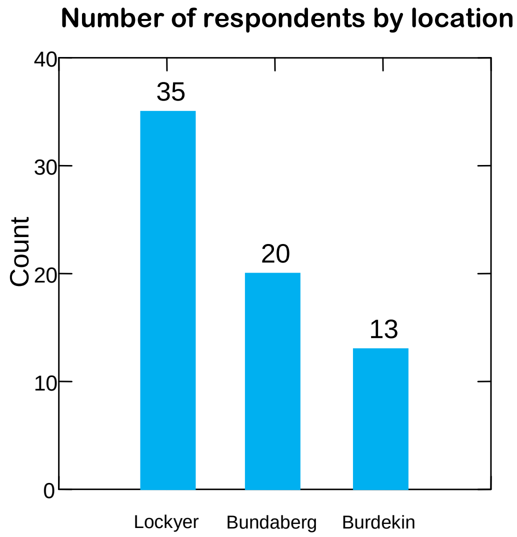


Figure 3. Number of growers participating in the survey from each of the three locations.

4. Please rate the primary industries below in order of what you grow most (if an option is not applicable to you, please leave it blank)

☐ Vegetables
☐ Cane
☐ Cotton
☐ Other ______________________________

Nearly two thirds of growers listed vegetables as the primary industry most important for their farm. The primary focus of growers in Bundaberg and the Burdekin region is either cane or vegetables, whereas in the Lockyer Valley the primary focus for the majority of growers is vegetables, with a minority stating that lucerne was their most important crop. B y far the greatest percentage of vegetable growers is from the Lockyer Valley. Cane was the highest priority for a significant portion of growers in the northern regions, but absent from the Lockyer Valley (Figure 4).

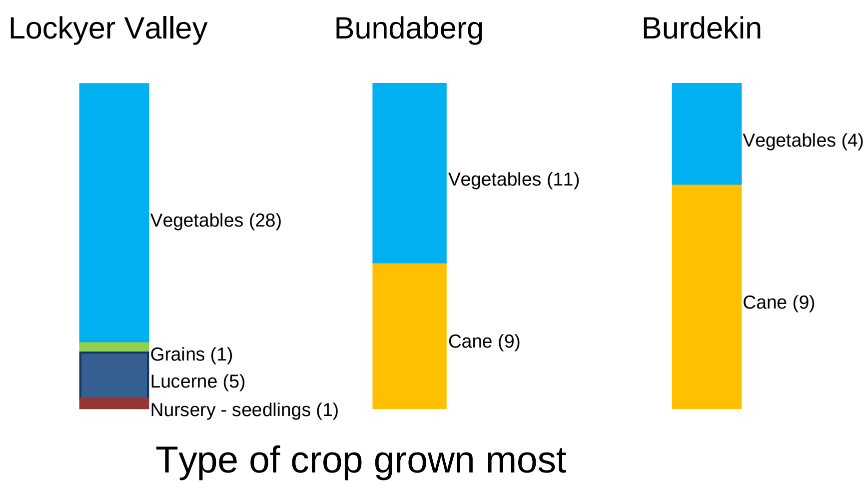


Figure 4. The crop type that is the main focus for growers by location

5. What other land use categories apply to your property? (please tick all that apply)

☐ Pasture
☐ Weedy fallow
☐ Stands of vegetation / trees (native or otherwise)
☐ Watercourse / Dam
☐ Fruit / nut orchards, eg. avocado, banana, custard apple, lychee, mango, passionfruit, stone fruit, citrus
☐ No other land use category applies to my property
☐ Other ___________________________

6. What land use categories apply to properties adjacent to yours? (please tick all that apply)

☐ Similar to mine
☐ Forestry / National park
☐ Watercourse / Dam
☐ Fruit / nut orchards
☐ Cotton
☐ Pasture
☐ Weedy fallow
☐ Vegetables
☐ Cane
☐ Other ___________________________

To establish if surrounding land use impacted on the whitefly management practices, or the perceived whitefly problem, growers were asked about the land uses conducted on their property and their neighbours' property. The biggest difference between the three areas was the significant presence of cane in the northern landscapes, listed as the second most common land use in Bundaberg and most common land use in the Burdekin region. Cotton was only present in the Burdekin region while vegetation, appears to be absent from Burdekin properties (or adjacent properties). Fruit or nut orchards were more common in Bundaberg and Burdekin than in the Lockyer (Figure 5). 70% of respondents said that their neighbour's farms were similar to their own.

Land uses on the growers own property or neighbouring property

Lockyer	#	Bundaberg	#	Burdekin	#
Vegetables	35	Vegetables	31	Cane	14
Watercourse/Dam	29	Cane	26	Vegetables	11
Pasture	23	Watercourse/Dam	16	Fruit/Nuts	4
Vegetation	15	Vegetation	14	Watercourse/Dam	3
Lucerne	11	Fruit/Nuts	9	Pasture	3
grains	4	Fallow	7	Cotton	2
Fallow	4	Peanuts	1	Corn	1
Fruit/Nuts	2	Cover crops	1		
Fodder	2	Small crops	1		
Forestry/NP	2	Forestry/NP	1		
Seedling Nursery	1	Pasture	1		

Figure 5. Number of growers listing a land use on their own property or a neighbour's property.

7. What size (cultivated area) is your property? ______Ha

Property sizes varied from 0.202 Ha in the Lockyer Valley to 2000 Ha in the Burdekin region, with Burdekin properties being the largest. The 2000 Ha farm has been omitted from Figure 6 below for clarity. The average sizes of properties in the different regions were: 87 Ha (Lockyer), 113 Ha (Bundaberg) and 390 Ha (Burdekin) (Figure 6). The area captured in the survey for each area was 3040 Ha (Lockyer), 2660 Ha (Bundaberg) and 5000 Ha (Burdekin).

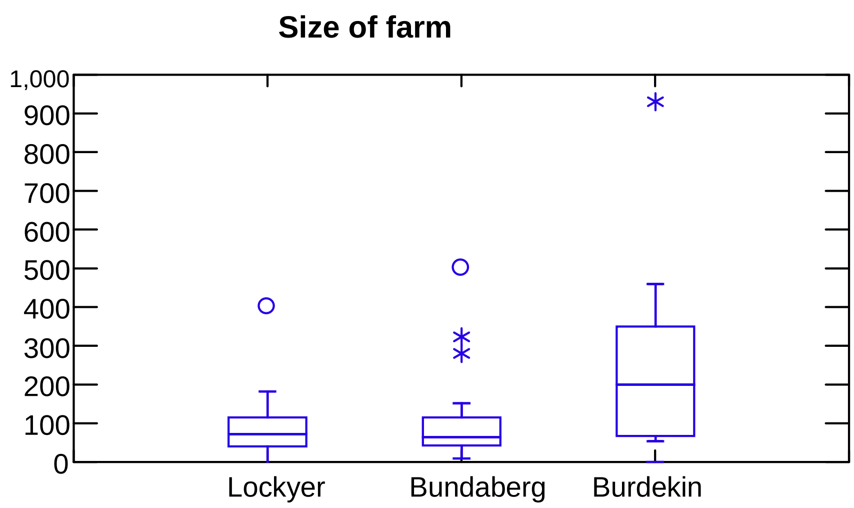


Figure 6. Property sizes by location

8. When you plant, do you tend to plant:

☐ The same crops together in adjacent fields
☐ The same crops spread out across your farm
☐ Other ________________________________
☐ Not applicable to me ________________________________

In Bundaberg and Burdekin it was more common for growers to spread similar crops across the farm, rather than plant similar crops next to each other. Growers from the Lockyer Valley are more likely to plant similar crops next to each other (Figure 7).

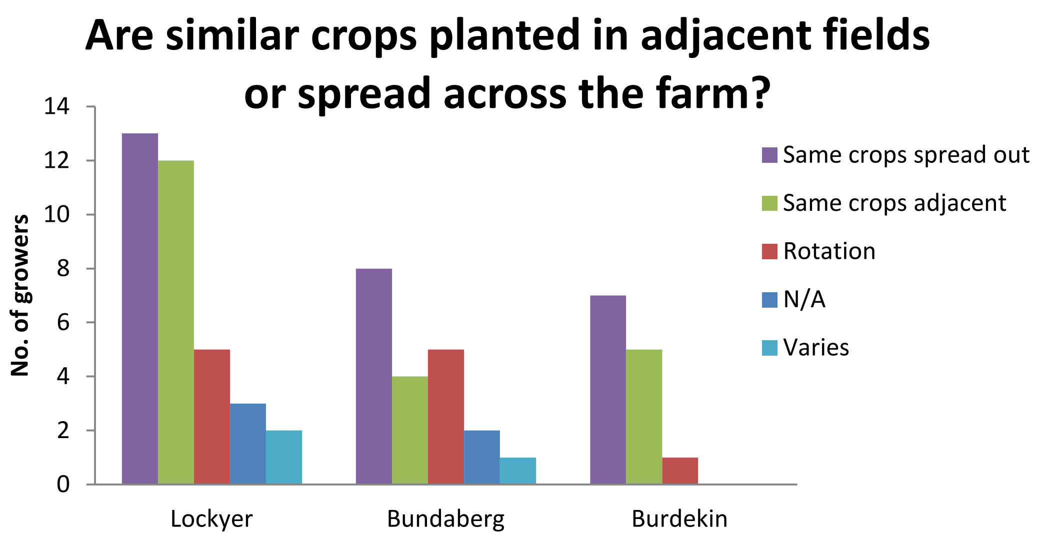


Figure 7. Spatial arrangement of crops on a farm by location.

9. When you plant, do you tend to:

☐ Plant the same crop in several fields about the same time
☐ Stagger the planting of the same crop in several fields over time
☐ Other ____
☐ Not applicable to me ____

In all areas, more growers staggered their crops rather than plant them all at the same time (Figure 8).

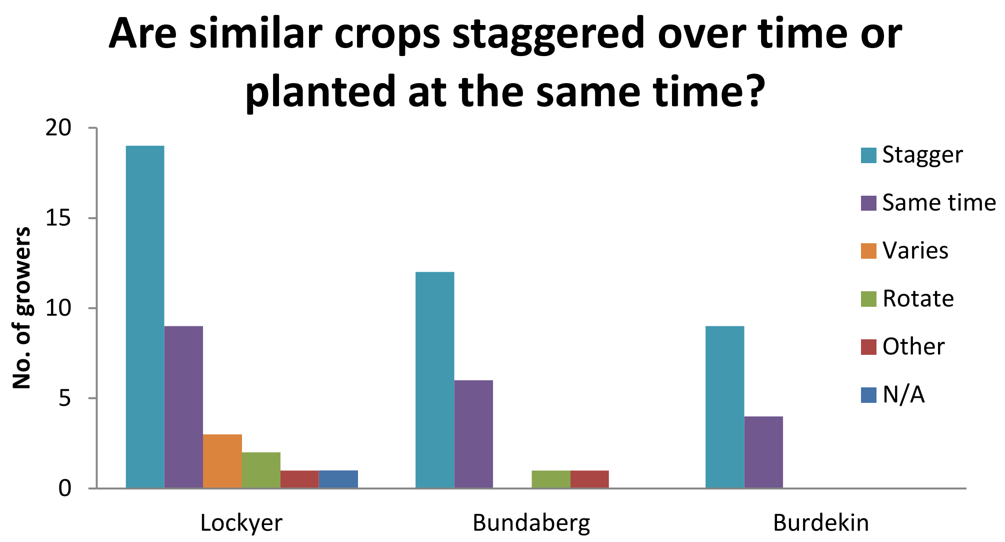


Figure 8. Temporal arrangement of crops on a farm by location.

10. In which year was whitefly worst for you? __________

The whitefly problem peaked earliest in the Lockyer Valley and latest in the Burdekin region. Only one grower in the Lockyer Valley reported that the worst year for whitefly was later than the summer of 2006/2007 (Figure 9), whereas all but one grower from the Burdekin region said the worst year for whitefly was 2008 or later (Figure 11). Around Bundaberg the response is more varied, with most growers reporting the worst year as between 2004 and 2010 (Figure 10).

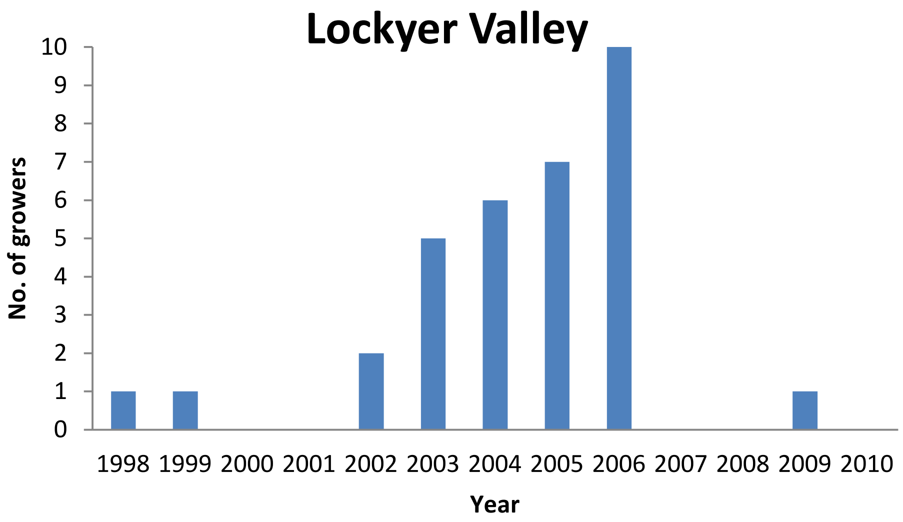


Figure 9. The year that whitefly was worst for growers from the Lockyer Valley.

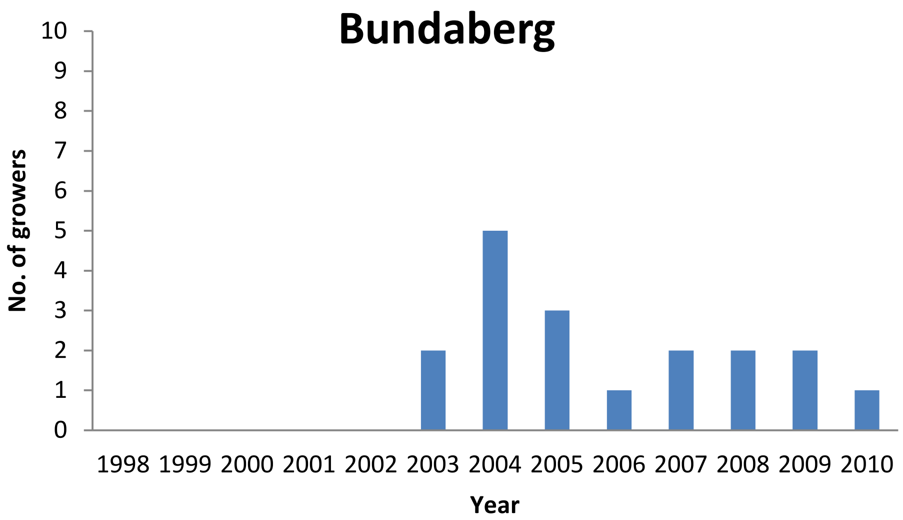


Figure 10. The year that whitefly was worst for growers from around Bundaberg.

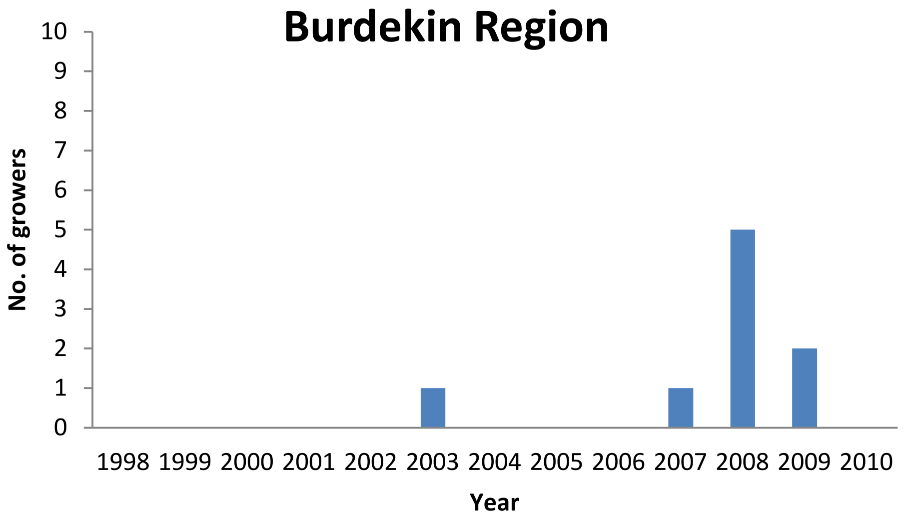


Figure 11. The year that whitefly was worst for growers from the Burdekin region.

How much of a problem was whitefly for you during that year? (please circle)

1	2	3	4	5	6	7	8	9	10
No problem		Minor problem		Occasional problem		Significant problem		Catastrophic problem	

11. How much of a problem is whitefly for you now? (please circle)

1	2	3	4	5	6	7	8	9	10
No problem		Minor problem		Occasional problem		Significant problem		Catastrophic problem	

Growers were asked how bad their current whitefly problem was on a scale of one (no problem) to ten (catastrophic problem). They were also asked which year was the worst year for whitefly pest problems and how bad the problem was in that year. These results are shown for each location in Figures 12, 13 and 14, respectively. The thick black line represents the average for that area. The whitefly problem has significantly decreased in all three areas. The whitefly problem in the Lockyer Valley peaked first and has now declined to a low level. The whitefly problem in the Burdekin region peaked most recently and, despite showing a sharp decline in the problem, is still more of a problem than in the other two areas. As the whitefly problem peaked much later in Burdekin, the full effect of whitefly management strategies may not yet have been realised.

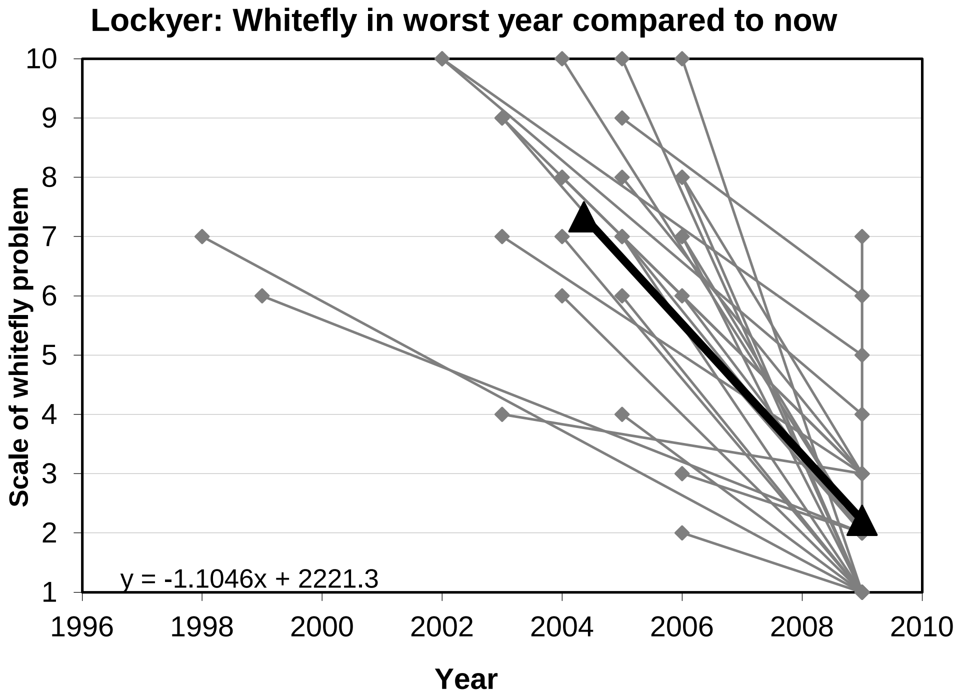


Figure 12. The whitefly problem in the worst year and in the current year for the Lockyer Valley.

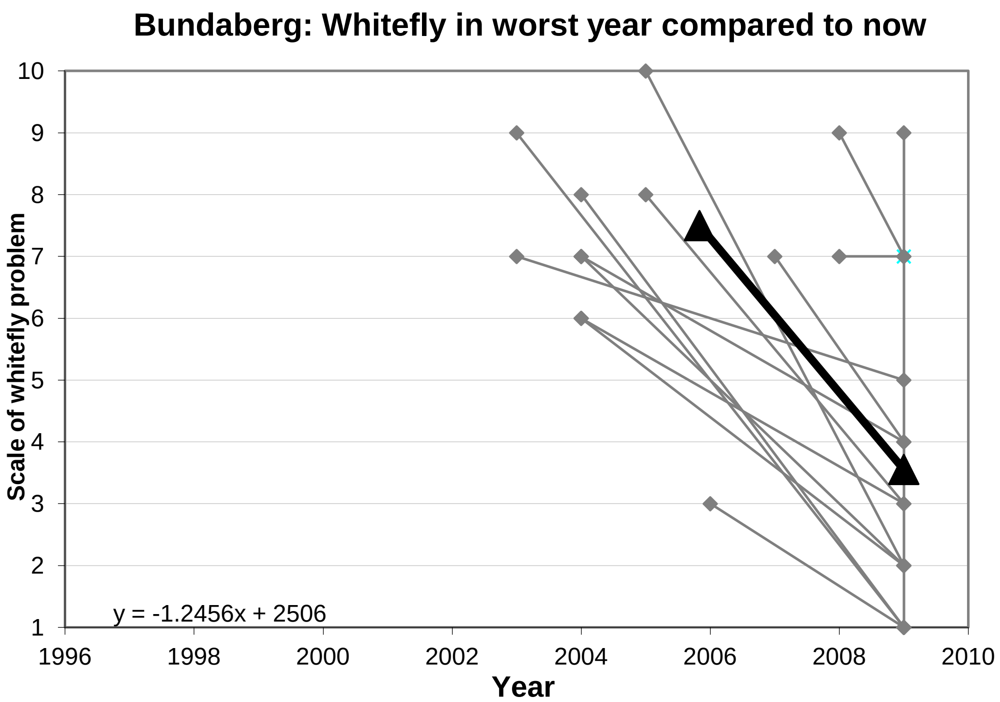


Figure 13. The whitefly problem in the worst year and in the current year for Bundaberg.

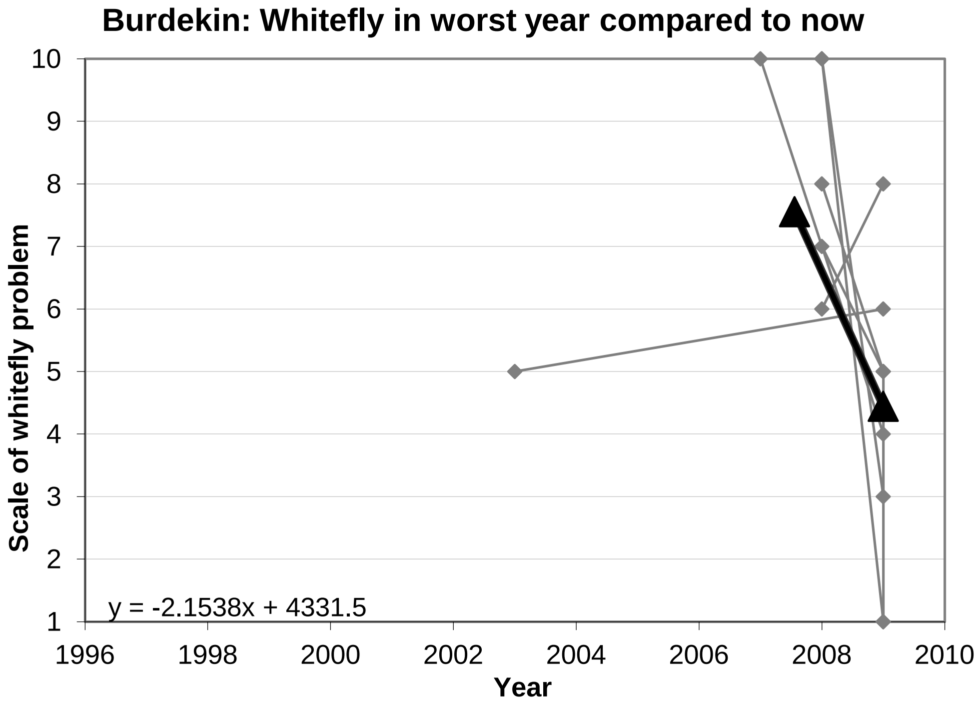


Figure 14. The whitefly problem in the worst year and in the current year for the Burdekin region.

On average, all areas ranked the current whitefly problem as minor, however some respondents from both Bundaberg (n = 4) and Burdekin (n = 2) reported the current whitefly problem was significant or worse giving it a score of 7 or more (Figure 15).

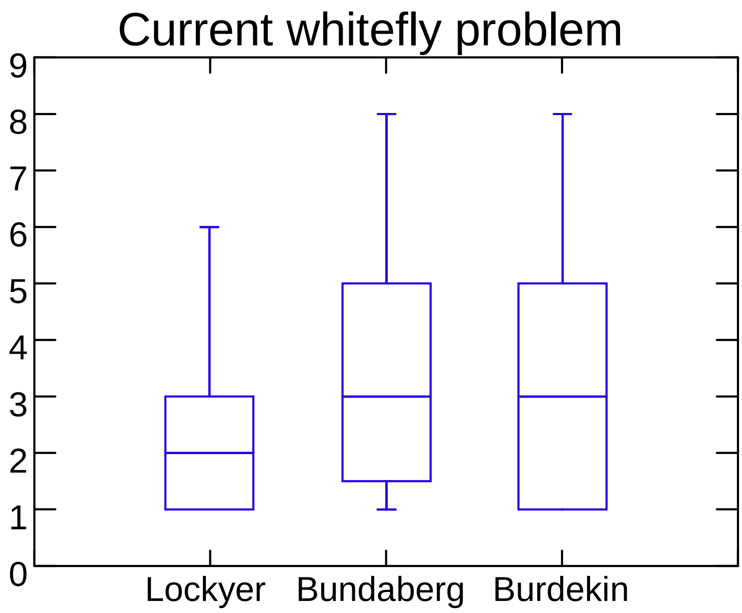


Figure 15. Current whitefly problem by location

Some growers experienced a big improvement in their whitefly problem from the worst year to the current year, by comparing the improvement in the scores of the growers in the Locker Valley with their farm practices, the survey revealed what practices resulted in the greatest improvement. Two factors were significant using a t-test. Firstly, growers that had changed how they controlled for whitefly reduced their whitefly problem score by 5.7 points on average between the worst and the current year. By comparison, those that hadn't changed their practices only reduced their whitefly problem score by 3.7 points on average between the worst and the current year (p = 0.007) (Figure 16). Secondly, growers that had improved their farm hygiene reduced their whitefly score by 6.8 points on average between the worst year and current year whereas those that hadn't improved their farm hygiene only reduced their whitefly score by 4.5 points on average between the worst year and the current year (p = 0.034) (Figure 17).

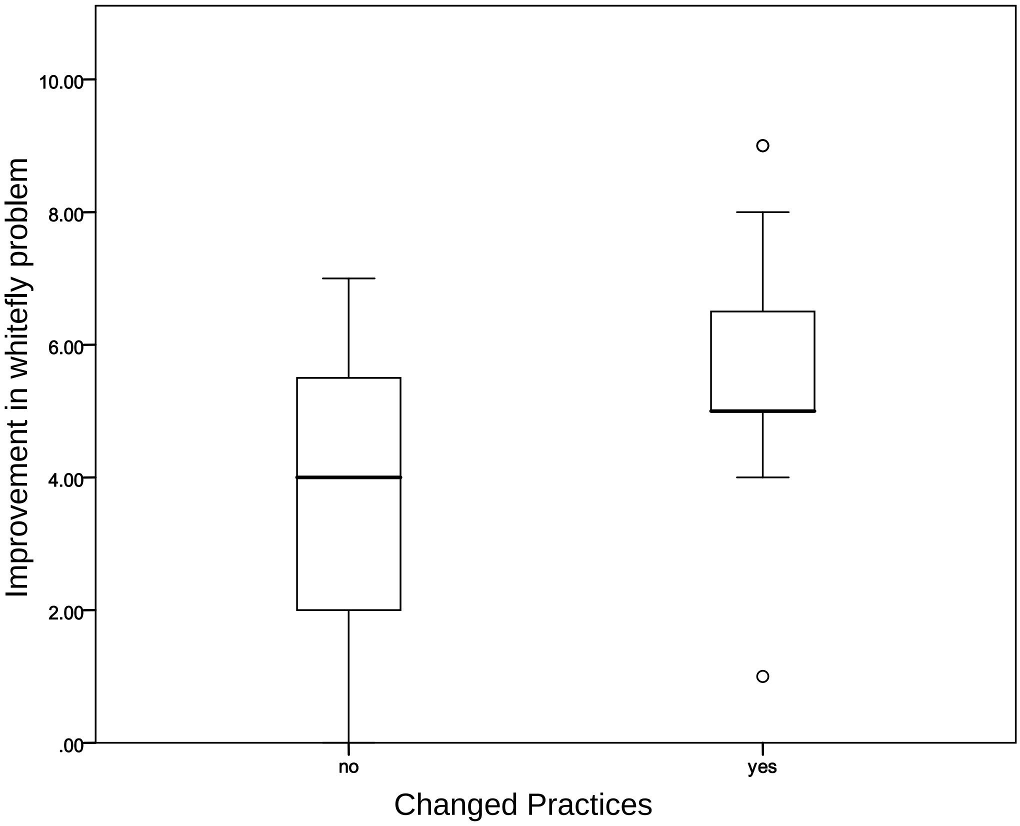


Figure 16. Improvement in whitefly problem for growers in the Lockyer Valley that had or had not changed their whitefly management practices.

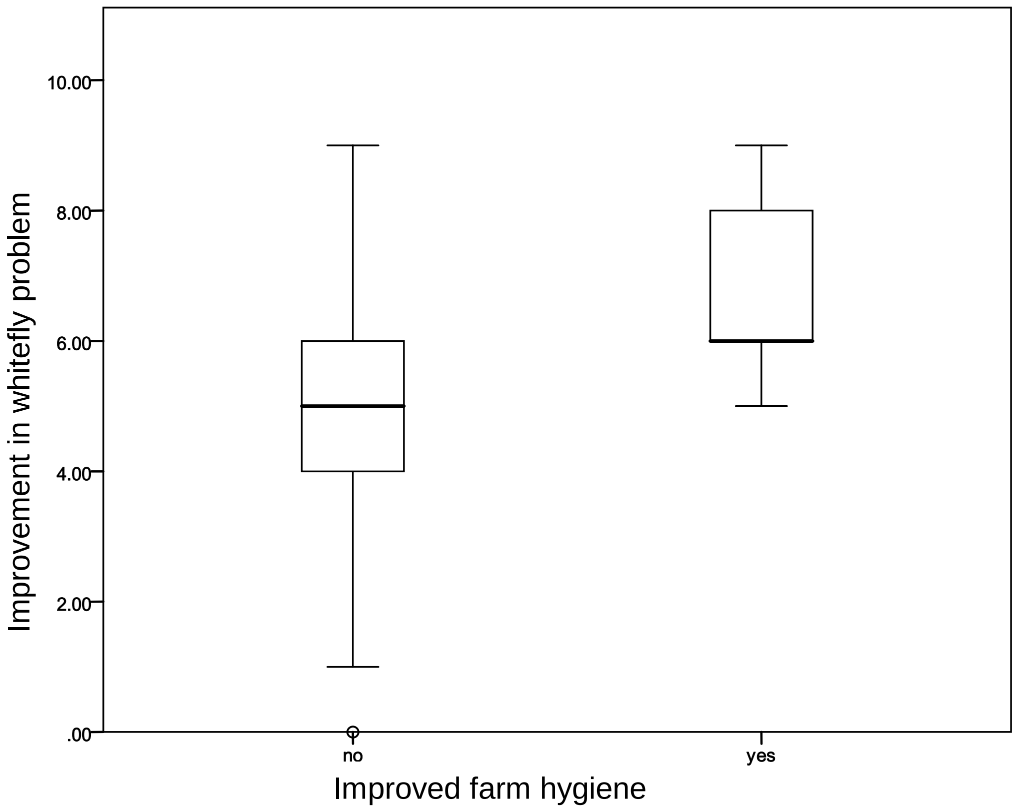


Figure 17. Improvement in whitefly problem since the worst year for grower in the Lockyer Valley that had or had not improved their farm hygiene.

This survey also provided the opportunity to compare the current whitefly problem experienced by growers to variables at each property. Collectively the results revealed that certain variables could be linked to greater problems with whitefly. Using multiple regression the answers provided by growers were compared to the whitefly score growers reported for the current year. Six answers showed significant correlations with the reported whitefly problem, but by far the strongest effect was whether a neighbour was growing cane.

1. A grower's whitefly problem was worse if their neighbour grew cane. That is, growers whose neighbours grew cane scored their whitefly problem higher on average than those growers whose neighbours didn't grow cane. Table 1 below shows that when a neighbour grows cane, growers scored their whitefly problem at double than if their neighbour did not grow cane. Given that cane is not a host to SLWF, this result is most likely due to the broad leaf weeds that grow at the edges of cane fields or throughout the newly planted cane fields when weed control is not possible (eg. too wet).

Table 1. Current whitefly problem for growers whose neighbours do / do not grow cane.

Factor	Whitefly Score	df	*F*	*p*	% variation
Neighbour grows cane	4.71	1	24.57	0.000	21.2%
Neighbour doesn't grow cane	2.31				

2. Another variable surrounding the farm that impacted on a grower's whitefly problem was the presence of a fruit/nut orchard on their neighbour's property. Those growers whose neighbours had an orchard experienced less problems with whitefly that those who did not have an orchard nearby (Table 2). This may indicate that some aspect of orchards provide a refuge or habitat for *E. hayati*.

Table 2. Current whitefly problem for growers whose neighbours have / do not have an orchard.

Factor	Whitefly score	df	*F*	*p*	% variation
Neighbours have a fruit/nut orchard	0.78	1	6.70	0.012	5.8%
Neighbours do not have an orchard	3.21				

3. Features of a property also have an impact because growers that grew food plants to encourage beneficial insects had a l ower whitefly score (Table 3). Food plants provide an unsprayed refuge as well as a food source for *E. hayati* allowing them to survive longer and healthier; this will assist in reducing the grower's whitefly problem.

Table 3. Current whitefly problem for growers that do / do not encourage beneficials by growing food plants.

Factor	Whitefly score	df	*F*	*p*	% variation
Growers encourage beneficial insects by growing food plants	1.67	1	4.69	0.032	4.1%
Grower do not encourage beneficial insects by growing food plants	3.33				

4. In addition to features on or around the farm, several on farm practices were found to be linked to the current whitefly problem experienced by growers. Growers that changed the type of insecticide they used to control whitefly had a higher perceived whitefly problem (Table 4). This could be because finding the best regime with a new product takes some trial and error, or possibly that a grower has changed insecticide because they were not getting good control with an existing insecticide. It's not clear how this result impacts on *E. hayati*, however it does explain 16% of the variation in current whitefly problems.

Table 4. Current whitefly problem for growers that have / have not changed the type of insecticide they use since 2005.

Factor	Whitefly score	df	*F*	*p*	% variation
Changed type of insecticide used since 2005	4.43	1	18.51	0.000	16.0%
Hasn't changed the type of insecticides used since 2005	2.84				

5. A second behavioural factor that can be linked to the whitefly problem experienced is monitoring by taking a quick walk through the crop. Growers that monitored for whitefly by taking a quick walk through the crop to look for whitefly had a worse whitefly problem than those that didn't (Table 5). This most likely reflects the fact that those growers who spend more time and energy searching for whitefly are more aware of the whitefly numbers in their fields and therefore rated their problem higher than those that didn't.

Table 5. Current whitefly problem for growers that monitor whitefly by taking a quick walk through their crop compared to those who don't.

Factor	Whitefly score	df	*F*	*p*	% variation
Monitors for whitefly by taking a quick walk through the crop	3.72	1	8.47	0.005	7.3%
Doesn't monitor whitefly or does so by another method.	1.95				

6. Finally, the last on farm behaviour that can be linked to the whitefly problem experienced by growers is strategic planting. Growers that plant strategically to avoid the build up of whitefly through the season have a lower whitefly score than those who don't (Table 6). By planting strategically, growers can prevent rapid increases in whitefly numbers and allow beneficial insect populations to respond to the whitefly population more effectively.

Table 6. Current whitefly problem for growers that plant strategically to avoid the build up of whitefly numbers compared to those that do not.

Factor	Whitefly Score	df	*F*	*p*	% variation
Growers plant strategically to avoid the build up of whitefly numbers	1.97	1	3.98	0.049	3.4
Growers don't plant strategically to avoid the build up of whitefly numbers	3.26				

12. What information do you use or on what basis do you start controlling for whitefly? (please tick all that apply)

- ☐ When numbers of whitefly adults / nymphs (please circle) per leaf reach a threshold on susceptible crops. [If you tick this option please complete the following sentence.] My threshold measurement is ______________________
- ☐ Recommendation by consultant
- ☐ Weather conditions / climatic forecast is favourable for whitefly
- ☐ Neighbours starting to report problems
- ☐ Preventative application(s) on all susceptible crops
- ☐ Preventative application(s) on highly susceptible crops
- ☐ Nothing, whitefly does not affect my production or output
- ☐ Other ____

Growers were asked what information they use when deciding if they would take measures to control for whitefly. Thirty percent of growers in the Lockyer and Burdekin said they do not control for whitefly, whereas only fifteen percent of growers in Bundaberg do not control for whitefly. Three growers said they controlled for whitefly without any gathering any information about the current whitefly problem – one from the Lockyer and two from near Bundaberg.

Most commonly, growers said they follow the recommendation of a consultant, particularly in the Burdekin region where nearly all growers are dependent on their consultant's recommendation (Figure 18). However, all the growers that were surveyed in the Burdekin region were sourced from one local consultant; therefore this may not truly reflect the population in the Burdekin region.

Preventative spraying does not rank highly as a method for control in all regions. No growers in the Burdekin said that they decide to control for whitefly by personally observing the number of whitefly (adults or nymphs) present in their crops, this may be because they rely entirely on their consultant for advice or they do nothing. In all three regions weather / climate or neighbouring whitefly problems were not commonly used as part of the decision-making process for applying whitefly controls (Figure 18).

No Burdekin growers reported using a threshold, however it is not known whether the consultant who determines when they should spray uses a threshold. More information about the method that consultants from the Burdekin use to recommend controlling for whitefly are discussed in the consultant survey (see Figure 47). In the Lockyer Valley, one quarter of the respondents (n = 9) said they used a threshold of whitefly adults (no Lockyer Valley growers checked for nymphs). Seven of those growers stated their actual threshold, of which three growers said their threshold was ONE whitefly. Bundaberg growers were more likely to monitor for whitefly adults or nymphs. Of the seven Bundaberg growers that commented on their threshold, four said they use their own judgement, which could be as low as 2-3 per leaf depending on crop stage. The remaining three growers were unsure but relied on the recommendation of their consultant. Overall, it appears that those growers that do monitor have a very low tolerance for whitefly before implementing control methods.

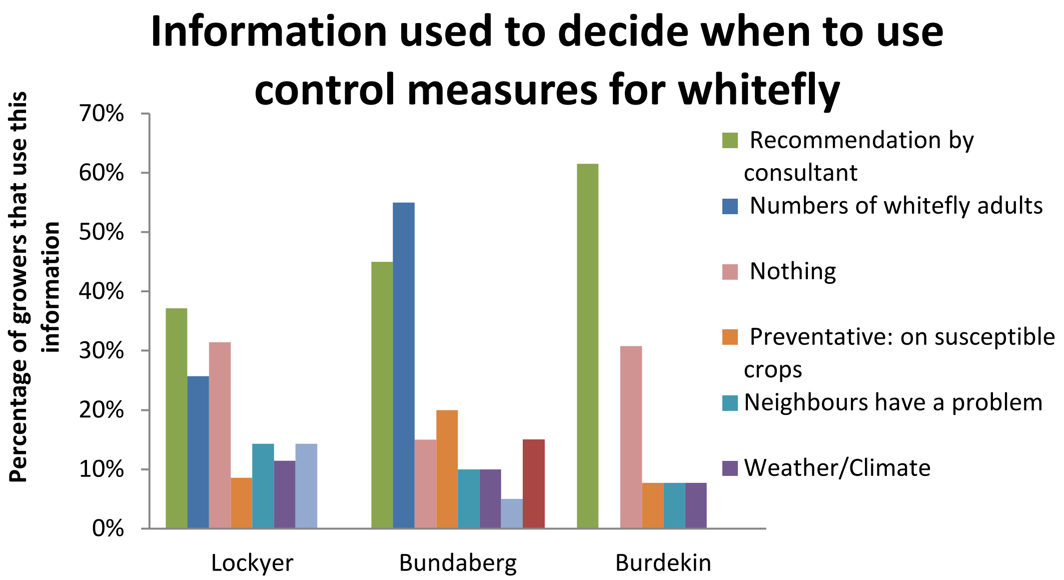


Figure 18. Information used by growers to decide when to start controlling for whitefly by location.

13. Do you monitor for whitefly?

☐ Yes → How do you and/or your consultant monitor for whitefly? (please tick all that apply)
- ☐ Quick walk through to look for any whitefly adults / nymphs (please circle)
- ☐ Standardised counting method of whitefly adults / nymphs (please circle) then compare to previous week
- ☐ Standardised counting method of whitefly adults / nymphs (please circle) then compare to a threshold
- ☐ Other ___________________________

or

☐ No → When do you apply control measures for whitefly in your crop? (please tick all that apply)
- ☐ I buy pre-treated seed or seedlings
- ☐ As soon as seedlings are established
- ☐ When crop starts to flower
- ☐ When fruit or vegetables start developing
- ☐ As fruit or vegetables near maturity
- ☐ Just prior to the required withholding period
- ☐ N/A – I tolerate whitefly
- ☐ Other ___________________________

More than half the growers said they monitor for whitefly (Figure 19). The years farming and size of the farm did not correlate with the tendency of growers to monitor for whitefly (Appendix I).

