Know-how for Horticulture™

Improved management strategies for silverleaf whitefly in vegetable crops

Dr Paul De Barro
CSIRO Entomology

Project Number: VX02016

VX02016

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

The research contained in this report was funded by Horticulture Australia Ltd with the financial support of Growcom, Sumitomo Chemical Australia Pty Ltd and the vegetable industry.

ISBN 0 7341 1235 1

Published and distributed by:
Horticulture Australia Ltd
Level 1
50 Carrington Street
Sydney NSW 2000
Telephone: (02) 8295 2300
Fax: (02) 8295 2399
E-Mail: horticulture@horticulture.com.au

Know-how for Horticulture™

Improved Management Strategies for Silverleaf Whitefly in Vegetables

Dr Paul De Barro, CSIRO Entomology
Dr Siva Subramaniam, DPIF, Queensland
Dr Marc Coombs, CSIRO Entomology
Mr Iain Kay, DPIF, Queensland
Ms Sue Heisswolf, DPIF, Queensland

Project Number: VX02016

HAL Project Number: VX02016

Project Leader's Name: Dr Paul De Barro

Mailing Address: CSIRO Entomology, 120 Meier Road, Indooroopilly, QLD 4068
Ph: 07 3214 2811
Fax: 07 3214 2885
Mobile: 043 903 2863

Funding was provided through HAL, QFVG/ Growcom, Sumitomo Chemical

A list of other key personnel

Dr Siva Subramaniam, DPIF, Bowen
Dr Marc Coombs, CSIRO Entomology, Brisbane
Mr Iain Kay, DPIF
Ms Shama Khan, CSIRO Entomology
Ms Veronica Brancatini, CSIRO Entomology
Dr Marc Coombs, CSIRO Entomology
Ms Sue Heisswolf, DPIF

Date of report: 31 December 2005

Table of Contents

MEDIA SUMMARY

CSIRO Entomology identified the need to introduce an effective parasitoid of silverleaf whitefly after determining that existing parasitoids were less effective than required to contribute significantly to management. Based on joint research with the USDA, they decided to import *Eretmocerus hayati* as it had been used successfully against SLW in the Lower Rio Grande Valley in south Texas, an area very similar climatically to coastal and Central Highland areas of Queensland.

Host range studies for *E. hayati* showed *E. hayati* posed no significant threat to non-target species. Based on these results the Australian Government Departments of Environment and Heritage, and Agriculture, Fisheries and Forestry (AQIS) granted permission for the release of *E. hayati*.

Releases of *E. hayati* commenced in late October 2004 and continued through until May 2005 in selected cropping areas in Queensland. Approximately 617,000 parasitoids were released with breeding populations becoming established at sites in the Lockyer, Bundaberg/Childers and Emerald areas. Field surveys have indicated that *E. hayati* is highly dispersive and able to locate and parasitise SLW over a wide range of crop and non-crop hosts. The status of populations in the Bowen and Ayr regions remain undetermined.

DPIF has shown that all imidacloprid soil treatments resulted in significant decreases in SLW in tomato, zucchini, eggplant and melon. In general application of imidalcoprid as a plant hole drench delivered the best control in terms of reduced whitefly numbers and increased quantities of marketable fruit. Control of SLW in capsicum was regarded as unnecessary as first instars rarely survived beyond this stage. Four different insecticide management regimes, imidalcoprid (Confidor) as a plant hole drench, pyriproxyfen (Admiral) early in the crop life, pyriproxyfen (Admiral) late in the crop life, and a standard treatment (bifenthrin, imidacloprid, D-C-Tron) were evaluated in controlling SLW on melons. Imidalcoprid as a plant hole drench provided the best control giving approximately five weeks protection. The other treatments provided reasonable control, although Admiral applied early provided poor control late in the crop's life. Bifenthrin gave little control of adults. There were no differences between treatments in measures of fruit number, weight or brix.

TECHNICAL SUMMARY

Biological control of silverleaf whitefly

The silverleaf whitefly (SLW), *Bemisia tabaci* biotype B (Hemiptera: Aleyrodidae), was first detected in Australia in October 1994. It is a major pest of cotton, vegetables and soybeans. SLW feeding can cause stunted growth, defoliation and poor yields. In some hosts, feeding can induce physiological disorders such as squash silverleaf, uneven ripening in tomatoes, white stem in broccoli and light root in carrots. They also secrete large quantities of very sticky honeydew. Sooty mould, which grows on honeydew, necessitates the costly washing of produce and reduces plant growth rates. A range of geminiviruses can be transmitted by SLW. The main one occurring in Australia is Australian tomato leaf curl virus which can cause severe losses in tomatoes.

While a range of pesticide and non-pesticide management strategies exist that contribute to the control of SLW, there is still a heavy reliance on the use of effective pesticides. The capacity of SLW to develop insecticide resistance makes reliance on chemical control unsustainable in the long term. The use of natural enemies is considered one of the main ways to effectively manage SLW and the introduction of exotic parasitoids as part of biological programs has proved successful in parts of the USA. In these places the agents have considerably reduced the impact of SLW. CSIRO Entomology identified the need to introduce effective natural enemies after determining that existing parasitoids were less effective than required to contribute significantly to management. Based on some joint research with the USDA, they decided to concentrate on the wasp *Eretmocerus hayati*, originally from Pakistan, and which has been used successfully against SLW in the Lower Rio Grande Valley in south Texas. This is an area very similar climatically to coastal and Central Highland areas of Queensland. In the Lower Rio Grande Valley, the numbers of SLW have been reduced to a level where they are readily managed by existing programs.

Host range studies for *E. hayati* undertaken at the CSIRO Long Pocket Laboratories Brisbane, have shown *E. hayati* to be able to complete development in the target pest *Bemisia tabaci* and to a lesser extent the closely related Australian native whitefly *Lipaleyrodes atriplex*. In no-choice tests, *E. hayati* regularly parasitised up to 98% of available *B. tabaci* nymphs, whereas parasitism of *L. atriplex* averaged only 6-16%. The presence of fringing wax and exuvial stacks on *L. atriplex* nymphs were thought to have a negative influence on parasitoid success. *Bemisia tabaci* nymphs do not possess these characters. Sixteen other species of whiteflies, representing a further 11 genera were tested. None were found to support development of the parasitoid. On the basis of these results, all other species of whitefly in Australia were predicted to be non-hosts. *Eretmocerus hayati* was amended to the list of species suitable for live import by the Minister for Environment and Heritage on the 14 August 2004.

Facilities were developed at the CSIRO Long Pocket Laboratories Brisbane, for mass rearing *E hayati*. These included areas for hibiscus cultivation (whitefly host), a whitefly insectary, an *E. hayati* insectary; a soybean seedling nursery (release plants), and controlled environment insect rearing rooms dedicated to whitefly infestation of soybean seedlings, parasite inoculation of early instar whitefly nymphs, and development of parasitoid larvae to the pupal stage prior to field release. All releases occurred as either as parasitoid pupae attached to host plants (soybeans) or direct release of adult parasitoids.

Releases of *E. hayati* commenced in late October 2004 and continued through until May 2005 in selected cropping areas in Queensland. Approximately 617,000 parasitoids were released with breeding populations becoming established at sites in the Lockyer, Childers, Bundaberg and Emerald areas. The status of *E. hayati* released in the Bowen and Ayr regions remains undetermined. Field surveys have indicated that *E. hayati* is highly dispersive and able to locate and parasitise SLW over a range of crop and non-crop hosts. At establishment sites near Bundaberg and Childers parasitism ranged from 25-89 % on melon. At sites near Emerald, parasitism ranged from 11-16 % on sunflowers and at Gatton 46% parasitism was observed on weed hosts. These levels of impact occurred within 1-2 generations (3-6 weeks) of being released indicating that the parasitoid readily establishes and is able to exert a moderate level of control within a short time.

The long term effectiveness of *E. hayati* as a biological control agent for silver leaf whitefly will depend on its ability to further disperse and locate *B. tabaci* populations. Persistence through the winter months and its ability to locate whiteflies at low densities will be critical in reducing the build up of whitefly populations in spring.

Effectiveness of Confidor® soil application methods against silverleaf whitefly on tomato

All imidacloprid soil treatments resulted in a significant decrease in the survival of adult and immature stages on plants. PHD (plant hole drench) treatment had significantly fewer SLW immature stages and adults at most sampling dates, and nymph numbers were well below the damage threshold level until harvest. PHD treatment gave long and effective residual control against colonising adults for up to 47 days. The FS (furrow spray) and TI (trickle injection) treatments provided only limited control against SLW stages until early fruiting stage (4 to 5 weeks). The untreated control plots had very high numbers of adults, eggs and nymphs compared with the imidacloprid treatments.

The mean percentage of fruits with external irregular ripening was significantly lower in the PHD, FS and TI treatments than in the untreated control plots. Only the PHD application provided high protection from internal fruit damage and yielded a high percentage of marketable fruit.

This study also suggests that achieving best whitefly control also depends on an efficient application technique to deliver the product within the root zone.

Effectiveness of Confidor® soil application methods against silverleaf whitefly on zucchini

Three imidacloprid (Confidor SC 200) soil application methods - furrow spray (FS), plant-hole-drench (PHD) and trickle injection (TI) - were evaluated for control of silverleaf whitefly (*Bemisia tabaci* Biotype B) on zucchini. All three treatments delivered a single soil application of imidacloprid at 5g ai/100 m row at transplanting. Systematic leaf and suction sampling to assess the egg, nymph and adult stages were undertaken every 14-day within treatments and control plots from planting to harvest. The effect of treatments on leaf silvering, fruit quality and marketable yield was also evaluated at harvest.

All three imidacloprid soil treatments had significantly fewer adults than untreated controls at most sampling dates, and provided residual control against whitefly adults for up to 48 days. All imidacloprid treatments resulted in fewer nymphs than on the control on the first three sampling dates. However, there were no significant differences in nymph numbers between treatments and control on the fourth sampling date (47 DAP). On most sampling dates, no significant differences in number of either adults or nymphs were observed between imidacloprid application methods.

PHD and FS treatments resulted in a lower level of silvery symptoms on leaves than TI and untreated control, although no treatment eliminated the silverleaf symptoms. The marketable fruits and yield were much higher in the imidacloprid treatments than in the untreated control.

Effectiveness of Confidor® soil application methods against silverleaf whitefly on eggplant

Three imidacloprid (Confidor SC 200) soil application methods, furrow spray (FS), plant-hole-drench (PHD) and trickle injection (TI), were evaluated for control of silverleaf whitefly (*Bemisia tabaci* Biotype B) on eggplant. All three treatments delivered a single soil application of imidacloprid at 5 g ai/ 100 m row at transplanting. Leaf and suction sampling to assess the egg, nymph and adult stages were undertaken within treatments and control plots from planting to harvest.

All imidacloprid soil treatments resulted in a reduction in the survival of adult and immature stages on plants. PHD and FS treated plants had significantly lower number of eggs than TI and untreated plants at early sampling dates. PHD treatment had significantly lower number of nymphs and adults at most sampling dates, and provided high level of protection for up to 7 weeks.

The FS treatments provided only limited control against SLW stages until flowering stage (5 weeks). TI treatment did not significantly reduce the nymph and adult numbers at second sampling date (22 DAP) but a significant reduction was recorded at third sampling dates. The control plots had very high numbers of adults, eggs and nymphs compared with the imidacloprid treatments.

This study also suggests that achieving best whitefly control also depends on an efficient application technique to deliver the product within the root zone.