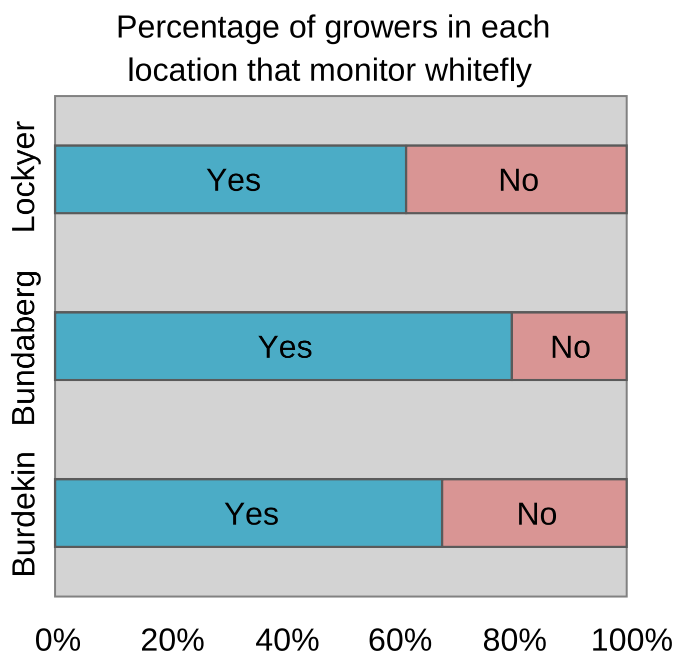


Figure 19. Percentage of growers that monitor for whitefly in each location.

Of the growers that monitored for whitefly, the most common method was a quick walk through to look for adults (Figure 20), particularly in the Lockyer Valley where this was the method used by nearly 90% of growers that monitored. Growers from

Bundaberg and the Burdekin region used a variety of methods. Growers could benefit from being provided with a recommended method for monitoring, this would allow for clear communication and comparisons between farms, consultants and growers.

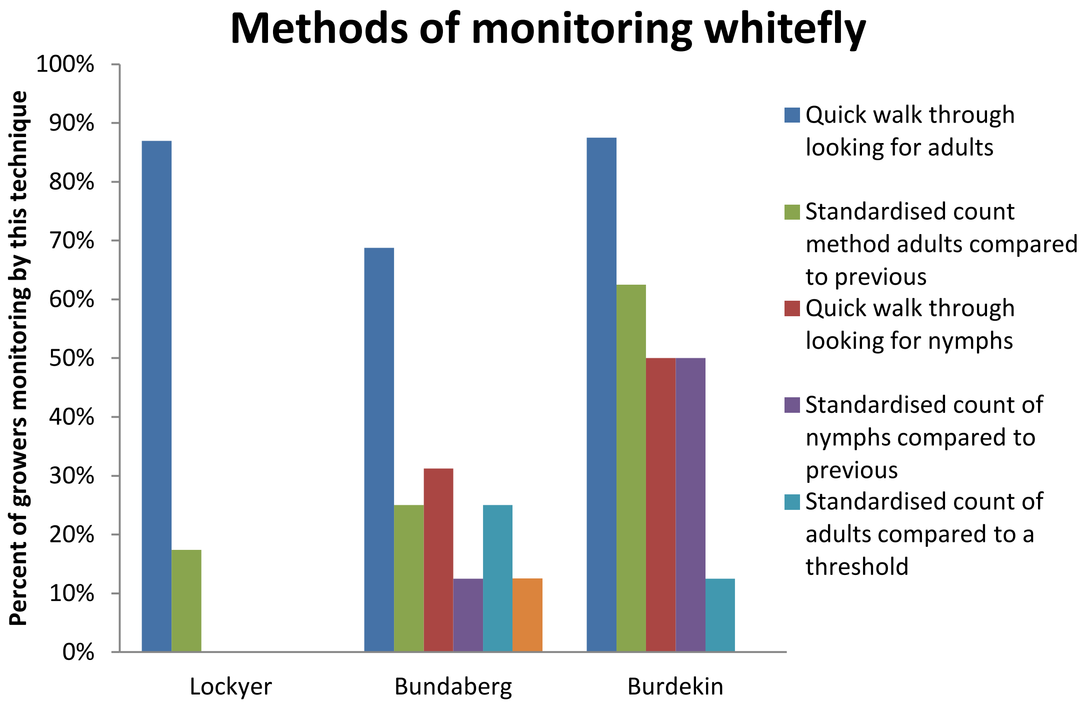


Figure 20. Methods used by growers who monitor for whitefly by location.

Few growers admitted to controlling for whitefly without any monitoring as most growers that do not monitor also do not control for whitefly. Nearly 40% of growers from the Burdekin region said they do not monitor for whitefly, but neither do they control for whitefly. Most of the growers from the Burdekin region that did not monitor for whitefly also said that cane growing was their main focus. Therefore, vegetable growing, and consequentially whitefly would only be a minor concern for their operation. Lockyer Valley had the next highest percentage with nearly 30% saying they did not monitor for whitefly, of those only one grower said that they controlled for whitefly at the seedling stage without monitoring. Only 10% (two growers) from Bundaberg said they did not monitor for whitefly. One grower said they treated at the flowering stage and the other grower said they treated at seedling and flowering stage (Figure 21).

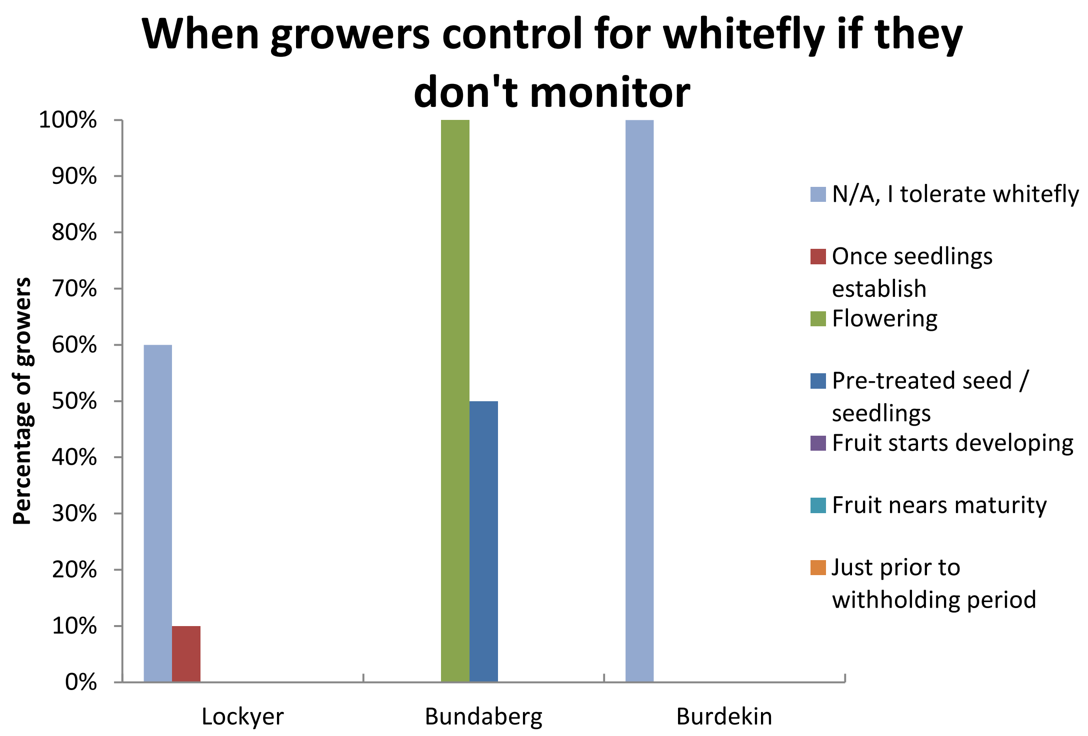


Figure 21. When growers control for whitefly if they don't monitor for whitefly.

The percent of growers monitoring for whitefly was different depending on the type of industry most important to their operation. Growers whose main priority was vegetables were most likely to monitor for whitefly (Figure 22).

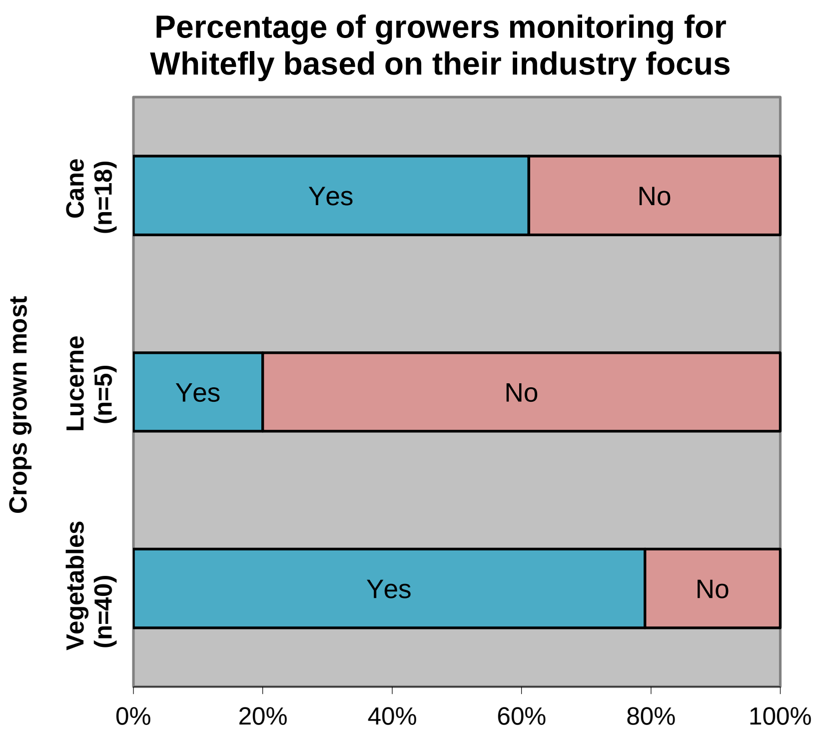


Figure 22. The percentage of growers that monitor for whitefly based on their industry focus.

Very few growers control for whitefly without monitoring. Three growers applied control measures without monitoring: one Lockyer grower sprayed after planting and two Bundaberg growers sprayed at either fourth leaf stage or flowering (Table 7).

Table 7. Reasons given by growers for not monitoring for whitefly.

	Control without monitoring	Tolerate	Not a problem
Lockyer Valley	1	6	4
Bundaberg	2	0	2
Burdekin	0	5	0

14.

14a. If you control for whitefly what do you use?

☐ The most cost effective insecticide
☐ Insecticides softer on beneficial insects – if possible
☐ Insecticides softer on beneficial insects – always
☐ N/A – I tolerate whitefly
☐ Other ______________________________

A moderate percentage of respondents said they use softer chemicals if possible (44% Lockyer Valley, 53% Bundaberg, 38% Burdekin), but fewer said they always choose softer chemicals (12% Lockyer Valley, 32% Bundaberg, 23% Burdekin). Growers from the Lockyer Valley (40%) are most likely to choose the cheapest insecticide available (Figure 23).

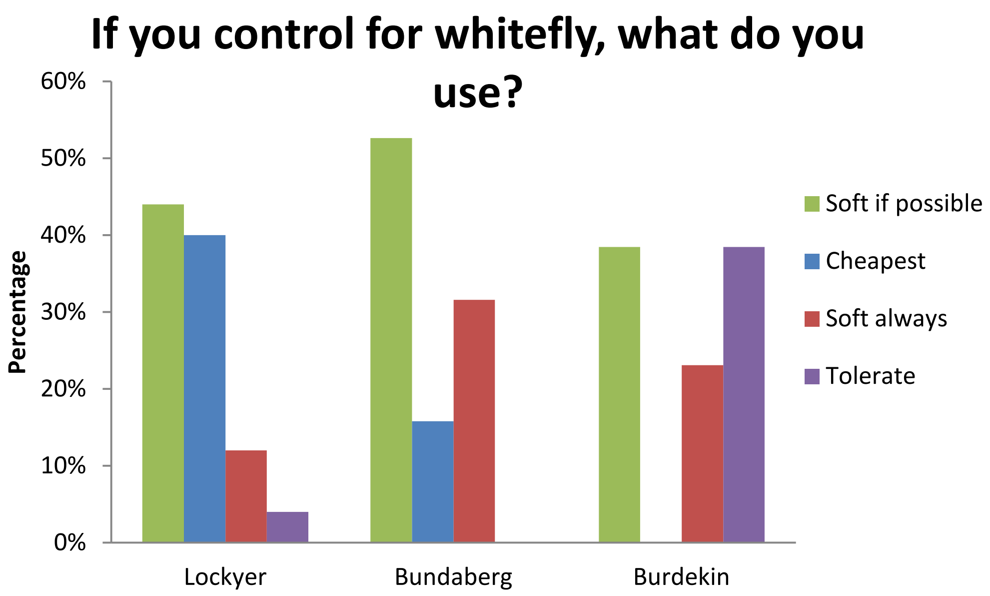


Figure 23. The type of insecticide a grower chooses to use when they control for whitefly.

14b. If you control for whitefly, how often do you apply it?

☐ Once, when the crop is young
☐ Only if I notice whitefly numbers becoming a problem, eg. reached a threshold
☐ Weekly / fortnightly throughout the life of the crop
☐ N/A
☐ Other ____

Growers from the Lockyer Valley tended to apply infecticides less frequently than those from Bundaberg or Burdekin. Almost all growers from the Burdekin followed a calendar spray regime, while the frequency of applications varied in Bundaberg (Figure 24).

Growers can be classed as frequent or infrequent sprayers. The proportion of frequent to infrequent sprayers in a region may impact on *E. hayati* survival. For example, the few "frequent sprayers" in the Lockyer Valley (Frequent = 6: Infrequent = 23), may be benefiting from neighbours that spray infrequently, whereas in the Burdekin region (Frequent=7: Infrequent=9) with a high percentage of "frequent sprayers", *E. hayati* may struggle to build up large enough numbers to have an impact on whitefly numbers.

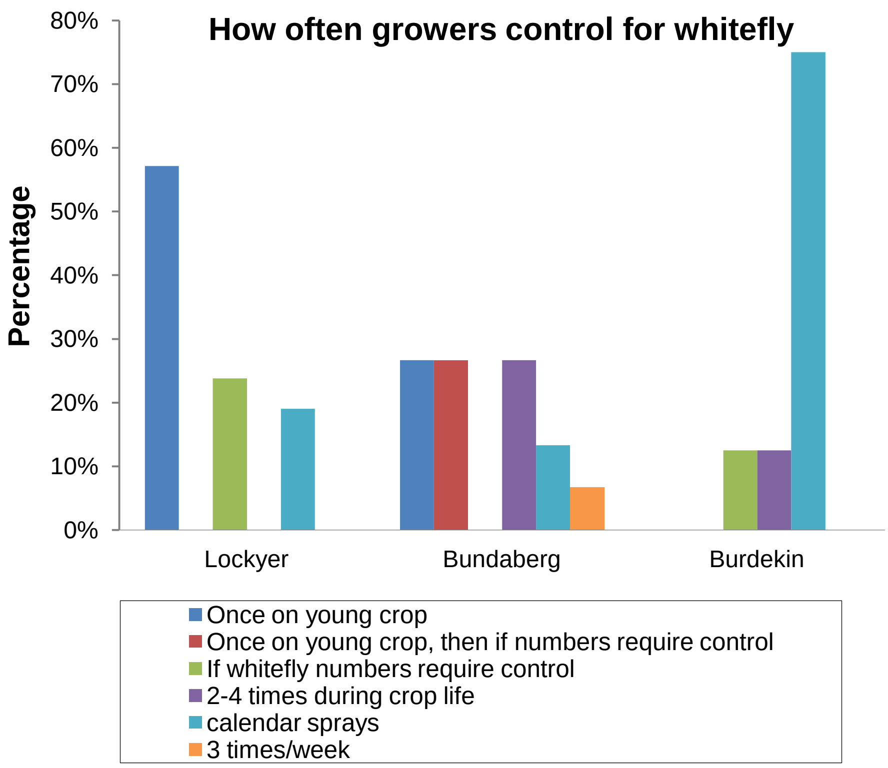


Figure 24. Frequency of insecticide use to control for whitefly in each location.

Between the three different regions the pattern of insecticide use varies. Around Bundaberg, growers choose (or consultants recommend) insecticides softer on beneficial insects and frequency of spraying varies from low to high frequency. In the Lockyer Valley growers are more likely to spray (or consultants recommend) the most cost effective insecticide, however, on average they tend to spray less frequently. In the Burdekin region, growers tend to spray (or consultants recommend) softer insecticides, and they either spray very frequently or as little as possible.

By looking at the spray styles of each location in terms of how damaging it is to *E. hayati*, both the frequency of insecticide use and type of insecticide used may impact on *E. hayati* survival. The graphs below compare the spray styles of each location on a scale of least to most disruptive to *E. hayati*. The size of the circle indicates the number of growers using that insecticide practice. The top left of the graph indicates behaviours least disruptive and bottom right, most disruptive (Figures 25, 26 and 27).

These graphs show that, although growers from the Lockyer Valley probably use broad spectrum insecticides more than the other regions, they are more likely to spray less (Figure 25). Bundaberg growers are using softer insecticides, but using them more frequently (Figure 26) and Burdekin growers fall into two groups, those that spray regularly, and those that only spray if necessary (Figure 27). How these different spray patterns ultimately impact on *E. hayati* is unknown but may be revealed in time.

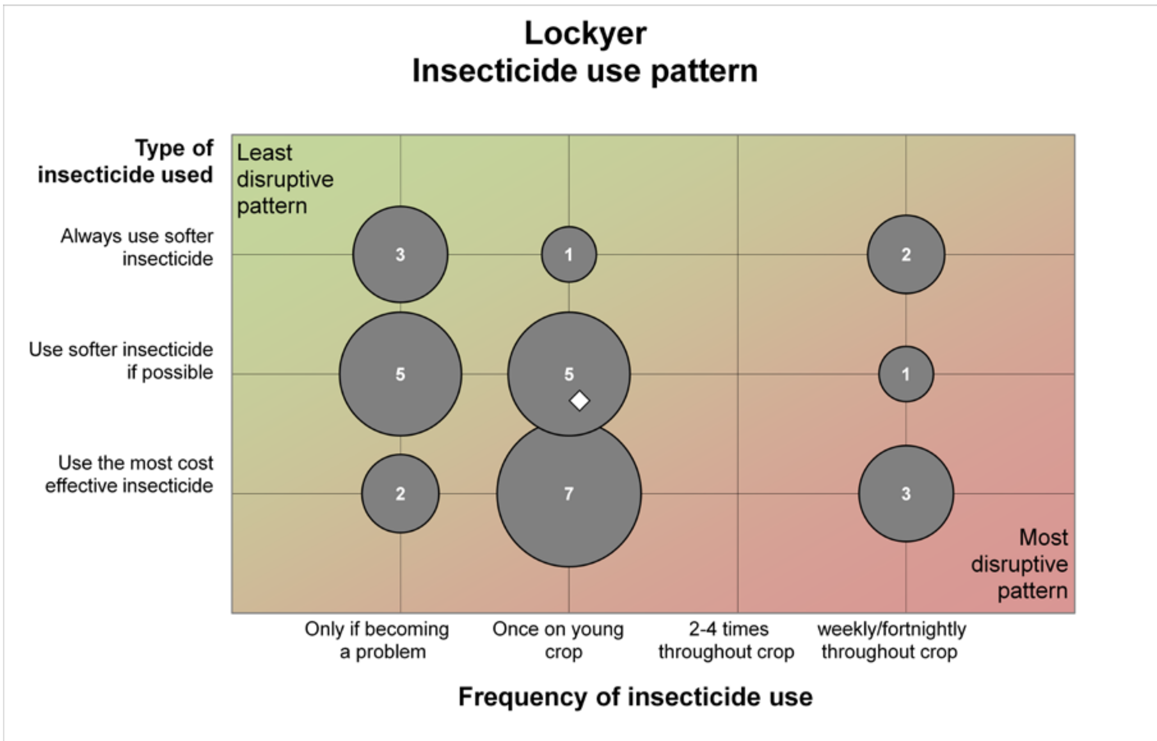


Figure 25. Pattern of insecticide use in the Lockyer Valley in terms of disruption to *E. hayati*.

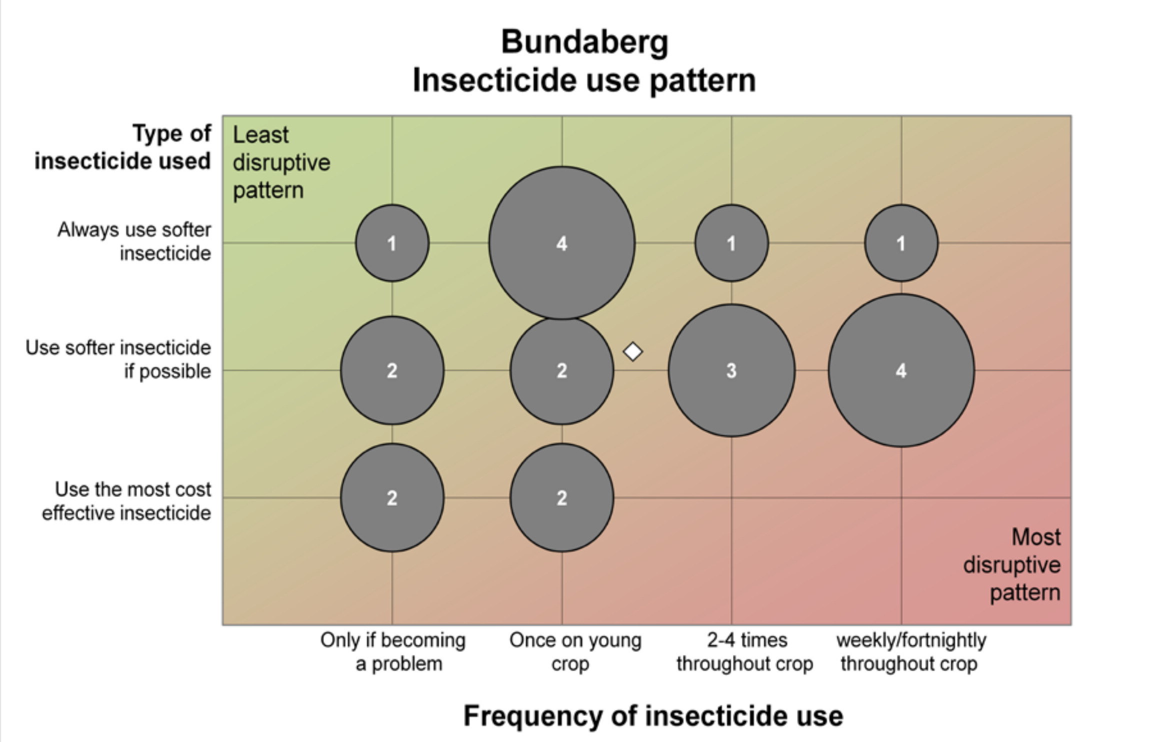


Figure 26. Pattern of insecticide use around Bundaberg in terms of disruption to *E. hayati*.

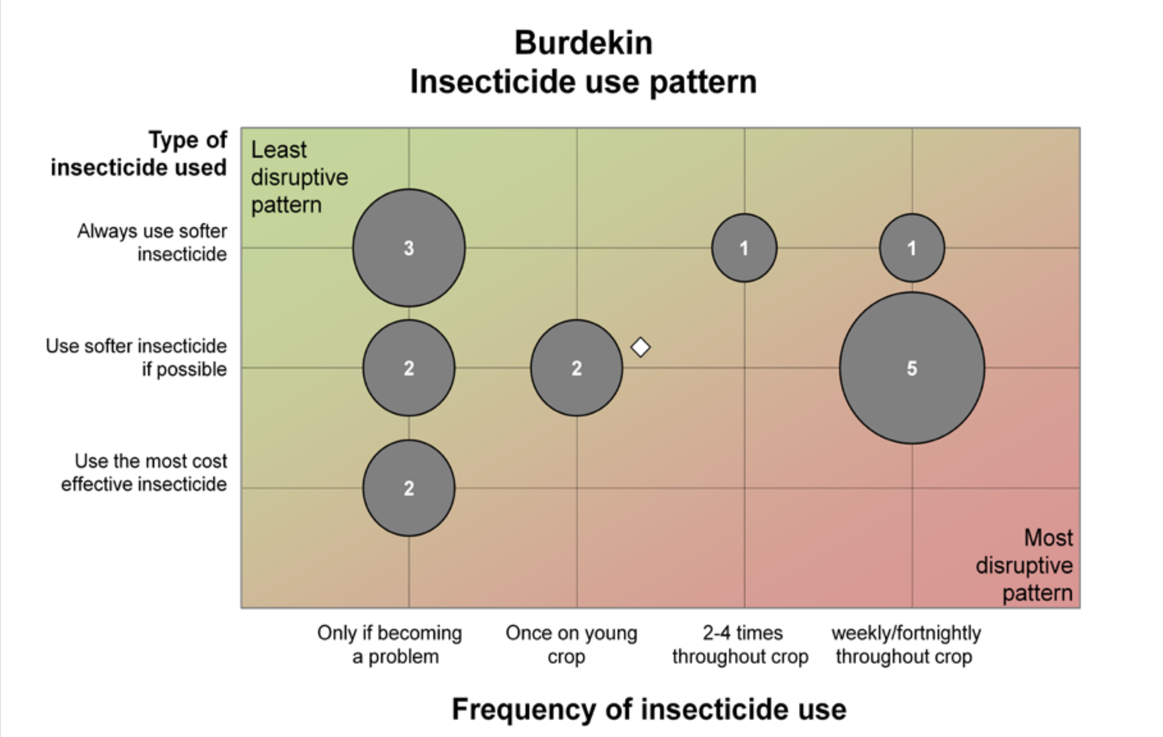


Figure 27. Pattern of insecticide use in the Burdekin region in terms of disruption to *E. hayati*.

The type of insecticide used was compared to the whitefly problem reported by growers but the results were not significantly different using ANOVA ($F = 0.866$, $p = 0.54$). The frequency of insecticide used was also compared to the whitefly problem using ANOVA, and a significant difference existed between those that only sprayed once at planting and those that sprayed weekly / fortnightly throughout the life of the crop ($F = 3.289$, $p = 0.03$) (Figure 28). No other differences were detected.

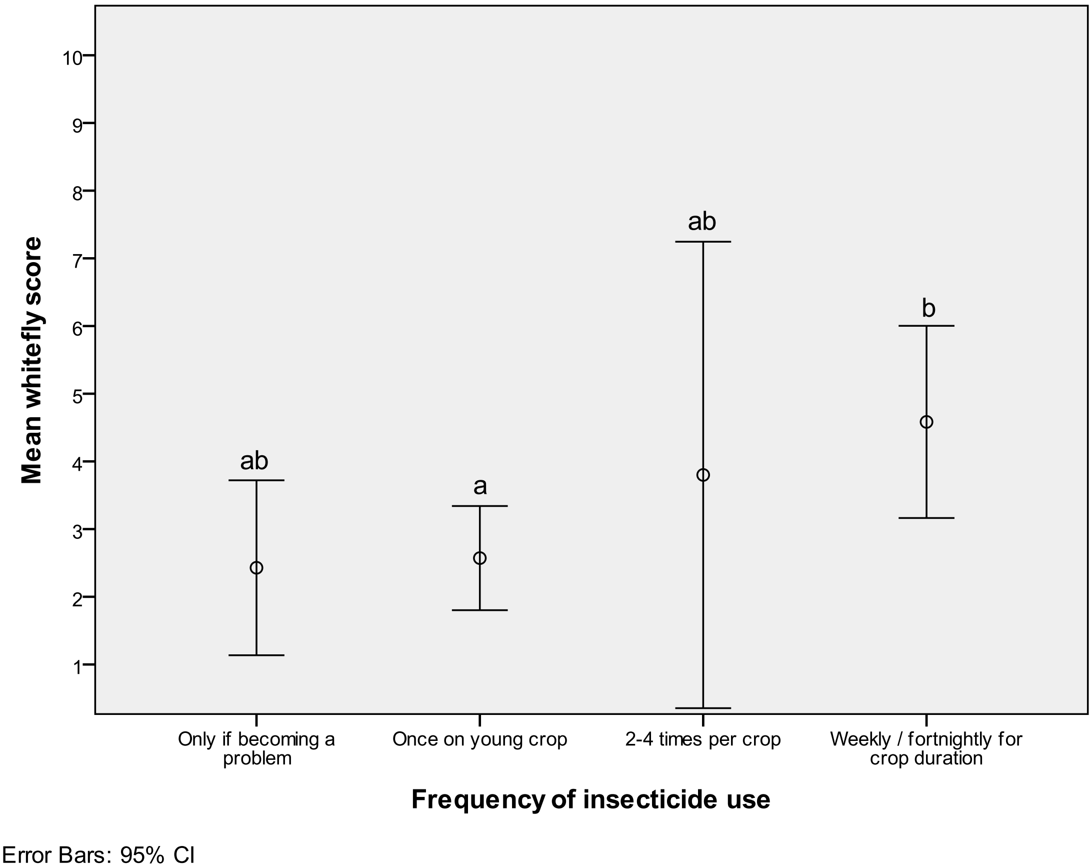


Figure 28. Frequency of insecticide used relative to the current whitefly problem experienced by growers.

15. Besides using insecticides, what else do you do to control for whitefly? (please tick all that apply)

- ☐ Farm hygiene, eg. ploughing in harvested plants, controlling broad leaf weeds.
- ☐ Avoid planting susceptible crops during peak whitefly season
- ☐ Avoid planting susceptible crops consecutively
- ☐ Encourage beneficials by providing refuges
- ☐ Other ______________________________

Growers were asked what other methods they used to minimise whitefly numbers. Active strategies such as maintaining good farm hygiene and providing refuges for beneficial insects were more common than avoidance strategies such as avoiding peak whitefly season or consecutive plantings (Table 8).

Bundaberg growers are most likely to take measures to reduce whitefly other than using insecticides, Burdekin growers least likely. A third of Lockyer growers avoided peak whitefly seasons, but did not say they avoided planting consecutively. This may be because the Lockyer is a large and concentrated growing area, where even if they avoid planting consecutively on their farm, it's likely their neighbour would be planting whitefly susceptible crops anyway. In which case, avoiding planting susceptible crops consecutively would be pointless. Farm hygiene appeared to be an important practice in the Lockyer Valley and Bundaberg, but was not practiced much in the Burdekin to reduce whitefly numbers.

Table 8. Methods used to control whitefly other then insecticides.

	Farm hygiene	Avoid planting susceptible crops during peak whitefly season	Avoid planting susceptible crops consecutively	Encourage beneficials by providing refuges
Lockyer	60%	31%	3%	49%
Bundaberg	80%	20%	20%	80%
Burdekin	15%	23%	23%	54%

The Burdekin case:

All Burdekin growers that control for whitefly (n = 8) reported they monitor for whitefly. However of those eight growers, five use calendar sprays on the advice of their consultant and one uses calendar sprays based on t he climatic/weather conditions. So it's not clear why they bother to monitor if they do not use monitoring information – unless it is used as a suppression technique.

One of the five growers that use calendar sprays on t he advice of their consultant reports that their whitefly problem has decreased from a score of 5/10 to 1/10 within a year, another reported that their whitefly problem decreased from 10/10 two years ago to 4/10 currently. The other three reported little change. These widely varying results from the Burdekin indicate that Burdekin growers seem to have little understanding of the extent of the whitefly problem (or lack of) on their property.

Some whitefly education could benefit the Burdekin region!

16. To help us understand your pest control challenges, for the crops listed below please list: when you normally plant, what insecticides you use, the application method used as well as the stage of the crop when the application method is used for **ALL** insect pests, including whitefly.

Application method	**Crop stage**
I = via irrigation	1 = seedling / seed
PH = plant hole drench	2 = vegetative / pre-flowering
S = spray (aerial or ground)	3 = flowering
	4 = mature fruit/vegetable / pre-harvest
	A = all stages

This question generated very good picture of what the temporal landscape at each location which could explain how whitefly and *E. hayati* survived throughout the season. The tables below (Tables 9, 10 and 11) show when whitefly host crops are grown and by what percentages of the growers responding to this survey. Crops that are highly suitable for whitefly *E. hayati* are in orange and crops minimally to moderately favoured by *E. hayati* are in blue. For example, nearly a third of growers from the Lockyer Valley planted pumpkin in August.

Table 9. Percentage of growers planting whitefly host crops in the Lockyer Valley each month.

Lockyer Valley

Crop	J	F	M	A	M	J	J	A	S	O	N	D
Pumpkins	9	3	3	3		3	6	29	23	17	17	20
Rockmelon	3	3					3			3		3
Soybean	6	3	3								3	11
Tomato	6	3	3	3	3	3				3	3	3
Cabbage	3	9	6	6	6	9	6	6	6	3	3	
Brassicas	3	9		3					3	3	3	3
Cauliflower		3	9	6	6	6	3					
Watermelon	3	3					3	9	3		3	3
Honeydew	3	3										3
Potatoes		9	6	6	3	17	6	3	3			
Beans	6	6	6	3	3	3		11	9	9	9	6
Zucchini	3	3	6	3	3	3		3	3	3	3	3
Lettuce	3	6	11	11	11	11	11	6	6	6	3	3

Crop	J	F	M	A	M	J	J	A	S	O	N	D
Beetroot			3	3	3							
Cucumber			3					6	3			
Sweet Potato	3	6	3	3	3	3	6	3	3	3	3	3
Squash			3					3				
Capsicum	3	3							3		3	6
Broccoli	3	6	3	3	3	6	6	3	3	3		3
Brocollini												3
Chinese Cabbage			3					3				
Asian greens	3	3	3	3	3	3	3	3	3	3	3	3
Onions			3	3	3							
Spinach	3	3	3	3	3	3	3	3	3	3	3	3

Table 10. Percentage of growers planting whitefly host crops around Bundaberg each month.

Bundaberg

Vegetable	J	F	M	A	M	J	J	A	S	O	N	D
Pumpkins	5	10	5	5	5	5	5	10	15	10	10	10
Rockmelon								10	10	10	15	15
Eggfruit	5	5	5	5	5	5	5	5	5	5	5	5
Watermelon	20	15	15	15	15		5	10	20	20	20	20
Potato				5	5	5	5	5				
Zucchini		5	5	10	10	10	10	10	10	5	5	
Sweet Potato	15	15	15	15	15	15	15	15	15	15	15	15
Capsicum		10	10	10	10	10	10	10	5	5		
Snowpeas		5	5	5	5	5	5	5	5	5		
Cucumber	15	15	15	15	15	15	15	15	15	15	15	15
Peanuts	5	5	5							5	5	5

Table 11. Percentage of growers planting whitefly host crops in the Burdekin region each month.

Burdekin

Vegetable	J	F	M	A	M	J	J	A	S	O	N	D
Pumpkin			31	31	23	23	23	23	23	8	8	
Cotton	15											15
Soybean					8							15
Tomato		15	15	15	15	15	15	15	15	15	15	
Eggplant		15	31	31	15	15	15	15	15	15	15	
Watermelon	8	8	8	8	8	8	8	8	8		8	8
Beans	8	8	8	8	8	8	8	8	8	8	8	15
Chilli	15	15	15	15	15	15	15	15	15	15	15	15

Colour in the three tables above represent the following:

Over 30% of growers growing a particular crop that is highly susceptible to SLW.
Over 20% of growers growing a particular crop that is highly susceptible to SLW.
Over 10% of growers growing a particular crop that is highly susceptible to SLW.
Over 30% of growers growing a particular crop that is highly susceptible to SLW.
Over 30% of growers growing a particular crop that is somewhat susceptible to SLW.
Over 20% of growers growing a particular crop that is somewhat susceptible to SLW.
Over 10% of growers growing a particular crop that is somewhat susceptible to SLW.
Over 30% of growers growing a particular crop that is somewhat susceptible to SLW.
Peak whitefly months

This question was also asked of growers to determine the types of insecticides being used, not only for whitefly but for all insect pests. The aim of this was to create a map of the insecticide usage in each landscape, not just directed at whitefly, but disruptive to *E. hayati*.

In the Lockyer Valley, growers surveyed were growing a total of 23 different crops that were a host to whitefly (listed in Table 9). The two most popular crops were pumpkin and potato. Of the 19 growers growing pumpkins, 74% used Confidor (active ingredient, Imidacloprid which is harmful to *E. hayati*). However, it was mostly as a plant hole drench which is less harmful than as a foliar application. Only one grower used Movento (active ingredient; Spirotetramat which is not harmful to *Eretmocerus sp*) and one grower did not use any insecticides. Spray patterns on potatoes was similar. Of the ten growers who said they grew potatoes, eight used Confidor. Only one grower did not use any insecticides on potato and the remaining grower used Lannate and Axe throughout the life of the crop (a Carbamate and synthetic pyrethroid, respectively, and both harmful to *Eretmocerus sp*). With spray practices such as these described above and without a nearby unsprayed refuge, there would be little chance of a substantial *E. hayati* population surviving to provide pest control services.

Around Bundaburg, growers surveyed were growing eleven different whitefly host crops. The two most popular crops grown were watermelon and pumpkin. Six growers grew watermelon and all used Confidor, primarily as a plant hole drench. Four growers grew pumpkin, three used Confidor at the seedling stage and the other grower used Rogor (active ingredient: Dimethoate, harmful to *Eretmocerus sp.*) throughout the life of the crop. As in the Lockyer Valley, the use of insecticides harmful to *E. hayati* was extensive on the most common crops.

In the Burdekin region, nine different whitefly host crops were grown, but by far the most common crop grown was cane. The most common insecticides used on the whitefly host crops were Confidor and Telstar (a synthetic pyrethroid), both harmful to *Eretmocerus sp.*

By looking at the frequency at which various insecticides were mentioned as being used on any whitefly host crop, Confidor was by far the preferred choice. In the Lockyer Valley, Confidor was mentioned for use on 56% of crops. Around Bundaberg, reliance on Confidor was even higher, being mentioned for use on 72% of crops. In the Burdekin region, Confidor use was only surpassed by Talstar (a synthetic pyrethroid, harmful to *Eretmocerus sp.*) Movento (active ingredient: spirotetramat) is one insecticide that is known to be safe to use with *E. hayati*, was mentioned as used on 31% of crops in Bundaberg, but used minimally or not at all in the other regions. For the survival of *E. hayati* the use of this insecticide should be encouraged (Table 26).

Table 12. Percentage of times that each insecticide was mentioned for use on a whitefly host crop in that region.

Lockyer	**90 crops**	**Bundaberg**	**29 crops**	**Burdekin**	**18 crops**
Imidacloprid: Confidor	56%	Imidacloprid: Confidor	72%	Bifenthrin: Talstar	39%
Dimethoate or other OP	9%	Spirotetramat: Movento	31%	Imidacloprid: Confidor	33%
Bacillus thuringiensis: Xentari	7%	Endosulfan	17%	Methomyl: Nudrin, Lannate	17%
Methomyl: Lannate, Marlin	6%	Spinosad: Success	10%	Piperonyl butoxide: Synergy	11%
Chlorantraniliprole: Coragen	4%	Chloropyrifos: Lorsban	7%	Pyriproxyfen: Admiral	6%
Spinosad: Success	4%	Natrasoap	7%	Endosulfan	6%
Copper	3%	Bifenthrin: Talstar	7%	Methamidophus: Nitofol	6%
Heliothis	3%	Indoxacarb: Avatar	3%	Diafenthiuron: Pegasus	6%
Oils	3%	*Bacillus thuringiensis*: Dipel	3%	Spinosad: Success	6%
Pyrethroid: Karate	2%	Dimethoate: Rogor	3%	Helicoverpa NPV: ViVUS	6%
Permethrin: Axe	1%	Abamectin: Vertimec	3%		
Flubendiamide: Belt	1%				
Carbaryl: Bugmaster	1%				
Spirotetramat: Movento	1%				
Methamidophos: Nitofol	1%				

The responses from this question offered the opportunity to compare the type of insecticide growers said they used to control for whitefly (Page 29) against what they actually used on the crops that are whitefly host crops. Only three growers had better spray practices that what they said they had, 25 growers accurately described their insecticide use, and the remaining 29 growers had worse spray practices than what they said (Figure 29).

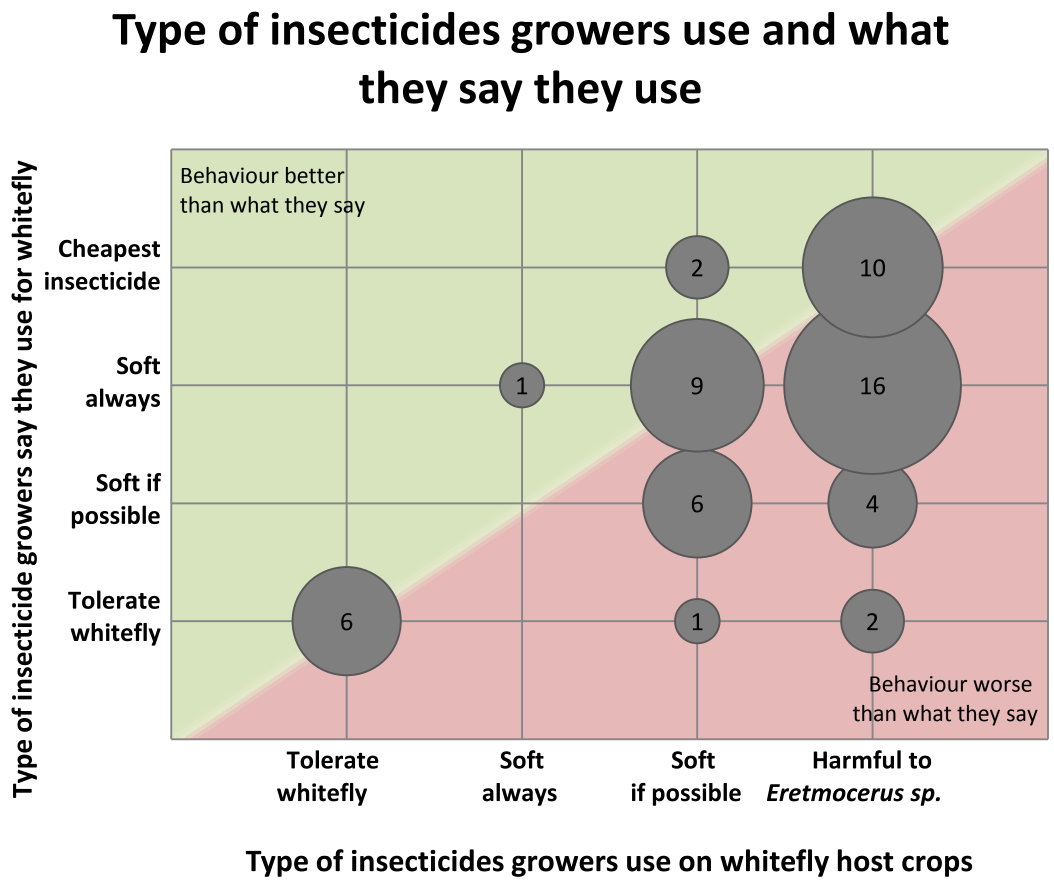


Figure 29. The type of insecticides that growers say they use for whitefly and what they actually use on their whitefly host crops. The size of the circle and number within indicates the number of growers in each group.