Effectiveness of Confidor® soil application methods against silverleaf whitefly on capsicum

Three imidacloprid (Confidor SC 200) soil application methods, furrow spray (FS), plant-hole-drench (PHD) and trickle injection (TI), were evaluated for control of silverleaf whitefly (*Bemisia tabaci* Biotype B) on capsicum. All three treatments delivered a single soil application of imidacloprid at 5g ai/100 m row at transplanting. Systematic leaf and suction sampling to assess the egg, nymph and adult stages were undertaken within treatments and control plots from planting to harvest.

No significant differences in adult numbers were observed between treatments at all sampling dates. There were no significance differences in egg and nymph densities found among the treatments at the first four sampling dates. At final sampling date (67DAP), the mean egg and small nymph densities on PHD and FS treated plants were lower than untreated control. The treatment effects were not clearly expressed in this experiment due to lack of SLW establishment in the crop.

Only the first instar nymphs were recorded on the leaves at all sampling dates. No nymph development past the first instar was observed on capsicum leaves throughout the trial period.

Evaluating insecticide strategies against silverleaf whitefly on melons

Four insecticide strategies, Confidor (imidacloprid) as a plant hole drench, Admiral (pyriproxyfen) early in the crop life, Admiral late in the crop life, and a Standard (bifenthrin, imidacloprid, D-C-Tron) were evaluated in controlling silverleaf whitefly on rockmelons in a trial at Bundaberg in 2004.

In general, the plant hole drench treatment provided the best control of silverleaf whitefly as measured by adult, egg and nymph numbers on leaves, giving approximately five weeks protection. The other treatments appeared to provide reasonable control, although Admiral Early did poorly late in the crop. Bifenthrin gave little control of adults. There were no differences between treatments in measures of fruit yield (number and weight) or quality (Brix values).

Evaluation of insecticide strategies against silverleaf whitefly on tomatoes

The IGR pyriproxyfen and pymetrozine, in rotation with bifenthrin, petroleum oil and soap provided high levels of whitefly control and high quality marketable fruit. These new chemistries are less harmful to beneficial species. The products are an appropriate choice to encourage the establishment of beneficial species early in the life of a crop. The highly disruptive pyrethroid and similar products should be avoided or used late in the crop as part of a clean up strategy. Imidacloprid foliar application has the limited potential for SLW management in tomatoes. However, approval for soil application of imidacloprid has recently been granted for SLW in some vegetables crops.

INTRODUCTION

This project follows VG99003. The project sought to deliver the following outcomes,

1) Improved IPM systems for key vegetable crops with subsequent improved quality and marketability of produce.
2) Increased benefits through efficient pesticide use and use of softer pesticides.
3) Environmental benefits through efficient pesticide use and the use of softer pesticides.
4) Long term sustainable management of SLW in vegetable crops.

To achieve these outcomes the research followed to two directions. The first was to seek to introduce and establish a more effective parasitoid of SLW as a biological control agent. The second was to seek registration or permitting of effective insecticides and to develop methods of utilising these pesticides in a manner that offered to reduce their impact on beneficial species while at the same time delivering effective control of SLW.

To achieve effective biological control, the research focused on the assessment and release of the SLW parasitoid, *Eretmocerus hayati*. The improved insecticide component focused on developing and evaluating effective insecticide use regimes for capsicum, eggplant, melons, tomato and zucchini. The report is divided into nine sections each of which focuses on a particular project activity.

Within the framework of the Best Management Guide, the added combination of an effective natural enemy with insecticide use regimes that focused either on insecticides with limited negative impacts on beneficials or delivery methods that reduced their harmful effects offered the best prospects of efficient pesticide use, long term sustainability and reduced negative environmental impacts.

Section 1

Biological Control of Silverleaf Whitefly

Biological Control of Silverleaf Whitefly

Introduction

The silverleaf whitefly, *Bemisia tabaci* (Gennadius) biotype B (Hemiptera: Aleyrodidae: Aleyrodinae) is a recent introduction to Australia being first detected in October 1994. It is a severe pest of ornamental nursery, vegetable and cotton production. In Australia, damage is caused by: (1) direct feeding which may induce irreversible physiological disorders and yield decline and (2) contamination with honeydew and sooty mould. In 2000 pest outbreaks in the coastal vegetable production areas from northern NSW to the Burdekin led to more than $6 million of additional pesticide applications while in the 2001/2002 season in excess of $3 million dollars of additional pesticides were applied to cotton crops in the Central Highlands of Queensland. Further, the risk to cotton quality through "sticky cotton" could see Australian cotton losing the premium it currently receives for quality.

Currently, the only means of attempting to control this pest is through the use of insecticides. However, resistance has reduced the efficacy of most registered products and the ability of the insect to become resistant makes an insecticide based management strategy unsustainable. The use of natural enemies is considered one of the main ways to effectively manage SLW and the introduction of exotic parasitoids as part of biological programs has proved successful in parts of the USA. In these places the agents have considerably reduced the impact of SLW. This research project concentrated on the wasp *Eretmocerus hayati* Rose and Zolnerowich, originally from Pakistan, and which has been used successfully against SLW in the Lower Rio Grande Valley in south Texas (Goolsby *et al*. 2005). This is an area very similar climatically to coastal and Central Highland areas of Queensland. In the Lower Rio Grande Valley, the numbers of SLW have been reduced to a level where they are readily managed by existing programs.

All *Eretmocerus* are parasitoids of the family Aleyrodidae, subfamily Aleyrodinae. There are 13 described species from the New World and 32 from the Old World (Zolnerowich & Rose, 1998; De Barro *et. al*. 2000a). Zolnerowich & Rose (1998), Rose & Zolnerowich (1997) and De Barro *et al.* (2000a) have shown that *E. hayati* belongs to a subgroup of Old World *B. tabaci* specialists that also contains *E. emiratus*, *E. melanoscutus*, *E. mundus*, *E.* nr *emiratus*. *Eretmocerus mundus* has been recorded from Australia (Gerling 1972; De Barro *et al*. 2000a), but is parthenogenetic. It has been found parasitising *B. tabaci* and *Lipaleyrodes atriplex*.

Eretmocerus hayati is a tiny wasp less than 1mm in length. It is a biparental haplodiploid species as are the other members of this subgroup. The biology of the group is similar and is described in Goolsby et al. (1998) and De Barro et al. (2000b). The adult female lays her egg under the first, second or third instar nymph. The egg hatches and the first instar parasitoid penetrates the nymph. It stays in a quiescent state until the nymphs moult to the fourth instar at which stage the parasitoid larva arrests whitefly development. The larva consumes and pupates inside the nymph. The adult parasitoid emerges through a hole chewed in the anterior dorsal surface of the whitefly mummy. Usually only a single egg is laid under each nymph.

This study aimed to provide quarantine evaluation on the suitability of *E. hayati* as a biological control agent for *Bemisia tabaci* in Australia. Quarantine studies

Materials and Methods

Host specificity testing

Culturing of E. hayati. *Eretmocerus hayati* was imported into QC3 quarantine at the CSIRO Long Pocket Laboratories, Indooroopilly during September and October 2002 as parasitised mummies of *B. tabaci* from various locations in the western USA. Parasitoids were identified as *E. hayati* following Rose & Zolnerowich (1998). Cultures of *E. hayati* were maintained in 3.5 L. plastic containers on Hibiscus 'plants' (two plants per container). Each 'plant' consisted of a single stem and leaf rooted in agar in a 45 ml plastic tube. Each plant had previously been infested with *B. tabaci* eggs. Following egg hatch parasitoids were then added to the cage. Parasitism of *B. tabaci* by *E. hayati* typically averaged 80–98 %.

Culturing of test species. Sustained cultures of each of the test species were maintained under glasshouse conditions on appropriate host plants (potted) (see Table 1) and held in mesh screened cages. All whitefly cultures were initiated from field collected material (mostly adults). Species identifications were made using morphological characters of 4^{th} instar nymphs following Martin (1999). Voucher material for each test species are held as both slide mounted and alcohol preserved nymphs.

Host testing protocol. Eretmocerus hayati was assessed for non-target attack using paired no-choice experiments. All *E. hayati* adults were naïve (no prior egg lay) and had been cultured on *B. tabaci*/hibiscus as described above. For each test, single age cohorts of settled 1^{st} – 2^{nd} instar nymphs of a given non-target species and *B. tabaci* were exposed separately to *E. hayati* adults (n= 30 females for each replicate). Three replicates of the non-target species/host plant combination and three replicates of *B. tabaci* on hibiscus were used in each paired test. Parasitoid age was not controlled for, but approximated 2-3 days post emergence with females having been held with conspecific males to enable mating. In each experiment, parasitoids remained with the test species for the duration of their (parasitoids) lifespan. All tests were carried out in mesh screened cages. Parasitism rates were assessed by recording either numbers of parasitised nymphs per leaf (n=3 per replicate) for small leaved (<3 cm in length) host plants or as number parasitised per 2.27 cm leaf disk. Development of *E. hayati* could be discerned directly through the host cuticle for pale bodied whiteflies. For dark bodied whiteflies, nymphs were allowed to develop either to emergence of the adult whitefly or the adult parasitoid, which ever occurred soonest. All observations were made using a stereo dissecting microscope.

The species originally identified for host specificity testing were;

Lipaleyrodes atriplex (Froggatt) (syn., *B*. nr *tabaci*, *B. capitata*).
Lipaleyrodes euphorbiae David & Subr..
Bemisia afer (Priesner & Hosny)
Bemisia giffardi (Kotinsky)
Bemisia gigantia Martin
Bemisia decipiens (Maskell)
Bemisia subdecipiens Martin

To further delineate the host range the following whitefly species were also tested;

Aleurocanthus spiniferus (Quaintance)
Aleuroplatus n. sp. (ex *Syzigium paniculatum*, Brisbane, Indooroopilly)

Aleyrodes proletella (Linn.)
Dialeurodes citri (Ashmead)
Dialeurodes n. sp.(ex *Hymenosporum flavum*, Brisbane, Brookfield)
Dialeuropora decempuncta (Quaintance & Baker)
Dumbletoniella eucalypti (Dumbleton)
Orchamoplatus citri (Takahashi)
Pseudaleuroplatus n. sp. (ex *Syzigium paniculatum*, Brisbane, Indooroopilly)
Trialeurodes vaporariorum (Westwood)
Viennotaleyrodes incomptus Martin
Xenaleyrodes eucalypti (Dumbleton)

As indicated above, *Bemisia decipiens* and *Bemisia subdecipiens* could not be found.

Mass rearing and dissemination of Eretmocerus hayati

Facilities developed for mass rearing of *E. hayati* comprised seven work areas; (1) a polyurethane shade house for hibiscus cultivation; (2) a dedicated glasshouse as a whitefly insectary; (3) an environment controlled insect rearing room for rearing *E. hayati* insectary; (4) a soybean seedling nursery, and (5-7) three controlled environment insect rearing rooms dedicated to whitefly infestation of soybean seedlings, parasite inoculation of early instar whitefly nymphs, and development of parasitoid larvae to the pupal stage prior to field release.

Hibiscus plant nursery. All hibiscus plants were grown from cuttings and maintained in a polyurethane shade house. Plant propagation followed standard nursery practise. Plants were grown in 15cm plastic pots utilising inorganic fertilisers, automated irrigation and premium grade potting mix. Management of associated plant pests (aphids, mealy bugs, mites) was achieved through use of beneficial insects and soap based sprays.

Whitefly cultures. All whitefly cultures were maintained on potted hibiscus plants in mesh screened cages. Individual cages were established at one week intervals to provide a continuous supply of whitefly adults.