This question revealed the number of different insecticide classes / groups used by each individual grower. This information can indicate the potential for insects to develop resistance to certain classes / groups. Disturbingly, 62% of growers in the Lockyer Valley only used one insecticide class / group on any whitefly host crops (Figure 30). Furthermore, a high percentage of growers in the Lockyer Valley are using Confidor (Imidacloprid) (Table 12). With such high reliance on Confidor, there is a risk of resistance increasing in the local population. Examples from Spain and China demonstrate that whitefly (*Bemisia tabaci* biotype B) is known to develop resistance to Imidacloprid in the field (Palumbo, Horowitz et al. 2001; Nauen and Denholm 2005). Fewer growers around Bundaberg and the Burdekin region relied on only one class / group of insecticide with 44% doing so in Bundaberg and 18% in the Burdekin region (Figure 30).

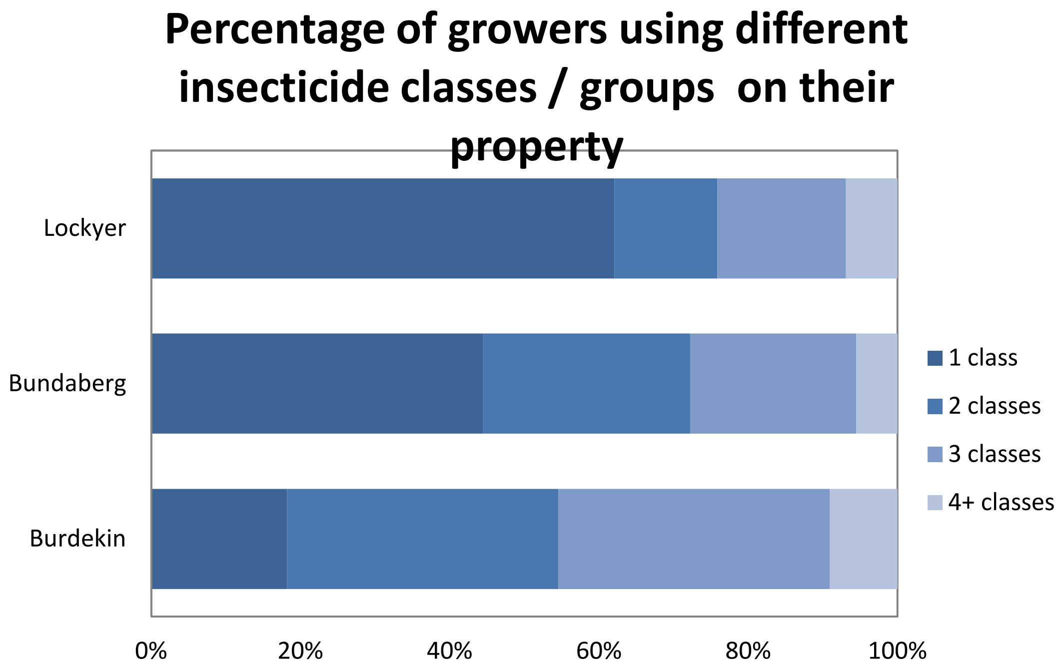


Figure 30. The percentage of growers in each location that use different numbers of insecticide classes / groups on their property.

17. Have you changed your whitefly pest management practices since 2005?

☐ No
☐ Yes →

Why did you change? (please tick all that apply)
- ☐ Whitefly are worse now
- ☐ Whitefly are less of a problem now
- ☐ More effective insecticides became available / old insecticide permits expired
- ☐ I was aware that a new biocontrol agent was released for silverleaf whitefly
- ☐ Other ______________________________

What have you changed? (please tick all that apply)
- ☐ Encourage beneficials
- ☐ Use softer chemicals and reducing use of OP insecticides
- ☐ Injecting / drenching in confidor when planting
- ☐ Rotating insecticides / insecticide resistance management strategy
- ☐ Improving farm hygiene: controlling weeds and cleaning up old crops
- ☐ Strategic planting to avoid build up and spread of whitefly between susceptible crops

Growers were asked if they had changed their whitefly management practices. If they answered yes, then they were asked why and what they had changed.

Changing whitefly control practices

E. hayati was released around 2005 and since that time half or more of the growers in each region said they had changed the way they managed whitefly (Table 13).

Table 13. Has the farm changed their practice of managing whitefly since 2005?

	Lockyer Valley	Bundaberg	Burdekin Region	Total
N/A	0%	1%	0%	1%
No	22%	13%	9%	44%
Yes	29%	14%	10%	54%

Reason for changing whitefly control practices

Of those that did change, the most common reason was because whitefly was less of a problem for them now, followed by changing the insecticide that they used. Only three growers had changed their practices because they were aware that a new biological control agent had been released for silverleaf whitefly. Three respondents said they had changed their practices because whitefly is more of a problem now (Figure 31).

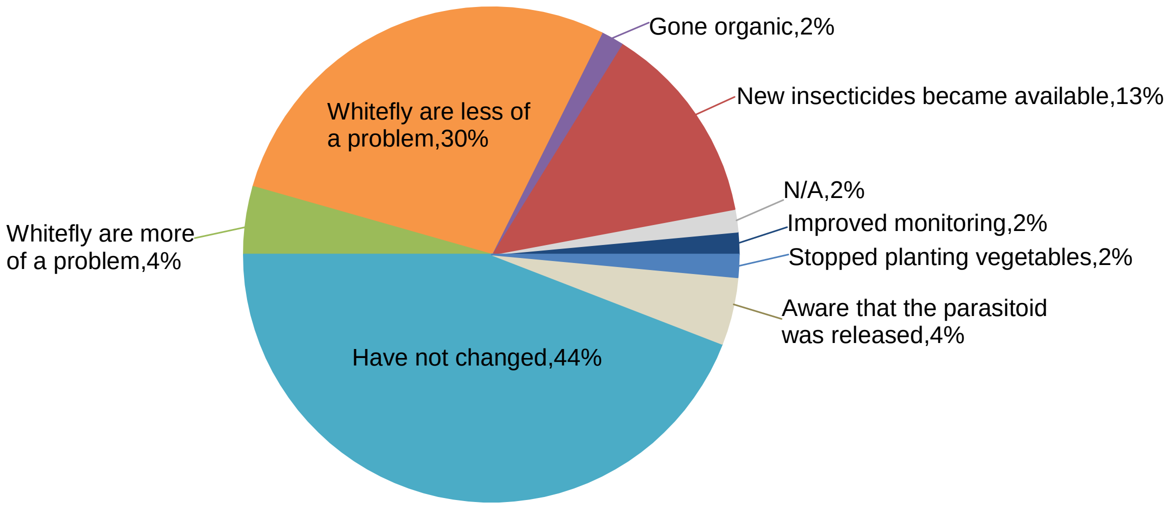


Figure 31. Growers were asked if their farm had changed practices since 2005 and if so, why.

Overall, the most common changes that growers have made in managing whitefly was to reduce use of insecticides or choose softer insecticides. This was the most common change in Bundaberg. However, in the Lockyer Valley the most common change was to plant strategically and around Burdekin the most common change was to encourage beneficial insects (Figure 32)

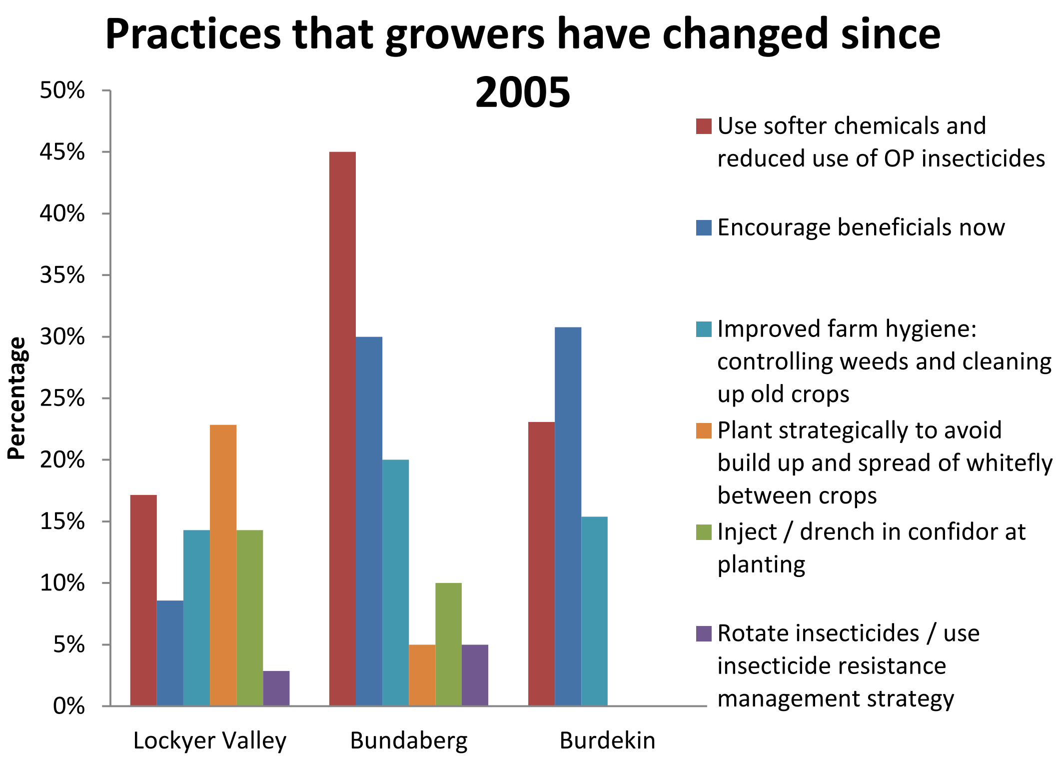


Figure 32. Whitefly management practices that growers have changed since 2005 by location.

18. Do you take measures to encourage other beneficials on your farm? Tick any reasons that help explain your answer.

☐ Yes
- ☐ Maintain native vegetation
- ☐ Choose softer chemicals
- ☐ Spray less often
- ☐ Leave some areas unsprayed
- ☐ Apply food sprays / grow food plants
- ☐ Other cultural, eg. plant trap crops
- ☐ Other ______________________________

or

☐ No
- ☐ Not possible on my farm
- ☐ Too expensive
- ☐ They provide negligible pest control services for my farm
- ☐ Other ______________________________

More growers said they take measures to encourage beneficial insects than those that don't (Figure 33).

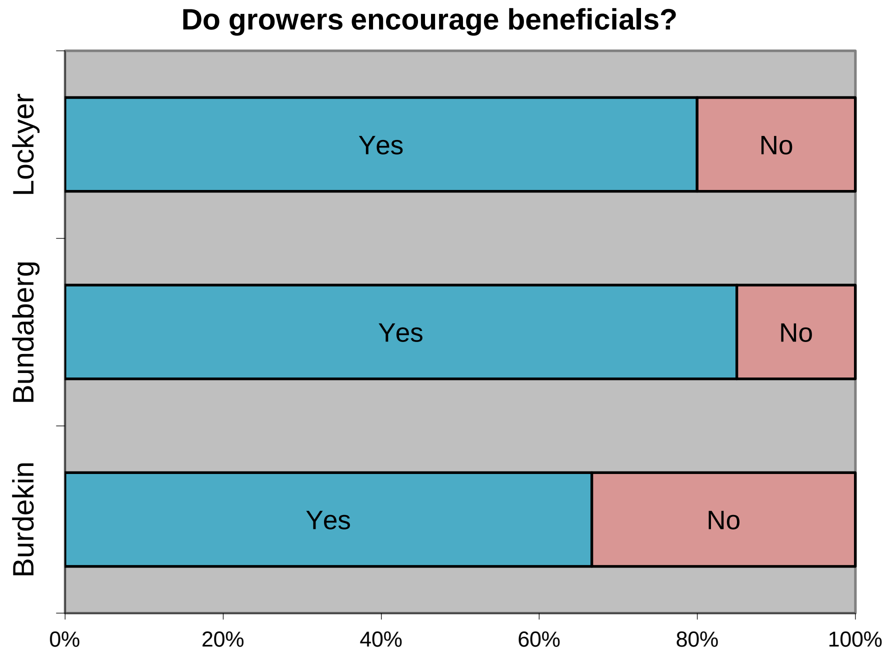


Figure 33. Growers were asked if they encouraged beneficial insects on their farm. Shown by location.

80% of growers said they tried to encourage beneficial insects on their property, slightly more around Bundaberg and slightly less from the Burdekin region. Of those growers that do encourage beneficial insects, they most commonly chose softer chemicals (n = 29), and sprayed less often (n = 24). Six growers actively invested time in encouraging beneficial insects: two growers provided food for beneficial insects and another four used other cultural methods. Few growers made no attempt to encourage beneficial insects on their farm. Seven growers said they didn't encourage beneficial insects because they believed that beneficial insects provided negligible pest control services (Figure 34). Therefore, information that demonstrates the pest control services provided by beneficial insects may be of value to these growers.

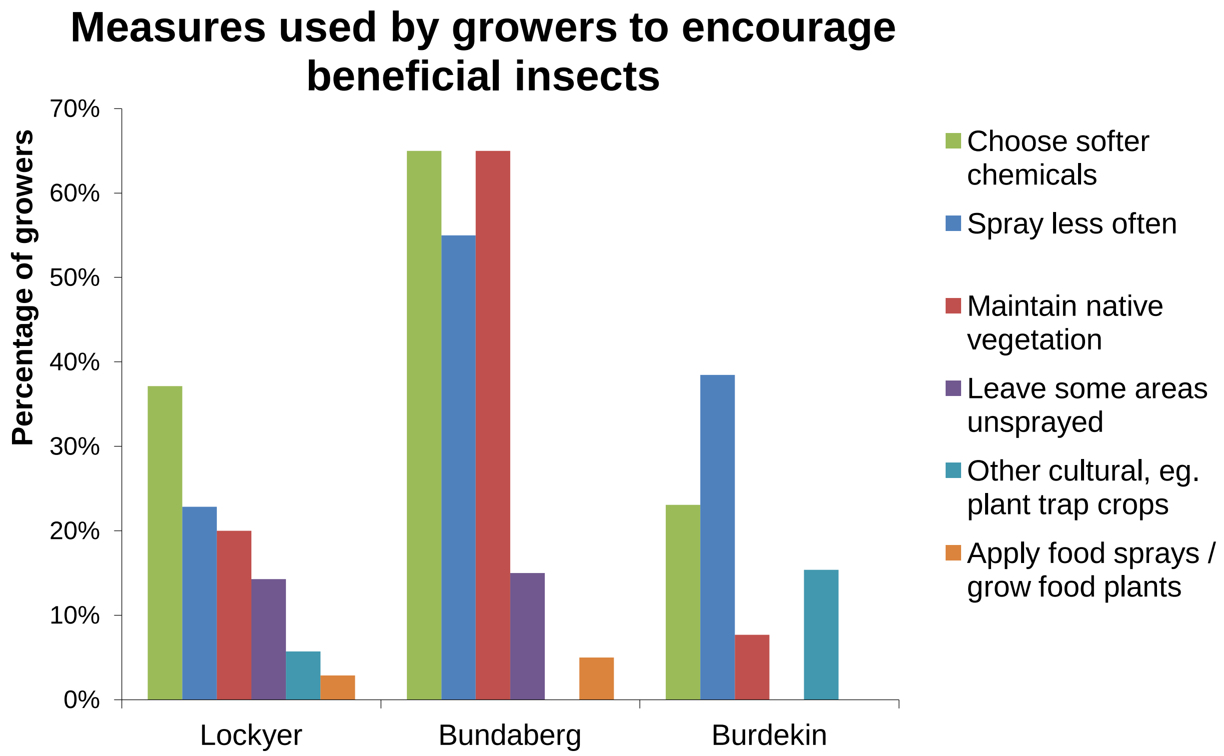


Figure 34. The percentage of growers that use various methods to encourage beneficial insects on their farm by location.

Few growers do not encourage beneficial insects on their farm. In the Lockyer, seven growers said they didn't encourage beneficial insects, of which six thought that beneficial insects provide negligible pest control services, the other grower said it was not possible on their farm. In Bundaberg, three growers said they didn't encourage beneficial insects, but none of them gave a reason why. In the Burdekin, four growers said they didn't encourage beneficial insects, two said it was too expensive (vegetable growers) and the other two said it wasn't possible (cane growers), one of the four thought that beneficial insects provided no pest control services (Table 14).

Table 14. Reasons why growers do not encourage beneficials on their property by location.

Reason	Lockyer (n = 7)	Bundaberg (n = 3)	Burdekin (n = 4)
Not possible	1	0	2
Too expensive	4	0	2
Not helpful	6	0	1
Just don't	0	2	0

19. To encourage the wasp on your farm, would you be prepared to take further action and modify your whitefly control practices? (please tick all that apply)

☐ I have already done so

☐ No, no time / not possible
☐ No, I feel I do enough already
☐ Not my decision to make
☐ No, I'm concerned it will lead to an increase in whitefly

☐ Possibly, with extensive evidence the wasp is highly effective
☐ Possibly, if I could fit it into my schedule
☐ Possibly, if my neighbours were also involved
☐ Possibly, but I don't know what it would involve
☐ Possibly, but I need more information

☐ Certainly, I am concerned about pesticide resistance
☐ Certainly, I consider that it will be better in the long run
☐
Other____

Growers were asked if they would make further changes to their whitefly managment practice to encourage *E. hayati*. The purpose of this question was to get an idea of how willing growers would be to make a change and the drivers behind a willingness, or lack of, to change.

Over half of growers (n = 38) said they were willing to make further changes to encourage *E. hayati* with another ten growers said they possibly would make further changes. Only two growers said they were not prepared to make further changes and seven said they already did enough.

The most common answer was "Certainly, I consider that it will be better in the long run", but this doesn't not reveal what growers consider will be better in the long run. The second most common answer "Certainly, I am concerned about pesticide resistance" (Figure 35). This is encouraging given the reluctance to change to date. Furthermore, growers may be more likely to make a change if they believed there was a positive and immediate benefit on their pest pressures.

In Figure 35, the options represented by a white box, were not considered a reason for change by any growers.

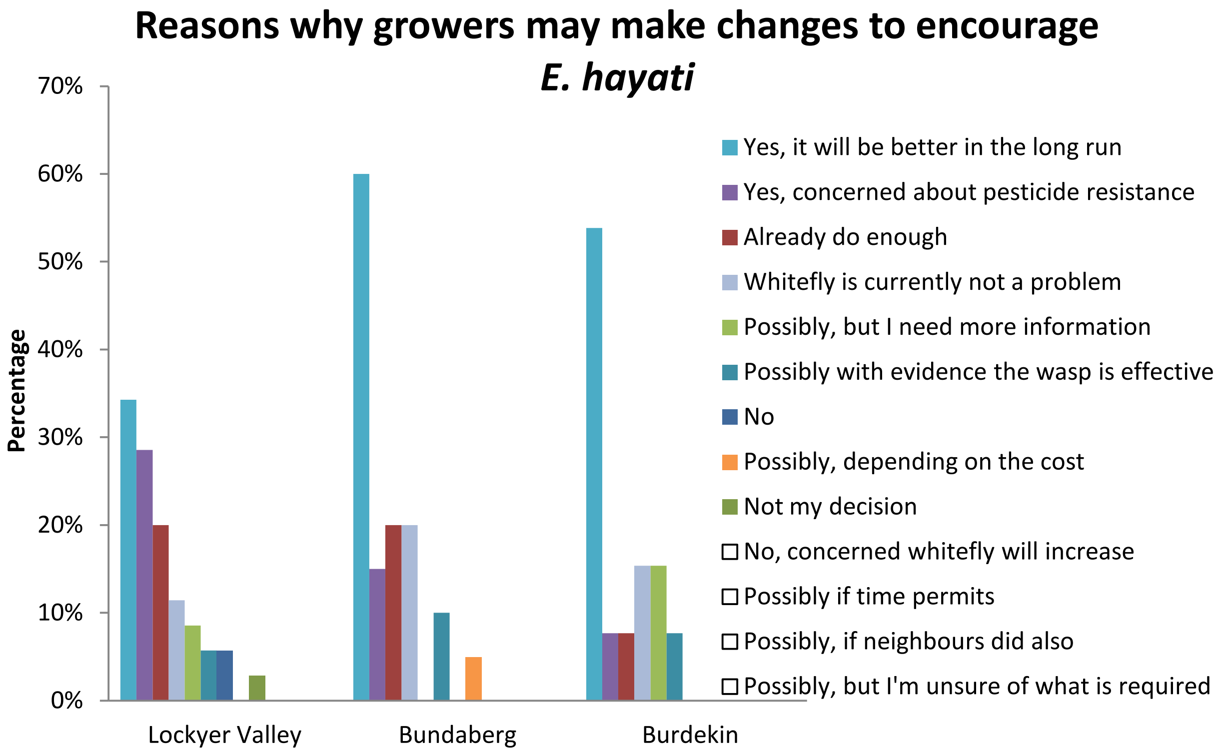


Figure 35. Growers were asked if they would be prepared to make further changes to their whitefly management practices to encourage *E. hayati* on their property, and the reason driving their answer.

Consultant Survey

1. Which district is closest to you?

☐ Burdekin River
☐ Bundaberg
☐ Lockyer

Twenty two consultants completed the survey – ten from the Lockyer Valley and six each from Bundaberg and Burdekin.

2. Who do you provide crop advice for?

☐ One grower in my region
☐ Several growers in my region
☐ Nearly all growers in region

The majority of consultants provide advice for several growers in their region, two consultants said they provided advice for nearly all growers in their regions. Of the two that said they provided advice for nearly all growers in their region, one of those consultants provided advice on c otton only in the Burdekin region and the other provided advice on vegetables and fruit trees in the Lockyer (Figure 36).

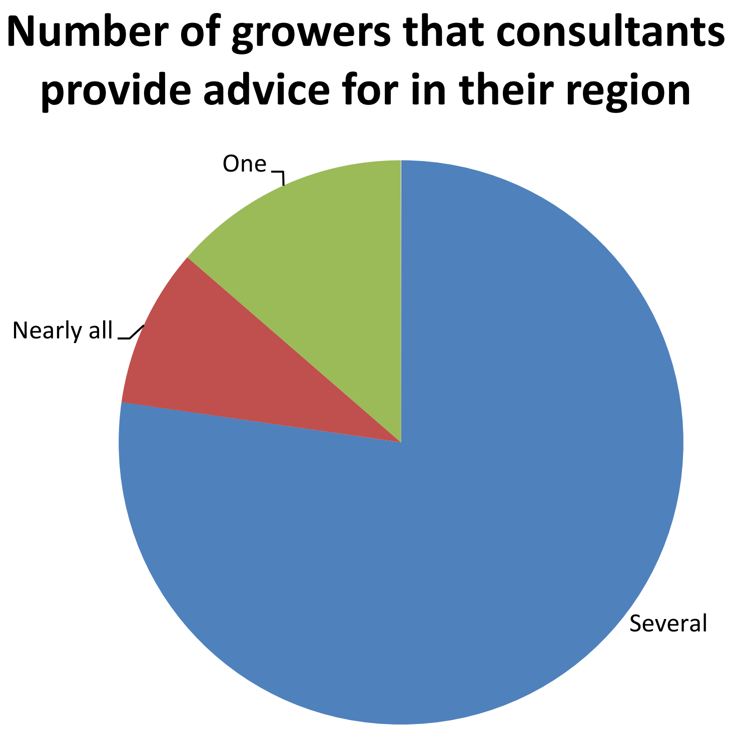


Figure 36. Number of growers that consultants provide advice for in their region.

3. Please rank the primary industry that you provide services to in order of your priority (if an option is not applicable to you, please leave blank)

☐ Vegetables
☐ Cane
☐ Cotton
☐ Other ___________________________

Of the twenty two consultants that answered the survey, the primary focus for all consultants surveyed except two was vegetables, the remaining two consultants were from the Burdekin region and primarily focused on Cotton. The secondary industries that consultants provided advice for were:

- Seven consultants over all regions provided advice on tree crops such as fruit avocado and nuts)
- Three consultants from Bundaberg and Burdekin provided advice for cane; and
- Three consultants from Lockyer and Burdekin provided advice for grain crops (Figures 37, 38 and 39).

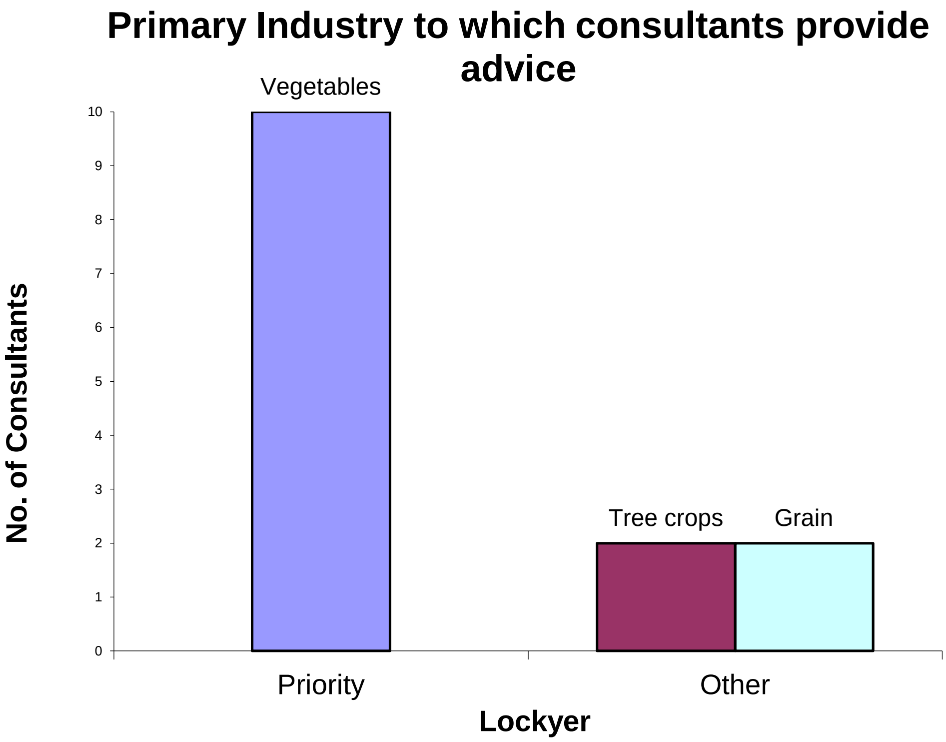


Figure 37. The type of primary industry to which consultants in the Lockyer Valley provide advice.

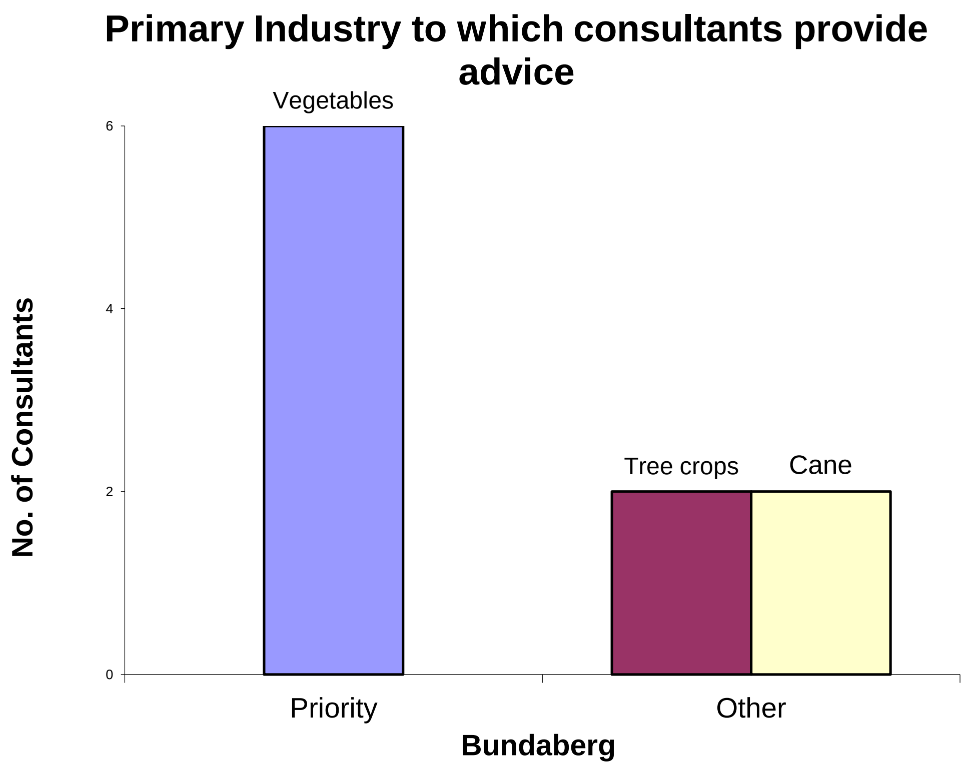


Figure 38. The type of primary industry to which consultants around Bundaberg provide advice.

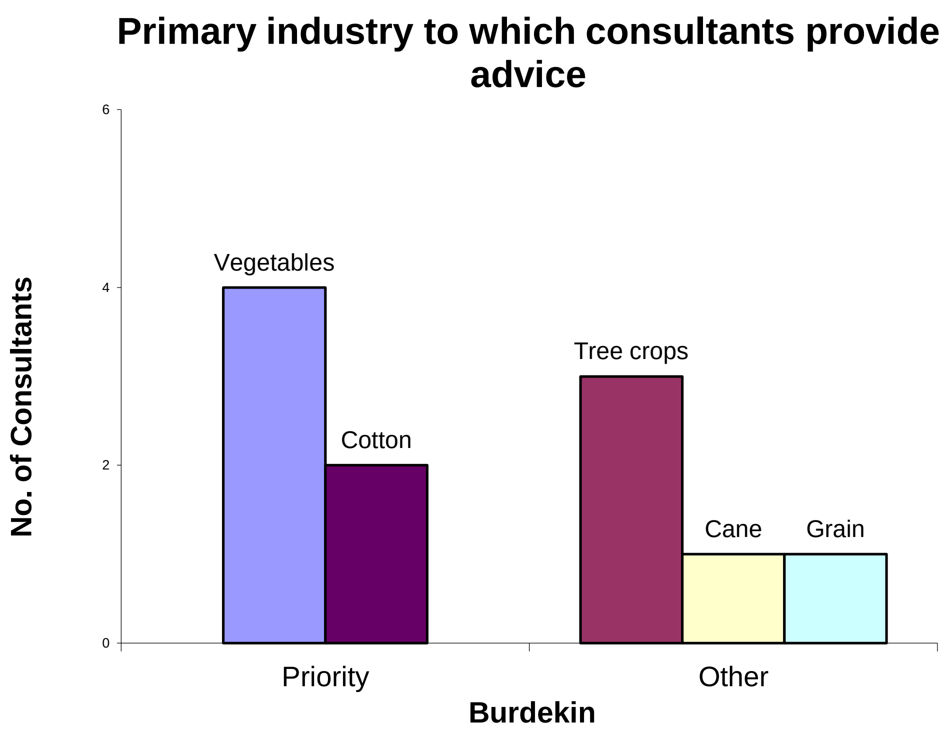


Figure 39. The type of primary industry to which consultants in the Burdekin region provide advice.

4. What crops do you provide advice for? (please tick all that apply)

☐ Beans	☐ Egg fruit	☐ Soybean
☐ Brassicas	☐ Honeydew melon	☐ Squash
☐ Cane	☐ Lucerne	☐ Sweet corn
☐ Capsicum	☐ Potatoes	☐ Tomato
☐ Chilli	☐ Pumpkins	☐ Watermelon
☐ Cotton	☐ Rockmelon	☐ Zucchini
☐ Cucumber	☐ Snowpeas	☐ Other __________

The most common crops that the consultants completing this survey provided advice for were Pumpkin, Watermelon and Beans. C onsultants in the Lockyer Valley provided advice for the greatest variety of crops. The top two crops that consultants provided advise for in each area were whitefly host crops (Table 15), therefore consultants should all be familiar with managing whitefly, most likely from a variety of crops.

Table 15. Number of consultants completing the survey that consult on different crops in each location.

Lockyer	# out of 10	Bundaberg	# out of 6	Burdekin	# out of 6
Beans	9	Tomato	6	Pumpkins	4
Brassicas	9	Capsicum	5	Beans	3
Pumpkins	9	Orchard	4	Cotton	3
Cucumber	7	Potatoes	4	Egg fruit	3
Lettuce	7	Pumpkins	4	Watermelon	3
Zucchini	7	Watermelon	4	Zucchini	3
Onion	6	Zucchini	4	Cane	2
Potatoes	6	Cucumber	3	Capsicum	2
Rockmelon	6	Rockmelon	3	Chilli	2
Sweet corn	6	Egg fruit	2	Cucumber	2
Tomato	5	Honeydew	2	Rockmelon	2
Honeydew	4	Snowpeas	2	Soybean	2
Lucerne	4	Soybean	2	Squash	2
Capsicum	3	Squash	2	Honeydew	1
Chilli	3	Sweet corn	2	Orchard	1
Snowpeas	3	Beans	1	Sweet corn	1
Watermelon	3	Brassicas	1	Tomato	1
Cabbage	2	Cane	1		
Egg fruit	2	Chilli	1		
Orchard	2				
Squash	2				
Beetroot	1				
Bitter melon	1				
Carrot	1				
Celery	1				
Grains	1				
Soybean	1				
Strawberries	1				

5. In your experience, which year was whitefly worst? _________
How much of a problem was whitefly for your growers during that year? (please circle)

1	2	3	4	5	6	7	8	9	10

No problem — Minor problem — Occasional problem — Significant problem — Catastrophic problem

Consultants were asked how bad their growers' current whitefly problem was on a scale of one (no problem) to ten (catastrophic problem). They were also asked which year was the worst year for whitefly pest problems and how bad the problem was in that year.

According to the consultants in this survey, the whitefly problem peaked in Bundaberg first with consultants from that area listing 2004 on average as the peak year (Figure 40). Of note, the average year listed by growers from Bundaberg is 2006 (Figure 13). Consultants from the Lockyer Valley on average listed 2005 as the worst whitefly year (Figure 40), similar to grower reports (Figure 12). All but one grower from the Burdekin, listed 2008 as the worst year and one nominated the current year (that the survey was conducted – 2009) (Figure 40), again, similar to grower reports (Figure 14).

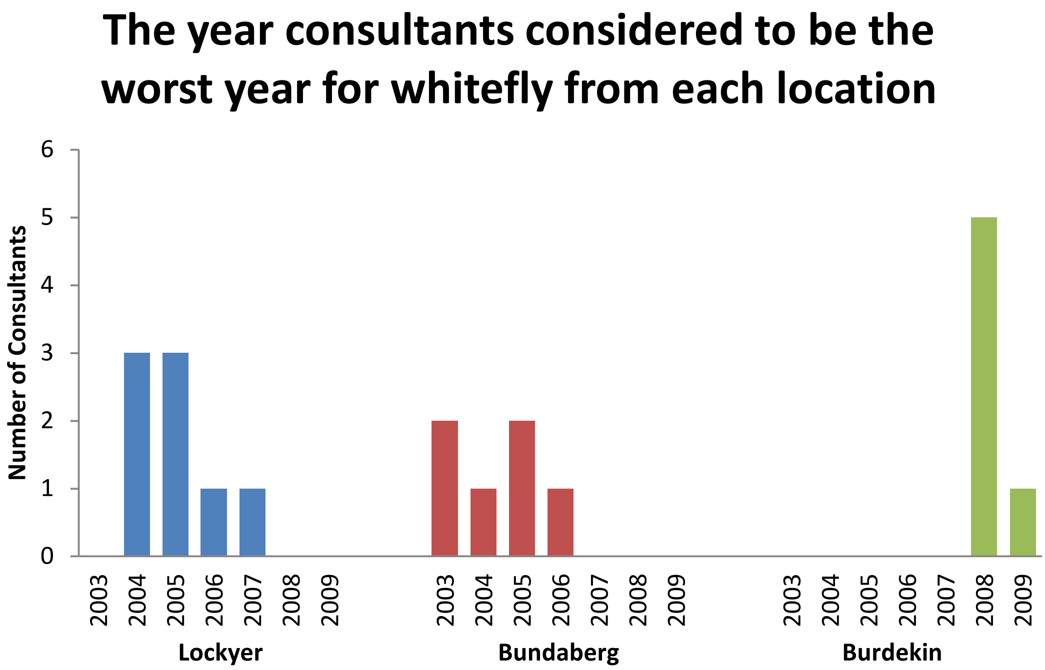


Figure 40. The number of consultants from each location that listed a particular year as the worst year for whitefly.

6. On average, how much of a problem is whitefly for your growers now? (please circle)

1	2	3	4	5	6	7	8	9	10

No problem — Minor problem — Occasional problem — Significant problem — Catastrophic problem

In the worst year, the whitefly problem was highest in Burdekin with a mean of 8.5, with Lockyer with a mean of 8 and Bundaberg with a mean of 7. Consultants from both Lockyer and Bundaberg now consider the whitefly problem to be minor. The Burdekin consultants consider the current whitefly problem as somewhere between 'an occasional problem' and a 'catastrophic problem'. Burdekin growers, however, don't perceive the problem to be as bad with a mean score of 4 in the current year.

These results may indicate that with an earlier peak in Lockyer and Bundaberg, the environment (including the wasp, modification of crops grown and practices by growers) may have had the time to develop into a tolerable whitefly situation, whereas Burdekin may not have yet made these adjustments (Figures 41, 42 and 43).

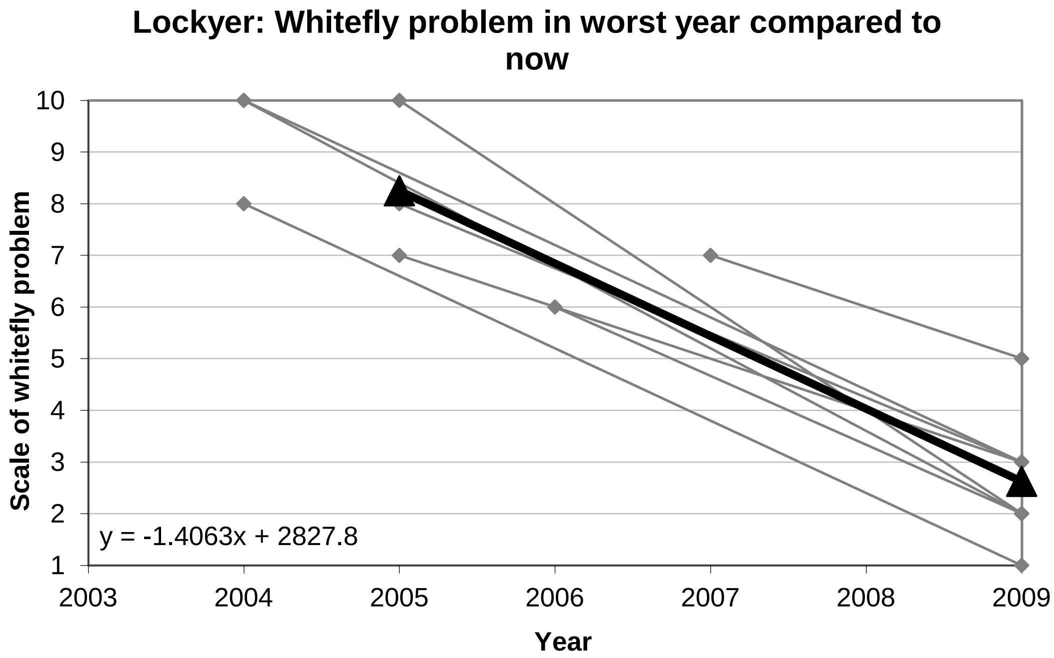


Figure 41. The whitefly problem in the worst year and in the current year in the Lockyer Valley.

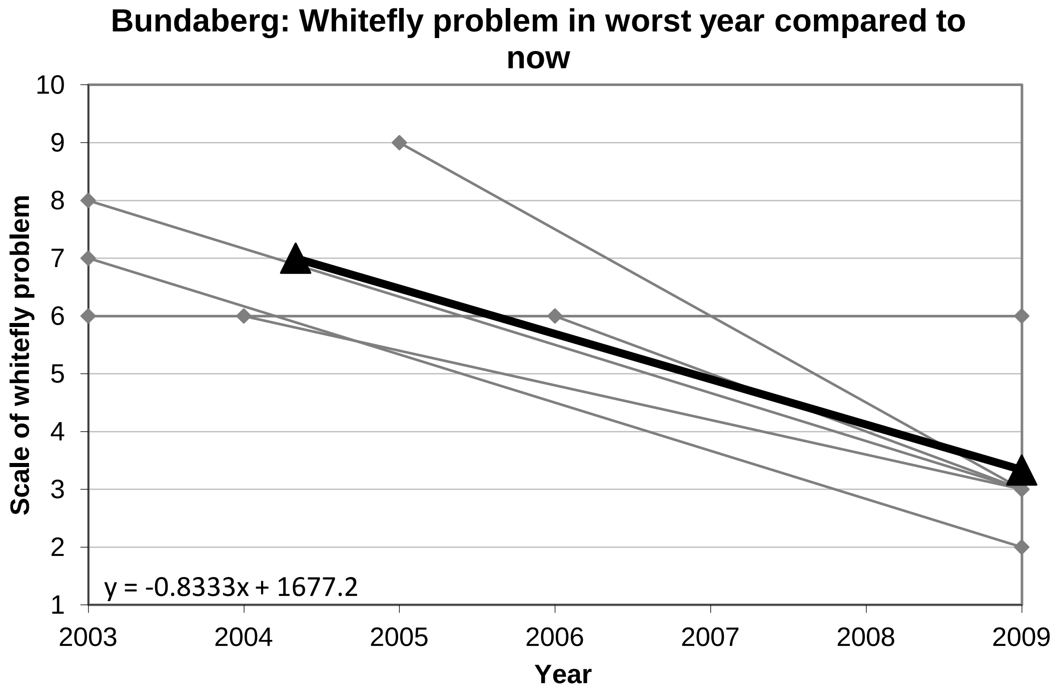


Figure 42. The whitefly problem in the worst year and in the current year around Bundaberg.

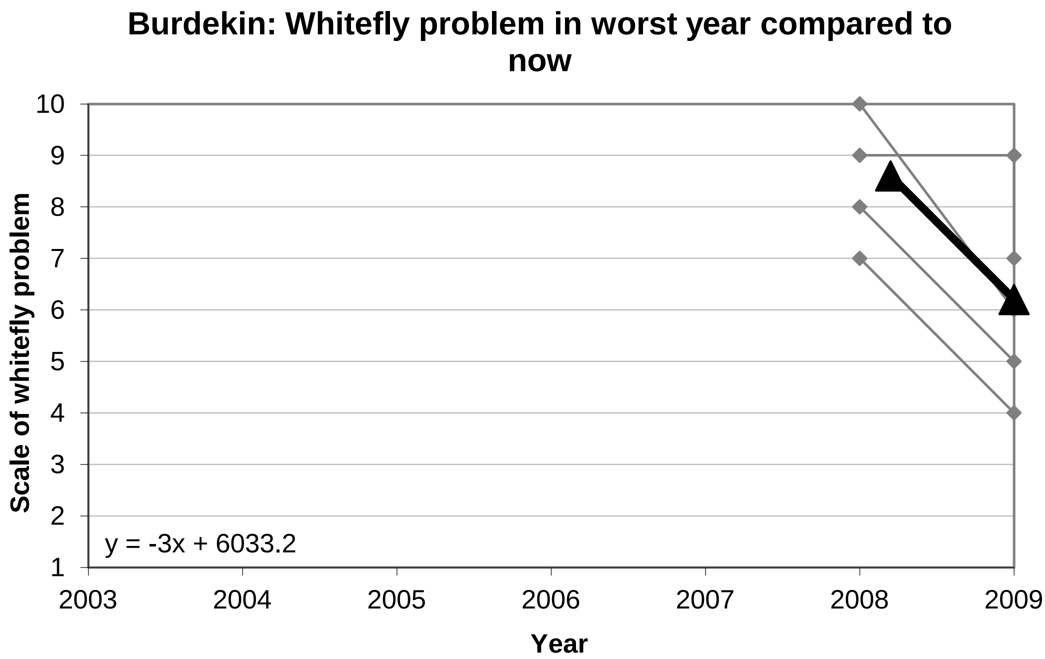


Figure 43. The whitefly problem in the worst year and in the current year in the Burdekin region.

7. Do you monitor specifically for whitefly?

☐ Yes → How do you monitor for whitefly? (please tick all that apply)

- ☐ Quick walk through to look for any whitefly adults / nymphs (please circle)
- ☐ Standardised counting method of whitefly adults / nymphs (please circle) then compare to previous week
- ☐ Standardised counting method of whitefly adults / nymphs (please circle) then compare to a threshold

or ☐ Other ____

☐ No → When do you recommend applying control measures for whitefly? (please tick all that apply)

- ☐ Buy pre-treated seed or seedlings
- ☐ As soon as seedlings are established
- ☐ When crop starts to flower
- ☐ When fruit or vegetables start developing
- ☐ As fruit or vegetables near maturity
- ☐ N/A – whitefly aren't a concern for my growers
- ☐ Other ____

Consultants were asked if they monitored specifically for whitefly. All but one consultant from Lockyer (n = 9) said they monitored for whitefly, whereas only half of consultants in Burdekin (n = 3) and Bundaberg (n = 3) said they monitored for whitefly. These results did not differ greatly to the grower survey, with the exception of Bundaberg where a greater percentage of growers (80%) said they monitored for whitefly.

In the comments related to this question, three consultants who said they didn't monitor specifically for whitefly, later commented that they decide to control: (1) after they "count and notice thresholds being reached"; (2) when "the pest has reached threshold"; and (3) "by monitoring nymphs". I suspect, this question was not framed correctly to uncover the methods used to make control decisions about whitefly. It's possible that the consultants recommend their grower monitor, but don't actually monitor themselves. In Figure 44, those three consultants that answered "no", have been included as if they answered "yes".

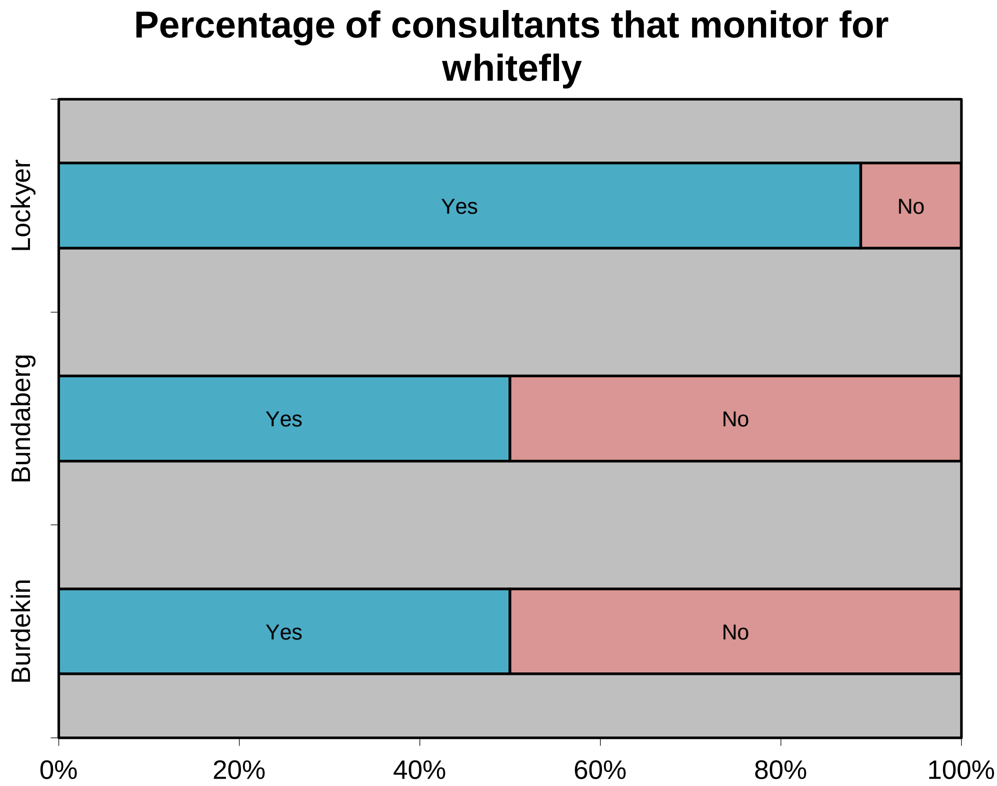


Figure 44. The percentage of consultants that monitor for whitefly by location.

Of the methods used by consultants to monitor for whitefly, no one method stood out. Consultants that said they monitored for whitefly were asked for the method they used to monitor. The method for monitoring whitefly varies between regions and between consultants and growers (Figures 45 and 20). No one method stood out, however, the most popular method was counting adults and comparing to a threshold, followed closely by counting nymphs and comparing to the previous week (Figure 45). Consequently, comparing data between growers or consultants would be difficult. This may be one area that would be easy to suggest change, ie. standardise whitefly monitoring methods for ease of communication.

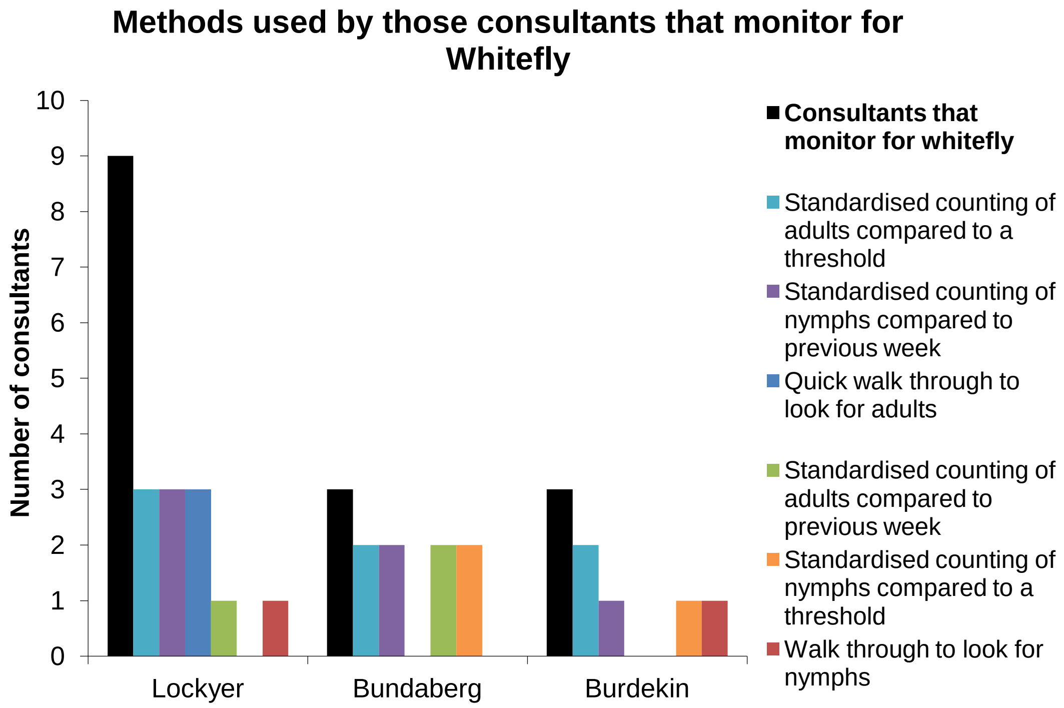


Figure 45. The methods of monitoring whitefly but those consultants that monitor.

If consultants said they didn't monitor for whitefly, then they were asked at what point they recommended growers control for whitefly. Three consultants in each area said that they did not monitor for whitefly. Figure 46 shows at what stage of crop they recommend spraying for whitefly. The Lockyer Valley consultants only recommended spraying seedlings or buying pre-treated seedlings and only one consultant (from Bundaberg) recommended spraying after the flowering period.

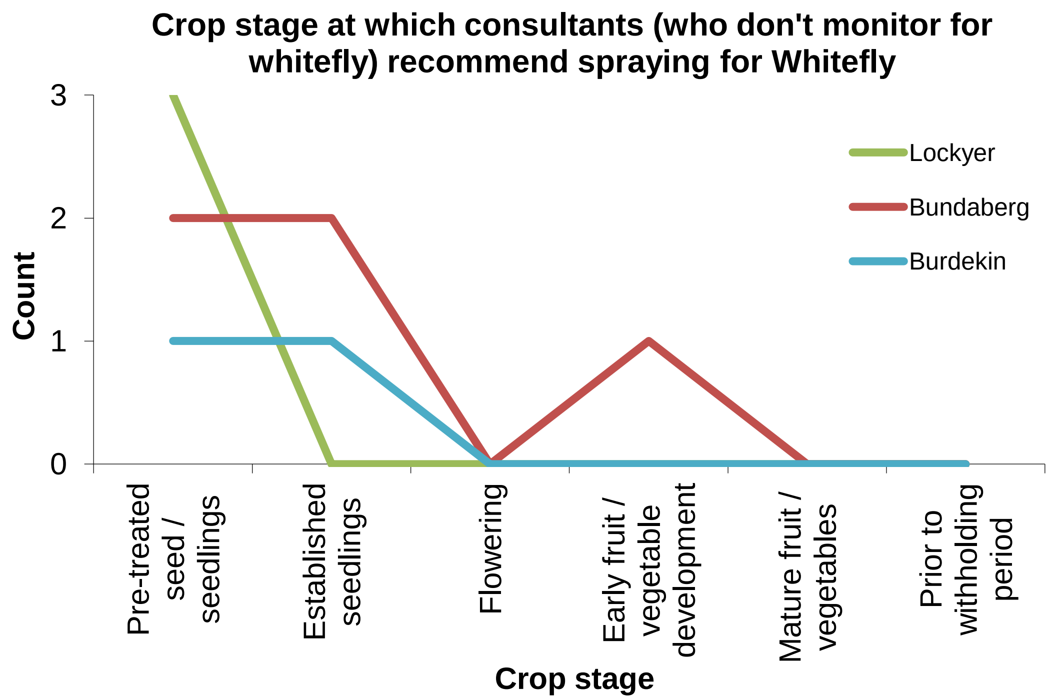


Figure 46. The crop stage at which consultant that don't monitor for whitefly recommend spraying for whitefly.

8. What information do you use to recommend that a grower should start controlling for whitefly? (please tick all that apply)

☐ Numbers of whitefly <u>adults / nymphs</u> (please circle) per leaf reach a threshold on susceptible crops
☐ Weather conditions / climatic forecast is favourable for whitefly
☐ Other growers in the region start to report problems
☐ Preventative application(s) on all susceptible crops
☐ Preventative application(s) on highly susceptible crops
☐ Nothing, whitefly does not impact on the production or output of my growers
☐ Other ______________________________

For consultants the most important information for deciding when a grower should spray for whitefly is the number of whitefly (adult or nymph) present. In Bundaberg, consultants often used reports from other local growers that they were experiencing a whitefly problem (Figure 47).

Seven consultants (one each from Bundaberg and Burdekin, and five from the Lockyer Valley) said that they use thresholds to recommend when to spray AND recommend preventative sprays, which seems contradictory. It is possible that the question was not worded correctly; alternatively, this could indicate there is some cognitive bias, where the consultants are providing answers they think that CSIRO researchers wish to hear.

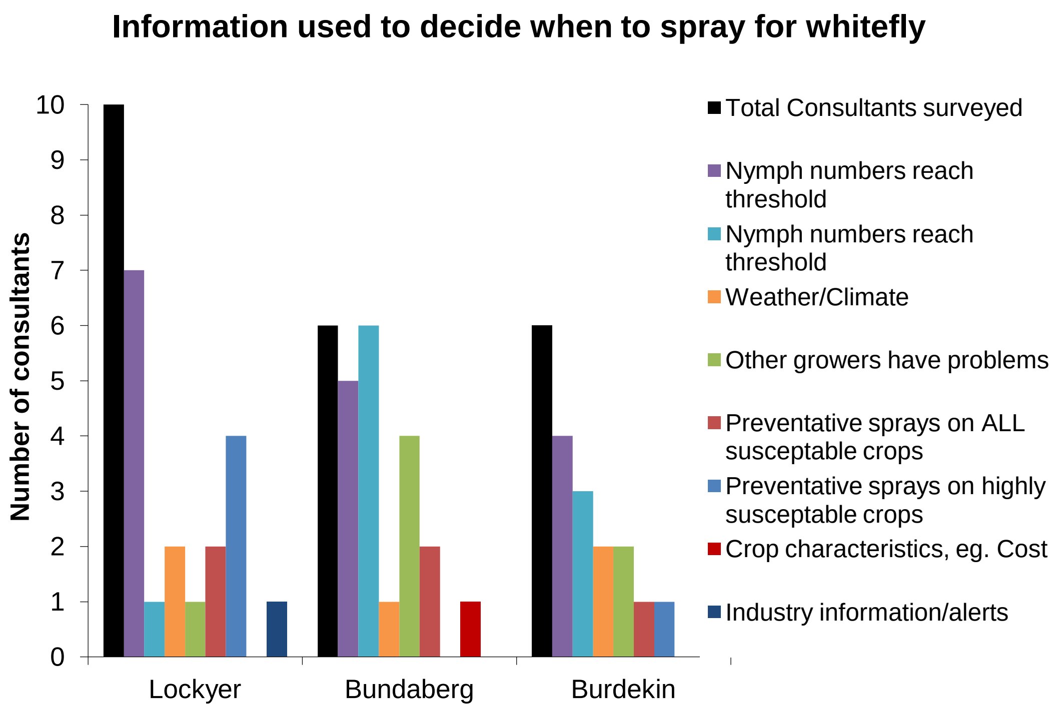


Figure 47. The information used by consultants to decide when a grower should spray for whitefly.

9. If you recommend that a grower control for whitefly:

9a. What do you recommend they use?

☐ The most cost effective insecticide
☐ Insecticides softer on beneficial insects – if possible
☐ Insecticides softer on beneficial insects – always
☐ N/A – I tolerate whitefly
☐ Other

____

Consultants were asked what type of insecticide they recommended growers use for whitefly. Lockyer Valley consultants indicate they are most likely to recommend insecticides that are softer on beneficial insects and Burdekin consultants least likely. This is in contrast to the insecticides that grower said they used, as growers from the Lockyer Valley tended to use the most cost effective and Burdekin growers preferred softer insecticides. However, looking closely at the sprays recommended for all insect pests (and not just whitefly), Lockyer Valley consultants were most likely to recommend insecticides harmful to *E. hayati* (see Table 18).

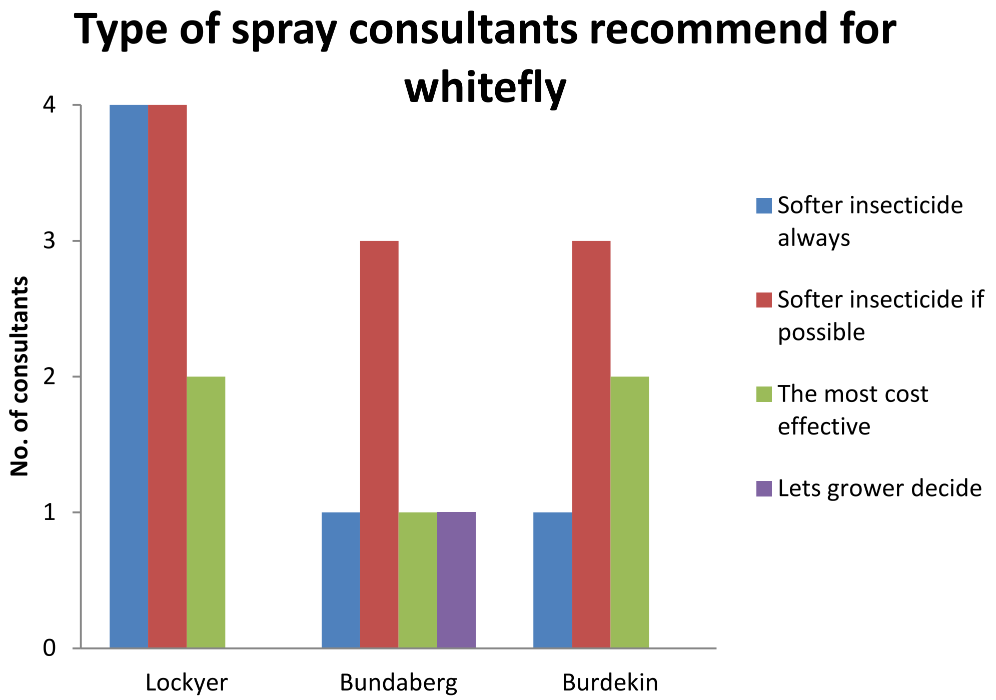


Figure 48. The type of insecticide that a consultant recommends for use on whitefly by location.

9b. How often do you recommend they deliver it?

☐ Once, when the crop is young
☐ Only if whitefly numbers are becoming a problem, eg. reached a threshold
☐ Weekly / fortnightly throughout the life of the crop
☐ N/A
☐ Other ____

Consultants in Bundaberg all said that they made recommendations based on t he whitefly numbers in the crop, as did most of the growers from Burdekin, but only 30% of consultants from the Lockyer made this recommendation. In fact a greater percent (40%) of consultants in the Lockyer Valley recommended treating the crop once when it was young, irrespective of the whitefly numbers. This type of recommendation is reflected in the spray style of growers in the Lockyer, where the majority of growers said they used Confidor on young crops that were whitefly susceptible. T wo consultants (20%) in the Lockyer also said they recommended spraying regularly throughout the life of a crop (Figure 49). O verall, consultants in the Lockyer appear to be less inclined to make spray frequency decisions based on the whitefly present and more likely to make general recommendations. T his creates unnecessary use of insecticides and may contribute to the very low numbers of *E. hayati* observed in the Lockyer Valley in the fieldwork experiments associated with this project.

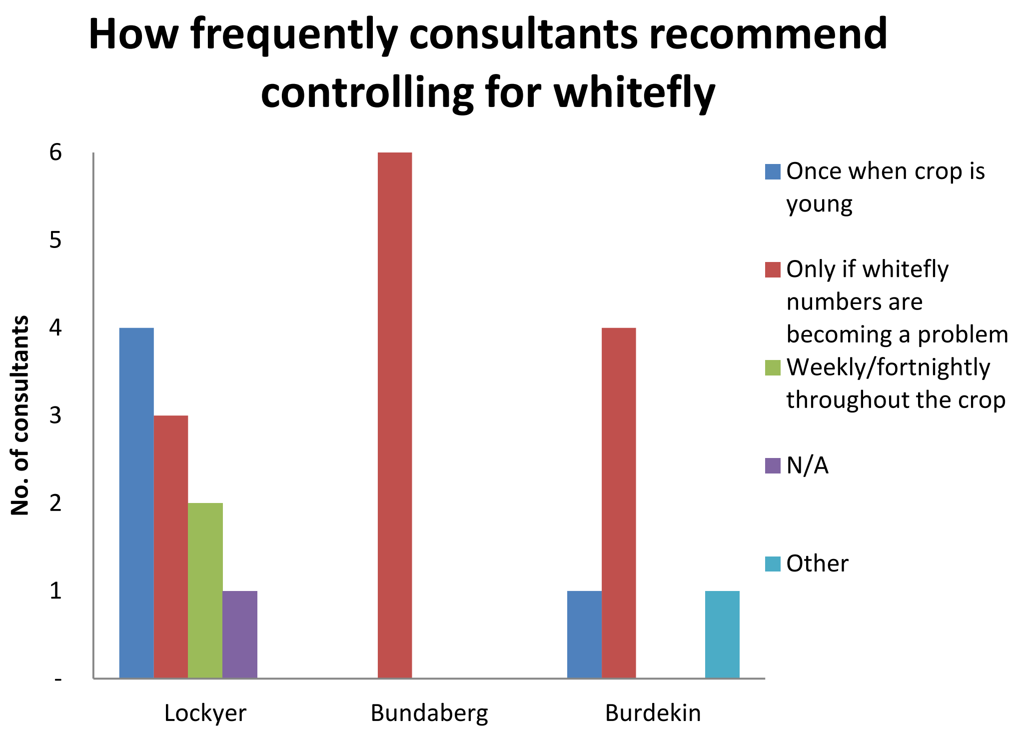


Figure 49. How often consultants recommend growers control for whitefly in each region.

10. Besides using insecticides, what else do you recommend your grower do to control for whitefly? (please tick all that apply)

☐ Farm hygiene, eg. ploughing in harvested plants, controlling broad leaf weeds.
☐ Avoid planting susceptible crops during peak whitefly season
☐ Avoid planting susceptible crops consecutively
☐ Encourage beneficials by providing refuges
☐ Other ___________________________

When consultants were asked what other techniques they recommended for controlling whitefly, nearly all recommended that growers practice good farm hygiene. R oughly half also recommended encouraging beneficial insects by providing refuges (Table 16). Other recommendations made by consultants to avoid whitefly included avoiding planting host crops next to each other; avoiding planting downwind of a sweet potato crop because they can generate a lot of whitefly, and; planting crops in line with the predominant wind direction.

Table 16. Methods other than using insecticides recommended by consultants to control for whitefly.

Method	Lockyer (n = 10)	Bundaberg (n = 6)	Burdekin (n = 6)
Improve farm hygiene	9	6	6
Encourage beneficials by providing refuges	4	2	4
Avoid planting susceptible crops consecutively	0	0	1
Avoid planting susceptible crops during peak whitefly season	1	0	0

11. If you advise growers on any of the crops listed below, please choose three that require the most intensive pest management and list what insecticides you recommend for **ALL** insect pests, including whitefly. Please also state the recommended application method and stage of the crop to which it should be applied.

Beans	Honeydew melon	Squash
Capsicum	Potatoes	Tomato
Chilli	Pumpkins	Watermelon
Cotton	Rockmelon	Zucchini
Cucumber	Snowpeas	Other whitefly host crop
Egg fruit	Soybean	

Application method
I = via irrigation
PH = plant hole drench
S = spray (aerial or ground)

Crop stage
1 = seedling / seed
2 = vegetative / pre-flowering
3 = flowering
4 = mature fruit/vegetable / pre-harvest
A = all stages

Crop	Control product	Application	Crop stage
Eg. Cucumber	*Applaud 440 SC*	*S*	*2, 3*
	Endosulfan	*S*	*2*

Consultants were asked to list the three crops that required the most intensive pest control and comment on the measures they recommended to control those pests. This table shows the crops listed. The most frequently listed crops were cucurbits (13), brassicas (9), tomatoes (9), and lettuce (7).

Table 17. Number of consultants that list a crop in their "top three" requiring the most intensive pest management.

Lockyer		Bundaberg		Burdekin	
Crop	No.	Crop	No.	Crop	No.
Lettuce	7	Tomato	4	Cotton	2
Cucurbits	4	Capsicum	2	Tomatoes	2
Brassicas	4	Pumpkins	2	Beans	2
Tomatoes	3	Sweet potato	1	Pumpkin	2
Beans	3	Potatoes	1	Squash	1
Potatoes	2	Cucurbits	1	Capsicum	1
Broccoli	2	Eggplants	1	Watermelon	1
Cauliflower	1	Cucumber	1	Chilli	1
Pumpkins	1	Rockmelon	1	Soybeans	1
Chinese cabbage	1	Watermelon	1	Melons	1
Sweetcorn	1			Eggplant	1
Onions	1				
Cabbage	1				

Lockyer Valley consultants shared their spray recommendations on three whitefly host crops, in total 29 recommendations were reported by ten consultants. Of those 29 recommended spray regimes, Confidor was recommended 52% of the time, more that twice as frequently as the next most popular insecticide (Table 18). Seven of consultants listed lettuce as one of those most intensively sprayed. Of the seven consultants in the Lockyer that listed their spray recommendations for lettuce, five recommended using Confidor (imidacloprid) as a plant hole drench or spray at the start of the crop. Confidor was also the most recommended insecticide on beans, cucurbits and brassicas. Confidor is very harmful to *E. hayati*. See appendix II for a list of insecticides used on whitefly host crops and the level of harm to *E. hayati*.

The six consultants from Bundaberg have their comments on the three most intensively sprayed whitefly host crops, with a combined total of fifteen spray recommendations recorded for Bundaberg. There was slightly less reliance on Confidor in Bundaberg, with it being recommended 33% of the time, as was Movento (spirotetramat) which is safe to use with *E. hayati*. However, other insectides harmful to *E. hayati* were frequently recommended such as Talstar (a synthetic pyrethroid) and Lannate (a carbamate) (Table 18).

A combined total of 15 recommended spray regimes were reported from the Burdekin. In the Burdekin, consultants were much more likely to recommend softer insecticides, and less likely to recommend insecticides in general. Confidor was only recommended for use 13% of the time. The four most popular insecticides recommended were categorised as moderately harmful (<75% mortality) or not harmful (< 25% mortality) to *E. hayati*. However, the sprays that Burdekin growers actually used did not correlate with consultant recommendations (Table 12). Where, in reality, there was much more reliance on insecticides harmful to *E. hayati*. Growers are either not following the recommendations of consultants or are not using a consultant.

Table 18. The frequency that each insecticide is recommended for use on any crop in that location.

Lockyer	29 crops	Bundaberg	15 crops	Burdekin	15 crops
Imidacloprid: Confidor	52%	Imidacloprid: Confidor	33%	Spinosad: Success	27%
Spinosad: Success	21%	Spirotetramet: Movento	33%	Pyriproxyfen: Admiral	20%
Emamectin: Proclaim	21%	Methomyl: Lannate	27%	Heliothis NVP: ViVUS	13%
Flubendiamide: Belt	17%	Bifenthrin: Talstar	20%	Spirotetramet: Movento	13%
Chlorantraniliprole: Coragen	14%	Natrasoap	13%	Imidacloprid: Confidor	13%
Indoxacarb: Avatar	14%	*Bacillus thuringiensis:* Dipel	13%	Diafenthiuron: Pegasus	7%
Thiodicarb: Larvin	10%	Abamectin: Vertimec	7%	Fipronil: Regent	7%
Bifenthrin: Talstar	10%	Pyriproxyfen: Admiral	7%	Buprofezin: Applaud	7%
Bacillus thuringiensis	7%	Pymetrozine: Chess	7%	Bifenthrin: Talstar	7%
Methomyl: Lannate	3%	Endosulfan	7%	Pymetrozine: Chess	7%
Pymetrozine: Chess	3%	Sulfur	7%	Pirimicarb: Pirimor	7%
Pyriproxyfen: Admiral	3%				
Dimethoate	3%				
Pyrethroid: Karate	3%				
Neem	3%				

Tables 19, 20 and 21 are some examples of the spray recommendations made by consultants on the most common whitefly host crops. The tables show the variety of recommendations (both in insecticide type and intensity of use) made by consultants for similar crops. For example, consultant "1" in Bundaberg recommends using Sulphur and Lannate through the entire life of the crop, whereas consultants "14" and "18" in the Lockyer Valley only recommend using a plant-hole drench of Confidor at planting then nothing else during the life of the crop.

Table 19. Spraying regimes consultants recommend for Cucurbits

Consultant	Plant Stage	Seed/ seedling	Vegetative/ pre-flowering	Flowering	Mature/ pre-harvest
13	Cucurbits *Lockyer Valley*	PH: Confidor			S: Telstar
14 & 18	Cucurbits *Lockyer Valley (2)*	PH: Confidor			
19	Pumpkin *Lockyer Valley*		S: Chess & Admiral →	→	
1	Cucurbits *Bundaberg*	S: Sulfur & Lannate →	→	→	→
3	Rockmelon *Bundaberg*				S: Dipel
4	Cucumber *Bundaberg*			S: Movento & Confidor	
4	Pumpkin *Bundaberg*	I: Confidor			
5	Pumpkins *Bundaberg*	PH: Confidor			
5	Watermelon *Bundaberg*	PH: Confidor S: Movento & Natrasoap →	→	→	→
8	Melon crops *Burdekin*		S: Movento →	→	
9	Watermelon *Burdekin*			S: Admiral	
9	Squash *Burdekin*	PH: Confidor			
9	Pumpkin *Burdekin*		S: Talstar →	→	
10	Pumpkin *Burdekin*		S: Admiral		

Table 20. Spraying regimes consultants recommend for Brassicas.

Consultant	Plant Stage	Seed/ seedling	Vegetative/ pre-flowering	Flowering	Mature/ pre-harvest
14 & 15	Brassicas *Lockyer Valley (2)*	PH: Confidor			
17	Cauliflower & Broccoli *Lockyer Valley*	S: Success, Proclaim, Belt, Corrigen, Avatar →			
18	Brassicas *Lockyer Valley*	Pretreated			
20	Chinese cabbage *Lockyer Valley*	S: Proclaim, Avatar & Belt →			
20	Cabbage *Lockyer Valley*	S: Dimethoate & Karate →			

Table 21. Spraying regimes consultants recommend for Tomato.

Consultant	Plant Stage	Seed/ seedling	Vegetative/ pre-flowering	Flowering	Mature/ pre-harvest
15	Tomato *Lockyer Valley*	PH: Confidor			
16	Tomato *Lockyer Valley*	S: Success, Proclaim, Larvin, Belt, Corrigen →			
21	Organic Tomato or Tomato *Lockyer Valley*	I: Neem → S: Bt →			
2	Tomato *Bundaberg*	S: "heaps of products" →			
3	Tomato *Bundaberg*				Talstar & Vertimec
5	Tomato *Bundaberg*	PH: Confidor S: Movento, Admiral, Natrasoap, Talstar →			
6	Tomato *Bundaberg*	S: Movento S: Talstar →			
8	Tomato or Cherry Tomato *Burdekin*	S: Admiral, Applaud, Chess → I: Confidor Guard			

12. Have you changed your general recommendations for whitefly pest management since 2005?

☐ No
☐ Yes → Why did you change? (please tick all that apply)
 ☐ Whitefly are worse now
 ☐ Whitefly are less of a problem now
 ☐ More effective insecticides became available / old insecticide permits expired
 ☐ I was aware that a new biocontrol agent was released for silverleaf whitefly
 ☐ Other ____________________

Most consultants had changed their recommendations since 2005 (Table 22), mainly because more effective insecticides became available or old permits expired (Figure 50). However in the Lockyer Valley, many consultants recommended changes because whitefly are less of a problem now. Only two consultants (one each from Burdekin region and around Bundaberg) said they had changed their recommendations because they were aware that a new biological control agent had been released for silverleaf whitefly.

These results, taken together with the results from the grower survey (Table 13) indicate that although consultants are recommending changes, growers tend to stick to what they know and are fairly resistant to change. Furthermore, growers are more likely to make changes because the circumstances have changed rather than to proactively make changes that would lead to an improvement in their circumstances.

Table 22. Has the Consultant changed the recommended whitefly management strategy since 2005?

	Lockyer	Bundaberg	Burdekin	Total
Yes	9	4	5	18
No	1	2	1	4

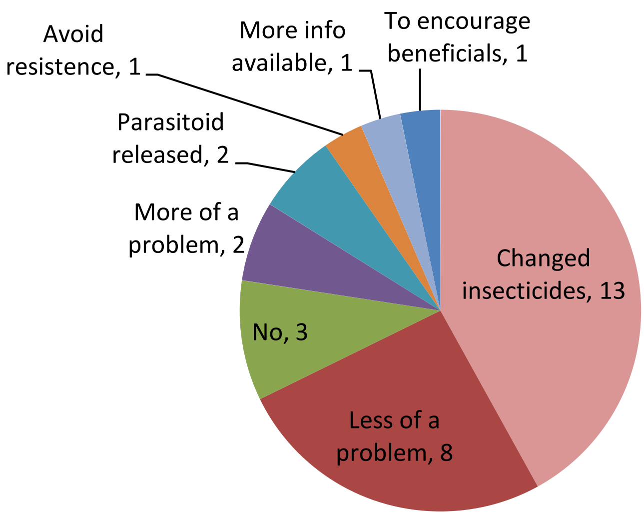


Figure 50. If the consultant has changed whitefly management recommendations since 2005, why?

13. Prior to this survey, were you aware of the tiny beneficial wasp (*Eretmocerus hayati*) that was released in Queensland between 2005 and 2007?

☐ No
☐ Yes → Where did you first learn about the wasp?
- ☐ Department of Primary Industries, DPI newsletter or workshop
- ☐ Local agronomist
- ☐ CSIRO
- ☐ Internet search
- ☐ Neighbour / other grower
- ☐ Local media, eg. grower magazine, newspaper, radio, etc
- ☐ Other ____

All consultants said that they were aware that the parasitoid had been released. However, only two of the consultants listed the release of the parasitoid as a reason for changing their whitefly management recommendations (Figure 50). This implies that consultants do not have much faith in biocontrol or they lack understanding of how insecticides impact on biocontrol agents.

70% of consultants heard about the parasitoid from a Queensland State Government Agency or Agency publication. 20% heard about it from CSIRO and the remaining three consultants heard about it from either local media, another agronomist or Bugs for Bugs.

E. hayati success in the first few years after the release may have benefited from greater industry awareness. Very few growers were aware that a biocontrol agent for silverleaf whitefly had been released, and consultants did not consider that it's release warranted a change of practice.

14. Do you recommend measures that encourage other beneficials on your grower's farms? Tick any reasons that help explain your answer. (please tick all that apply)

☐ Yes
- ☐ Maintain native vegetation
- ☐ Choose softer chemicals
- ☐ Spray less often
- ☐ Leave some areas unsprayed
- ☐ Apply food sprays /grow food plants
- ☐ Other cultural, eg. plant trap crops

or ☐ Other _________________

☐ No
- ☐ Not possible for my growers
- ☐ Too expensive
- ☐ They provide negligible pest control services for my growers
- ☐ Other __________________________

All but one consultant said they recommended encouraging beneficial insects to their growers. The consultant, from the Lockyer Valley, who did not recommend it, said that it was not their place to make such recommendations. Nearly all consultants that recommended encouraging beneficial insects on-farm recommended choosing softer chemicals. One third also recommended maintaining native vegetation (primarily in the Lockyer Valley) but only three consultants recommended spraying less often. Other methods that consultants recommend is releasing beneficial insects to reduce reliance on insecticides and removing weeds that harbour pests.

Looking at the spray recommendations that consultants give for individual crops, it doesn't appear that consultants are recommending softer sprays, particularly in Bundaberg, where the majority of the recommended insecticides are harmful to *E. hayati*. Only one consultant in Bundaberg actually recommended insecticides that didn't harm *E. hayati* where possible. Consultants in the Burdekin region were much more likely to recommend insecticides that were only moderately harmful. Consultants in the Lockyer Valley tended to be either pro Confidor (60%) or pro softer insecticides (40%).

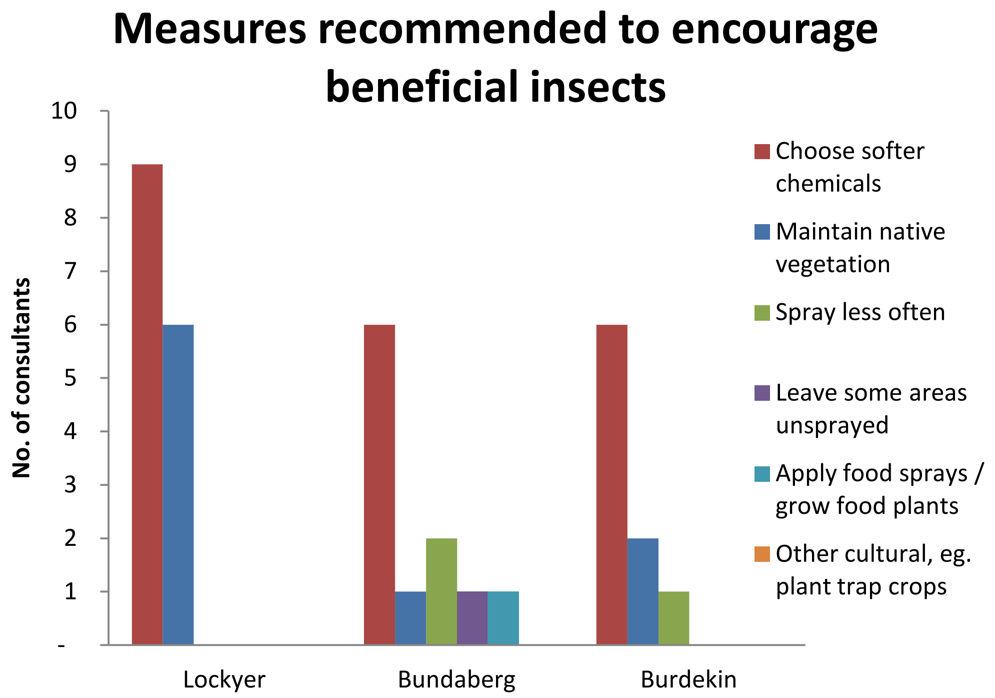


Figure 51. Measures that consultants recommend other than using insecticides to encourage beneficial insects.

15. Would you modify your recommendations for whitefly control to encourage the wasp on your grower's farms? (please tick all that apply)

☐ I have already done so

☐ *No, it would take too much time / wouldn't be possible*
☐ *No, I feel my growers do enough already*
☐ *No, I'm concerned it would lead to an increase in whitefly*

☐ *Possibly, with extensive evidence the wasp was highly effective*
☐ *Possibly, if there was a whole of region approach*
☐ Possibly, but I don't know what I would change yet

☐ Certainly, I am concerned about pesticide resistance
☐ Certainly, I consider that it will be better in the long run
☐ Other____

When asked if they would modify their recommendations for whitefly control, only the first answer and the final three answers were listed. The reasons in italics above were not listed by any consultant. They have been omitted from Figures 52, 53 and

54. Lockyer Valley consultants were most likely to say that they have changed their recommendations to encourage *E. hayati*. Two consultants from Bundaberg and one from the Burdekin region said they needed more information before changing their recommendations. Only one consultant from Bundaberg (of six) said they had already made a ch ange to encourage the *E. hayati*. Information about the effects of the insecticides on *E. hayati* and the benefits of *E. hayati* would be beneficial for the Bundaberg consultants.

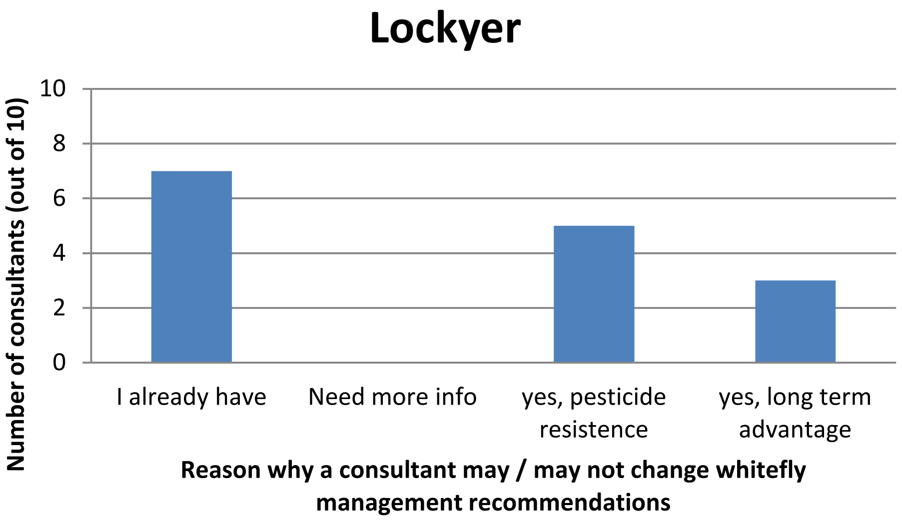


Figure 52. Reasons why consultants in the Lockyer Valley may or may not change their whitefly management recommendations.