Parasitoid culture. Adult parasitoids were maintained in mesh screened cages on hibiscus that had been previously infested with whiteflies. Eight cages were established weekly to provide sufficient adults to maintain the parasitoid stock culture and provide additional adults to parasitise whiteflies on soybean for release.

Soybean plant nursery and infestation with whitefly and E. hayati. All soybean plants were grown from seed sown individually into biodegradable 60mm Jiffy pots. Soybean seedlings were infested with whitefly adults. Adult whiteflies were enclosed on these plants for egg lay. Following hatching and settling of first instar nymphs (8-10 days after oviposition) plants were exposed to *E. hayati* adults for parasitism. Plants were held for a further 14 days to allow development of the parasitoid to the pupal stage prior to release.

Release program for Eretmocerus hayati

Releases of *E. hayati* were scheduled to occur in the Lockyer, Bundaberg, Emerald and Bowen areas on a weekly basis with any one area targeted monthly. An unexpected reduction in funds from Growcom led to the shortening of the release program which was wound down in April/May and terminated in June. In each of these areas, three release sites were chosen based on crop type and suitability for maintaining moderate to high whitefly densities (melons, pumpkin, soybean) and pest management practises (nil pesticide application). All releases were to occur as soybean infested plants. Parasitoid emergence was timed to commence within 1-2 days of plants being taken to the field. All plants were transported by CSIRO vehicle to release localities.

Post release surveys were undertaken at the immediate release sites to determine firstly, whether successful emergence of parasitoids had occurred and secondly whether successive generations of the parasitoid persisted within the target crop. Samples of leaves bearing late instar whitefly nymphs were collected from each site and returned to the laboratory to allow for parasitoid development. Whitefly numbers and the proportion parasitised were recorded per leaf. The presence of *E. hayati* was assessed by the recovery of adult males. A 60:40 female: male ratio based on laboratory observations was assumed for *E. hayati* adults in the field. The native *Eretmocerus mundus* is uniparental (all females).

Results

Host specificity testing

In paired, no-choice experiments *E. hayati* routinely parasitized 80-98% of *B. tabaci* nymphs (Table 1.1). Only one nontarget species (*Lipaleyrodes atriplex*) supported development of *E. hayati*. Parasitization of *L. atriplex* averaged 5.9% on *Rhagodia spinescens* (saltbush) and 15.6% on *Einadia trigonos* (fish weed). All parasitoids (n = 11) successfully emerged from *L. atriplex* on *Rhagodia*. However, parasitoid adults (n = 38) emerging from *L. atriplex* on *Einadia* became immobilized in the waxy coating of the parasitized nymph. Adult parasitoids were observed to groom their body repeatedly resulting in additional wax particles accumulating on their legs, wings and antennae. All adults eventually died either on the leaf surface or fell to the cage floor and died.

None of the other taxa tested supported development of *E. hayati*.

Table 1.1. Results of paired, no-choice host specificity tests for *Eretmocerus hayati* against selected Australian native or exotic whitefly and *Bemisia tabaci*.

Test species	Host Plant	Mean no. nymphs per leaf or leaf disk (± s.d.) (n=9and 9 for each pair)	Mean percent parasitism (± s.d.)
B. afer	*Breynia nivosa*	41.9 ± 14.6	0
B. tabaci	*Hibiscus rosa-sinensis*	49.0 ± 17.4	93.8 ± 7.2
B. gigantia	*Elaeocarpus angustifolius*	5.3 ± 2.3	0
B. tabaci	*Hibiscus rosa-sinensis*	32.8 ± 9.3	91.7 ± 7.2
B. giffardi	*Citrus limon*	3.4 ± 1.1	0
B. tabaci	*Hibiscus rosa-sinensis*	28.9 ± 7.1	89.9 ± 10.7
L. atriplex	*Rhagodia spinescens*	47.9 ± 31.5	5.9 ± 11.9
B. tabaci	*Hibiscus rosa-sinensis*	61.1 ± 25.8	92.6 ± 6.6
L. atriplex	*Einadia trigonos*	36.4 ± 17.3	15.6 ± 12.8
B. tabaci	*Hibiscus rosa-sinensis*	47.9 ± 10.7	89.7 ± 11.8
L. euphorbiae	*Euphorbia hirta*	19.7 ± 11.7	0
B. tabaci	*Hibiscus rosa-sinensis*	31.1 ± 10.2	80.4 ± 10.7
D. eucalypti	*Corymbia citriodora*	20.4 ± 11.0	0
B. tabaci	*Hibiscus rosa-sinensis*	34.8 ± 9.9	88.8 ± 9.7
A. spiniferus	*Cupaniopsis anacardioides*	39.3 ± 10.9	0
B. tabaci	*Hibiscus rosa-sinensis*	37.1 ± 9.1	86.9 ± 13.6
D. decempuncta	*Callistemon viminalis*	21.8 ± 11.6	0
B. tabaci	*Hibiscus rosa-sinensis*	30.3 ± 8.6	93.2 ± 8.9
D. citri	*Citrus limon*	11.3 ± 1.7	0
B. tabaci	*Hibiscus rosa-sinensis*	34.3 ± 5.9	84.2 ± 11.3
Dialeurodes sp.	*Hymenosporum flavum*	19.2 ± 6.8	0
B. tabaci	*Hibiscus rosa-sinensis*	36.4 ± 5.8	89.2 ± 10.6
T. vaporariorum	*Euphorbia peplis*	*32.3 ± 8.5*	*0*
B. tabaci	*Hibiscus rosa-sinensis*	25.4 ± 6.9	97.7 ± 3.7
A. proletella	*Brassica* spp.	39.7 ± 17.3	0
B. tabaci	*Hibiscus rosa-sinensis*	42.3 ± 6.9	92.9 ± 8.7
X. eucalypti	*Eucalyptus acmenoides*	27.1 ± 8.8	0
B. tabaci	*Hibiscus rosa-sinensis*	39.4 ± 5.8	92.2 ± 8.4
V. incomptus	*Acacia aulacocarpa*	14.9 ± 12.5	0
B. tabaci	*Hibiscus rosa-sinensis*	31.2 ± 6.9	91.3 ± 8.6
Aleuroplatus sp	*Syzigium paniculatum*	20.2 ± 2.9	0
B. tabaci	*Hibiscus rosa-sinensis*	29.1 ± 6.7	96.3 ± 4.7
Pseudoaleuroplatus sp.	*S. paniculatum*	*14.0 ± 3.5*	*0*
B. tabaci	*Hibiscus rosa-sinensis*	48.6 ± 6.6	89.6 ± 9.1
O. citri	*Citrus limon*	*24.4 ± 6.6*	*0*
B. tabaci	*Hibiscus rosa-sinensis*	39.1 ± 7.1	92.8 ± 6.9

Approval for release of *Eretmocerus hayati* as a biological control agent for *Bemisia tabaci* was granted by the Australian Government Department of Environment and Heritage and the Department of Agriculture, Fisheries and Forestry on the basis on these findings.

Mass rearing and dissemination of Eretmocerus hayati

Releases of *E. hayati* commenced in late October 2004 at localities in the Lockyer, Childers and Bundaberg regions (Table 1.2) either as direct release of adult parasitoids or as parasitoid pupae attached to host plant leaves. An estimated 617,000 parasitoids were released between October 2004 and May 2005. Establishment of the parasitoid has been monitored at selected localities with records of percent parasitism and dispersal documented at these sites.

Table 1.2. Releases of *Eretmocerus hayati* at localities in Queensland, Australia.

Date	Locality	Crop type	No released (1,000s)
29 Oct 2004	Patrick Estate	soybean	5
	Gatton	pumpkin	14
5 Nov 2004	Bundaberg	melon/zucchini	30
9-10 Nov	Patrick Estate	eggplant	5
	Gatton	pumpkin	10
17 Nov	Childers	tomato	5
	Bundaberg	melon	5
	Bundaberg	eggplant	5
24 Nov 2004	Patrick Estate	soybean	2
	Gatton	pumpkin	2
25 Nov	Helidon	tomato	5
28 Nov	Childers	tomato	2.5
	Bundaberg	melon	7
3 Dec	Helidon	tomato	10
	Grantham	pumpkin	1.5
14 Dec 2004	Bundaberg	melon	10
	Childers	melon	5
21 Dec	Helidon	tomato	40
23 Dec	Logan Village	herbs	50
2 Feb 2005	UQ Gatton	soybean	60
4 Feb	UQ Gatton	soybean	50
8 Feb	UQ Gatton	soybean	60
9 Feb	Bundaberg	soybean	10
13 Feb	Gatton	soybean	50
21 Feb	Gatton	broccoli	3
9/10 Mar	Aratula	green bean	130
17 Mar	Forest Hill	green bean	20
17 Mar	Emerald	sunflower	20
3 May 2005	Bowen	soybean	10
25 May 2005	Ayr	weeds	10

Recovery of Eretmocerus hayati *in the field*

The summary of parasitoids recovered from release sites is detailed in Table 1.3.

Table 1.3. Recovery of parasitoids from release sites in Queensland.

Locality	Site	Establishment	Crop type
Bundaberg	Windemere	+	melon
	Alloway	-	zucchini
	Fairydale	-	soybean
Childers	Foley Rd	+	melon
Lockyer	Tenthill	-	pumpkin
	Patrick Estate	-	soybean
	Fernvale Road	-	pumpkin
	Gatton	+	soybean
	Helidon	+	tomato
	Aratula	+	green bean
Emerald	Gindi	+	sunflower
	Arcturus	+	sunflower
Bowen	-	?	soybean
Ayr	-	?	weeds

Post release evaluations were completed at each of these sites. Leaf samples bearing 4th instar whitefly nymphs were collected at approximately one generation intervals from the release crop and immediate surrounding area. All samples were returned to the laboratory and held to allow development of any parasitoids. All parasites were examined under a dissecting microscope. Breeding populations of *E. hayati* were confirmed at seven of the fourteen release sites (50%).

Bundaberg

Windemere: Parasitoids were released as pupae attached to hosts planted into an area measuring 20m x 7m at one end of a melon crop. Parasitoids commenced emergence within 1-2 days of their placement in the crop. Percent parasitism was subsequently measured (3 wks later) within the release area and at increasing distances along the length of the crop. Parasitism was greatest (89%) within the immediate release area, declining to approximately 38-40 % at 20-40 m of the release point and 20 % at the opposite limit of the crop at 320 m. Ninety-eight percent of the parasitoids recovered were *E. hayati* with the remaining 2 % an unidentified *Encarsia* spp. Subsequent sampling determined that E. hayati had spread up to 1.5 km of the release site to invade sweet potato and weeds (*Euphorbia*).

Alloway: No parasitoids were recovered following the initial release

Fairydale: No parasitoids were recovered following the initial release

Lockyer Valley

Helidon: Samples of whitefly infested weeds (bell vine, milk thistle) were collected from Helidon on 6 May 2005 and yielded a sample of 147 parasitoids. Overall, percent parasitism of 4th instar nymphs was 90.7%, of which 45.8% was attributed to *E. hayati*, 37.1% to *E. mundus* and 7.8 % to *Encarsia* species.

Gatton: Percent parasitism of 4th instar *B. tabaci* nymphs on soybean averaged 13.6 % during February and March. *Eretmocerus* and *Encarsia* adults (including male *E. hayati*) were observed searching soybean plants during this period, however, the relative proportions attributed to each species were not determined.

Aratula: *Eretmocerus* adults (including male *E. hayati*) were observed searching green bean plants during this period, however overall parasitism and relative contribution of each species were not determined.

Tenthill: No parasitoids were recovered following the initial release.

Patrick Estate: No parasitoids were recovered following the initial release.

Fernvale Road: No parasitoids were recovered following the initial release.

Childers

Foley Road: Weed samples (milk thistle) collected on 20 Jan 2005 yielded a sample of 191 parasitoids. Overall, percent parasitism was 43.8%, of which 7.6 % was attributed to *E. hayati* and 36.2 % to *E. mundus*

Foley Road: Collections of melon leaves infested with 4th instar *B. tabaci* nymphs (n=20) on 18 April 2005 yielded a sample of 563 parasitoids. Overall, percent parasitism was 90.0 % of which 31.1 % was attributed to *E. hayati*, 54.6 % was attributed to *E. mundus*, and 4.1 % to *Encarsia* species.

Emerald

Gindi: Collections of sunflower leaves infested with 4th instar *B. tabaci* nymphs (n=20) from Gindi on 13 April 2005 yielded a sample of 282 parasitoids. Overall, percent parasitism was 56.5% of which 11.5% was attributed to *E. hayati*, 31.5 % was attributed to *E. mundus*, and 13.5 % to *Encarsia* spp.

Gindi: Samples collected on the 25 May 2005 from sunflower yielded a sample of 180 parasitoids. Overall, percent parasitism of 4th instar nymphs (n=425) was 78.3 %, of which 16.0 % was attributed to *E. hayati*, 51.1 % to *E. mundus* and 10.9 % to *Encarsia* spp.

Arcturus: Collection of sunflower leaves infested with 4th instar *B. tabaci* nymphs (n=20) from Arcturus on 13 April 2005 yielded a sample of 61 parasitoids. Overall, percent parasitism was 50.4% of which 8.3 % was attributed to *E. hayati*, 19.0 % was attributed to *E. mundus*, and 23.1 % to an *Encarsia* spp.

Bowen

No post-release evaluation was undertaken in the Bowen region.

Ayr

No post-release evaluation was undertaken in the Ayr region

Discussion

Host specificity tests showed *E. hayati* to be narrowly specific to the target pest *B. tabaci* and the closely related native whitefly *L. atriplex*.

Physical attributes (presence of was and exuvial stacks) of *L. atriplex* nymphs were considered to negatively influence its suitability as a host for *E. hayati*. All other species of whitefly in Australia are predicted to be non-hosts. Field records of *E. hayati* in the USA show no non-target attack (K.A. Hoelmer unpublished data).

Laboratory testing has further shown that a range of other pest species of whiteflies present in Australia (viz. *Bemisia giffardi*, *Trialeurodes vaporariorum*, *Aleyrodes proletella* and *Lipaleyrodes euphorbiae*) were all non-hosts. Approval was granted On the basis of this, the risk to non-target whitefly in Australia was considered extremely low.

Preliminary results are promising. *Eretmocerus hayati* establishes readily. In all there was less than 7 months available to release the parasitoid. Further, there has been insufficient time to evaluate the releases. At this stage the parasitoid is showing promise, but how well it will eventually establish and how grower practice needs to be modified in order to enable them to make the best use of the parasitoid has yet to be developed. It is possible that a landscape approach to managing a region will enable parasitoids to persist more effectively and so effect earlier control of whitefly numbers.

References

De Barro PJ, Driver F, Naumann ID, Clarke GM, Schmidt S, Curran J (2000a). Descriptions of three species of *Eretmocerus* Haldeman (Hymenoptera: Aphelinidae) parasitising *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae) and *Trialeurodes vaporariorum* (Westwood) (Hemiptera: Aleyrodidae) in Australia based on morphological and molecular data. *Australian Journal of Entomology* 39, 259-269.

De Barro PJ, Hart PJ, Morton R (2000b) The biology of two *Eretmocerus* spp. (Haldeman) and three *Encarsia* spp. Forster and their potential as biological control agents of *Bemisia tabaci* biotype B in Australia. *Entomologia experimentalis et applicata* 94, 93-102.
Gerling (1972)

Goolsby, J.A., Ciomperlik, M.A., Legaspi, B.C. Jr., Legaspi, J.C., Wendel, L. E. (1998) Laboratory and Field Evaluation of exotic parasitoids of *Bemisia tabaci* (Biotype 'B') in the Lower Rio Grande Valley of Texas. *Biological Control* 12, 27-135.

Goolsby JA, De Barro PJ, Kirk AA, Sutherst R, Canas L, Ciomperlik M, Ellsworth P, Gould J, Hartley D, Hoelmer KA, Naranjo SJ, Rose M, Roltsch B, Ruiz R, Pickett C, Vacek D (2005) Post-release evaluation of the biological control of *Bemisia tabaci* biotype "B" in the USA and the development of predictive tools to guide introductions for other countries. *Biological Control*, 32, 70-77.

Rose, M. & Zolnerowich, G. (1997) *Eretmocerus* Haldeman (Hymenoptera: Aphelinidae) in the United States, with descriptions of new species attacking *Bemisia* (*tabaci* complex)

(Homoptera: Aleyrodidae). *Proceedings of the Entomological Society of Washington* 99, 1-27.

Zolnerowich, G. & Rose, M. (1998) *Eretmocerus* Haldeman (Hymenoptera: Aphelinidae) imported and released in the United States for control of *Bemisia* (*tabaci* complex) (Homoptera: Aleyrodidae).). *Proceedings of the Entomological Society of Washington* 100, 31-323.

Section 2

Effectiveness of Confidor® Soil Application Methods against Silverleaf Whitefly on Tomato

Effectiveness of Confidor® Soil Application Methods against Silverleaf Whitefly on Tomato

Introduction

Silverleaf whitefly (SLW), *Bemisia tabaci* Biotype B, also known as *Bemisia argentifoli*, is a serious pest of many vegetable crops in Queensland. This polyphagous pest causes severe economic damage to the crops through direct feeding, injecting toxic saliva into the plant and through honeydew contamination on fruits.

SLW infestation of tomato plants is associated with irregular ripening in fruits. The external symptom is characterised by green, yellow or orange streaks or blotches on the exterior surface of the fruit. Internally, the affected fruit exhibits white or yellow tissues. In some tomato varieties the external symptoms may not be seen clearly but often internal damage is very apparent, and thereby potentially increasing market rejection (Siva Subramaniam, unpublished).

SLW adults feed and oviposit on the lower surface of leaves therefore a large proportion of eggs and nymphs infesting the crops are protected from contact insecticide sprays. An effective systemic insecticide against the pest would therefore alleviate the coverage problem associated with SLW control in tomato.

Imidacloprid (Confidor®, Bayer Crop Science Australia), a chloronicotyl insecticide, has systemic activity through soil application and controls sucking pests such as aphids and whiteflies. Imidacloprid is relatively immobile in the soil and efficient root uptake is dependent on precise placement of the chemical within the root zone (Mullins 1993).

The objective of this study was to evaluate the efficacy of three imidacloprid soil application techniques on controlling SLW colonisation of tomatoes and preventing subsequent tomato fruit damage.

Materials and Methods

Experimental details

The trial was established on a clay loam soil (light medium non-cracking clay, with cation exchange capacity 20 meq/ 100 g) at the QDPI research station, Bowen, Queensland. The experimental area consisted of polythene covered raised beds at 1.5 m row spacing. All experimental plots were grown with the trickle irrigation system (the commercial standard in Queensland) and irrigated at weekly intervals until final harvest. Commercial agronomic practices were followed to grow and maintain the experimental crops. Insecticides and fungicides to control other pests and diseases were carefully selected and only those known to have no significant impact on SLW were used so as not to confound the result.

Tomato seedlings (Guardian, a ground-grown determinate variety) were transplanted 75 cm apart on 25 July 2002. Plots consisted of a single row 25m long with a 1m buffer row on both ends. Treatments were arranged in a randomised complete block design with three replicates (Appendix 1). The four treatments were plant hole drench (PHD), furrow spray (FS) and trickle injection (TI) and untreated control. A single soil application of imidacloprid (Confidor 200 SC, Bayer crop Science, Australia) was used during the planting time. Treatment details are summarised in Table 2.1.

Table 2.1. Confidor (200 SC) application methods, rate and application volume

Application method	Rate used for 25m row		Water volume per 25 m row	Application time
	Product (ml)	Active ingredient (g)		
Plant Hole Drench (PHD)	7 ml (0.2 ml / plant)	1.4g (0.04g/ plant)	1.6 L (45 ml / plant)	1 DAP
Furrow Spray (FS)	9 ml	1.8g	3 L	1 DBP
Trickle Injection (TI)	6.25 ml	1.25g	15 L	5 DAP

DAP = Days after planting; DBP = Days before planting

Application methods

Trickle Injection – The treatment was applied 5 days after planting (DAP). Imidacloprid solution (15 L) was injected through the trickle irrigation system (emitter spaced at 30 cm and flow rate 1.0 L/hr) using a pressure pump operated at 15 psi. At the end of injection, 5 L of water was used to wash out the tubes.

Plant Hole Drench - Pre-mixed imidacloprid solution was drenched around the base of each plant. A motorised knapsack sprayer fitted with adjustable nozzle was calibrated to deliver 40 to 45 ml of imdidacloprid solution per plant hole.

Furrow spray - Imidacloprid solution was applied into pre-moistened furrows (8-cm wide and 5 cm depth) one day before planting. The spray volume was equally distributed to the furrow using a motorised sprayer fitted with high flow nozzle (TP 80.06 VP). The raised bed was covered with the plastic mulch immediately after the application.

Sampling methods

Tomato plants were sampled for immature whitefly stages at 14-day intervals. Four mature base leaflets (from the 6th or 7th main stem node position down from the terminal leaf) and four young leaflets (from the 3rd or 4th main stem node position) were collected from four random plants in each plot. A total of eight leaflets were assessed for each plot. Leaf samples were taken to the laboratory where four 1 cm^2 areas were selected on each leaflet and immature stages were counted under the microscope. Immature stages on each leaflet were classified as eggs, small nymphs (1st and 2nd instar), large nymphs (3rd instar and red-eye pupae) and exuviae (enclosed pupal cases).

Whitefly adults were sampled from four random plants per plot using a modified vacuum sampling machine. The suction samples were taken from the top one-third of the plants.

Fruit harvest and assessment

Tomato fruits were harvested on 3 October, 2002 - 70 DAP. Twenty-five to thirty mature green fruits were harvested from 10 plants in each plot and were placed in an ethylene gas room at 20 °C for ripening. Fully ripened fruits were assessed for external and internal irregular ripening and honeydew contamination using a 0 to 4 scoring system (Table 2.2).

Table 2.2. Scoring system used for the assessment of SLW damage on tomato fruit

Score	External irregular ripening	Internal irregular ripening	Honeydew or sooty mould contamination	Marketable grade
0	Full red colour	No white tissue inside	Clean fruit	First grade
1	Slight blotches, but < 5% of fruit surface with uneven colour	< 5% internal area with slight white tissue	< 5% of fruit surface with light honeydew deposit	First grade
2	Moderate blotches, 6 to 20% of fruit surface with uneven colour	6 to 25% internal area with white or yellow tissue	5 to 20% of fruit surface with contamination	Second grade
3	High uneven colours, 21 to 40% of fruit surface with uneven colour	26 to 50% internal area affected	21 to 40% of fruit surface with contamination	Unmarketable
4	> 40% fruit surface with uneven colour	> 50% internal area affected	> 40% of fruit surface with contamination	Unmarketable

Results

Effect on adult population

SLW adult colonisation of seedlings started within a week of planting and increased gradually towards the end of the trial, especially in the untreated plots (Fig. 2.1). No significant differences in adult numbers were observed between treatments at the first sampling date (6 DAP).

All three imidacloprid soil treatments provided early protection against whitefly adults compared with the untreated control. However, residual control level varied between the application methods.