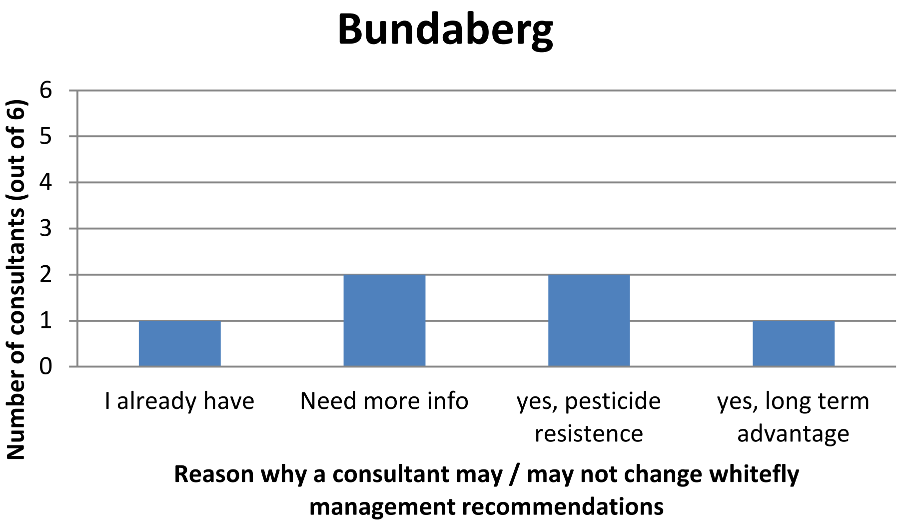


Figure 53. Reasons why consultants around Bundaberg may or may not change their whitefly management recommendations.

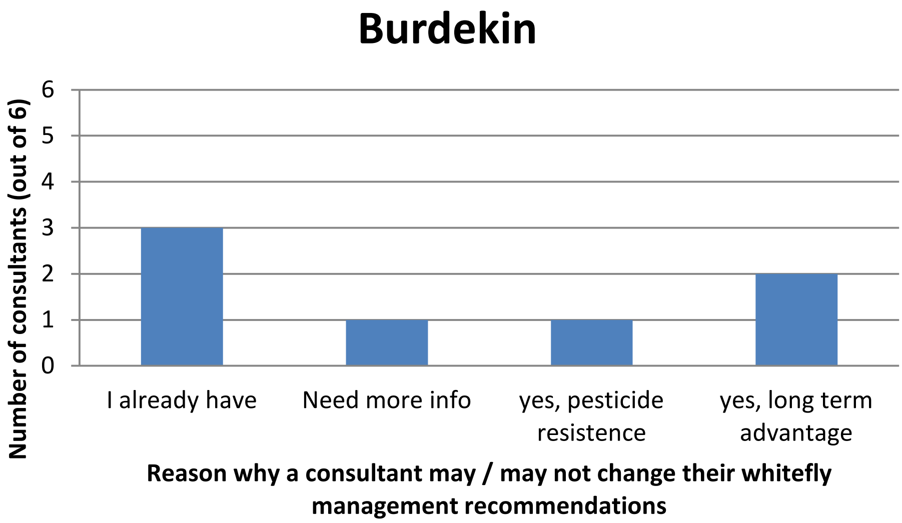


Figure 54. Reasons why consultants in the Burdekin region may or may not change their whitefly management recommendations.

16. Is there anything else you would like to add about your experiences managing whitefly?

In the Lockyer Valley, many consultants said that they thought whitefly numbers were now manageable with current control methods. Put more specifically by one consultant, “Treating seedlings with Confidor is the way to go...”. Another said, “Confidor has almost eradicated the pest..”. One consultant made the comment that an industry standard on whitefly thresholds would be valuable. One consultant from the Lockyer Valley said that they had previously worked in the Burdekin region and the problem was much worse up north and Burdekin growers would benefit from seeing what is happening in the Lockyer Valley.

In Bundaberg, several consultants commented that the parasitoid had made a difference but that numbers of the parasitoid had now dropped and they would benefit from more releases. However, one consultant said they had recorded the presence of the parasitoid before *E. hayati* was released and there has been no change in the whitefly problem since the release. Note that, *E. mundus*, the native parasitoid that looks identical to *E. hayati* was recorded from Bundaberg region before the release (De Barro and Coombes 2009). Two consultants alluded to the fact that it’s very hard to get growers to make a change and they tend to stick to what they know even though whitefly ‘just explode’ after using heavy chemicals. One consultant noted that because they have leaf curl virus in Bundaberg, only very low numbers of whitefly can spread the virus and the parasitoid can’t help in that situation.

In the Burdekin region, two consultants said they felt the parasitoid was making a difference but unfortunately it’s much easier for growers to immediately ‘blast their paddocks’ with a broad spectrum. It was noted by one of those consultants that only 50% of growers engage a consultant, therefore information is lacking. A consultant is more likely to encourage growers to persist with giving the parasitoid a chance. One consultant commented that they were not aware of the parasitoid being released and more information and clear guidelines on thresholds would be valuable. Another consultant complained that, for beans, there are very few insecticide options and they are beginning to notice resistance.

Summary

Although the mini-survey conducted for VG06029 suggested that growers had modified their pest management practices to minimise harm to *E. hayati*, our results show that broad spectrum insecticide is still the predominant means of controlling insects on whitefly host crops in all three major vegetable producing regions (Lockyer Valley, Bundaberg, Burdekin area). These insecticides are highly disruptive to *E. hayati* and the more growers said they used these chemicals the worse they rated their SLW problem. This result is somewhat understandable in that there are limited soft options for control SLW and, more importantly for controlling other pests of the crop. Regardless of this challenge, SLW has significantly decreased in all areas since the release of *E. hayati*, with the worst year being 2006 for Lockyer, 2004 for Bundaberg, and 2008 for Burdekin. Growers that improved their farm hygiene had a significant reduction in SLW problems. Based on the results of the grower survey, to reduce whitefly numbers the most effective actions are to (1) avoid using broad spectrum insecticides, (2) control broad-leaf weeds, (3) plant near a refuge for the parasitoid (orchards and food plants for beneficial insects are good), and (4) when possible plant strategically to avoid peak SLW times. These actions are listed in the grower guide (Section 5).

Section 2

Getting the most out of *E. hayati*: field survey, model and model testing

2. Getting the most out of *E. hayati*: Field survey, model and model testing

Introduction

A key role in the effectiveness of natural enemies in suppressing pest populations, but which has received little attention, is the relative timing of pest and natural enemy arrival in the crops, and how the landscape context facilitates or hinders colonisation processes. There are a limited number of theoretical studies that highlight the importance of a timely arrival of natural enemies for pest suppression (Ekbom et al. 1992; van der Werf, 1995; Ives and Settle 1997; Chang and Kareiva, 1999; Bianchi and van der Werf, 2003). Although each study uses different approaches and addresses different questions, the basic mechanism of how earliness affects the build up of pest populations in these models is similar. Early removal of pests avoids future damage, and often more importantly, it avoids future damage of the pest offspring.

The landscape context can influence the process of early arrival of natural enemies by providing habitats, such as crops and non-crops that host natural enemies. Crop and non-crop habitat can vary in space, time, susceptibility to silverleaf whitefly (SLW) (*Bemisia tabaci*), and effectiveness of *E. hayati*. Vegetable production in many sub-tropical and tropical locations in Australia occurs year round, so does host availability of SLW. However, there are many types of SLW susceptible crops grown throughout the year that differ in their seasonal rotation. For example, growing a winter crop followed by a summer crop, both which are susceptible to SLW, while some growers don't grow a w inter-susceptible crop, but go straight into summer crops highly susceptible to SLW. These different rotation strategies can have broad implications for getting *E. hayati* into the crop early, and keeping SLW populations lower for longer. Therefore, the aims of this component of VG08051 were to: 1. Survey crops and non-crop habitat for the presence of SLW and *E. hayati*, 2. Use this data to develop simulation models to investigate the best rotation strategies to get *E. hayati* into crops early and keep SLW populations lower for longer, and 3. Test the predictions of the model with field experiments.

Methods

Insect Survey

To gather information on SLW and *E. hayati* sources (both on- and off-farm) at different times of the season and in different regions, we: 1. Made new collections, and 2. Processed preserved samples. For new collections, we placed sticky traps (ca. 850) throughout the Lockyer Valley, and in crop and non-crop habitats in November 2009 and March 2010 for a total of 28 days covering an area approximately 60 km diameter. The traps were placed in corn, fresh beans, cucurbits (pumpkin, watermelon, rockmelon, honeydew melon), carrots, brassica vegetables (cabbage and broccoli) silverbeet, beetroot, lucerne, onions, sunflower, pasture, weedy fallow and native vegetation. In addition, plant clippings (ca. 300) were taken at the same time from crops and weeds (eg. lantana imbedded in native vegetation habitats) known to host SLW. These samples were placed in emergence bags in the laboratory allowing

SLW and *E. hayati* to emerge. In addition, preserved samples from plant clippings (ca. 98) collected from Bundaberg QLD in sweet potato, english potato, cucurbits (including pumpkin, watermelon, rockmelon, honeydew), and eggplant were processed and counted. In total more than 1000 samples have been collected in different landscapes and at different times of the season. This information is expressed below in Table 23, and was used to: determine SLW suitability on host crops, inform model scenarios and field experiments, and contribute to the pest management guidelines.

Model description

Landscape, habitats and harvesting

The model simulates the interaction of silverleaf whitefly (SLW) and its parasitoid *E. hayati* at the landscape scale. The landscape is represented as a grid containing 20 x 20 cells whereby each cell (100x100m) represents a single habitat with a particular land use. Land use categories are distinguished by management (crop versus non-crop habitats) and suitability for SLW development (zero, low, medium and high). Crop habitats are harvested and SLW and *E. hayati* populations are therefore exposed to periodic mortality events (killing all immature stages of SLW and *E. hayati*, but not adults), whereas no such mortality events occur in non-crop habitats. The suitability for SLW development is captured in terms of the potential for SLW population growth (relative growth rate, see below). For this purpose, crops have been classified in four SLW suitability groups (Table 23).

Table 23. Classification of crops and plants grown in the Lockyer and Bundaberg region in four SLW suitability classes.

High suitability	Medium suitability	Low suitability	Un-suitable
Pumpkins	Cabbage	Silverbeet	Sorghum
Rock melon	Eggplant	Lucerne	Sugar cane
Sunflower	Brassicas	(Green) beans	Onions/shallots
Cotton	Cauliflower	Lab lab	Capsicum
Soybean	Watermelon	Zucchini	Carrot
Tomato	Honeydew melon	Cow pea	Apple
Sonchus oleraceus	English Potato	Lettuce	Corn
Emilia sonchifolia	Cucumber	Beetroot	grass spp.
	Lantana camara	Grapes	Native Vegetation*
	Lactuca seriole	Sweet Potato	Casuarinas spp.
	Convolvulus arvensis	Celery	
		Bitter Melons	
	Malvastrum coromandellum	*Sida* spp.	
		Malva parviflora	

*Most native plants do not host SLW, but non-crop habitats may contain weeds that support SLW. Some of these weeds are listed in the table. The same can be said for un-suitable crops, such as sugarcane, however broad-leaf weeds – hosts of SLW – often reside on the edges of the crop.

As in the coastal sub-tropical and tropical regions SLW host crops are grown year-round, a sequence of crops may occur at a particular field (i.e. crop rotation), separated by SLW and *E. hayati* mortality events (i.e. harvesting). A wide range of combinations of crop rotations are possible, including:

1. Zero-zero crops representing two subsequent non-host crops or a perennial non-host crop (e.g. Fallow, Sorghum)
2. Zero-medium crops representing a non-host crop (e.g. Fallow) followed up by a medium suitable crop (e.g. English potato)
3. Zero-high crops representing a non-host crop (e.g. Fallow) followed up by a highly suitable crop (e.g. Rockmelon)
4. Low-low crops representing a low suitable crop (e.g. Lucerne) followed up by another low suitable crop (e.g. Zucchini)
5. Low-medium crops representing a low suitable crop (e.g. Lucerne) followed up by a medium suitable crop (e.g. Brassicas)
6. Low-high crops representing a low suitable crop (e.g. Sweet potato) followed up by a highly suitable crop (e.g. Rockmelon)
7. Medium-medium crops representing two subsequent medium suitable crops (e.g. English potato, Cauliflower)
8. Medium-high crops representing a medium suitable crop (e.g. English potato) followed up by a highly suitable crop for SLW (e.g. Rockmelon)

Undisturbed non-crop habitats (e.g. weedy native vegetation) may act as a refuge and support SLW and *E. hayati* populations throughout the year. As such, non-crop habitats may play a critical role in the recolonisation of fields after harvests. We assume that non-crop habitats have a medium SLW suitability as it may contain weeds that are highly suitable for SLW. It is further assumed that summer crops have an equal or higher suitability for SLW than winter crops. For instance, in the medium/high crop rotation, the summer crop has a high suitability for SLW, whereas the winter crop has a medium suitability. In the simulations summer crops are always planted in early October and harvested in the end of February, and winter crops planted in early March and harvested in the end of September. The model further allows variation in the timing of harvest between fields. That is, the harvest date for each field is drawn from a normal distribution around the end of February and September such that not all crops in the landscape are harvested at the same day.

SLW population dynamics

The model explicitly includes stage structure of the SLW and *E. hayati* populations, dividing the population into different instars. SLW and *E. hayati* dynamics are modelled using a Leslie matrix in which density-independent survivorship of all SLW stages and adult reproduction. In addition to density-independent mortality, there is also density-dependent mortality which results in decreased survivorship for all SLW stages with increases in the total immature SLW density (including parasitised but still-living SLW nymphs).

The model considers 6 SLW instars (egg, 4 nymphal stages and adult). As the observed mean developmental times are approximately 6.1, 3.9, 3.0, 4.0 and 5.9 days for the 5 juvenile stages (Liu and Stansly 1998; Tsai and Wang 1996; Lin and Ren 2005; Musa and Ren 2005), a Leslie matrix with 2 stages for eggs and 2 stages for the 4th nymph stage was created, leading to a total of 8 stages in the Leslie matrix for SLW. A time step of 3 days is used, so the 7 immature stages translate to a development time of 21 days, which is close to empirically assessed development times (22.3 days).

Immature (density-independent) survival rates and reproduction rates are specific for crops that differ in suitability for SLW development. That is, immature survival and reproduction rates increase with increasing crop suitability (Table 24). Immature survival rates of 0.84 per time step for high suitability crops was chosen to account for lower survival in the field than under laboratory conditions (0.93 per time step; derived from Liu and Stansly 1998; Tsai and Wang 1996; van Giessen *et al*. 1995; Lin and Ren 2005; Musa and Ren 2005; Zang *et al*. 2006). This parameterisation as presented in Table 24 results in r_{max} values (maximum rate of increase, theoretical maximum rate of increase of a population per individual when population size approaches zero) ranging from 0.033 t o 0.115 per day, and R_0 values (basic reproduction rate, the average number of offspring produced over the lifetime of an individual) ranging from 2.7 to 40.3 (Table 25).

Table 24. Immature density-independent survival rates and per capita reproduction rates (per time step of 3 days) for habitats with a low, medium and high suitability for SLW.

	Survival (per stage)	*Per capita* reproduction rate
Low	0.7	14
Medium	0.8	16
High	0.84	26

Table 25. r_{max} and R_0 values for SLW for habitats with a low, medium and high suitability for SLW.

	r_{max} (per day)	R_0
Low	0.033	2.69
Medium	0.082	13.4
High	0.115	40.3

A reproduction rate to 26 offspring per time step for high suitability habitats was chosen to reflect that SLW females can generate on average 110 o ffspring (Liu and Stansly 1998; Tsai and Wang 1996; van Giessen *et al*. 1995; Lin and Ren 2005; Musa and Ren 2005; Zang *et al*. 2006). Using this reproduction rate an r_{max} of 0.115 per day for highly suitable crops is obtained, which is close to the r_{max} reported for laboratory studies (0.12 per day; Liu and Stansly 1998; Tsai and Wang 1996; van Giessen *et al*. 1995; Lin and Ren 2005; Musa and Ren 2005; Zang *et al*. 2006). Also, the simulated R_0 (40.3) reflects that of the average empirically assessed value of 37.5 (Liu and Stansly 1998; Tsai and Wang 1996; van Giessen *et al*. 1995; Lin and Ren 2005; Musa and Ren 2005; Zang *et al*. 2006).

For the density-dependent part of the of the SLW population dynamics in the high, medium and low quality crops *k* values of 3, 5 a nd 7 were used, respectively. High *k* values result in strong population suppression at high SLW densities. This parameterisation results in carrying capacities of about 60, 20 a nd 6 at the landscape scale for high, medium and low suitability crops.

E. hayati population dynamics

E. hayati parasitises first, second and third instar SLW, with relative attack rates of 0.45, 0.45, and 0.1, r espectively. *E. hayati* thus prefers first and second instar SLW above third instar SLW. Parasitism is described using a Holling type I functional response. *E. hayati* has 7 stages within whiteflies and an adult stage, giving a generation time of 24 days, which is close to average observed generation times (23 days; Ardeh 2004; Urbaneja *et al*. 2006; Powell and Bellows 1992; Qui *et al*. 2005).

SLW and *E. hayati* dispersal

The population dynamics of SLW and *E. hayati* in individual habitats (grid cells) are linked via dispersal. As SLW are good dispersers, we assume that SLW disperses globally, such that individuals move to any cell in the grid with equal probability. The proportion of SLW adults that take part in dispersal increases with increasing SLW densities in the habitat (i.e. density-dependent emigration). *E. hayati* has a lower dispersal capacity than SLW, and its dispersal is affected by wind. Therefore, *E. hayati* dispersal is modelled with a wind-biased Gaussian dispersal kernel, accounting for diffusion and drift. The *E. hayati* dispersal model has been parameterised such that simulations reflect observations on the spread of *E. hayati* after a point release (Schellhorn, unpublished data). The grid has wrap-around boundaries (i.e., is placed on a torus) so that individuals moving off one edge of the grid appear in the corresponding location at the opposite edge.

Scenario studies

The model uses scaled SLW population densities, such that a scaled density of 1 corresponds with roughly 10^8 SLW at the landscape scale or 25 SLW per m^2. The model is initialised with a low uniform distribution of 0.02 female SLW and 0.004 *E. hayati* at the landscape scale, corresponding to initial densities of 0.5 and 0.1 SLW and *E. hayati* per m^2. Simulations are conducted with a time step of 3 days, such that a year translates to approximately 120 time steps. Simulations were conducted for 5 years, whereby the first year of the simulation (120 time steps) have been discarded to allow SLW and *E. hayati* to reach equilibrium. All scenarios are conducted for landscapes consisting of 20 x 20 field, hence 400 fields in total. Output is generated at the landscape scale (i.e. SLW and parasitism averaged across all 400 fields) unless otherwise indicated.

In a **first** set of simulations a situation is considered without *E. hayati* such that SLW is not controlled other than by harvest inflicted mortality. This scenario serves as a control. In a **second** set of simulations homogeneous landscape are considered that are composed of a single habitat or crop rotation (e.g. 100% medium/high SLW suitability crop rotation). However, for rotations containing a crop that do not support SLW a single non-crop cell had to be included to introduce SLW and *E. hayati* in the landscape. In a **third** set of simulations we study SLW dynamics in heterogeneous landscapes. For this purpose, we consider landscapes with 399 fields of a particular rotation and study the effect of these fields on the SLW population dynamics of a single focal field with a contrasting crop rotation (Figure 55A). For instance, a low-low SLW suitability crop surrounded by 399 medium-high SLW suitability crops. This scenario reflects a situation in which an a-typical crop is grown in a landscape that is dominated by just few crop types. In a **fourth** set of simulations heterogeneous landscapes are considered that are split in half and each half has a particular crop rotation (Figure 55B). For instance, a landscape which the right half (200 fields) has a medium-medium SLW suitability crop rotation, and the left half (200 fields) a low-high SLW suitability crop rotation. This scenario reflects a situation of two adjacent farms with different crops/SLW management.

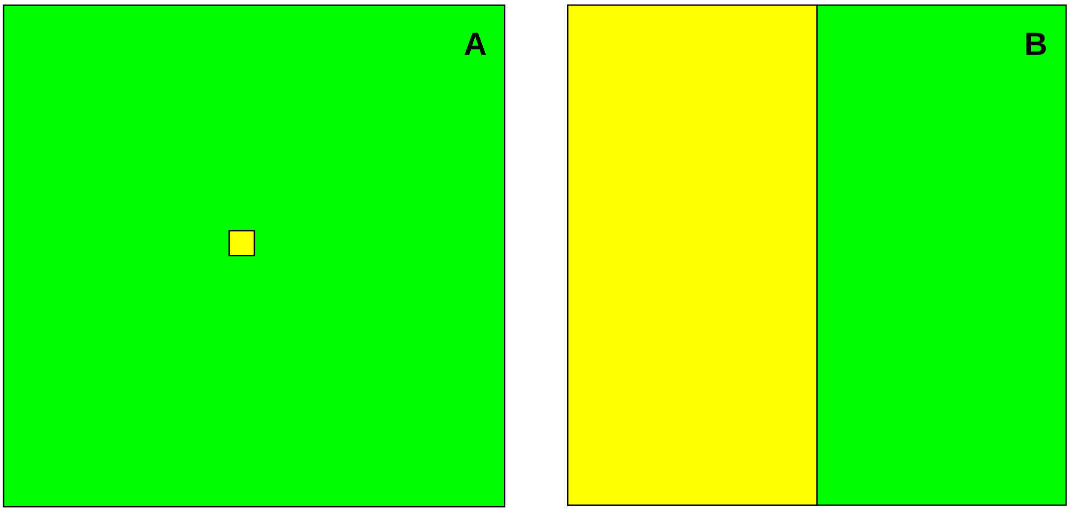


Figure 55. Example of landscape designs for the third set of simulations with a single field with a particular crop rotation embedded in a landscape with another crop rotation (A) and the fourth set of simulations with 200 fields of a particular rotation on side and 200 fields of another rotation to the other side (B).

Field experiment

Fieldwork was conducted by Lynita Howie, Rebecca Garrad, Anna Marcora, Belinda Walters, Andy Hulthen and Lino Bin. The fieldwork began in August 2011 after being delayed by the extensive flooding in the Lockyer Valley earlier that year. From August to November 2011 we measured the percentage of whitefly parasitised by *E. hayati* using sentinel plants and field collections at nine properties across the Lockyer Valley. Then from April to May 2012 we again measured parasitism from field collections only.

Field selection and data recorded

Two months before experiments started several growers were called throughout the Lockyer Valley and asked what crops they were growing and what crops their neighbours were growing. This allowed us to select a variety of landscapes. About a month before starting experiments, we assessed the whitefly populations several properties. Based on the field assessments and phone calls to growers a selection of nine fields were chosen representing a continuum of sites from “no winter whitefly host crops” to “highly preferred winter whitefly host crops” (Figure 56). For the spring collections the site labelled C2 was not used and for the autumn collections the site labelled HH2 was not used.

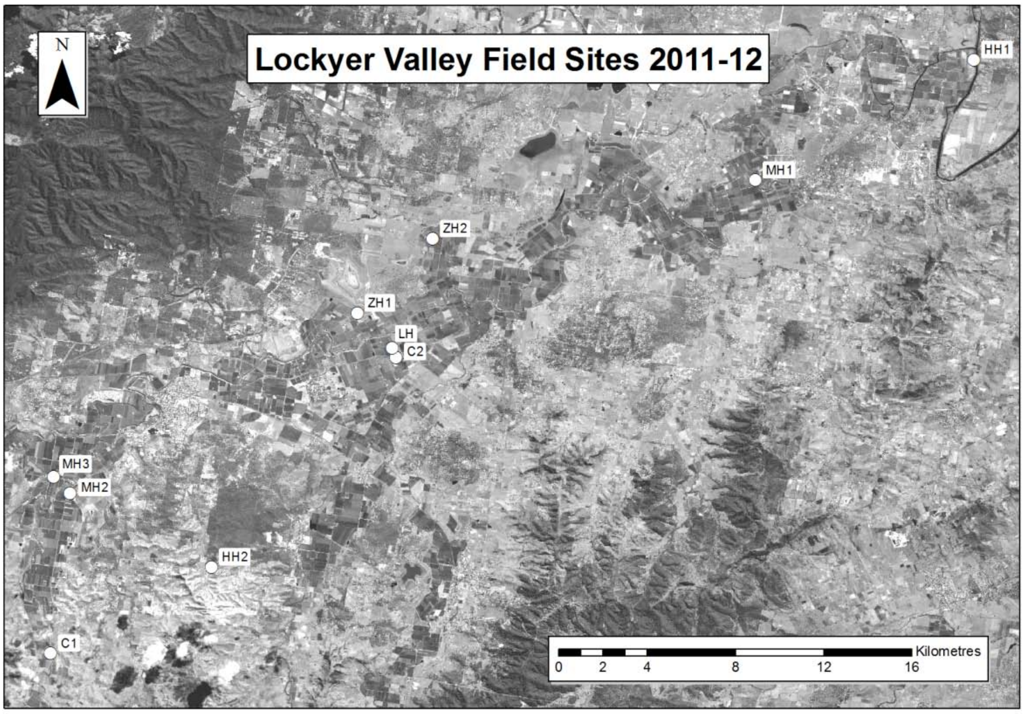


Figure 56. Location of field sites across the Lockyer Valley (Map: Andrew Hulthen).

Seedlings were taken to the selected fields and left for 4 days and then collected, this was repeated seven times every two weeks over a fourteen week period from 23 August to 18 November 2011. Three days before seedlings were taken to the fields the grower / manager was called and asked if anything had been sprayed on the field in the past 7 days or if anything would be sprayed in the next 7 days. This information was recorded.

Experimental design

Nine fields were selected as described above, and each fortnight 40 rockmelon (var. Journey 1) seedlings were left in the field for 4 days. Seedlings were 17 – 35 days old and had 1-6 true leaves at the time they were taken into the field. Seedlings were grown in a glasshouse at a constant temperature between 22 – 25°C until they were taken into the field. Half of the seedlings (n = 20) in each field were insect free ‘clean plants’, and the other half of the seedlings contained whitefly nymphs ‘infested plants’. At the time the seedlings were taken to the field, the nymphs on the infested plants were 1st - 2nd instar nymphs, the stage that *E. hayati* prefer to parasitise. In the field, plants were placed in four blocks of ten plants, five clean and five infested, separated by 4-8m. Each block was separated by 6 – 8m (Figure 57). The fields selected had a whitefly host crop planted either shortly before starting or during the experiment.

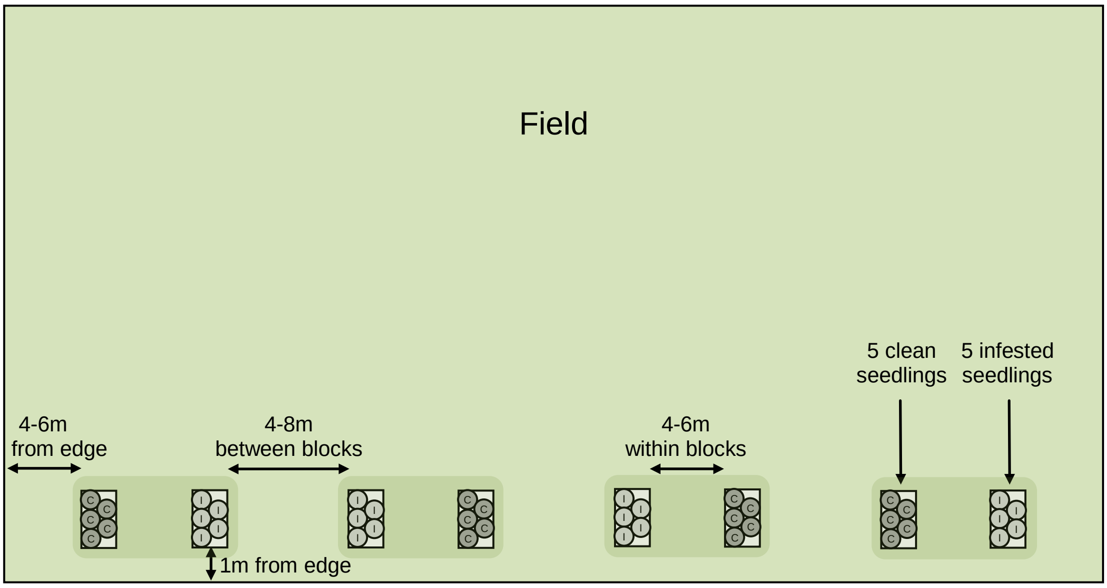


Figure 57. Diagrammatic layout of sentinel plants in fields.

Infested plants

To assess percent parasitism, half of the seedlings were infested with whitefly nymphs. Ten to eleven days before going into the field, the 'infested plants' were placed in cages with whitefly adults in the early morning and then monitored every two hours until plants averaged 30 whitefly eggs. After seedlings had the required number of eggs, all adult whitefly were removed using a hair-dryer (cool setting) and gentle suction device. Seedlings had 1 – 6 true leaves at the time of infesting. The number of true leaves present at infesting was noted for checking later. Plants were then held at 24-25°C to ensure that the immature whitefly were 1st or 2nd instars when they went into the field. When the plants were removed from the field four days later they would have been 2nd or 3rd instars.

On collecting the plants from the field, any parasitoids, whitefly or other insects present were removed. The 20 infested plants from each field were covered with a net and stored at 25°C for another five days after which the leaves were removed and placed into an emergence bag or container. The emergence bag or container had a small upright funnel on the top to self collect whitefly and parasitoids that emerged and travelled up through the funnel toward light and became trapped in the cup at the top of the funnel. Leaves were left in the emergence bag or container for another 25 - 40 days (approx). This timing allowed us to capture whitefly and parasitoids as they emerged. The number of adult whitefly and parasitoids in the cup and in the bag/container were counted to determine percent parasitism.

Clean plants

Clean plants were kept insect free for the duration of their pre-field growth by isolating in a separate glasshouse and covering with thin polypropylene cover (nonwoven, spunbound) as an additional measure.

When plants were collected from the field, they were checked for whitefly and other beneficial insects. The number of true leaves present on the plants was recorded when the plants came back from the field. The 20 'clean plants' from each field were covered and stored at 25°C in the glasshouse for another 16 days. After 16 days the true leaves that were open in the field were checked for whitefly nymphs under a microscope. The number of whitefly per plant was recorded.

Field assessments and collections

At the same time that sentinel plants were taken into the field, an assessment of the whitefly population in the field was made. A total of 24 minutes was spent turning over leaves to look for adult whitefly, recording the number of leaves with or without whitefly. A further 24 minutes were spent looking for immature (3rd or 4th instar nymph) whitefly on leaves in the crop. Leaves with nymphs of the correct age were collected, up to a maximum of 15 leaves per field. These leaves were brought back to the lab in a cool box and stored in a fridge over night. The following day, each leaf was examined under the microscope and the number of 3rd or 4th instar nymphs within a 2.5cm diameter circle surrounding one nymph as well as the number of 3rd or 4th instar nymphs on the whole leaf was recorded. Each nymph was checked for signs of parasitism and recorded. The leaves were then stored in a ventilated container for a minimum of 25 days. After this time, the containers were checked for any emerged whitefly or parasitoids. When the number of whitefly nymphs reached very high numbers, only the number within the 2.5cm diameter circle were counted.

Field assessments were conducted in the field where the experiment was placed, or in the absence of a crop in the field, a nearby or adjacent field was used. As the immature crops started to grow, field assessments were started in the actual field and assessments in the nearby/adjacent field were reduced so that only half of the time (12 minutes) was needed to look for adults or nymphs.

An additional three field collections were made approximately six months later to determine if *E. hayati* parasitism had changed. The first and main fieldwork was conducted from late winter to late spring (August – November 2011) in the lead up to the peak whitefly season in the Lockyer Valley. A second collection six months later, allowed assessment of whether *E. hayati* parasitism had changed by the end of the peak whitefly season autumn (April-May 2012). Again collections were made from nine properties across the Lockyer Valley, eight fields were within 300m of the original fields on the same properties. In the second collection the field labelled HH2 was replaced with C2 (Figure 56).

Collecting procedures were the same in autumn as in spring, however the management in the laboratory was slightly different. After the collections were brought back to the laboratory they were checked following day, as before. Following this, they were then checked three times per week and any whitefly or *E. hayati* that had emerged were removed. This process was continued until no more insects moved from the bag into the collection cups. Once the insects had stopped emerging, the leaf material was checked for trapped insects. The total number of *E. hayati* and whitefly that emerged for each field was pooled to determine percent parasitism of whitefly.

Results- *Model*

SLW dynamics without *E. hayati*

When *E. hayati* is absent, SLW densities at the landscape scale reach densities of approximately 58, 22 and 6 for high, medium and low suitability crops, respectively (Figure 58).

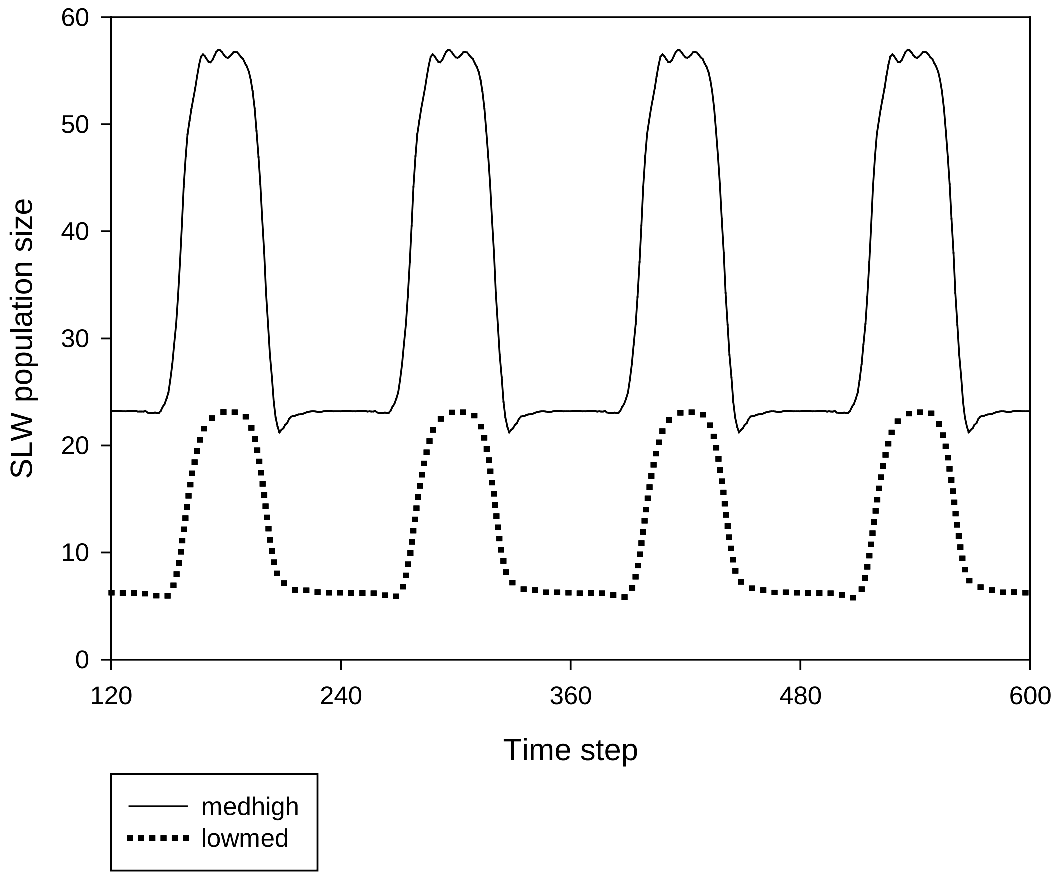


Figure 58. Five-year population dynamics of SLW for a homogeneous landscape consisting of *medium-high* and *low-medium* SLW suitability crop rotation without *E. hayati*. The first year of the simulation (120 time steps) have been discarded to allow SLW densities to reach equilibrium.

Homogeneous landscapes

When considering crop rotations with a summer crop that is highly suitable for SLW, and winter crops that have medium, low or no s uitability for SLW, simulations indicate that peak densities of SLW are higher for low or non-suitable crops than for crops with a medium suitability for SLW. This somewhat counter intuitive result can be explained by the fact that medium suitable winter crops support a considerable *E. hayati* population, which can readily suppress SLW populations in summer crops. Indeed, a medium-high SLW quality crop rotation often reaches parasitism rates of up to 80% (Figure 59), whereas such parasitism rates are rare in a low-high SLW quality crop rotation (Figure 60). In case of a zero-high SLW quality crop rotation, parasitism is virtually absent (Figure 61). A more or less similar trend is observed for medium suitable summer crops and winter crops that have a medium, low or no suitability for SLW (Figures 64-66). In case of a low quality summer and winter crop, SLW densities are too low to establish *E. hayati* populations, such that SLW parasitism is virtually absent (Figure 65). As expected, in landscapes composed of crops that do not support SLW, SLW and *E. hayati* go extinct (Figure 66). Finally, in landscapes composed of medium SLW quality refuges SLW and *E. hayati* population dynamics are more or less comparable to a situation with a medium quality winter and summer crop (Figure 67 vs. Figure 62). In this case harvesting has a relatively limited effect on SLW- *E. hayati* population densities.

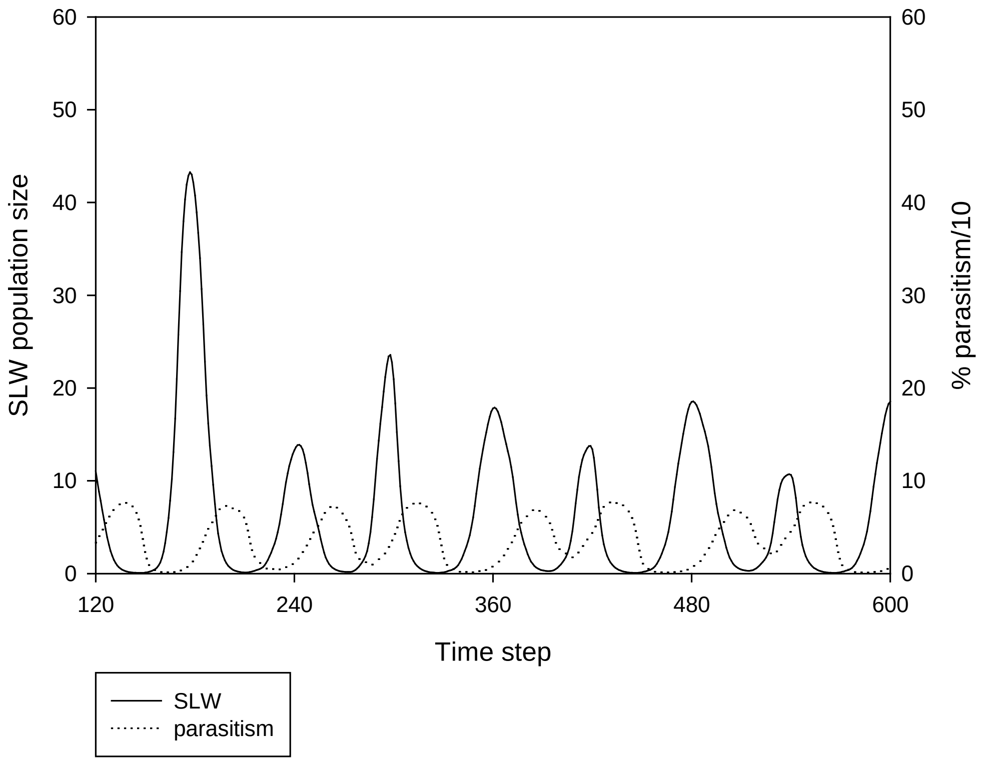


Figure 59. Five-year population dynamics of SLW and *E. hayati* for a homogeneous landscape consisting of *medium-high* SLW suitability crop rotation. The first year of the simulation (120 time steps) have been discarded to allow SLW and *E. hayati* to reach equilibrium.

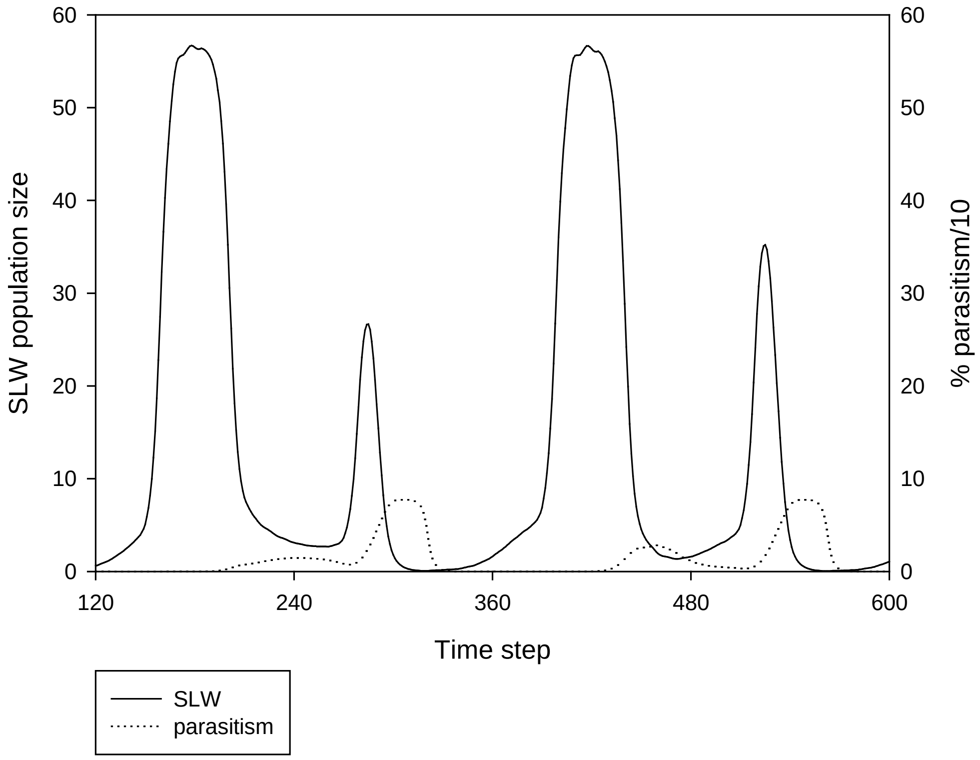


Figure 60. Five-year population dynamics of SLW and *E. hayati* for a homogeneous landscape consisting of *low-high* SLW suitability crop rotation.