PHD treatment maintained adult numbers at a significantly lower level than the untreated control at most sampling dates, and the reduction ranged from 57 to 94%. Trickle injection and furrow spray treatments provided shorter protection than PHD treatment (Fig.2.1). After 7 weeks, even though the adult numbers were significantly lower than the untreated control, adult numbers in all treatments had increased to higher levels (Table 2.4).

The adult numbers increased steadily on untreated plots after 40 days. This sudden increase was mainly due to the completion of generations within the crops. In the untreated plots, the plants were less attractive to adults due to high honeydew contamination, especially towards the end of the experiment. This may have increased adult movement from untreated plots to adjacent plots.

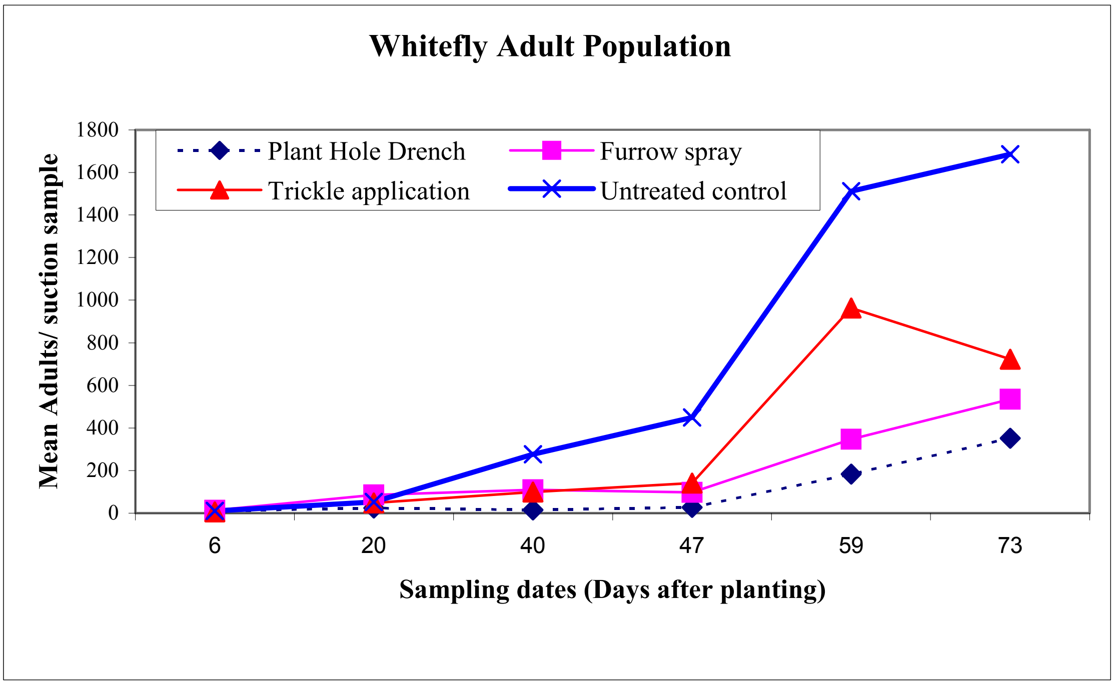


Fig 2.1. Effect of three soil application methods on silverleaf whitefly adult population

Effect on oviposition

The effects of imidacloprid soil application on the immature stages are shown in Table 2.3. At the first sampling date (12 DAP) only fresh eggs were detected in all plots and the treatment effect on egg densities was not significant. A similar result was recorded for the adult population where adult numbers did not differ significantly at the first sampling date. This could be due lack of root development in the seedling to absorb and translocate the chemical to the leaves. Additionally, pest pressure was too low during the first week to see any significant differences.

In the PHD treatment, the mean egg densities were significantly lower than in other treatments and the reduction persisted at successive sampling dates (Fig. 2). An increase in egg numbers occurred close to harvest (63 DAP), but numbers were still much lower (97 %) than the untreated control (Table 2.3).

The number of whitefly eggs on furrow and trickle treated plants was significantly lower than untreated plants. However, in the trickle treatment the egg densities increased to a higher level at the last sampling date (63 DAP).

During the early crop growth period, imidacloprid treatments provided good adult control, thus reducing egg numbers on the treated plants.

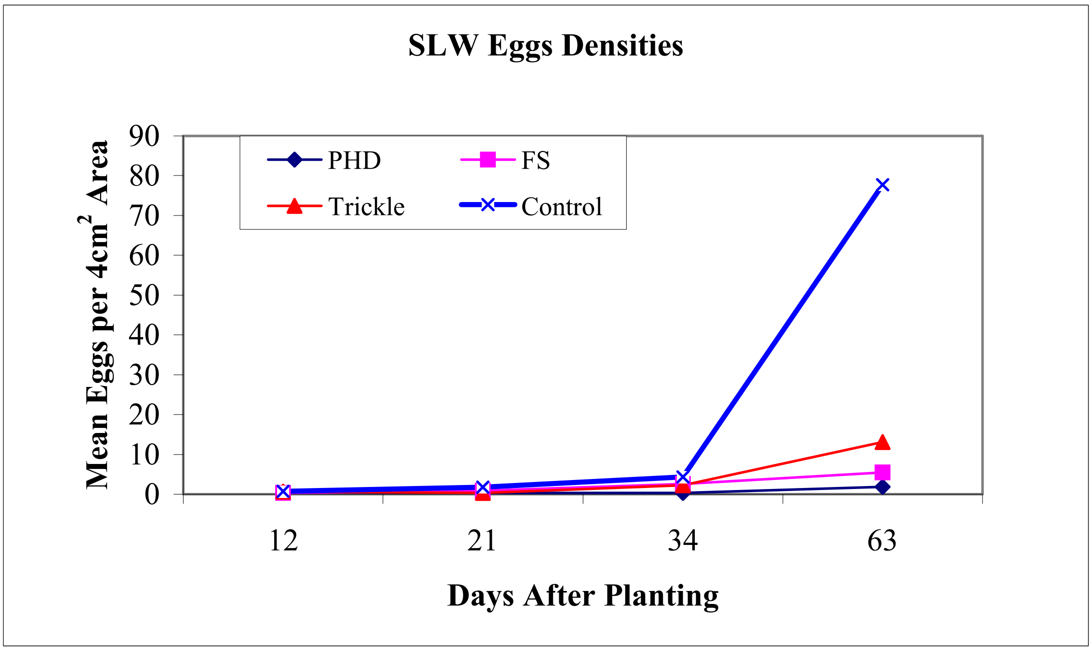


Fig 2.2. Effect of three imidacloprid soil application methods on egg densities

Effect on nymph population

Small nymph stage (1st and 2nd instar) establishment was detected from the second sampling date (21 DAP) and the numbers gradually increased towards the end of the trial (Fig 2.3). All imidacloprid treatments had significantly lower numbers of small and large nymphs compared with the untreated control at early sampling dates (Table 2.3).

In the PHD treatment, the mean number of small and large nymphs was significantly lower than in the untreated control at all sampling dates (Table 3). The overall nymph densities were around 1.1 nymphs/4 cm^2 which was well below the damage threshold level. The PHD provided the higher reduction in nymph densities (81 – 94 %) at all sampling dates (Fig. 2.3).

Our previous studies indicated that a damage threshold exceeding 2 nymphs/4 cm^2 can cause up to 40 % fruit damage (irregular ripening) at harvest (Siva Subramaniam, HAL 2001).

In the furrow spray treatment the mean nymph densities were significantly lower than in the untreated plots only at the second sampling date (21 DAP), thereafter the number exceeded the damage threshold level of 2 nymphs/4 cm^2 (Table 2.3).

Similarly, the nymph densities on trickle injected plants were significantly lower than the untreated control at the second and third sampling dates (21 and 34 DAP) and nymph densities were below the damage threshold level. Thereafter the numbers exceeded the damage threshold level (Table 2.3).

In the untreated control plots nymph numbers increased at an exponential rate and the densities increased from 0.41 nymphs/4 cm^2 at 21 DAP to 20.3 nymphs/4 cm^2 at 63 DAP (Table 2.3).

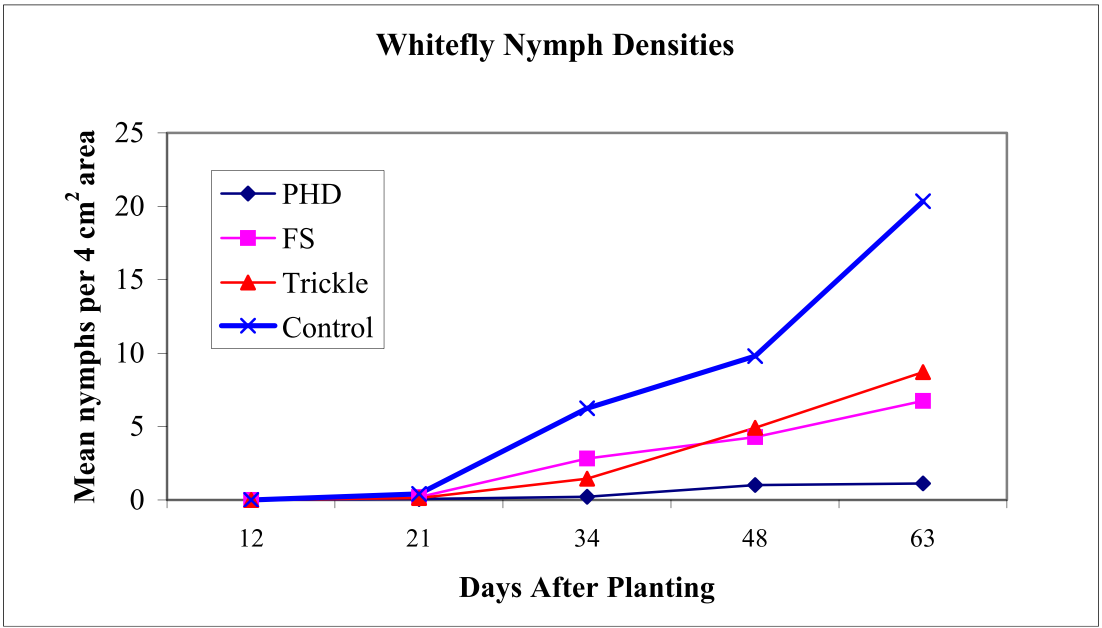


Fig 2.3. Effect of imidacloprid soil application methods on whitefly nymph (small and large) densities

Table 2.3. Effect of Imidacloprid Soil Application Methods on Whitefly Egg and Nymph Densities on Tomato - August to November, 2002

	Days After Planting (DAP)				
	12	21	34	48	63
	Mean Whitefly Eggs / 4 cm^2 leaf area				
Treatments					
PHD	0.52 a	0.29 b	0.33 c	N.A	1.83 b
Furrow Spray	0.31 a	0.92 a	2.58 b	N.A	5.50 b
Trickle Injection	0.66 a	0.36 b	2.25 b	N.A	13.08 b
Untreated Control	0.69 a	1.76 a	4.33 a	N.A	77.68 a
	Mean Small Nymphs / 4 cm^2 leaf area				
PHD	0.0	0.06 c	0.21 b	0.72 c	0.67 b
Furrow Spray	0.0	0.19 b	2.17 a	2.03 b	4.79 b
Trickle Injection	0.0	0.14 b	0.92 b	2.17 b	5.83 b
Control	0.0	0.41 a	3.42 a	3.80 a	12.92 a
	Mean Large Nymphs / 4 cm^2 leaf area				
PHD	0.0	0.0	0.01 b	0.30 b	0.46 b
Furrow Spray	0.0	0.0	0.67 b	2.25 b	1.96 b
Trickle Injection	0.0	0.0	0.54 b	2.75 b	1.87 b
Control	0.0	0.0	2.84 a	6.00 a	7.41 a

Means within column followed by the same letter did not differ significantly at $P > 0.05$
N.A = data not available for the sampling date

Table 2.4. Effect of Imidacloprid Soil Application Methods on Whitefly Adult numbers on Tomato - August to November, 2002

Treatments	Days After Planting (DAP)					
	6	20	40	47	59	73
	Mean number of Adults / suction sample					
PHD	11.0 a	23.3 b	15.7 c	27.0 c	183.7 c	351.0 b
Furrow Spray	13.0 a	85.3 a	109.0 b	98.0 b	343.3 c	535.0 b
Trickle Injection	06.3 a	48.7 a	99.7 b	141.0 b	963.7 b	723.0 b
Untreated Control	10.3 a	52.0 a	277.0 a	449.0 a	1511.0 a	1686.0 a

Means within column followed by the same letter did not differ significantly at $P > 0.05$

Effect on whitefly generation development

Exuviae (empty pupal cases) on the leaves were recorded to indirectly assess the treatment effect on adult emergence. The first set of exuviae was detected on plants only at the fourth sampling date (48 DAP) and the numbers gradually increased towards harvest (63 DAP).

All three imidacloprid treatments had significantly lower numbers of exuviae than the untreated control at all sampling dates. Mean exuviae densities were much lower in PHD treatments (0.08/4 cm^2) than in other treatments (Fig. 2.4)

A gradual increase in adult numbers was noticed in the crop for the first 21 days indicating continued colonisation by adults from outside sources. During the experimental period the SLW appeared to complete two generations within the crop. This can be seen by two distinct peaks in adult numbers at 40 and 59 DAP (Table 4) and the presence of exuviae during that period. The first generation of adults possibly emerged from the first set of eggs detected on the leaves 12 DAP. This shows that it took 25-30 days to complete the first generation (from egg to adult).

Imidacloprid applied at planting as PHD effectively controlled both first and second generation development. However, furrow spray and trickle injection only provided effective control for the first generation.

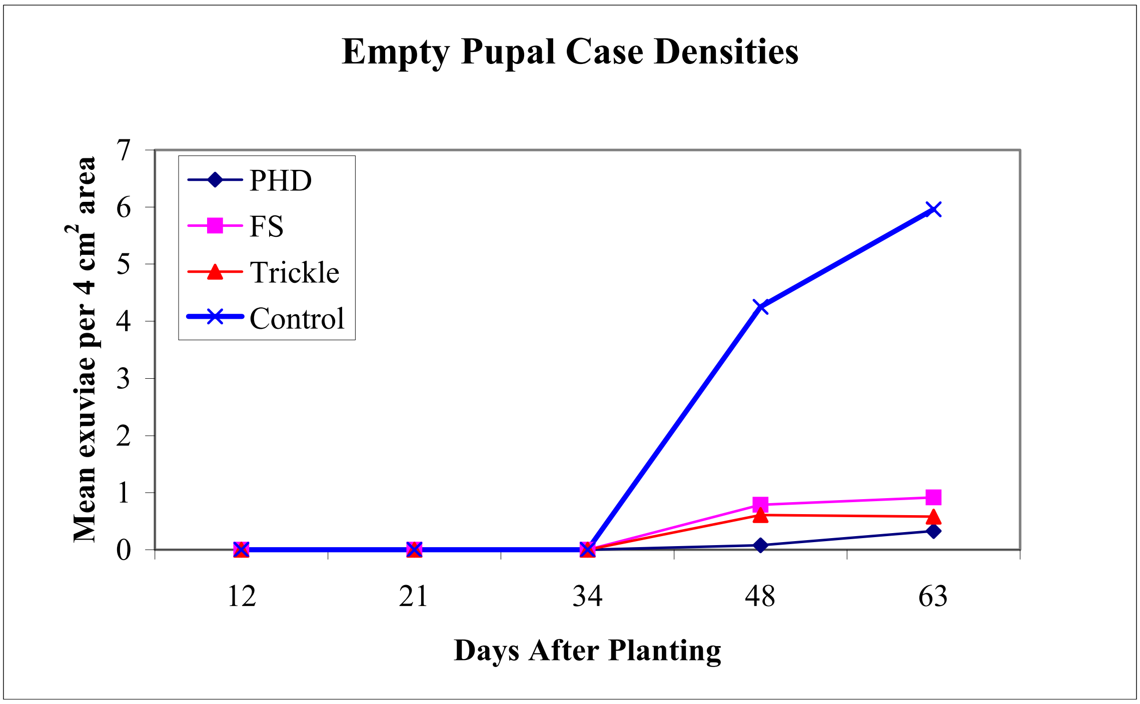


Fig 2.4. Effect of imidacloprid soil application methods on adult whitefly emergence (assessed as empty pupal cases on leaves)

Effect on fruit quality and marketable yield

The percentage of unmarketable fruit due to external irregular ripening was reduced from 41.5 in the untreated control to 13, 10.9 and 0 for the trickle injection, furrow spray and plant hole drench applications respectively (Fig. 2.5)

The percentage of unmarketable fruit due to internal symptoms (white tissue) was reduced from 86.6 in the untreated control to 50.7, 47 and 2.6 by the furrow spray, trickle injection and plant-hole drench treatments respectively (Fig. 2.6).

High quality fruit was harvested from the PHD treatment plots where the crop was protected from SLW colonisation for up to 9 weeks. However, the percentage of internally damaged fruit (white tissue) was high in the furrow spray and trickle injection treatments where around 50% of fruit was unmarketable. The untreated control had fewer marketable fruits (13%) and the rejection was mainly due to severe internal damage and sooty mould contamination.

The honeydew and sooty mould contamination on the fruit surface is shown in Figure 2.7. The fruit harvested from the PHD treatments was completely free from contamination.

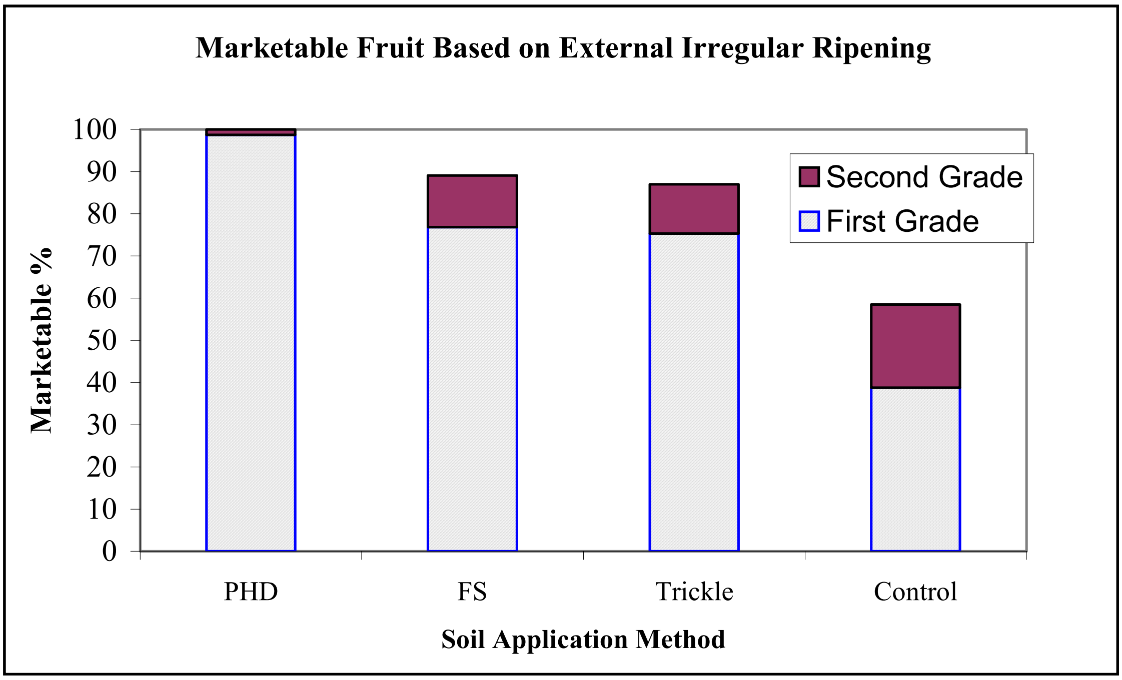


Fig 2.5. Effect of imidacloprid soil treatment on tomato marketable yield based on external irregular ripening

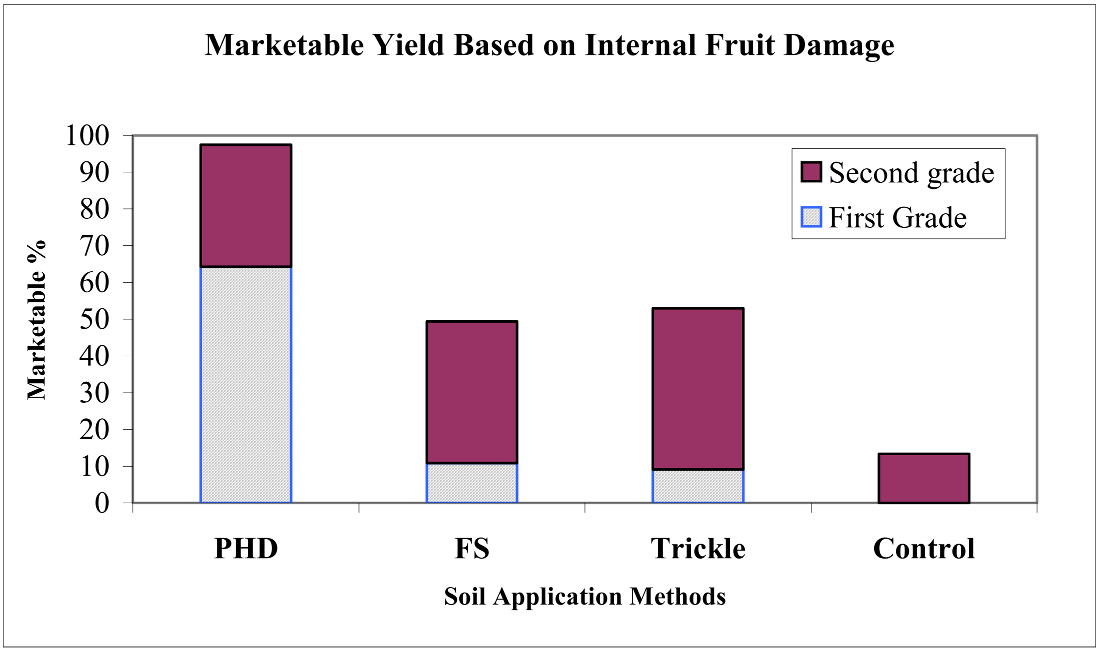


Fig 2.6. Effect of imidacloprid soil treatments on tomato marketable yield based on internal damage