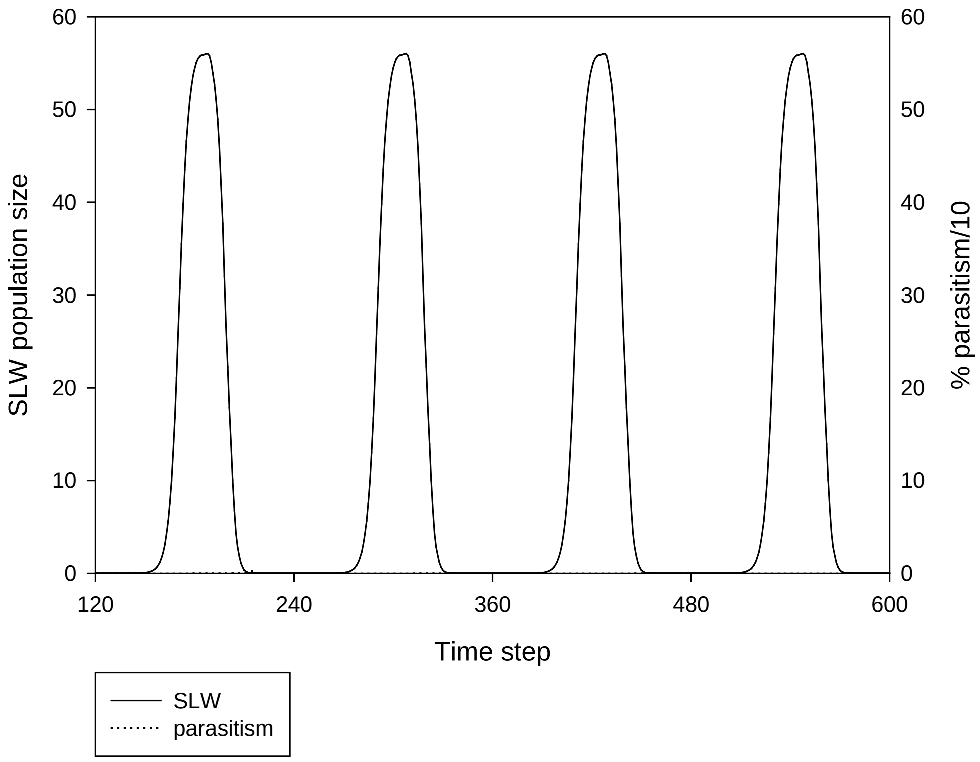


Figure 61. Five-year population dynamics of SLW and *E. hayati* for a homogeneous landscape consisting of *zero-high* SLW suitability crop rotation.

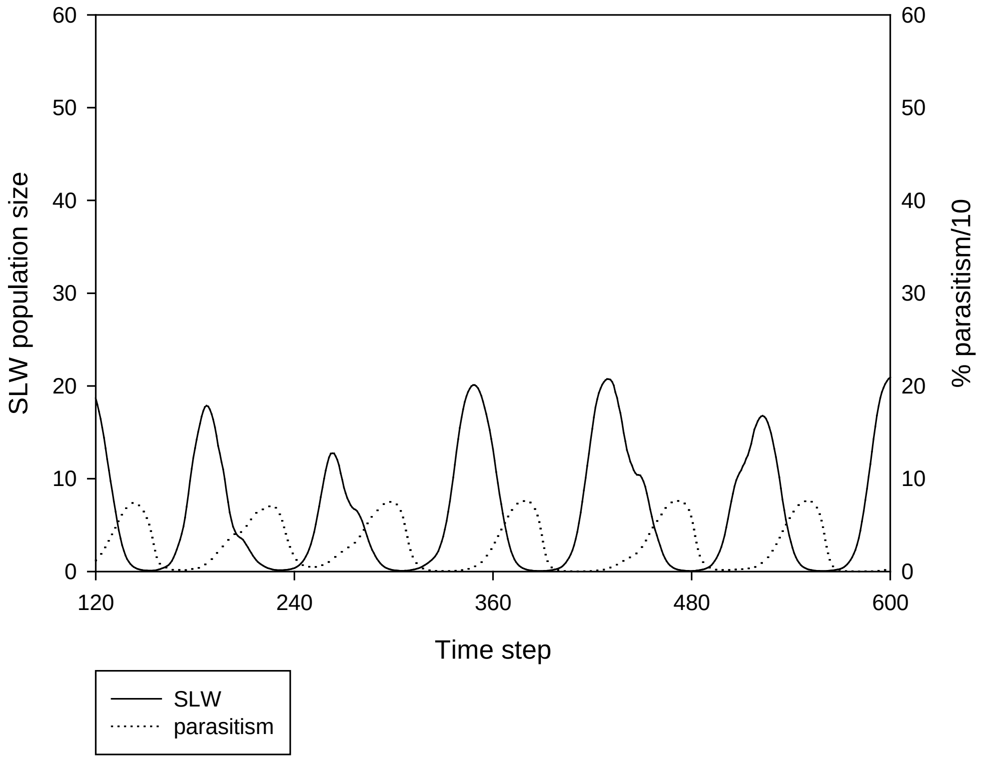


Figure 62. Five-year population dynamics of SLW and *E. hayati* for a homogeneous landscape consisting of *medium-medium* SLW suitability crop rotation.

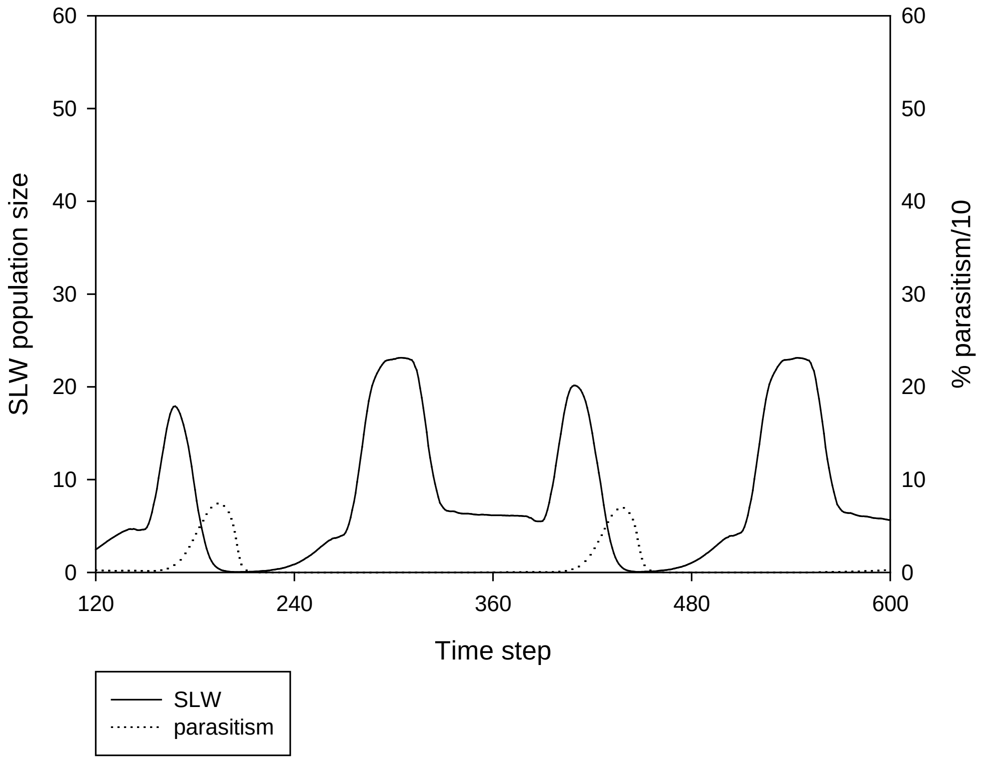


Figure 63. Five-year population dynamics of SLW and *E. hayati* for a homogeneous landscape consisting of *low-medium* SLW suitability crop rotation.

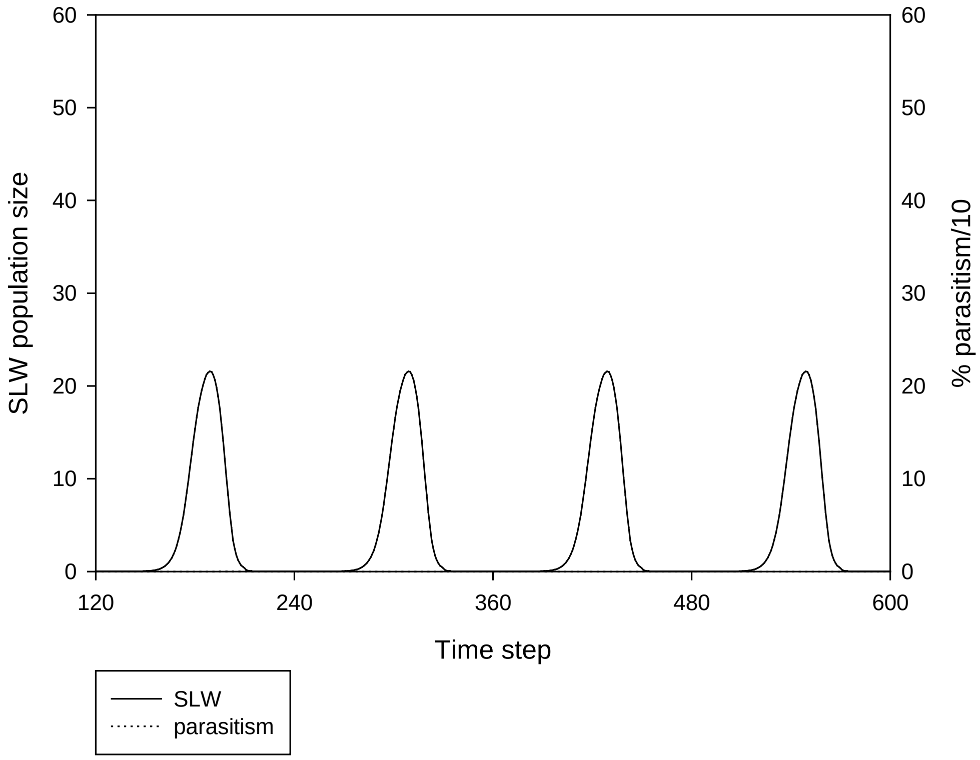


Figure 64. Five-year population dynamics of SLW and *E. hayati* for a homogeneous landscape consisting of *zero-medium* SLW suitability crop rotation.

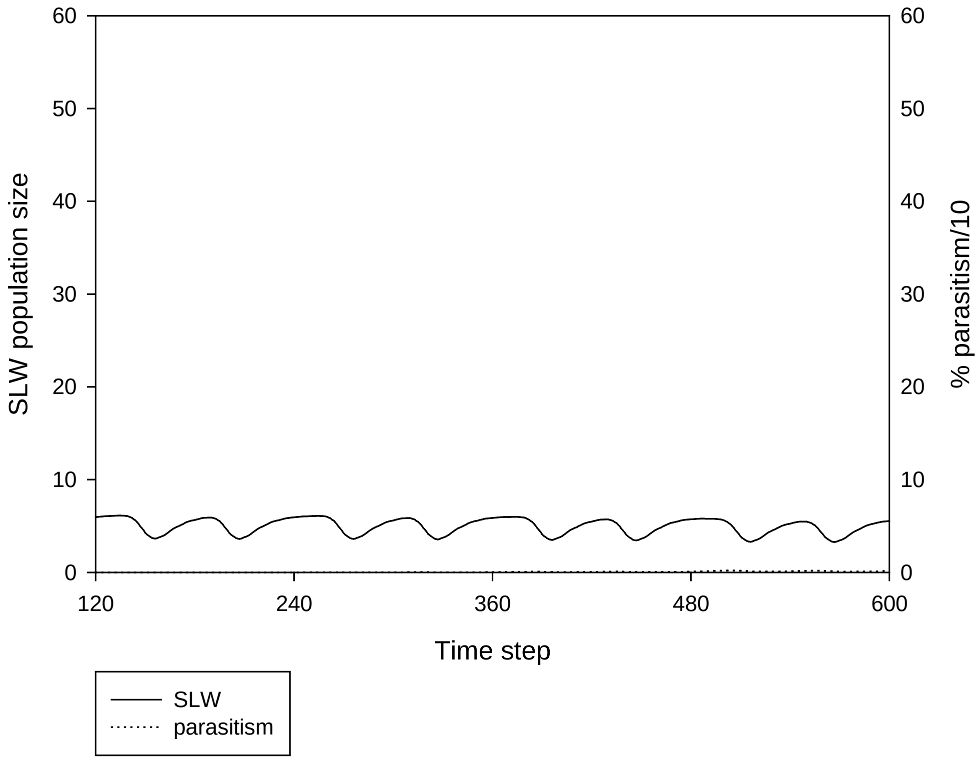


Figure 65. Five-year population dynamics of SLW and *E. hayati* for a homogeneous landscape consisting of *low-low* SLW suitability crop rotation.

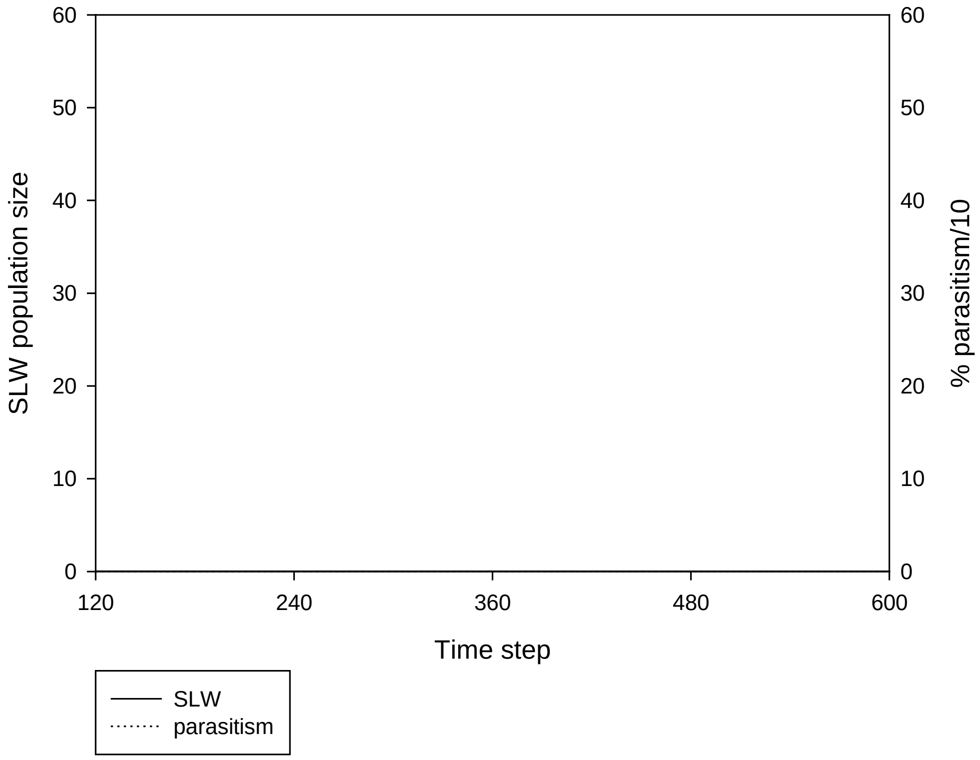


Figure 66. Five-year population dynamics of SLW and *E. hayati* for a homogeneous landscape consisting of *zero-zero* SLW suitability crop rotation.

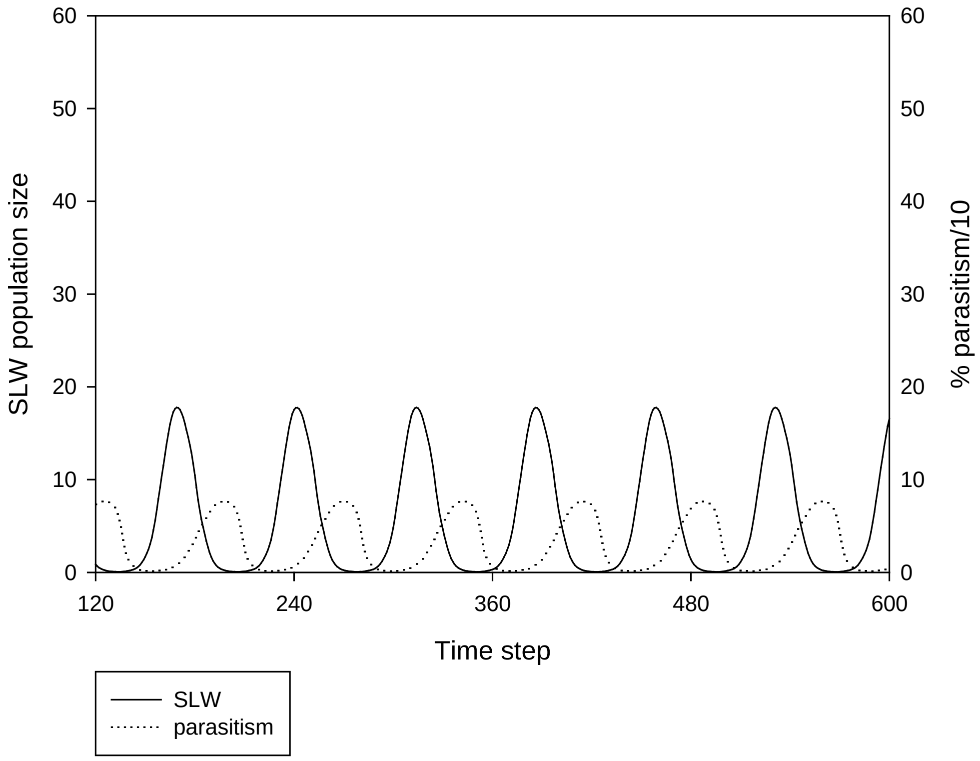


Figure 67. Five-year population dynamics of SLW and *E. hayati* for a homogeneous landscape consisting of medium SLW suitability *refuge*.

Heterogeneous landscapes

Simulations indicate that the surrounding landscape can have a clear effect on the SLW population dynamics of a focal field. That is, SLW densities in a field with a low-low crop rotation can differ an order of magnitude depending on whether this field is embedded in landscapes with 399 fields of low-low, zero-zero, medium-high or zero-high SLW suitability crop rotations (Figure 68).

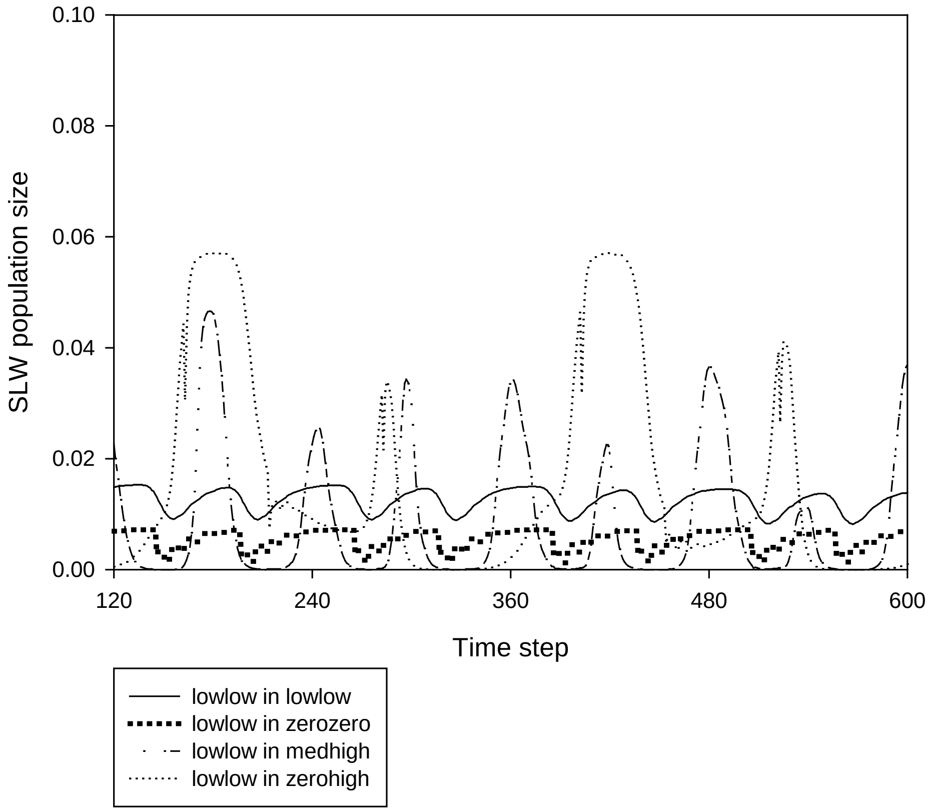


Figure 68. Five-year population dynamics of SLW in a single field with a low-low SLW suitability crop rotation embedded in a landscape with 399 fields with a *low-low* SLW suitability crop rotation (i.e. a homogeneous landscape), 399 fields with a *zero-zero* SLW suitability crop rotation, 399 fields with a *medium-high* SLW suitability crop rotation, and 399 fields with a *zero-high* SLW suitability crop rotation. Note that this figure shows SLW population size of a single focal field, not the average across all 400 fields.

When considering 'split' landscapes with different crop rotations on each side, simulations suggest that heterogeneous landscapes can have synergistic effects on SLW suppression. That is, a split landscape with a low-low and a medium-high crop rotation supports a lower SLW population than homogeneous landscapes composed of either a low-low or a medium-high crop rotation (Figure 69). A more or less similar pattern is found when a split landscape with a medium-medium and low-high SLW quality is considered (Figure 70). Again, the two crop rotations in the split landscape have a reduced SLW density than when these crop rotations were grown in homogeneous landscapes. This finding suggests that crop diversification in terms of SLW suitability is a promising tool for landscape management for SLW suppression. Landscape mosaics of high and low suitable crops could benefit from enhanced parasitoid populations from high SLW quality crops, whereas SLW densities at the landscape scale are kept within bounds by having a substantial area of low SLW suitability habitat.

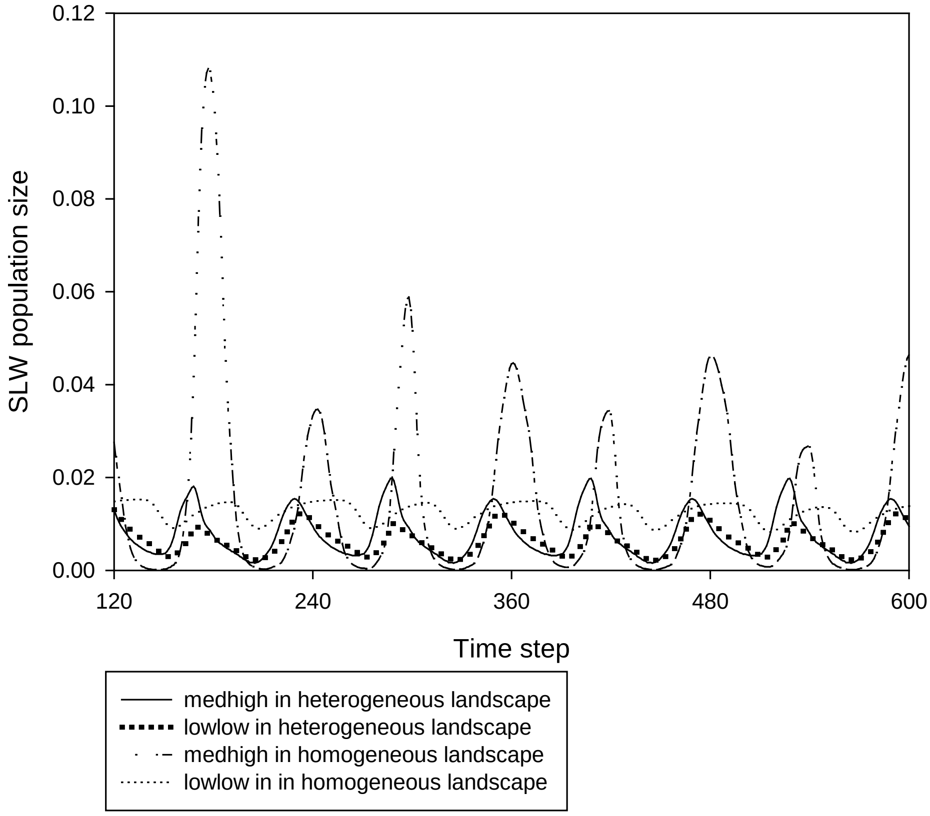


Figure 69. Five-year population dynamics of SLW in a landscape which the right half (200 fields) has a *medium-high* SLW suitability crop rotation, and the left half (200 fields) a *low-low* SLW suitability crop rotation. SLW dynamics in homogeneous landscapes with a *medium-high* and *low-low* SLW suitability crop rotation has been included as a reference. SLW population size is averaged across 200 fields for the split landscape, and averaged across all 400 fields for the reference landscapes.

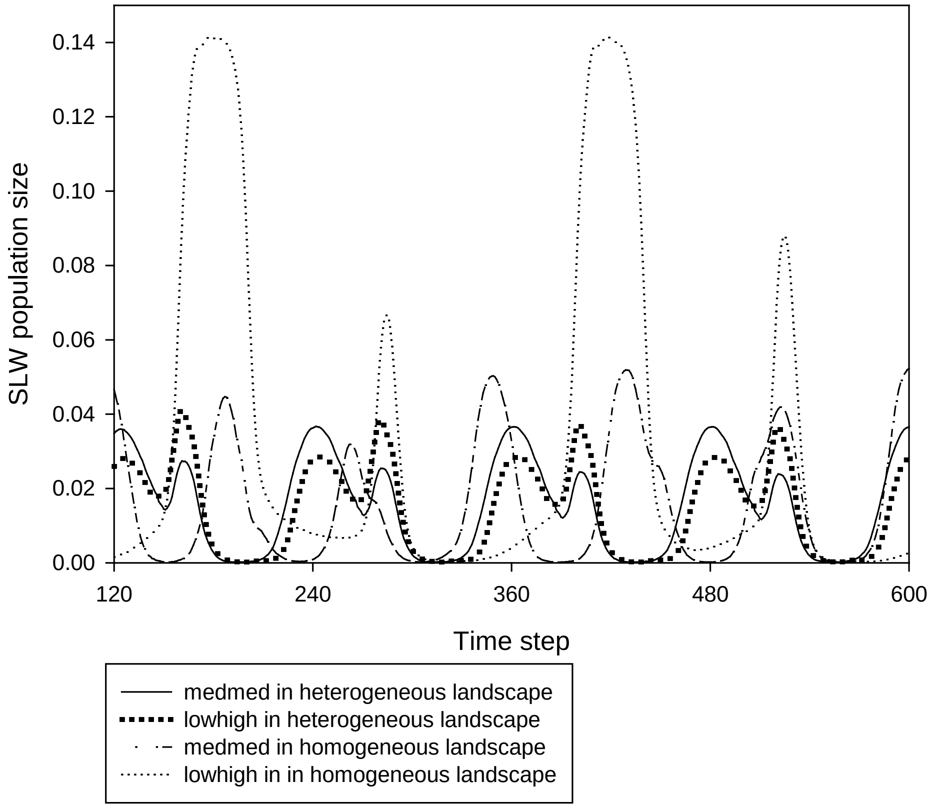


Figure 70. Five-year population dynamics of SLW in a landscape which the right half (200 fields) has a *medium-medium* SLW suitability crop rotation, and the left half (200 fields) a *low-high* SLW suitability crop rotation. SLW dynamics in homogeneous landscapes with a *medium-medium* and *low-high* SLW suitability crop rotation has been included as a reference. SLW population size is averaged across 200 fields for the split landscape, and averaged across all 400 fields for the reference landscapes.

Results - *Field Experiments*

Surprisingly, *E. hayati* was virtually absent from the Lockyer Valley during the field experiment starting September 2011. This was unexpected, given previous work in VG06029 had shown *E. hayati* established and widespread. However, the field surveys of November 2009 and March 2010 were pointing to a decline, but not to the extent that was experienced starting September 2011. Below shows the result of SLW on sentinel plants and field collections, and % parasitism by *E. hayati* on sentinel plants and field collections for the nine farms, hence treatments ranging in rotation strategies from zero-high susceptibility (ZH1, ZH2), medium-high (MH1, MH2, MH3), to high-high (HH1, HH2), the control (C1) and the regional average (Figures 71 to 80). Parasitism by *E. hayati* appeared only towards the end of the experiment, summer, and only for LH, MH2, and HH2. However, the levels were so low and for such a short period of time that a statistical analysis was not possible.

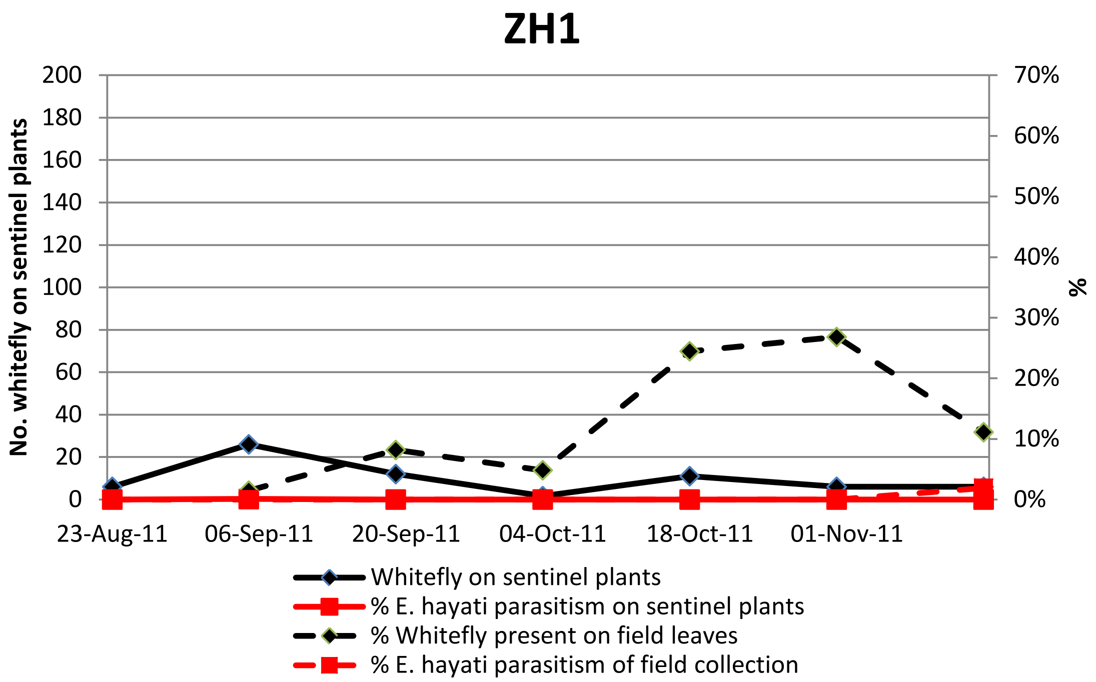


Figure 71. Whitefly numbers and *E. hayati* parasitism in field ZH1.

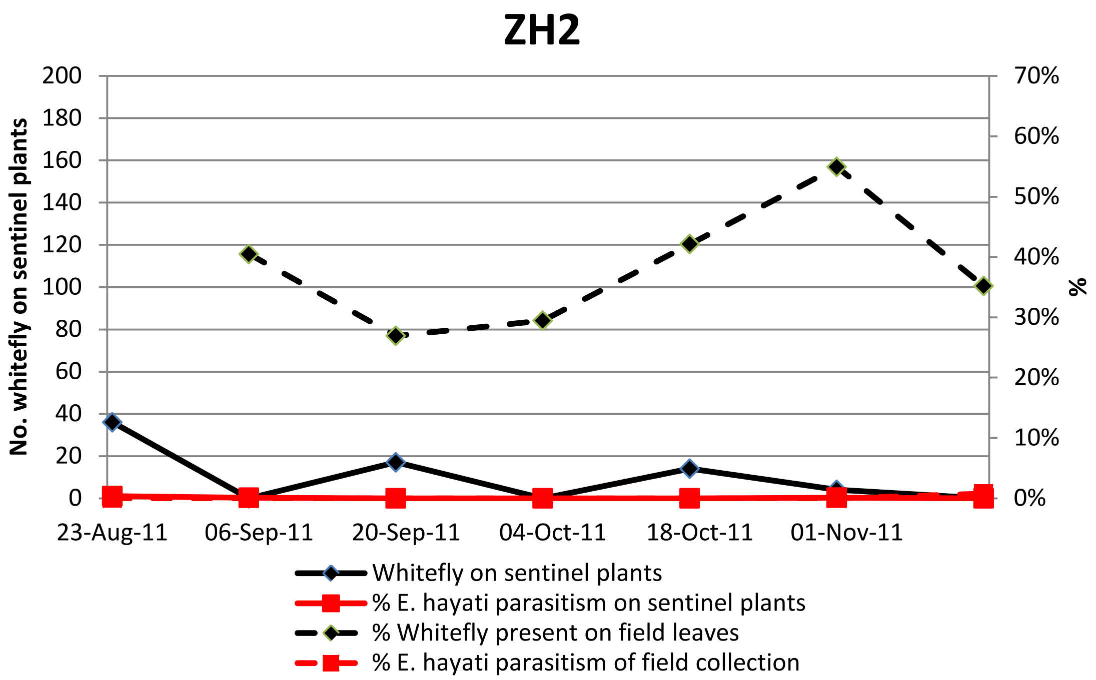


Figure 72. Whitefly numbers and *E. hayati* parasitism in field ZH2.

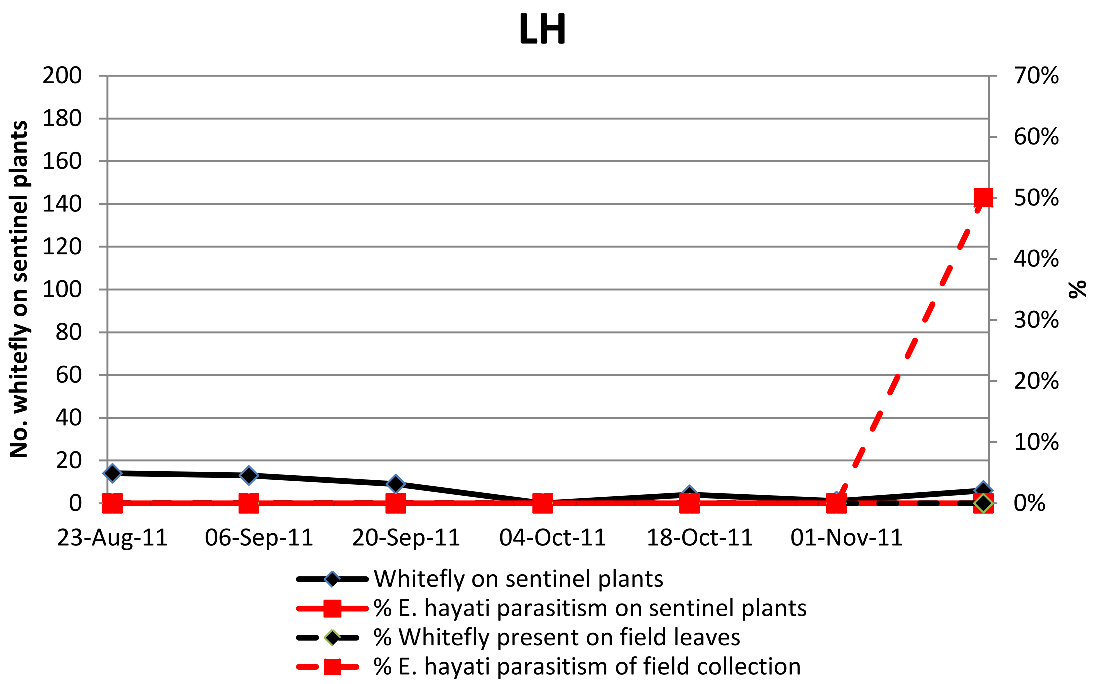


Figure 73. Whitefly numbers and *E. hayati* parasitism in field LH.

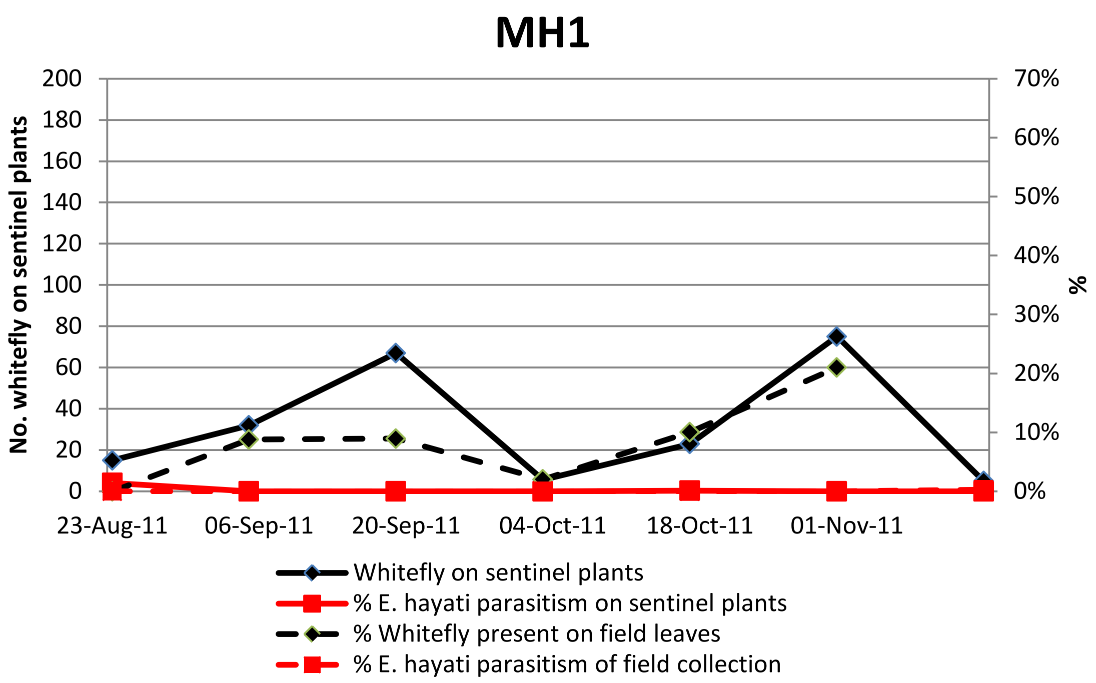


Figure 74. Whitefly numbers and *E. hayati* parasitism in field MH1.

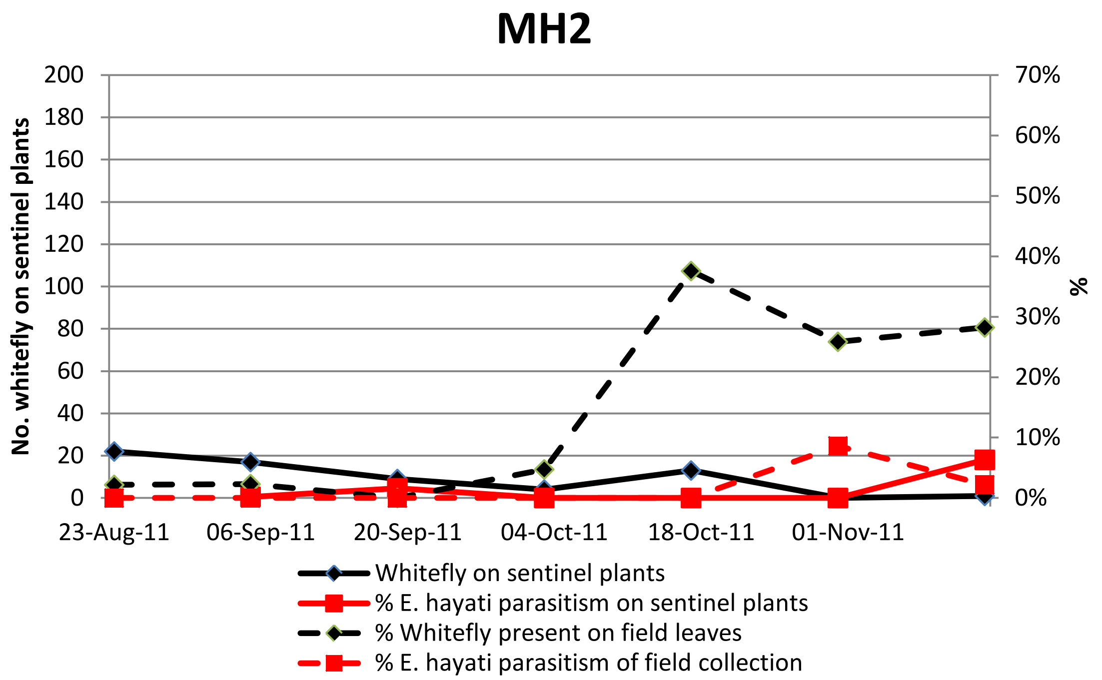


Figure 75. Whitefly numbers and *E. hayati* parasitism in field MH2.

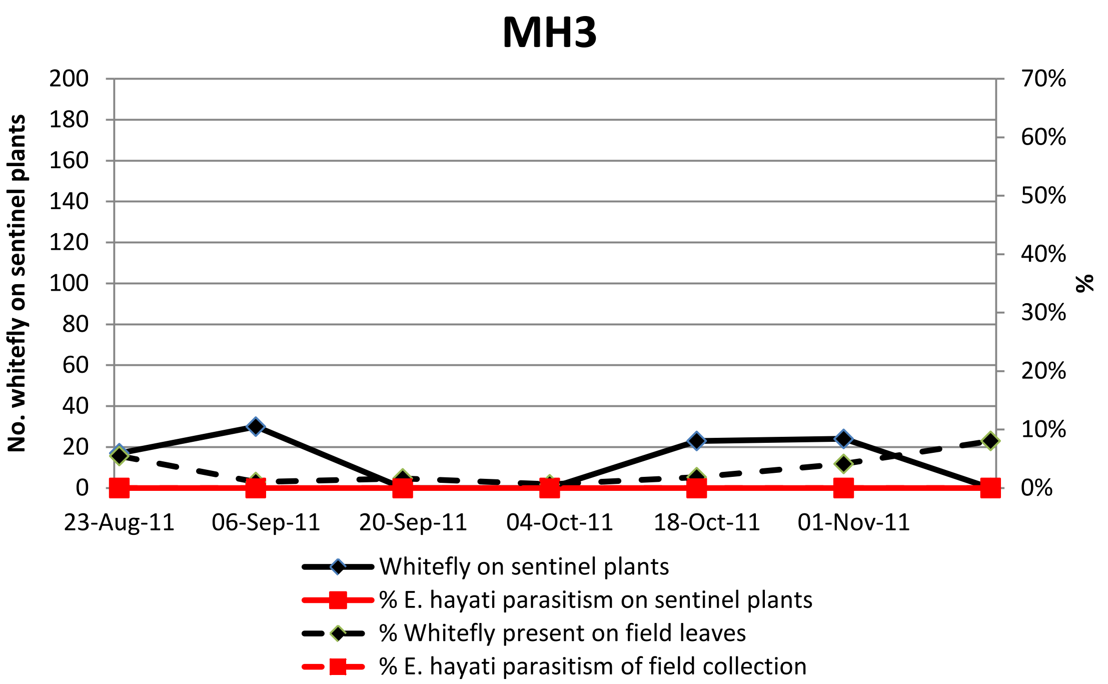


Figure 76. Whitefly numbers and *E. hayati* parasitism in field MH3.