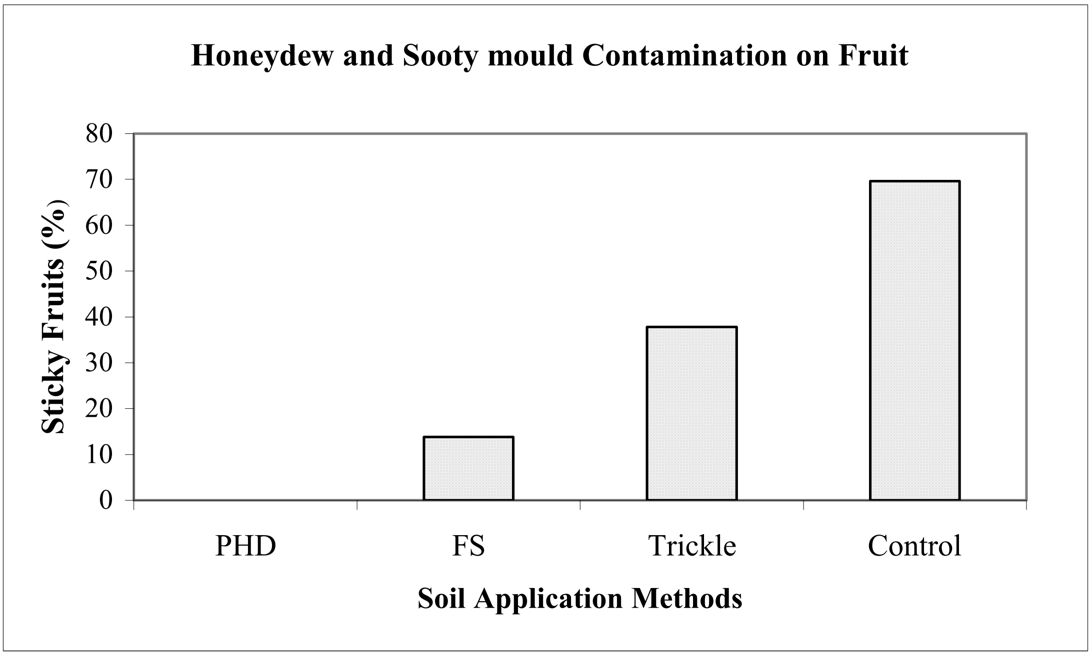


Fig 2.7. Effect of imidacloprid soil treatment on honeydew and sooty mould contamination on tomato fruit

Discussion

This study clearly shows that the soil application of imidacloprid is an effective method in the control of adult whiteflies and suppresses the development of immature stages. Reduction in immature colonisation following soil application showed a similar trend in all treatments, but the length of residual control varied with application technique.

The lower numbers of eggs and nymph stages in the PHD treated plants throughout the experiment indicates that the required rate of imidacloprid should be delivered within the root zone to achieve good SLW control. The PHD technique effectively places the chemical around the root zone, therefore the amount of chemical available to the plants is much higher than in the FS and TI treatments. Palumto *et al* (1996) reported that soil placement of imidacloprid below 7.5 cm was not effectively taken up by the lettuce plants and did not prevent SLW colonisation.

FS and TI treatments did not provide residual whitefly control for the whole life of the crop. This may be due to insufficient chemical present in the leaves to provide adequate control, especially when the plants are growing rapidly. After the mid-crop stage (35 DAP), adult and nymph numbers were still above the damage threshold level even though the population was significantly lower than the untreated control. Therefore supplementary insecticide sprays are required to provide adequate control until harvest. Westwood et al (1998) reported that imidacloprid is persistent in the soil for up to 97 days. The optimum imidacloprid rate required to provide adequate SLW control, especially in mature plants, is not clearly known.

In the FS and TI methods the same amount of imidacloprid as in the PHD method was distributed across the entire row and therefore only a small proportion of the applied chemical would have been present in the active root zone and thus available to the plant. Trickle injection of imidacloprid is a more convenient and labour saving technique on a commercial scale. It is important to position the trickle emitters close to the root zone to optimise chemical uptake. However, it is difficult to align the emitters with the plant hole, especially in wider-spaced crops, so chemical wastage is high.

In commercial packing houses field-harvested tomato fruit are sorted based on external colour. There is no reliable non-destructive method available to detect internal damage. Undetected internal damage can cause consumer dissatisfaction and potentially risks loss of sales.

In most parts of Queensland, late season tomato crops (August to December) often experience high SLW pressure, mainly due to hot and dry weather and migration from adjacent crops. Soil application of imidacloprid, with optimal application methods, at planting would be an effective control option for SLW under these higher risk conditions.

These application methods require validation on a commercial scale. However, it should be considered that prophylactic application of imidacloprid increases the potential for development of resistance in SLW and aphid populations.

Conclusion

This study clearly demonstrated the long residual efficacy of soil applied imidacloprid against SLW colonisation in tomatoes.

Imidacloprid applied as a PHD at the time planting provided up to 9 weeks protection, even during the high pest pressure period. A single application imidacloprid as a PHD at planting can maintain SLW populations at a level that is low enough to reduce irregular ripening damage in tomatoes. However, trellis grown gourmet tomatoes may require supplementary insecticide applications.

This study suggests that the amount of imidacloprid delivered through FS and TI methods was only sufficient to provide adequate control against whitefly stages during early crop growth (4 to 5 weeks). To achieve a profitable marketable yield, an effective spray program should be supplemented with trickle or furrow treatments, especially during high pest pressure period.

Soil applied imidacloprid should be used when SLW populations are beginning to build or be applied at planting as a preventive measure during the high risk period. For example, in North Queensland tomatoes planted from mid-July to September are often at higher risk, therefore soil application of imidacloprid is more appropriate during this period.

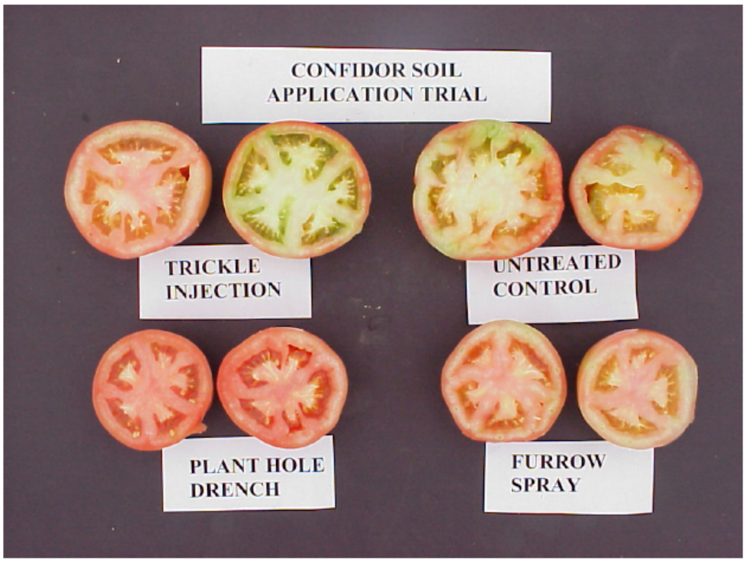
References

Mullin, JW. 1993. Imidacloprid: a new nitoroguanidine insecticide, pp 184-198. *In* Pest control with environmental safety. American Chemical Society Symposium Series 524.

Palumbo, JC; Kerns, DL; Engle, CE and Wilcox, M (1996). Imidacloprid formulation and soil placement effects on colonisation by sweet potato whitefly: Head size and incidence of chlorosis in lettuce. Journal of Economic Entomology. 89 (3): 735-742.

Westwood, FK; Bean, KM and Chamberlain, K (1998). Movement and persistence of [C14] imidacloprid in sugar-beet plants following application to pelleted sugar-beet seed. Pesticide Science. 52: 92-103.

Siva Subramaniam (2001). Relationship between the silverleaf whitefly infestation and the irregular ripening symptom in tomato. *Silverleaf Whitefly Research Project Milestone 4 report*. Submitted to Horticulture Australia 15 Feb 2001.



Picture 2.1. Tomato internal irregular ripening symptoms relative to imidalcoprid soil treatments

Picture 2.2. Tomato external and internal irregular ripening symptoms relative to imidalcoprid soil treatments

Section 3

Effectiveness of Confidor® Soil Application Methods against Silverleaf Whitefly on Zucchini

Effectiveness of Confidor® Soil Application Methods against Silverleaf Whitefly on Zucchini

Introduction

Silverleaf whitefly (SLW), *Bemisia tabaci* Biotype B, also known as *Bemisia argentifolii*, is a serious pest of many vegetable crops in Queensland. This polyphagous pest causes severe economic damage to the crops through direct feeding, injecting toxic saliva into the plant and through honeydew contamination on fruits.

Zucchini (*Cucurbita pepo* L) is an important cucurbit crop in Queensland. The production area and value of zucchinis and squashes were estimated in 1999 at 2170 ha and $24.3m (ABS 2002).

SLW feeding is associated with silverleaf symptom on leaves in zucchini (Schuster et al 1991, Siva Subramaniam, 2000). The symptom is characterised by silver colouration along the veins of younger leaves. The interveinal areas subsequently become increasingly silvered in appearance until entire upper leaf surface is affected. In severe infestations, fruit can also become lighter green or yellow.

SLW adults feed and oviposit on the lower surface of leaves therefore a large proportion of eggs and nymphs infesting the crops are protected from contact insecticide sprays. An effective systemic insecticide against the pest would therefore alleviate the coverage problem associated with SLW control in zucchini.

Imidacloprid (Confidor®, Bayer Crop Science Australia), a chloronicotyl insecticide, has systemic activity through soil application and controls sucking pests such aphids and whiteflies. Imidacloprid is relatively immobile in the soil and efficient root uptake is dependent on precise placement of the chemical within the root zone (Mullins 1993).

The objective of this study was to evaluate the efficacy of three imidacloprid soil application techniques on controlling SLW colonisation of zucchini and preventing subsequent silvering on leaves and fruit damage.

Materials and Methods

Experimental details

The trial was established on a clay loam soil (light medium non-cracking clay, with cation exchange capacity 20 meq/ 100 g) at the QDPI research station, Bowen, Queensland. The experimental area consisted of polythene covered raised beds at 1.5 m row spacing. All experimental plots were grown with the trickle irrigation system (the commercial standard in Queensland) and irrigated at weekly intervals until final harvest. Commercial agronomic practices were followed to grow and maintain the experimental crops. Insecticides and fungicides to control other pests and diseases were carefully selected and only those known to have no significant impact on SLW were used so as not to confound the result.

Zucchini seedlings (variety Zukit) were transplanted 55 cm apart on 25 July 2002. Plots consisted of a single row 25m long with a 1m buffer row on both ends. Treatments were arranged in a randomised complete block design with three replicates (Appendix 1). The four treatments were plant hole drench (PHD), furrow spray (FS) and trickle injection (TI) and untreated control. A single soil application of imidacloprid (Confidor 200 SC, Bayer crop Science, Australia) was used during the planting time. Treatment details are summarised in Table 3.1.

Table 3.1. Confidor (200 SC) application methods, rate and application volume

Application Method	Rate used for 25m row		Water volume per 25 m row	Application time
	Product (ml)	Active ingredient (g)		
Plant Hole Drench (PHD)	6.3 ml (0.14ml/ plant)	1.26g (0.03g/ plant)	1.85 L (40 ml / plant)	1 DAP
Furrow Spray (FS)	8.8 ml	1.76g	3 L	1 DBP
Trickle Injection (TI)	6.25 ml	1.25g	15 L	5 DAP

DAP = Days after planting; DBP = Days before planting

Application methods

Trickle Injection – The treatment was applied 5 days after planting (DAP). Imidacloprid solution (15 L) was injected through the trickle irrigation system (emitter spaced at 30 cm and flow rate 1.0 L/hr) using a pressure pump operated at 15 psi. At the end of injection, 5 L of water was used to wash out the tubes.

Plant Hole Drench - Pre-mixed imidacloprid solution was drenched around the base of each plant. A motorised knapsack sprayer fitted with adjustable nozzle was calibrated to deliver 40 to 45 ml of imidalcoprid solution per plant hole.