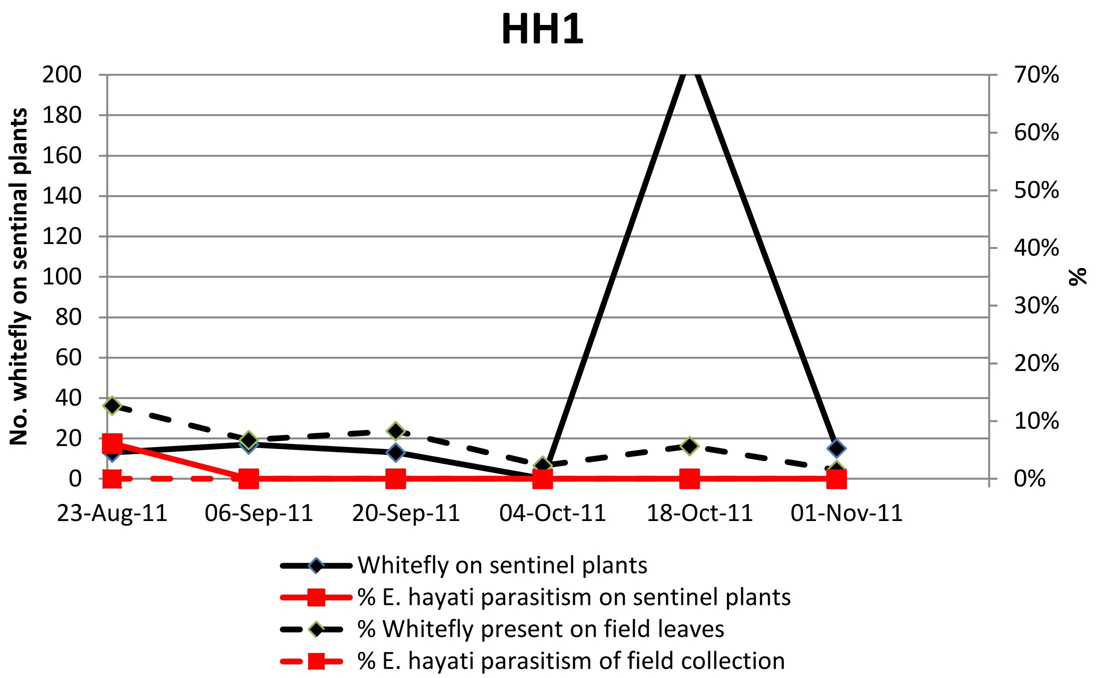


Figure 77. Whitefly numbers and *E. hayati* parasitism in field HH1.

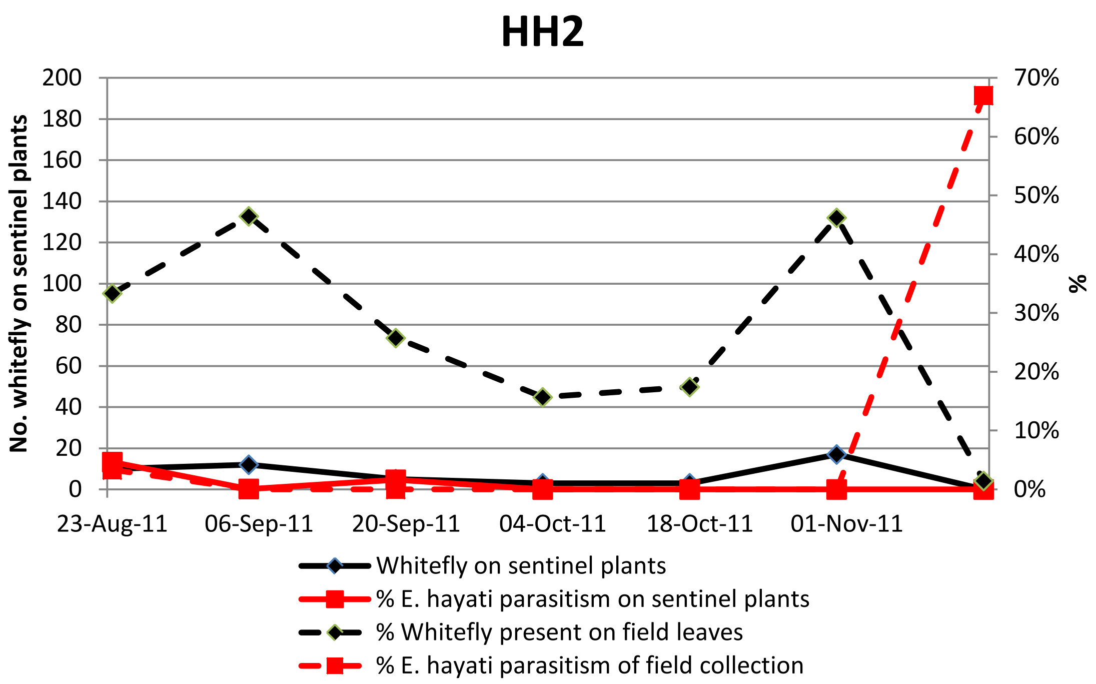


Figure 78. Whitefly numbers and *E. hayati* parasitism in field HH2.

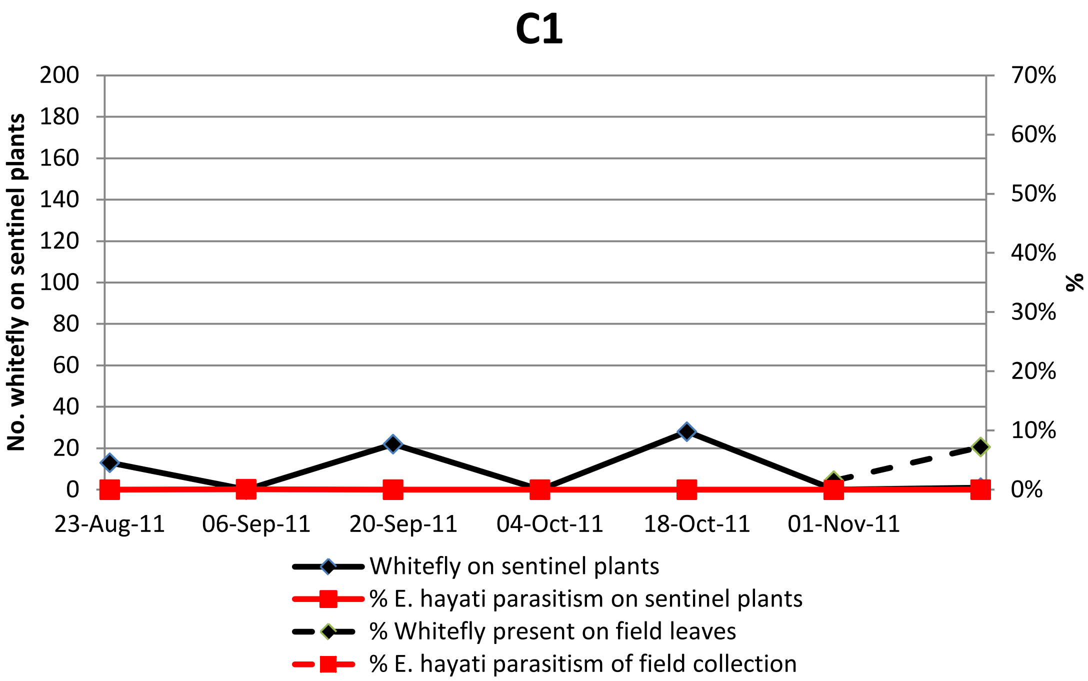


Figure 79. Whitefly numbers and *E. hayati* parasitism in field C1.

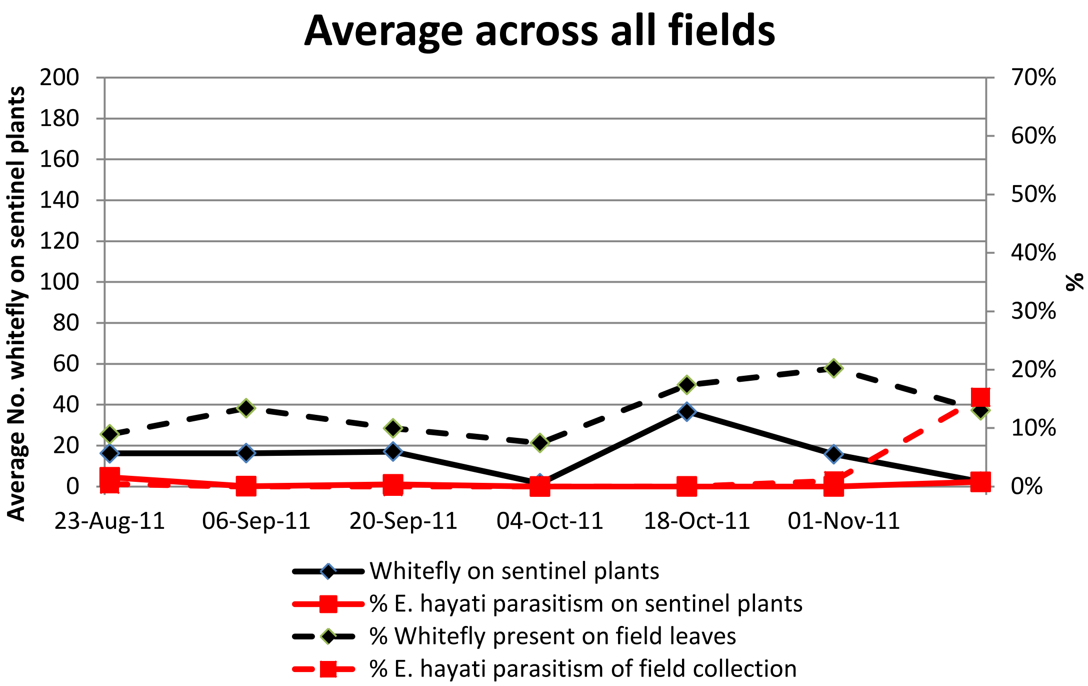


Figure 80. Average whitefly numbers and *E. hayati* parasitism across all fields.

In an attempt to pull out some pattern from the data we also considered the cumulative numbers of SLW and *E. hayati* overtime. However, there was no trend for greater accumulation overtime as a function of rotation strategy. For accumulation of SLW only C1 and MH1 showed an increase. For *E. hayati*, only HH2 and MH2 showed an increase. This is the expected result as generated from the model, however, the result is too tenuous to draw strong conclusions. Furthermore, there was no r elationship between SLW sentinel nymphs and the percent of crop leaves infested with SLW (R^2=0.009).

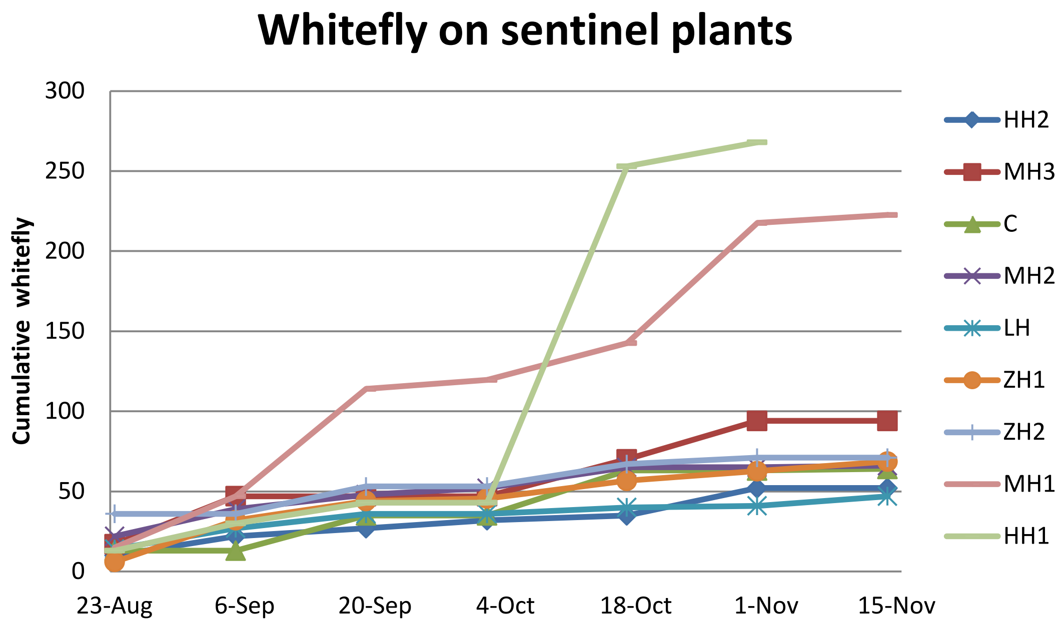


Figure 81. Cumulative whitefly on sentinel plants.

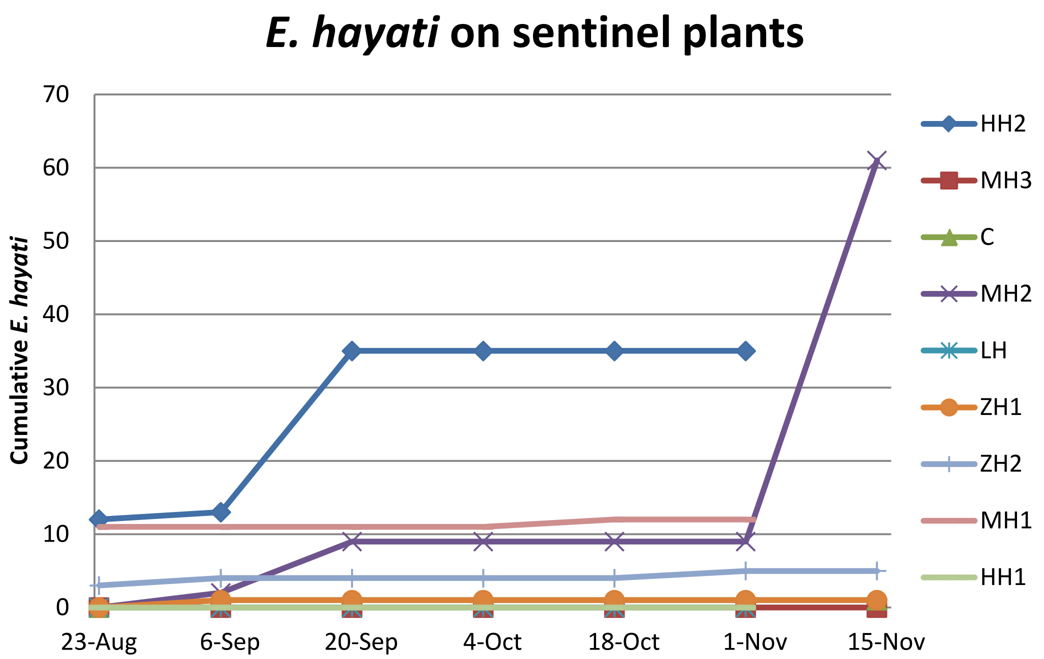


Figure 82. Cumulative *E. hayati* on sentinel plants.

As stated in the methods, an unplanned autumn collection was made. The results showed that in five out of seven cases parasitism was higher than what was found in the spring (Fig. 83). This suggests a severe time-lag in *E. hayati* compared to SLW populations. A lag that has not been seen in previous experiments, eg. VG06029.

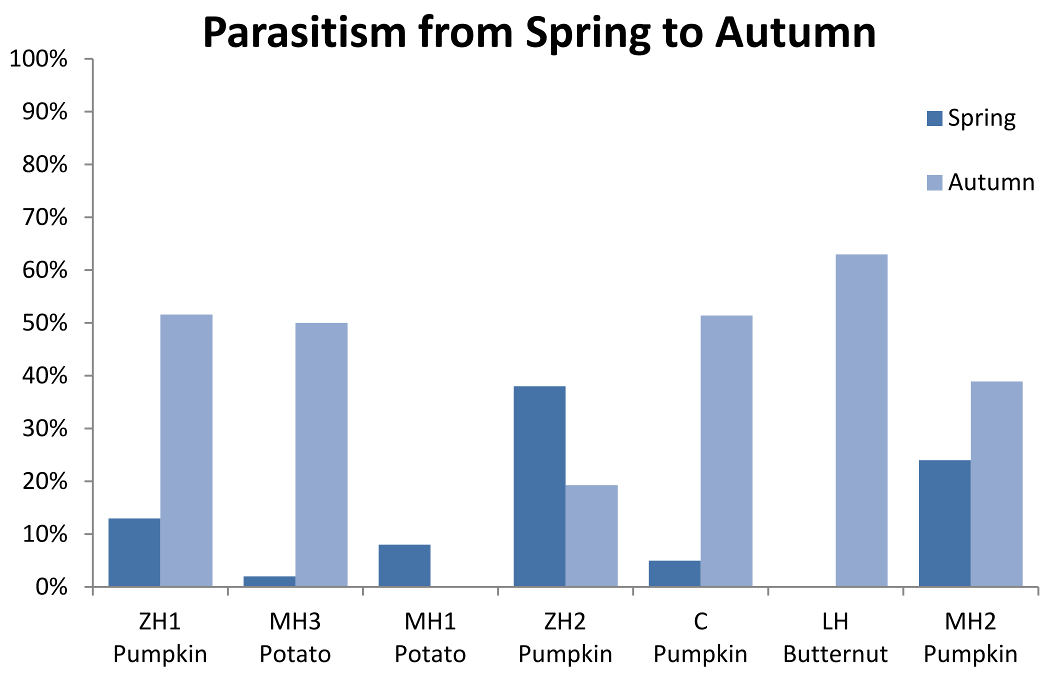


Figure 83. Comparison of *E. hayati* parasitism rates between spring and autumn.

Given the poor quality of the field data, many attempts were made to extract information. Another way is to consider the odds ratios or the ratio of the probability of occurrence of leaves positive for SLW to that of non-occurrence. A value of one suggests no difference in the probably of leaves with versus without SLW. A value greater than one suggest a probability of occurrence greater than non-occurrence. Interestingly the season started off as predicted by the model that a greater probability of non-occurrence in the medium-high rotation. However, by early summer the medium-high rotation had the highest probability of leaves positive for SLW, and was twice as likely for SLW to occur than not.

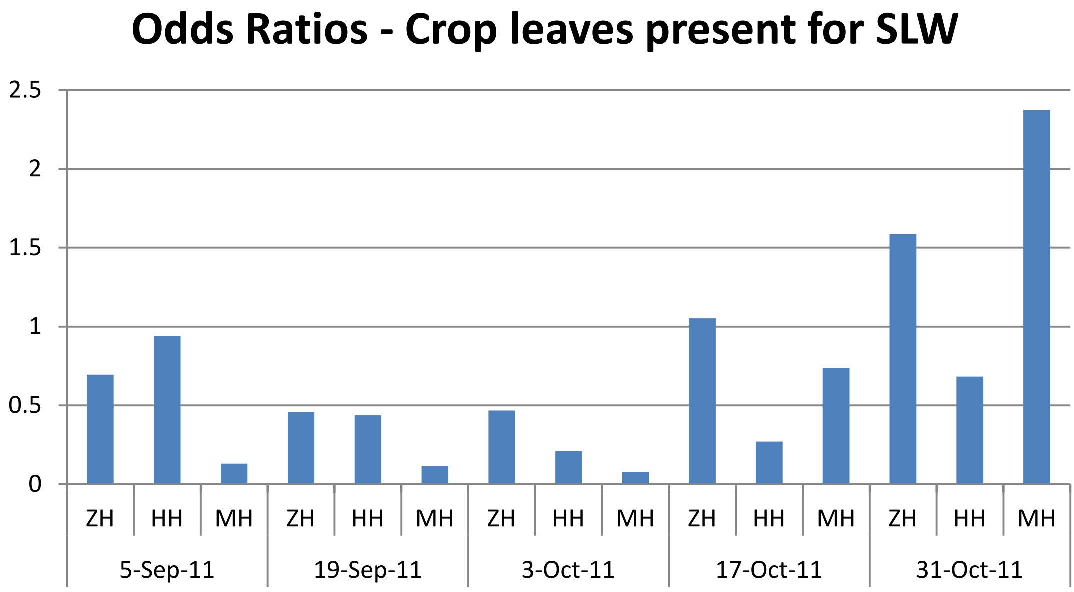


Figure 84. Odds of crop leaves being present for SLW in the rotation treatments of zero-high, high-high, and medium-high.

Summary

Results from the model suggest firstly that *E. hayati* results in a 100 fold decrease in SLW numbers. Further, the modelling exercise demonstrated that some rotation strategies can result in early colonisation of *E. hayati* and keep SLW lower for longer. When growers in the area do similar rotations, then planting a low-medium SLW susceptible crop before a highly susceptible crop can achieve the best SLW control. Going straight into a highly susceptible SLW crop in the summer can result is a rapid increase of SLW numbers. In this instance, an innundative release of *E. hayati* is highly recommended. If half of the growers in the region do one rotation and the other half do something else, then a low-high rotation strategy will only benefit the grower, if the neighbour is growing a medium susceptibility SLW crops. If the neighbour is going straight into highly susceptible SLW crops, then an innundative release will be required to keep SLW populations from exploding.

The experimental component to test the model was disappointing due to the extremely low numbers of *E. hayati*. This was most likely due to a couple of factors. Firstly, the flood. Much of the Lockyer Valley was underwater during January 2011, including lantana and areas that host SLW and *E. hayati*. In addition, the extensive use of Confidor as a drench for many crops may be keeping SLW and the parasitoid at extremely low levels. Therefore, when an outbreak of SLW does occur – particularly on crops that are not using a drench, there are no *E. hayati* to respond. Again, a situation in which an innundative release combined with a soft chemical may be required.

Section 3

The dispersal and spread of *Eretmocerus hayati* at three spatial scales

3. The dispersal and spread of *Eretmocerus hayati* at three spatial scales

As part of VG06029, many field releases of *E. hayati* were conducted. As an additional component, the release in the Fassifern Valley also included an experimental design that allowed us to investigate the rate and mode of dispersal of *E. hayati* at various spatial scales. We have recently completed the modelling exercise, (an exercise separate from VG06029 and VG08051), but complimentary. The results from the work show that *E. hayati* adults can disperse up to 1 kilometre per day. Fitting models to field data shows that *E. hayati* use flight to disperse at the local scale (tens of metres), a combination of wind and flight to disperse at the field scale (hundreds of metres) and wind to disperse at the landscape scale (kilometres). This work clearly demonstrates the high dispersive capacity of *E. hayati*. The article titled, 'The initial dispersal and spread of an invader at three spatial scales', is in review PLoS ONE (2012 *in review*). This data is summarised in the grower guide.

The initial dispersal and spread of an invader at three spatial scales.

Nadiah P. Kristensen[1], Paul J. De Barro[2], Nancy A. Schellhorn[2*]

[1]CSIRO Ecosystem Sciences, GPO Box 1700, Canberra, ACT 2601, nadiah.kristensen@gmail.com

[2] CSIRO Ecosystem Sciences, GPO Box 2583, Brisbane, QLD 4001, Australia. nancy.schellhorn@csiro.au, paul.debarro@csiro.au

*Corresponding author. CSIRO Ecosystem Sciences, GPO Box 2583, Brisbane, QLD 4001, Australia. nancy.schellhorn@csiro.au

Abstract

1. The way an invasion progresses through space is a theme of interest common to invasion ecology and biological pest control. Models and mark-release studies of organisms have been used extensively to extend and inform invasion processes of establishment and spread. However, the immense challenge to study initial dispersal of organisms by direct observation yields information from small spatial scales. This in turn influences model parameterisation.

2. Using the intentional release of a novel biological control agent (a parasitic hymenoptera, *Eretmocerus hayati* Zolnerowich & Rose (Hymenoptera: Aphelinidae), we studied its initial dispersal and spread at three different spatial scales, the local scale (tens of metres), field scale (hundreds of metres) and landscape scale (kilometres) around the release point. We fit models to each observed spread pattern at each spatial scale.

3. We show that *E. hayati* exhibits stratified dispersal; moving further, faster and by a different mechanism than would have been concluded with a single local-scale post-release sampling design. In fact, interpretation of each scale independent of other scales gave three different models of dispersal, and three different impressions of the dominant dispersal mechanisms.

4. Our findings demonstrate that using a single-scale approach may lead to quite erroneous conclusions, hence the necessity of using a multiple-scale hierarchical sampling design for inferring spread and the dominant dispersal mechanism of either human intended or unintended invasions.

Section 4

Comparing the reproductive performance of *Eretmocerus mundus* and *Eretmocerus hayati*

4. Comparing the reproductive performance of *Eretmocerus mundus* and *Eretmocerus hayati*

CSIRO hosted a visiting scientist jointly funded by Endeavour Scholarships, VCs, and CSIRO, Juan Villanueva-Jimenez, from Colegio de Postgraduados, Veracruz, Mexico. As part of his visit, he conducted a study on the relative reproductive performance of *Eretmocerus mundus* and *Eretmocerus hayati* under laboratory conditions. F or copyright reasons, the full article is not included. The main finding is that *E. hayati* adults survived longer and produced more progeny than *E. mundus*. This may explain why *E. hayati* is the more effective biocontrol agent compared to the native *E. mundus*.

The article titled, 'Comparison between two species of *Eretmocerus* (Hymonoptera: Aphelinidae): Reproductive performance is one explanation for more effective control in the field', can be found in Biological Control (2012 *in press*).

Comparison between two species of *Eretmocerus* (Hymenoptera: Aphelinidae): Reproductive performance is one explanation for more effective control in the field.

Villanueva-Jimenez, Juan A.[1], Nancy A. Schellhorn[2], Paul J. De Barro[2*].

[1] Colegio de Postgraduados, Campus Veracruz. Km 88.5 carretera Xalapa-Veracruz, Veracruz, 91690. Mexico. javj@colpos.mx.

[2] CSIRO Ecosystem Sciences, GPO Box 2583, Brisbane, QLD 4001, Australia. nancy.schellhorn@csiro.au, paul.debarro@csiro.au.

*Corresponding author. CSIRO Ecosystem Sciences, GPO Box 2583, Brisbane, QLD 4001, Australia. paul.debarro@csiro.au

After the invasion of Australia by the *Bemisia tabaci* species Middle East-Asia Minor 1 (MEAM1, commonly known as the B biotype), the native parasitoid *Eretmocerus mundus* (Australian parthenogenetic form) was found to be an ineffective control agent. *Eretmocerus hayati* was therefore introduced and has substantially improved the level of control. A laboratory study was under taken to determine whether superior life history traits were one explanation for the better performance of *E. hayati*. We compared adult longevity, daily fecundity and proportion of female progeny of both mated and unmated females. We also compared the traits across females that were either treated with or without the antibiotic rifampicin, an antibiotic that had already been shown to deplete *Wolbachia* and enable *E. mundus* to produce males. We found that *E. hayati* adults survived longer and produced more progeny than *E. mundus*. Unmated *E. hayati* females produced only males. Rifampcin had no effect on any of the traits for *E. hayati*. In contrast, without rifampicin *E. mundus* females produced mostly female progeny whereas treated females produced mostly males. Recent studies suggest that *E. hayati* co-evolved with MEAM1, whereas the *E. mundus* in Australia co-evolved with the entirely distinct Asia members of the complex. This suggests that the underlying evolutionary relationships within the *B. tabaci* complex may be an important consideration when selecting agents for biological control.

Section 5

5. Grower Guide: How to get the most out of *hayati*

Insecticides for Silverleaf Whitefly and how they affect *hayati*

Harmful

- Imidacloprid: Confidor®, Surefire®, Savage®, Couraze®, Annihilate®, Senator®, Voodoo®
- Bifenthrin: Talstar®
- Diafenthiuron: Pegasus®
- Piperonyl butoxide: Synergy®

A little harm

- Thiamethoxam: Actara®
- Pyriproxyfen: Admiral®
- Thiamethoxam/Chlorantraniliprole: Durivo®

Not harmful

- Spirotetramat: Movento®
- Pymetrozine: Chess®
- Imidacroprid (applied via drip irrigation only)

Information: http://www.biobest.be/neveneffecten/3/3/ and http://side-effects.koppert.nl/

Pesticides for other pests and diseases and how they affect *hayati*

Harmful

- Imidacloprid: Confidor®, Surefire®, Savage®, Couraze®, Annihilate®, Senator®, Voodoo®
- Bifenthrin: Talstar®
- Diafenthiuron: Pegasus®
- Piperonyl butoxide: Synergy®
- Methomyl: Lannate®, Marlin®
- Acephate: Lancer®
- Carbaryl: Bugmaster®

A little harm

- Spinosad: Success®
- Indoxacarb: Avatar®
- Pyriproxyfen: Admiral®
- Sulfur

Not harmful

- Spirotetramat: Movento®
- Pirimicarb: Pirimor®, Atlas®, Pirimidex®
- Flubendiamide: Belt®
- Bt's: Dipel®, Xentari®
- NPV's: Gemstar®, ViVUS®
- Chlorantraniliprole: Coragen®
- Pymetrozine: Chess®
- Fungicides: Copper, Chlorothalonil, Amistar®, Bravo®

Information: http://www.biobest.be/neveneffecten/3/3/ and http://side-effects.koppert.nl/

hayati facts

* ***hayati*** can get into crops quickly within 1-3 days of Silverleaf Whitefly arriving
* ***hayati*** reproduce really fast one female can produce 230 offspring
* ***hayati*** can get around moving up to 1 km/day by flying or catching a lift on the wind
* ***hayati*** live for about 20 days
* ***hayati*** only reproduce in SLW otherwise they die out

The best way to get *hayati* working for you

If you **have** ***hayati*** around your property:

1. Plant a low-medium suitability whitefly crop prior to peak production season. This will build *hayati* numbers ready to move into your next crop.
2. Keep weeds to a minimum.
3. Spray only when necessary by monitoring pests.
4. Only use insecticides that don't harm *hayati*.

If you **don't have** ***hayati*** around your property consider releasing some - particularly prior to peak production season. Contact Bugs for Bugs. Ph: 07 4165 4663 www.bugsforbugs.com.au

For further information, please contact: Ms Lynita Howie, CSIRO Research Projects Officer 07 3833 5707 lynita.howie@csiro.au

This project has been funded by HAL using the Vegetable Industry levy and matched funds from the Australian Government.

How to get THE MOST out of *hayati*

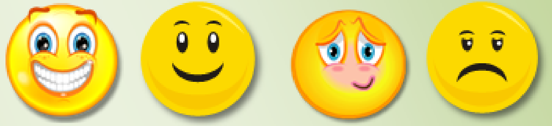
Whitefly Public Enemy #1

hayati [hay-AR-ti] is a very small parasitoid wasp that can help control Silverleaf Whitefly, a serious pest of fruit and vegetable crops

Ask questions … find solutions … change for the better

Silverleaf Whitefly's crop preferences

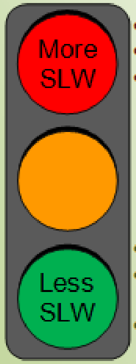
Love it	Like it a lot	Like it a little	Don't like it



High suitability	Medium suitability	Low suitability	Not suitable
Rockmelon	Cabbage	Silverbeet	Sorghum
Pumpkin	Cauliflower	Lucerne	Sugarcane
Sunflower	Eggplant	Green beans	Corn
Soybean	Watermelon	Beetroot	Carrot
Cotton	Honeydew	Lettuce	Onions
Tomato	English potato	Sweet Potato	Shallots
	Cucumber	Zucchini	
		Capsicum	

Information: combined scientific literature research, lab and field studies, grower discussions and 'best guess' of how fast whitefly can multiply on different crop plants.

Management practices and land uses nearby* that affect Silverleaf Whitefly populations



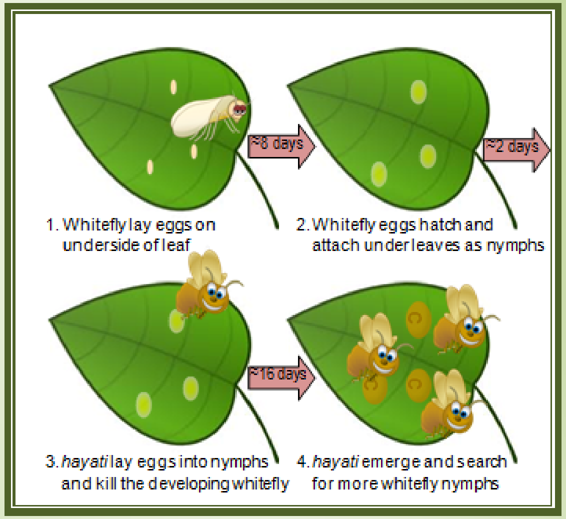
- No monitoring, only calendar sprays
- Spraying insecticides that harm *hayati*
- Broad-leaf weeds nearby, eg. Weedy cane fields

- Regular monitoring
- Good farm hygiene, eg. Controlling broad-leaf weeds
- Modifying management practices as conditions change
- Fruit or nut orchard nearby*
- Lucerne nearby*
- Grazed pasture nearby*

*nearby = on your property or your neighbour's property

Information: grower survey of Silverleaf Whitefly and management practices (2010). HAL project VG08051 (2012)

How *hayati* works

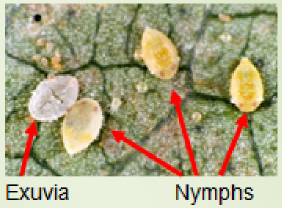


Do you have *hayati*?

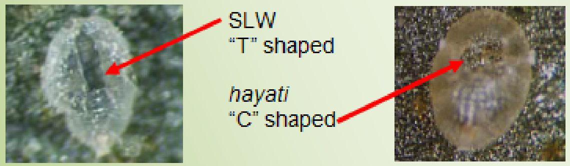
How to find out

Pick leaves that clearly have Silverleaf Whitefly nymphs underneath.

Like this →



Then: If you have a hand lens, have a close look at the exuvia (the 'shell' left behind when the whitefly or *hayati* have emerged). Whitefly exit holes are "T" shaped, *hayati* exit holes are "C" shaped. See next panel for development.

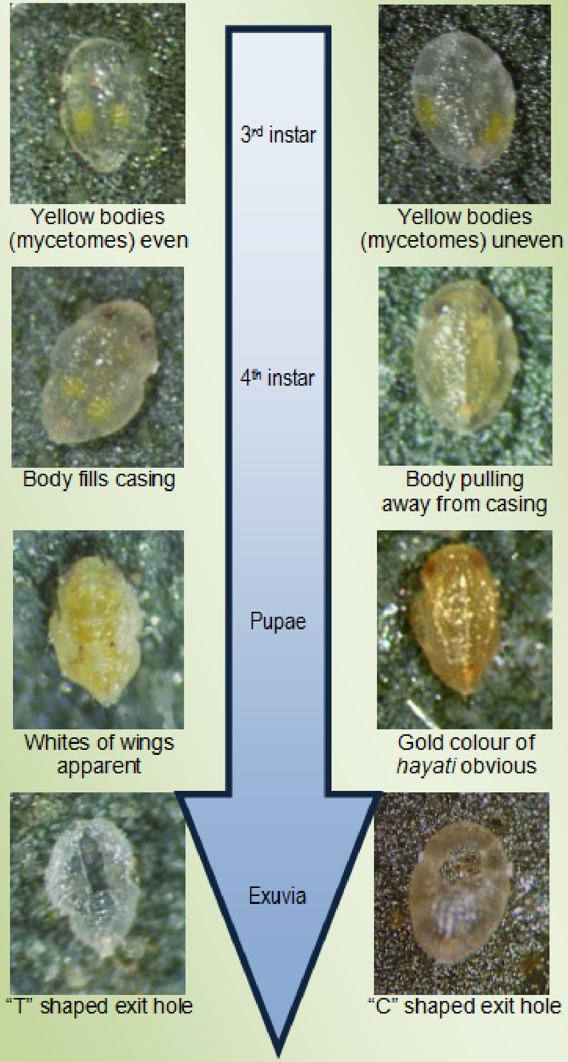


Otherwise: Put the leaves in a take-away container and leave on the kitchen table. Check every couple of days for adults to emerge. They are about as big as this comma (,) and golden coloured. Whiteflies are twice as big and white, see pictures on front panel.

Do you have *hayati*?

Nymph development

Development of Silverleaf Whitefly | **Development of *hayati* in SLW**



Photos: Bill Roltsch, California Department of Food & Agriculture

Technology Transfer

There were several activities undertaken to communicate and engage with growers and consultants to promote awareness and benefits of *E. hayati* in several of the major growing regions. At the outset of the project, Ms Lynita Howie talked with consultants and growers from Toowoomba to Ayr in Queensland about the project to gain an understanding of their current knowledge and perceptions of *E. hayati*. This was followed up by a survey of 68 growers and 22 consultants, conducted by an independent survey company to understand how *E. hayati* and whitefly is managed.

During the project, Ms Lynita Howie and Mr Andrew Hulthen travelled to Carnarvon, WA, to test the dispersal of *E. hayati*. Whilst there they spoke with local growers and distributed information about *E. hayati* and discussed the project and *E. hayati*.

Throughout the project, Drs Paul De Barro and Nancy Schellhorn and Ms Lynita Howie gave talks about the project to growers, consultants and industry.

Gatton	6 May 2011	Workshop lead by David Carey, Qld Department Agriculture, Fisheries and Forestry.
Northern NSW	3 June 2011	Northern Rivers Pest Management Forum, Lead by Soil Care.
Bundaberg	16 August 2011	Fruit fly and IPM forum, run by Bundaberg Fruit & Vegetable Growers.
Bowen	21 August 2012	Workshop promoted by Dr Siva Subramaniam, Qld Department Agriculture, Fisheries and Forestry and Bowen Gumlu Growers Association.
Ayr	22 August 2012	Meeting promoted by Landmark, Ayr.
Gatton	23 August 2012	Workshop lead by David Carey, Qld Department Agriculture, Fisheries and Forestry (Appendix III).

Lynita Howie developed and will distribute a field guide with information about *E. hayati*, the findings of the research done as part of this HAL project and how to get the most out of *E. hayati*. The draft version of the field guide (Section 5) was distributed at all workshops and meetings held during 2012 for feedback was refined based on that feedback.

During the fieldwork component of this project, Dr Nancy Schellhorn and Ms Lynita Howie and a team of five worked with 10 growers and their families across the Lockyer Valley, Qld. The team communicated with several additional growers about the project during field site selection process.

Two articles are currently in-press or in-review in peer reviewed journals, 'Comparison between two species of *Eretmocerus* (Hymenoptera: Aphelinidae): Reproductive performance is one explanation for more effective control in the field', *Biological Control* 2012, and 'The initial dispersal and spread of an invader at three spatial scales', *Plos One* 2012.

Dr Nancy Schellhorn gave an invited guest lecture at University of Queensland on 29 August 2012 where she talked about insect movement and the role of various crop and non-crop habitat for biological control.

Dr Nancy Schellhorn and Ms Lynita Howie are presenting a poster summarising the findings from this project (Appendix IV) at the Entomological Society of America Annual Meeting in Tennessee, USA in November 2012.

A popular press article for *Vegetables Australia* was printed in Nov/Dec 2010 titled, 'Beaten by the Foreigner'. The article was also printed in the UK grower magazine *Outlooks in Pest Management*. Another article is currently in preparation by Dr Nancy Schellhorn and Ms Lynita Howie, with CSIRO communications and will be submitted by end of September to *Vegetables Australia* summarising the project and research findings.

Recommendations – scientific and industry

Scientific

E. hayati is a highly effective biological control agent and can substantially reduce silverleaf whitefly (SLW) numbers. However, to continue to improve the effectiveness of *E. hayati*, three key science areas need improving: 1) the development of economic thresholds of SLW in vegetable crops, 2) integration of SLW thresholds and *E. hayati* parasitism levels (similar to that published by Hamilton *et al.* 2005), and 3) integration of chemical control for SLW AND other pest of SLW host crops. There is currently no publ ished information available on silverleaf whitefly thresholds in most vegetable crops. When presenting to growers the best methods of dealing with SLW without harming *E. hayati*, they frequently comment that our recommendations would be fine if SLW was the only insect pest they needed to deal with. They often ask how to integrate our recommendations with the other major crop pests. Accompanying this is the need for the development and communication of a standardised method for monitoring SLW. As shown from the survey, growers and consultants use a variety of methods which impedes communication of whitefly infestation levels. This can potentially lead to misunderstandings about spray decisions, and taking action unnecessarily against SLW and therefore knocking out *E. hayati*.

Results from the modelling work and supported by the fieldwork clearly show that it is important to keep *E. hayati* numbers at a level in the environment where it is possible to provide pest control services. As demonstrated from the model, the best pest control is provided when *E. hayati* numbers build up naturally prior to the peak whitefly season by growing a slightly-moderately suitable whitefly crop before growing a highly suitable whitefly crop. These results, plus those from VG07040 support the concept of on-farm refuges to host beneficial insects for early colonisation. Using standardised monitoring methods, not spraying before economic threshold is reached, and providing an on-farm refuge such as food plants for beneficial insects, an orchard or a small unsprayed section of a crop will allow *E. hayati* to survive locally. However, the commercialisation of *E. hayati* also offers opportunity of innundative release.

Industry

More effort is needed towards communicating the benefits of *E. hayati*. It is clear from the surveys that some growers and consultants are unaware that *E. hayati* has been released. In addition, very little is known about soft option chemicals. Our field guide is a first step in the direction towards better integration. *E. hayati* is a highly effective control agent – more so than most – and its recent commercialisation offers a tremendous opportunity for a fully integrated pest management strategy. A SLW management package that includes thresholds for host crops of SLW, guidelines about the timing of innundative releases, *E. hayati* levels needed that are sufficient to keep SLW numbers below economic injury, and familiarisation about chemical options soft on *E. hayati* – along with an extensive communication strategy would go a long way in assisting growers with transitioning to sustainable SLW control.

Although the recent commercialisation of *E. hayati* is a further advancement towards sustainable SLW control, growers must also follow an insecticide program that is not excessively harmful to *E. hayati*. That is, avoiding sprays of broad spectrum insecticides, instead using a plant hole drench or pre-treated seedlings if necessary and using softer chemistry such as spirotetramat, thiamethoxam, pyriproxyfen or chlorantraniliprole.

Acknowledgements

Dr. Nancy Schellhorn would like to acknowledge and thank: Ms. Lynita Howie for her exceptional job conducting the fieldwork, preparing the survey questions, interpreting the survey results and developing the field guide. She would like to thank Dr. Felix Bianchi for modelling the dynamics of SLW and *E. hayati* under various crop rotation scenarios. She would like to thank Ms. Anna Marcora, Mr. Andrew Hulthen, Dr. Cassie Jansen, Dr. Hazel Parry for feedback and comments on survey questions and field guide. She would particularly like to thank Ms. Rebecca Garrad, Ms. Anna Marcora, Ms. Belinda Walters, Mr. Andrew Hulthen and Mr. Lino Bin for supporting the fieldwork component of the project; Ms. Rebecca Garrad especially spent many hours collecting and counting insects back in the laboratory; as well as the growers who allowed us to work on their properties – Mr. Dale Marschke, Mr. David Keller, Mr. Michael Neumann, Mr. Neville Heenan, Mr. Baden Lester, Mr. David Neumann, Mr. Calvin Zische, Mr. Neil Natalier, Mr. Russel Reck and Mr. Lindsay Ziser. She would like to thank Mr. David Carey and Dr. Siva Subramaniam for organising grower workshops and promoting this research to growers.

Ms. Lynita Howie would like to thank Ms. Anne Bourne for assistance analysing the survey data and interpreting the results. She would like to thank Mr. Dale Abbott of Bowen Crop Monitoring Services and Mr. David Carey from DAFF QLD for providing contacts of local growers to survey about their whitefly management practices; and Mr. Jeff Coutts and Ms. Amy Samson from the survey company Coutts J&R for conducting the survey. Not least, she would like to thank the growers and consultants that gave their time to complete the survey.

Finally we wish to acknowledge the Vegetable Industry levy, without which this work would not have been possible.

References

Ardeh, MJ. (2004) Whitefly control potential of *Eretmocerus* parasitoids with different reproductive modes. Ph.D Thesis, Wageningen University. The Netherlands.

Bianchi, FJJA. & Van Der Werf, W. (2003) The effect of the area and configuration of hibernation sites on the control of aphids by *Coccinella septempunctata* (Coleoptera : Coccinellidae) in agricultural landscapes: A simulation study. Environmental Entomology 32(6):1290-1304.

Chang, GC. & Kareiva, P. (1999) The case of indigenous generalists in biological control. *Theoretical Approaches to Biological Control*, ed Cornell HV (Cambridge University Press, Cambridge).

De Barro, PJ. & Coombs, MT. (2009) Post-release evaluation of *Eretmocerus hayati* Zolnerowich and Rose in Australia. Bulletin of Entomological research 99:193-206.

De Barro, P. & Schellhorn, N. (2008) Release, post-release evaluation and habitat management of the silverleaf whitefly parasitoid *Eretmocerus hayati*, CSIRO**:** 41.

Ekbom, BS., Wiktelius S., & Chiverton PA. (1992) Can polyphagous predators control the bird cherry-oat aphid (Rhopalosiphum padi) in spring cereals? A simulation study. Entomologia Experimentalis et Applicata 65:215-223.

Hamilton, AJ., Schellhorn, NA., Endersby, NM., Ridland, PM., & Ward SA. (2004) Dynamic binomial samplig plan for Plutella xylostella on Brocolli and Cauliflower in Australia. Journal of Economic Entomology 97:127-135.

Heisswolf, S. & Kay, I. (2007) Analysing industry needs to fine tune IPM project activities. Proceedings of the IIIrd International Symposium on Cucurbits. R. McConchie & G. Rogers. Leuven 1, International Society Horticultural Science**:** 283-294.

Invasive Species Specialist Group. (2012) "Global Invasive Species Database." Retrieved 17 July, 2012, from http://www.issg.org/database/species/search.asp?st=100ss&fr=1&str=&lang=EN.

Ives, AR. & Settle, WH. (1997) Metapopulation dynamics and pest control in agricultural systems. The American Naturalist 149(2):220.

Lin, L. & Ren, SX. (2005) Development and reproduction of 'B' biotype *Bemisia tabaci* (Gennadius) (Homoptera: Aleyrodidae) on four ornamentals. Insect Science 12: 137-142.

Liu, TX. & Stansly, PA. (1998) Life history of *Bemisia argentifolii* (Homoptera: Aleyrodidae) on *Hibiscus rosa-sinensis* (Malvaceae). Florida Entomologist 82: 437-445.

Musa, PD. & Ren, SX. (2005) Development and reproduction of *Bemisia tabaci* (Homoptera: Aleyrodidae) on three bean species. Insect Science, 12: 25–30

Nauen, R. & Denholm, I. (2005) Resistance of insect pests to neonicotinoid insecticides: Current status and future prospects. Archives of Insect Biochemistry and Physiology 58(4): 200-215.

Palumbo, JC., Horowitz, AR. & Prabhaker, N. (2001) Insecticidal control and resistance management for Bemisia tabaci. Crop Protection 20(9): 739-765.

Powell, DA. & Bellows, TS. (1992) Adult longevity, fertility and population growth rates for *Bemisia tabaci* (Genn.) (Hom. Aleyrodidae) on two host plant species. Journal of Applied Entomology 113: 68-78.

Qiu BL., De Barro P. & Ren, SX. (2005) Development, survivorship and reproduction of *Eretmocerus* sp. nr. *furuhashii* (Hymenoptera: Aphelinidae) parasitizing *Bemisia tabaci* (Hemiptera: Aleyrodidae) on g labrous and nonglabrous host plants. Bulletin of Entomological Research 95: 313–319.

Schellhorn, N. (2007) Phase II: Native Vegetation to enhance biodiversity, beneficial insects and pest control in horticulture systems, Horticulture Australia Limited**:** 78.

Tsai, JH. & Wang, K. (1996) Development and reproduction of *Bemisia argentifolii* (Homoptera: Aleyrodidae) on five host plants. Environmental Entomology 25: 810-816.

Urbaneja, A., Sánchez, E. & Stansly, PA. (2006) Life history of *Eretmocerus mundus*, a parasitoid of *Bemisia tabaci*, on tomato and sweet pepper. BioControl, 52: 25-39.

van Giessen, WA., Mollema, C. & Elsey KD (1995) Design and use a simulation model to evaluate germplasm for antibiotic resistance to the greenhouse whitefly (*Trialeurodes vaprariorum*) and the sweetpotato whitefly (*Bemisia tabaci*). Entomologia Experimentalis et Applicata 76: 271-286.

Van Der Werf, W. (1995) How do i mmigration rates affect predator / prey interactions in field crops? Predictions from simple models and an example involving the spread of aphid-borne viruses in sugar beet. *Arthropod natural enemies in arable land. I. Density, spatial heterogeneity and dispersal*, eds Toft S & Riedell W (Aarhus University Press, Denmark).

Zang, LS., Chen, WQ. & Liu, SS. (2006) Comparison of performance on different host plants between the B biotype and a non-B biotype of *Bemisia tabaci* from Zhejiang, China. Entomologia Experimentalis et Applicata 121: 221–227.

Appendix I

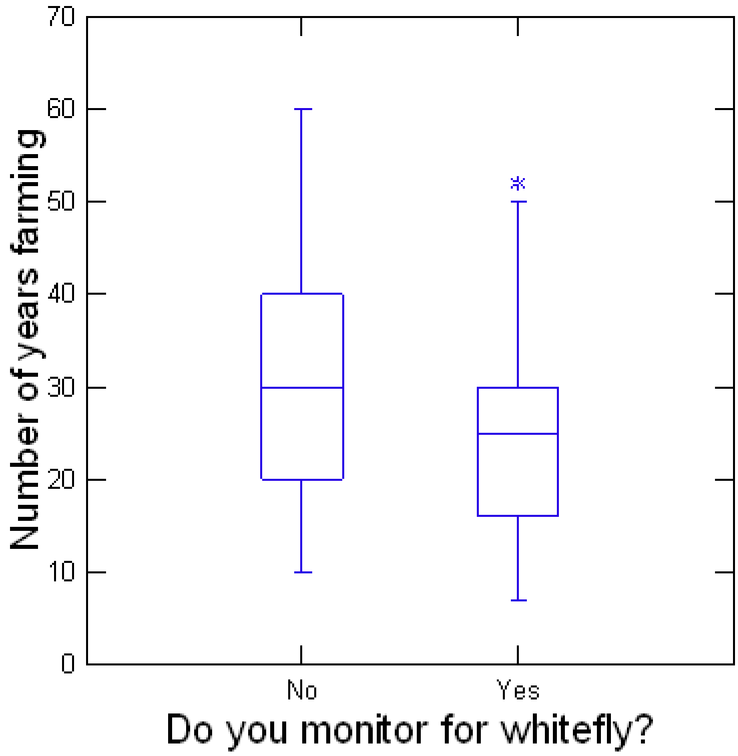


Figure 84. Relationship between years farming and monitoring for whitefly.

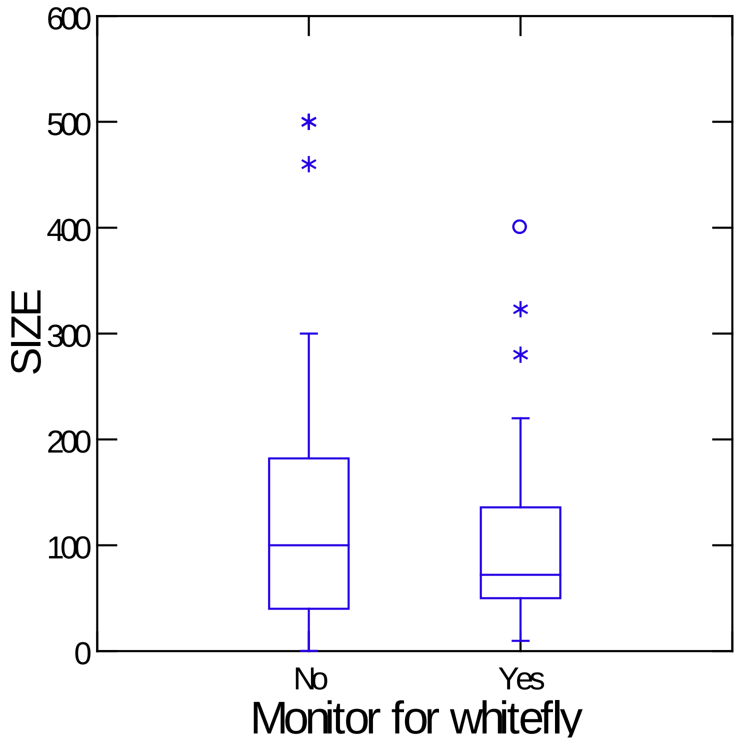


Figure 85. Relationship between farm size and monitoring for whitefly (two largest farms 930Ha and 2000Ha, set to 500Ha for the purposes of the graph).

Appendix II

A table of all insecticides used by growers in this survey, the active ingredient, insecticide class and the highest level of harm to *Eretmocerus* sp. are listed in the table below.

Table 26. Common insecticides used on whitefly host crops, their active ingredient, class and level of harm to *Eretmocerus* sp., if known.

Trade Name	Active ingredient	Pesticide Class	Harm to *Eretmocerus sp**
Actara	Thiamethoxam	4A Insecticide	Moderate
Admiral	Pyriproxyfen	7C Insecticide	Moderate
Amistar	Azoxystrobin	C K Fungicide	Low
Avatar	Indoxacarb	22A Insecticide	Moderate
Axe	Permethrin	3A Insecticide	High
Belt	Flubendiamide	28 Insecticide	Low
Bt, Dipel, XenTari	Bacillus thuringiensis	11 Insecticide	Low
Bravo	Chlorothanonil	Y Fungicide	Low
Bugmaster	Carbaryl (Carbamate)	1A Insecticide	High
Chess	Pymetrozine	9A Insecticide	Low
Confidor	Imidacloprid	4A Insecticide	High
Copper	Copper hydroxide	M1 Fungicide	Low
Coragen	Chlorantraniliprole	28 Insecticide	Minor
Dimethoate	Dimethoate (OP)	1B Insecticide	High
Durivo	Thiamethoxam & Chlorantraniliprole	4A & 29 Insecticide	Moderate
Endosulfan	Endosulfan	2A Insecticide	Low
Lancer	Acephate	1B Insecticide	High
Lannate, Marlin, Nudrin	Methomyl (Carbamate)	1A Insecticide	High
Lorsban	Chloropyrifos (OP)	1B Insecticide	High
Larvin	Thiodicarb (Carbamate)	1A Insecticide	
Movento	Spirotetramat	23 Insecticide	Low
Natrasoap	Organic soap		
Nitofol	Methamidophos (OP)	1B Insecticide	
OP's	Organophosphates	1B Insecticide	
Pegasus	Diafenthiuron	12B Insecticide	High
Pirimor, Atlas, Pirimidex	Pirimicarb	1A Insecticide	Minor
Proclaim	Emamectin	6A Insecticide	
Pyrethroid, Talstar, Karate	Synthetic Pyrethroid	3 Insecticide	High
Regent	Fipronil	2C Insecticide	Moderate
Rogor	Dimethoate	1B Insecticide	High
Success	Spinetoram, spinosad	5 Insecticide	Moderate
Sulfur	Lime Sulphur	M Fungicide	Minor

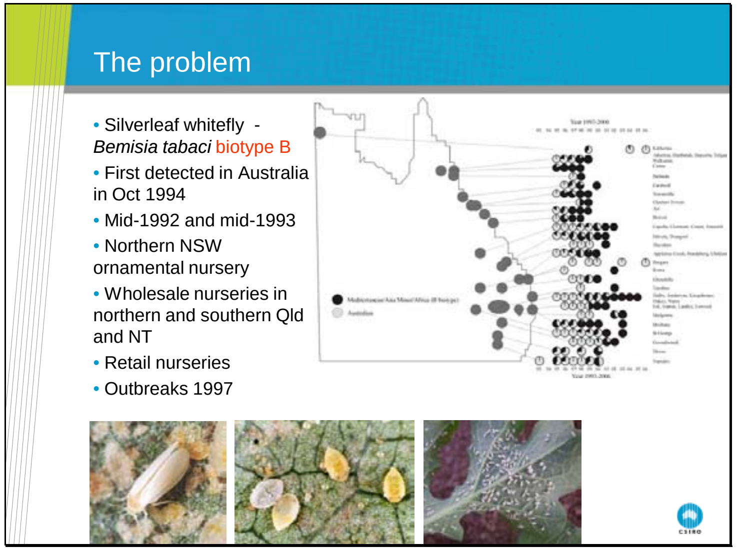
Trade Name	Active ingredient	Pesticide Class	Harm to *Eretmocerus sp**
Synergy	Piperonyl butoxide (synthetic pyrethroid synergist)		High
Talstar	Bifenthrin (synthetic pyrethroid)	3A Insecticide	High
Vertimec	Abamectin	6A Insecticide	High
ViVUS, Gemstar	Nucleopolyhedrovirus of *Helicoverpa*		Low

*highest level of harm to any life stage and by any means of application

Information gathered from various sources, primarily http://www.biobest.be/neveneffecten/3/3/ and http://side-effects.koppert.nl/

Appendix III

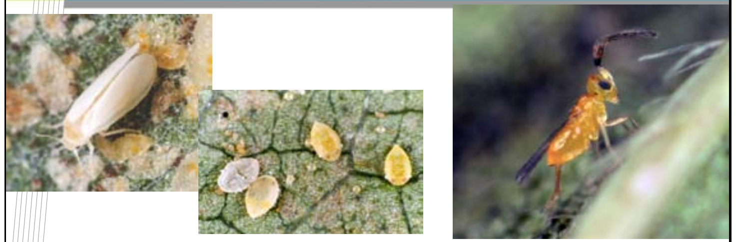
Example of the presentation given at a grower talk in the Lockyer Valley.



The problem

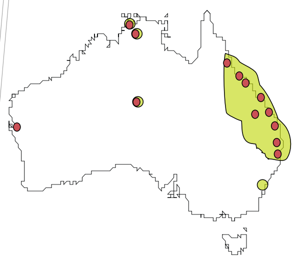
- Attacks a broad range of crops e.g. tomatoes, eggplant, potatoes, beans, squash, pumpkin, zucchini, brassicas, melons, cotton, soybeans & ornamentals
- Yield, quality (contamination & physiological colour change)
- Virus transmission – begomoviruses TLCV, TYLCV

The natural enemy, parasitoid – *Eretmocerus hayati* - Hayati



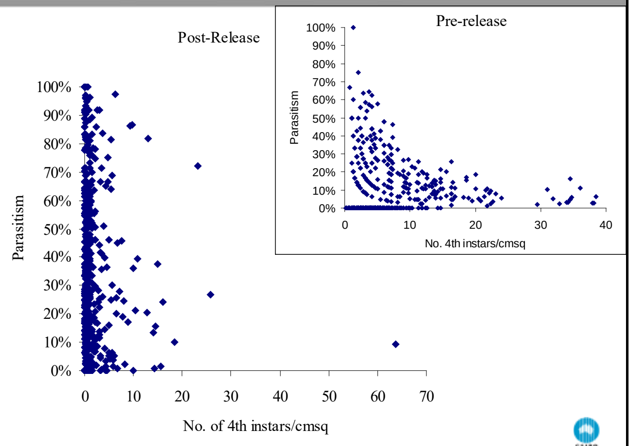
- ***Eretmocerus hayati* - Aphelinidae**
  - Originated in Pakistan
  - 1st release Oct 2004, released Bundaberg Nov 2004
  - Attacks 1st and 2nd instar nymphs

Releases

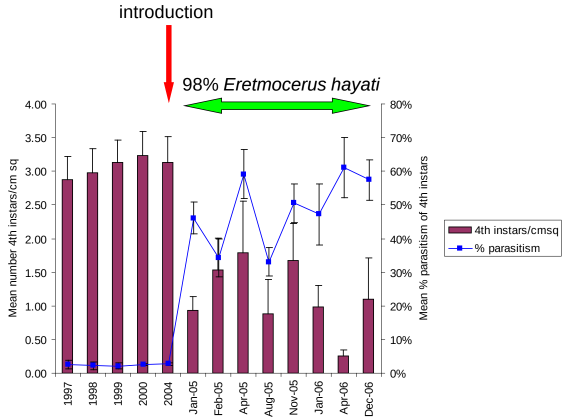


- Imported into quarantine Sept 2002
- Releases commenced 29 Oct 2004
- 1 million+ released in Bundaberg, Childers, Chinchilla, Lockyer Valley, Fassifern Valley, Emerald, Bowen & Ayr, Mareeba, Darwin, Katherine, Alice Springs, Carnarvon
- Final release March 2008

How is Hayati performing?



Silverleaf whitefly, Bundaberg 1997-2006



Current situation

- More plants with SLW are parasitized
  76% of all collections hit (parasitized), up from 24%
- 81% of all parasitism *Hayati*
- Parasitism levels have increased 6 fold
- Fewer host plants escaping parasitism i.e. marked reduction in enemy free space

How can we get the most out of this parasitoid?

- Understand SLW control practices of growers (survey results)
- Develop models to explore how to keep SLW lower for longer
- Conduct field experiments to test suggestions of models

Lynita Howie & Grower Survey Results

Eretmocerus hayati - the Whitefly parasitoid

CSIRO. Whitefly Management Practices

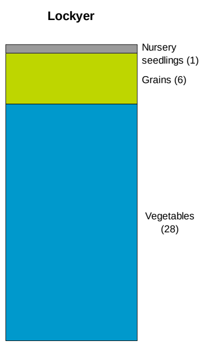
The Survey

CSIRO. Whitefly Management Practices

Who was surveyed?

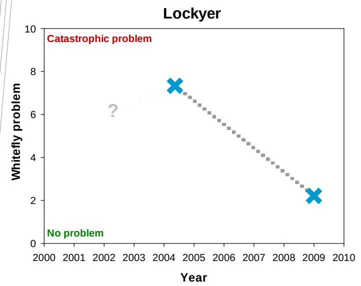
Growing Region	Number of Grower Respondents
Lockyer Valley	35
Bundaberg	20
Burdekin Region	13

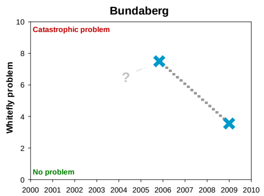
Industry Focus

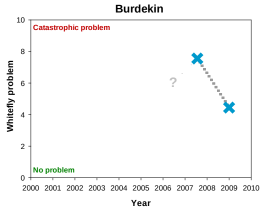


The Whitefly Problem

Whitefly Problem – The worst year







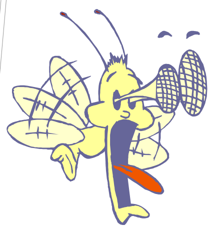
Whitefly Problem – What's around the farm?

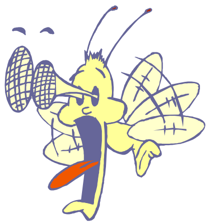
Cane: whitefly problems are worse if neighbours grow cane
➔ too many weeds in cane that harbour whitefly?

Food plants for beneficials (nectar): whitefly is less of a problem for growers that grow food plants
➔ a resource for *hayati*?

Orchards: whitefly is less of a problem if an orchard is nearby
➔ provide a refuge for *hayati*?

Managing the Whitefly problem





Decision making - Information growers use

Lockyer
1. Consultant recommendation
2. Nothing
3. Monitoring adult whitefly

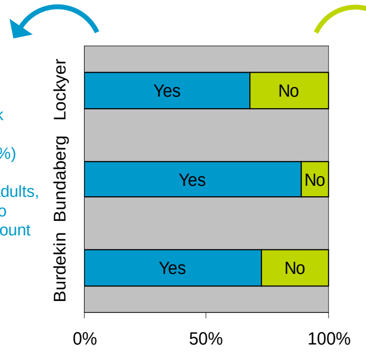
Bundaberg
1. Monitoring adult whitefly
2. Consultant recommendation
3. Just use preventative sprays

Burdekin
1. Consultant recommendation
2. Nothing

Decision making – do growers monitor whitefly?

Yes – how?

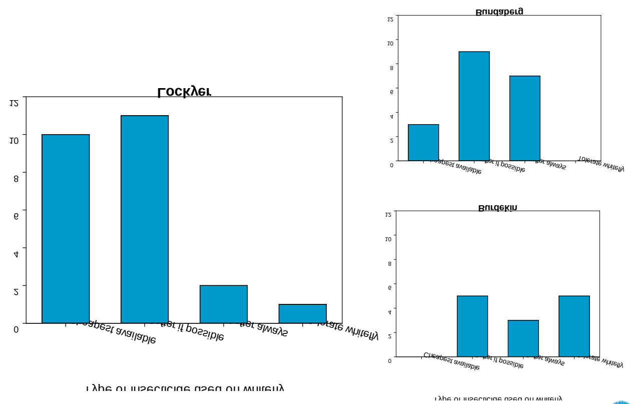
1. Quick walk looking for adults (85%)
2. Counting adults, compare to previous count (15%)



No – why not?

1. Just tolerate whitefly
2. Not really a problem
3. Control without monitoring

Insecticides for whitefly – what type?



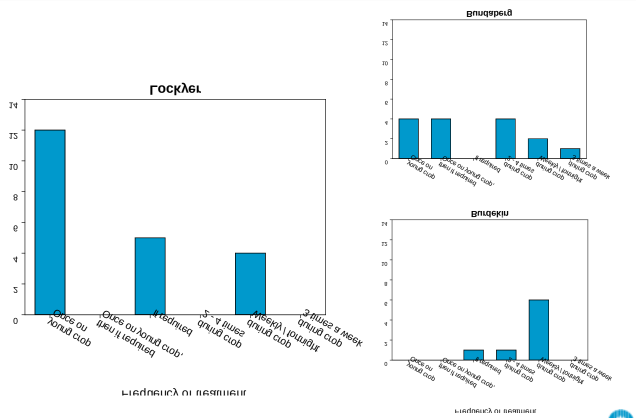
Insecticides for whitefly – what type?

Does the type of insecticide used affect the whitefly problem?

Yes: whitefly problems are worse for growers that use the cheapest insecticides

➔cheap = broad spectrum → dead Beneficials + resistance
→ more whitefly

Insecticides for whitefly – Application frequency



Insecticides for whitefly – Application frequency

Does using insecticide more often affect the whitefly problem?

Yes: The more frequently insectide is used the worse the whitefly problem.

Other ways of managing whitefly - Lockyer

Practices

1. Farm hygiene (60%)
2. Provide refuges for Beneficials (50%)
3. Avoid peak whitefly season (30%)

Making changes

1. Strategic planting to avoid build up and spread of whitefly (40%)
2. Using softer insecticides (30%)

Other ways of managing whitefly

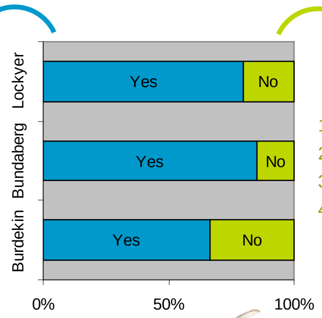
What actions can reduce the whitefly problem?

Growers that plant strategically have less whitefly problems

Do growers encourage Beneficials?

Yes - how?

1. Choose softer chemicals
2. Spray less often
3. Maintain native vegetation
4. Leave some areas unsprayed



No - why not?

1. Not helpful
2. Too expensive
3. Not possible
4. Don't bother

Encouraging *hayati*

Would growers make changes to encourage *hayati*?

1. Yes – because it will be better in the long run (30%)
2. Yes – to reduce insecticide resistance (30%)
3. No – because I already do enough (20%)

In a nutshell – for researchers

What changes could improve *hayati* effectiveness

- Reduce use of cheap broad spectrum insecticides
- Increase the refuges available for Beneficials
- Demonstrate that *hayati* can provide immediate benefits in whitefly control

In a nutshell – for growers

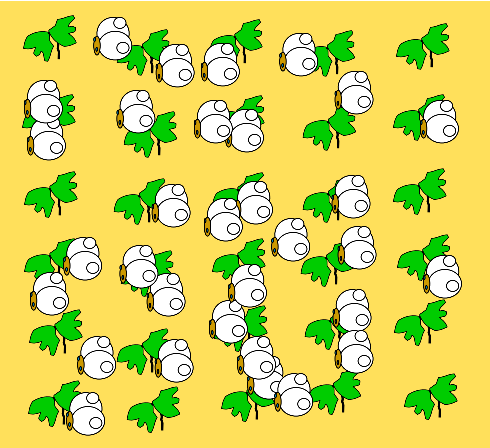
Ways to improve the whitefly problem

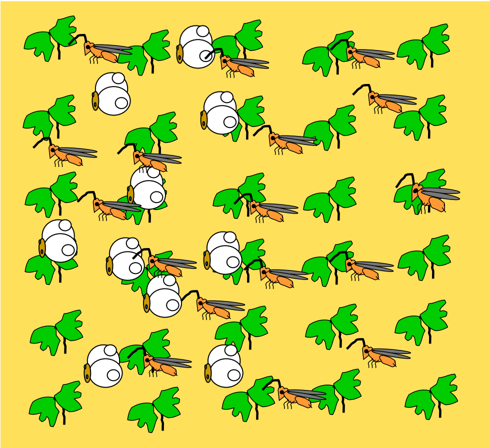
- Where possible use softer insecticides
  → fewer whitefly problems
- Use insecticides wisely not frequently
  → fewer whitefly problems
- Planting strategically
  → fewer whitefly problems

Encouraging *hayati* – Do you?

Can we capture their free services?

CSIRO. Whitefly Management Practices





Getting the most from Hayati

What role can crop rotation play?

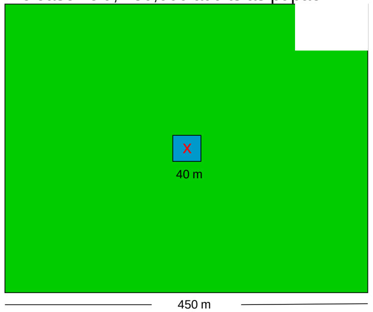
Facts about hayati

Highly mobile

- Disperses 0.7 – 1.0km per day
- Move locally by flying, and further by the wind

Establishment & spread

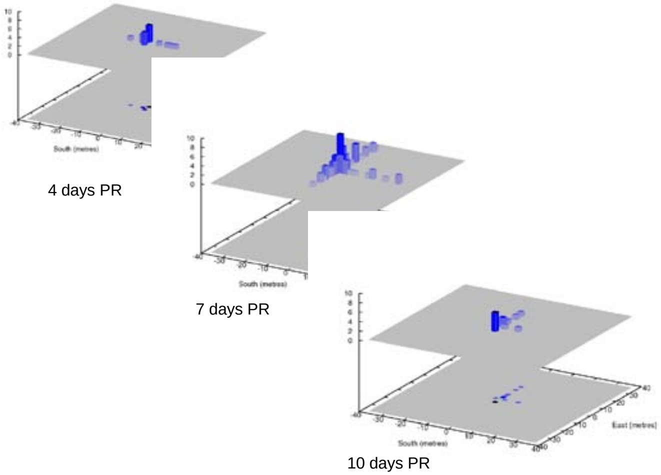
Release field; 130,000 adults as pupae



1 Scale:
10s of meters

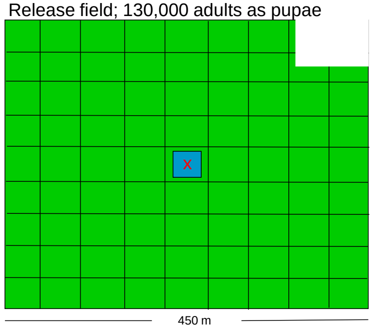
Kristensen, Schellhorn & DeBarro *PLoS One* (in review)

Local Scale – 10s of meters



Establishment & spread

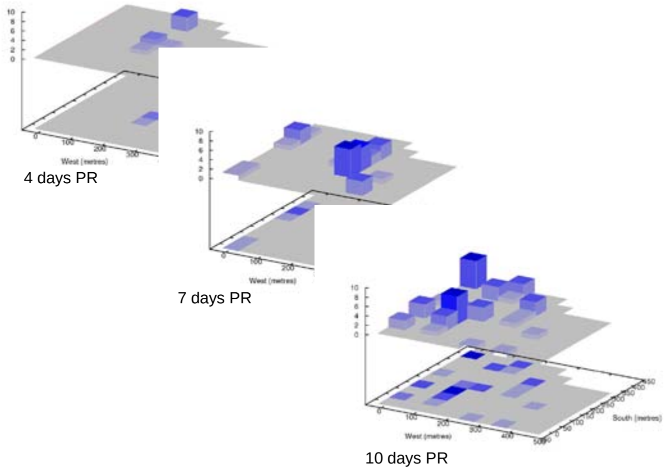
Release field; 130,000 adults as pupae



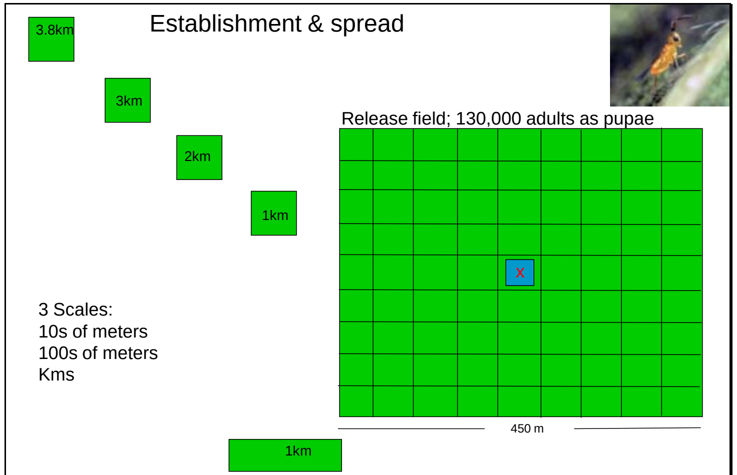
2 Scales:
10s of meters
100s of meters

Kristensen, Schellhorn & DeBarro *PLoS One* (in review)

Field Scale – 100s of meters



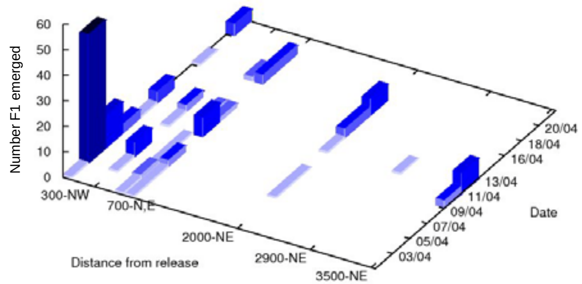
Establishment & spread

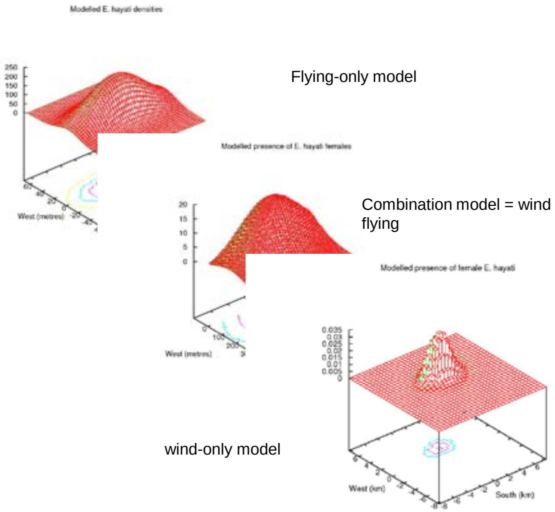


3 Scales:
10s of meters
100s of meters
Kms

Kristensen, Schellhorn & DeBarro *PLoS One* (in review)

Landscape Scale – kilometers





Facts about *hayati*

Highly mobile
•Disperses 0.7 – 1.0km per day
•Move locally by flying, and further by the wind

Quickly colonize newly planted fields
•1-3 days after SLW hosts are present

Highly fecund and long-lived
•Each female produces 228 offspring
•Lives ca. 20 days

Getting the most from Hayati

What role can crop rotation play?

Host Plants of silverleaf whitefly

Love it	Like it a lot	Like it a little	Don't like it
			
High suitability	Medium suitability	Low suitability	Unsuitable
Rock Melon Pumpkin Sunflower Soybean Cotton Tomato	Cabbage Cauliflower Eggplant Watermelon Honeydew melon English potato Cucumber	Silverbeet Lucerne Green beans Beetroot Lettuce Sweet Potato Capsicum Zucchini Lab lab	Sorghum Sugar cane Corn Carrot Onions / Shallots
Weeds: Dandilions Thistles	Weeds: Lantana Morning glories		Natives: Native plants She Oaks

Getting the most from Hayati – when you grow crops that SLW likes

Some scenarios that we tested include:

1. All growers in your area do the same crop rotation strategy
   - -eg. Lockyer Valley -Brassica vegetables in winter; pumpkins in summer
   - -eg. Burdekin – Pumpkins in late winter; tomatoes in summer

2. Half of growers in your area do one thing, the other half do another rotation strategy

The Fieldwork

CSIRO.

What we did

Spring 2011

Sampled at nine properties from Lowood to Tenthill
7 trips, two weeks apart (August – November)

1. Collected leaves with whitefly nymphs and checked for parasitism

2. Placed seedlings in the field for 3 days
   - ½ were clean ie. no whitefly nymphs and checked for whitefly
   - ½ were infested with whitefly nymphs and checked for parasitism

CSIRO.

What we did

Autumn 2012

Sampled at nine properties from Lowood to Tenthill
3 trips, two weeks apart (April – May)

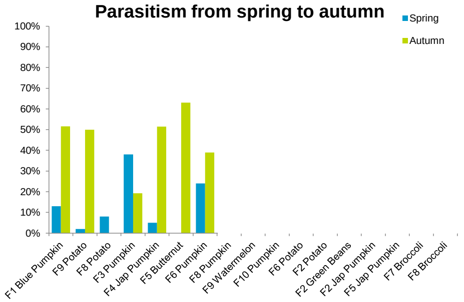
8 properties the same, 1 new property

1. Collected leaves with whitefly nymphs and checked for parasitism

CSIRO.

What we found

- Parasitism was very very low in Spring
- Parasitism built up over the summer to good numbers in Autumn



CSIRO.

Results 1 – Growers in your area do similar rotations

Without *hayati* SLW populations are 100 fold higher

	Low - Medium suitability	High suitability
Rotation ex. 1	Brassica vegs. / Sweet potato	Pumpkin

Very low suitability crops, eg. capsicum, are only marginally better than rotating with zero suitability crops

	zero suitability	High suitability
Rotation ex. 2	Fallow	Pumpkin

If you avoid insecticides that harm *hayati* **AND** you have *hayati* around (on-farm)

Results scenario 2 – Half of the growers do a similar rotation, half do something very different

Crop diversification of SLW suitability is the most promising tool for area-wide management of SLW

Your neighbours Ex. 1	Medium suitability: Brassica vegetables	Medium suitability: English potatoes
Your farm	Low suitability: Zucchini	High suitability: Pumpkin
Your neighbours Ex. 2	Zero / Very low suitability: Fallow / lettuce	High suitability: Pumpkin

Field Guide

Field Guide

Flyer feedback

- Mistakes?
- Changes?
- Extra Information?

CSIRO

Thank You & Acknowledgements

- Felix Bianchi
- Paul DeBarro
- Anne Bourne
- The Spatial Ecology Team

- **Vegetable Levy payers!!!**

Queensland Government

HAL

Appendix IV

Poster that will be presented at the Entomological Society of America Annual Meeting in Tennessee, USA in November 2012.

Getting the most out of *Eretmocerus hayati*

An introduced parasitoid to control *Bemisia tabaci* (MEAM1) in Australia

Lynita J Howie[1], Felix JJA Bianchi[2], Paul J DeBarro[1] and Nancy A Schellhorn[1], [1]Ecosystem Sciences, Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia, [2]Centre for Crop Systems Analysis, Wageningen University, Netherlands

CSIRO ECOSYSTEM SCIENCES
www.csiro.au

By getting the most out of *E. hayati* we can prevent food losses caused by silverleaf whitefly (SLW) *B. tabaci* (MEAM1), delay the development of insecticide resistance, and reduce the amount of active insecticide entering the environment.

1. Are we already getting the most out of *E. hayati*?

We surveyed 90 growers and consultants in three growing regions of Australia about their SLW management practices to determine the environmental challenges faced by *E. hayati*. We asked questions like, "how bad is your SLW problem?", "how often and what do you spray for SLW?", and "what land use surrounds your property?". We were able to associate their practices with SLW problems.

We found:

- Insecticides harmful to *E. hayati* are commonly used
- Fewer SLW problems are experienced when orchards or plants grown for beneficial insects are nearby
- Greater SLW problems are associated with adjacent sugarcane – probably due to weedy field margins that may support SLW populations

2. Can we get more out of *E. hayati*? A model perspective.

We used a spatially explicit simulation model to explore *E. hayati* impact on SLW, taking into account the surrounding land use, seasonal changes in crop rotations and crop susceptibility to SLW.

The model shows:

- Parasitism by *E. hayati* can potentially result in a 100 fold decrease in SLW density
- The earlier *E. hayati* arrives, the lower the crop damage from SLW
- The rotation of crops that act as SLW hosts can alter the impact of *E. hayati*

For example, planting a crop slightly susceptible to SLW before planting a crop highly susceptible to SLW can result in more *E. hayati* in the target crop and better SLW control (see Figure 1).

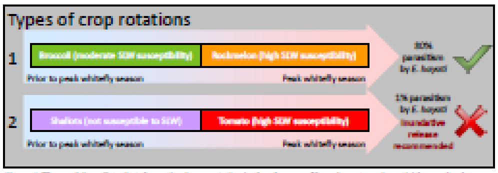


Figure 1: The model predicts that the optimal crop rotation in the absence of broad spectrum insecticides can lead to very good control of SLW by *E. hayati*.


Figure 2: Silverleaf whitefly – the pest that arrived in Australia in 1994 [left]. *Eretmocerus hayati* – the parasitoid introduced to Australia in 2004 to control SLW [right].

3. What other knowledge will help us get the most out of *E. hayati*?

Dispersal and spread of *E. hayati*[a]

- *E. hayati* can travel 1000m/day
- *E. hayati* will fly short distances but uses wind to move long distances – shown by fitting models to our field and weather data

Consequently, *E. hayati* can disperse quickly into SLW infested crops.

Reproductive ability of *E. hayati*[b]

- *E. hayati* adults live for about 20 days
- *E. hayati* females produce up to 230 offspring

Therefore, *E. hayati* can potentially be a very effective control agent.

How do we get the most out of *E. hayati*?

1. Determine if *E. hayati* is present in SLW susceptible crops. If not conduct an inundative release prior to the peak whitefly season.
2. Plant a slightly to moderately susceptible crop prior to the peak whitefly season.
3. Keep broad-leaf weeds to a minimum – eg. Weedy borders in cane.
4. Identify nearby refuges for *E. hayati* or plant a slightly susceptible SLW crop nearby.
5. Monitor SLW numbers and spray only when necessary.
6. Avoid insecticides that harm *E. hayati*.

FOR FURTHER INFORMATION
Lynita Howie
e lynita.howie@csiro.au
w www.csiro.au/Organisation-Structure/Divisions/Ecosystem-Sciences.aspx

REFERENCES
[a]Kristensen NP, De Barro PJ & Schellhorn NA (2012 in review). The initial dispersal and spread of an invader at three spatial scales. *PLoS ONE*
[b]Villanueva-Jimenez JA, Schellhorn NA & De Barro PJ (2012 in press). Comparison between two species of *Eretmocerus* (Hymenoptera: Aphelinidae): Reproductive performance is one explanation for more effective control in the field. *Biological Control*

ACKNOWLEDGEMENTS
The project was funded by Horticulture Australia from the vegetable industry levy and matched funds from the Australian Government. We would like to thank David Carey from DAFF Qld and many grower collaborators.