Furrow spray - Imidacloprid solution was applied into pre-moistened furrows (8-cm wide and 5 cm depth) one day before planting. The spray volume was equally distributed to the furrow using a motorised sprayer fitted with high flow nozzle (TP 80.06 VP). The raised bed was covered with the plastic mulch immediately after the application.

Sampling methods

Zucchini plants were sampled for immature whitefly stages at 14-day intervals. Four young leaves (from the 3rd or 4th main stem node position down from the terminal leaf) and four mature leaves (from the 8th or 9th main stem node position) were collected from four random plants in each plot. A total of eight leaves were assessed for each plot. Leaf samples were taken to the laboratory where four 1 cm^2 areas were selected on each leaf and immature stages were counted under the microscope. Immature stages on each leaf were classified as eggs, small nymphs (1st and 2nd instar), large nymphs (3rd instar and red-eye pupae) and exuviae (enclosed pupal cases).

Whitefly adults were sampled from four random plants per plot using a modified vacuum sampling machine. Two suction samples (covering a young and a middle mature leaves) were taken from each plant.

Silver leaf symptom assessment

Silverleaf (SL) symptoms were evaluated on 23 August (28 DAP) and 31 August (36 DAP) by randomly choosing 10 plants in each plot. Severity of silvering on each leaf was assessed with the following rating:

0 = leaves with no SL symptoms
1= silvering adjacent to vein or < 25% leaf area with SL symptoms
2 = 26 to 50 leaf area with SL symptoms
3 = 50 to 75 leaf area with SL symptoms
4 = above 75% leaf area with SL symptoms

The SL rating on the leaves were added to calculate cumulative SL score on each plant.

Fruit harvest and assessment

Zucchini fruits were sequentially harvested from five marked plants of each plot at 4 to 5 day intervals. The first harvest was commenced on 23 August (28 DAP) and continued until 18 September (54 DAP), a total of six harvests. During each harvest, marketable fruits (10 to 15 cm long with dark green colour) from each plot were counted and weighed. Light green and undersize fruits were considered as unmarketable fruits.

Results

Effect on adult population

SLW adult colonisation of seedlings started within a week of planting and increased gradually towards the end of the trial, especially in the untreated plots (Fig. 3.1). PHD and FS treatments maintained adult numbers at a significantly lower level than the untreated control at first sampling date (6 DAP), and the reduction ranged from 79 to 87%.

All three imidacloprid soil treatments had significantly lower number of adults than untreated control, and provided good protection against whitefly adults for up to 7 weeks. The residual control level did not vary between the application methods. After 7 weeks, adult numbers in all treatments had increased to very high levels (Table 3.2).

The adult numbers increased steadily on untreated plots from 20 DAP. At last sampling date (60DAP), the adult numbers were at higher level in all treatments and no significant differences in adult numbers were observed between treatments (Table 3.2). This sudden increase was mainly due to the completion of generations within the crops. In the untreated plots, the plants were less attractive to adults due to high honeydew contamination, especially toward end of the experiment. This may have increased adult movement from untreated plots to adjacent plots.

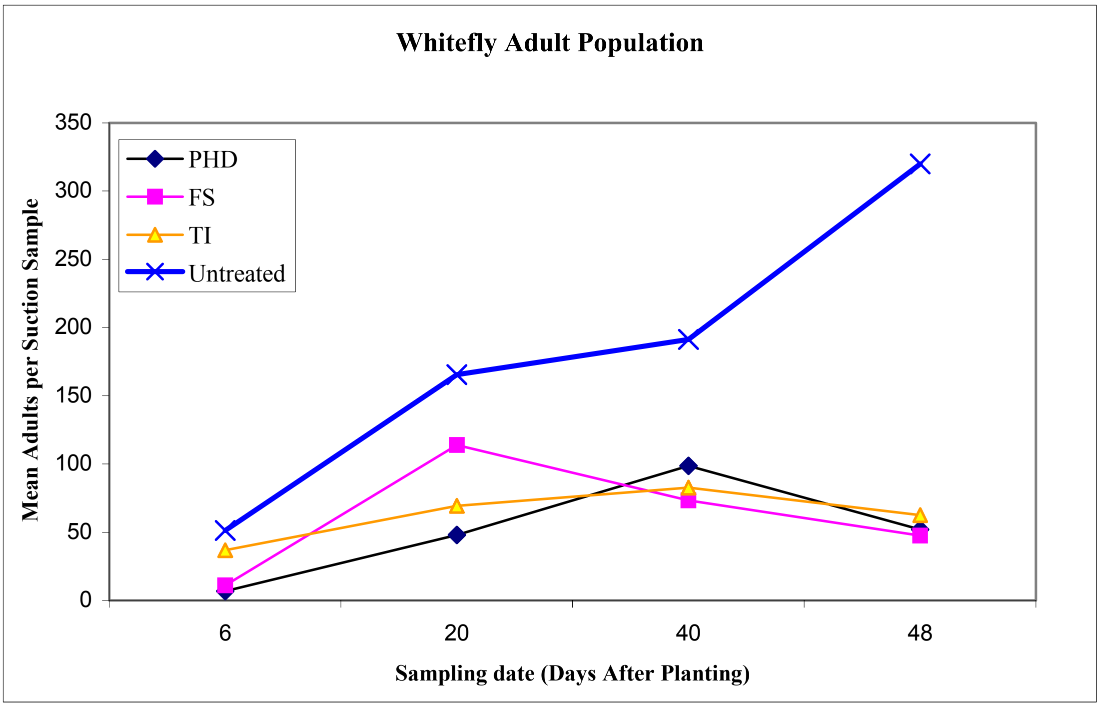


Fig 3.1. Effect of imidacloprid soil applications on adult populations on zucchini

Table 3.2. Effect of Imidacloprid Soil Application Methods on Whitefly Adult numbers on Zucchini - August to November, 2002

	Days After Planting (DAP)				
	6	20	40	48	60
Treatments	Mean number of Adults / suction sample				
PHD	6.7 b	48.0 b	98.7 b	52.0 b	1207 a
Furrow Spray	11.0 b	114.0 c	73.3 b	47.7 b	996 a
Trickle Injection	36.7 a	69.5 b	82.7 b	62.7 b	1297 a
Untreated Control	51.3 a	165.5 a	191.3 a	320.0 a	1582 a

Table 3.3. Effect of Imidacloprid Soil Application Methods on Whitefly Egg Densities on Zucchini - August to November, 2002

Treatments	Days After Planting (DAP)				
	12	21	33	47	60
	Mean Whitefly Eggs / 4 cm^2 leaf area				
PHD	1.9 b	4.2 b	5.7 b	N.A	30.1 a
Furrow Spray	2.1 b	4.7 b	7.7 b	N.A	31.4 a
Trickle Injection	7.2 a	4.8 b	6.2 b	N.A	25.6 a
Untreated Control	13.2 a	14.1 a	17.4 a	N.A	20.3 a

N.A = data not available for the sampling date
Means within column followed by the same letter did not differ significantly at $P > 0.05$

Effect on oviposition

The effects of imidacloprid soil application on the egg densities are shown in Table 3.3.

At the first sampling date (12 DAP) only fresh eggs were detected in all plots and PHD and FS treatments had significantly lower number of eggs than untreated control (Table 3.3). However, TI treatment had higher egg densities than PHD and FS treatments. A similar result was recorded for the adult population where adult numbers were higher in TI treatments at the first sampling (Table 3.2). This could be due lack of root development in the seedling to absorb and translocate the chemical to the leaves.

All imidacloprid treatments resulted in fewer eggs compared with the untreated control on the second and third sampling dates (21 and 33 DAP). An increase in egg numbers occurred at last sampling date (60 DAP), and the numbers recorded in the treatments were not significantly different from each other (Fig 3.2).

During the early crop growth period, imidacloprid treatments provided good adult control, thus reducing egg numbers on the treated plants.

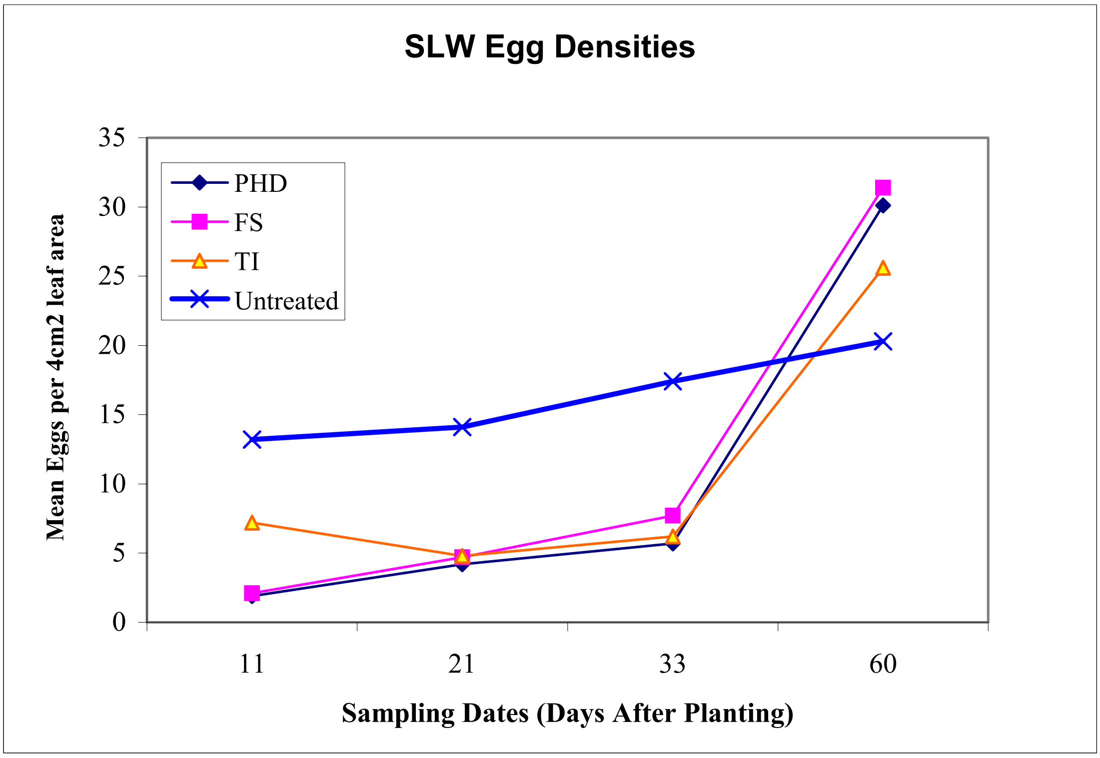


Fig 3.2. Effect of imidacloprid soil application methods on whitefly egg densities

Effect on nymph population

Small nymph stage (1st and 2nd instar) establishment was detected from the second sampling date (21 DAP) and the numbers gradually increased towards the end of the trial (Fig 3.3).

All imidacloprid treatments resulted in significantly lower numbers of nymphs compared to the untreated control on the third sampling dates (33 DAP). Thereafter the nymph numbers exceeded the damage threshold level of 2 nymphs/ 4 cm^2 (Table 3.4). No significant differences in nymph numbers were observed between treatments on the fourth sampling date (47DAP). Although significant differences in the nymph numbers occurred on the last sampling date (60 DAP), the overall nymph densities were above the damage threshold level.

In the untreated control plots overall nymph numbers increased at an exponential rate and the densities increased from 3.1 nymphs/4 cm^2 at 21 DAP to 34.2 nymphs/4 cm^2 at 60 DAP (Table 3.4).

All three soil application methods provided up to 33 days of protection against the nymph stages. Nevertheless, the nymph numbers recorded in the imidacloprid treatments were not significantly different from each other.

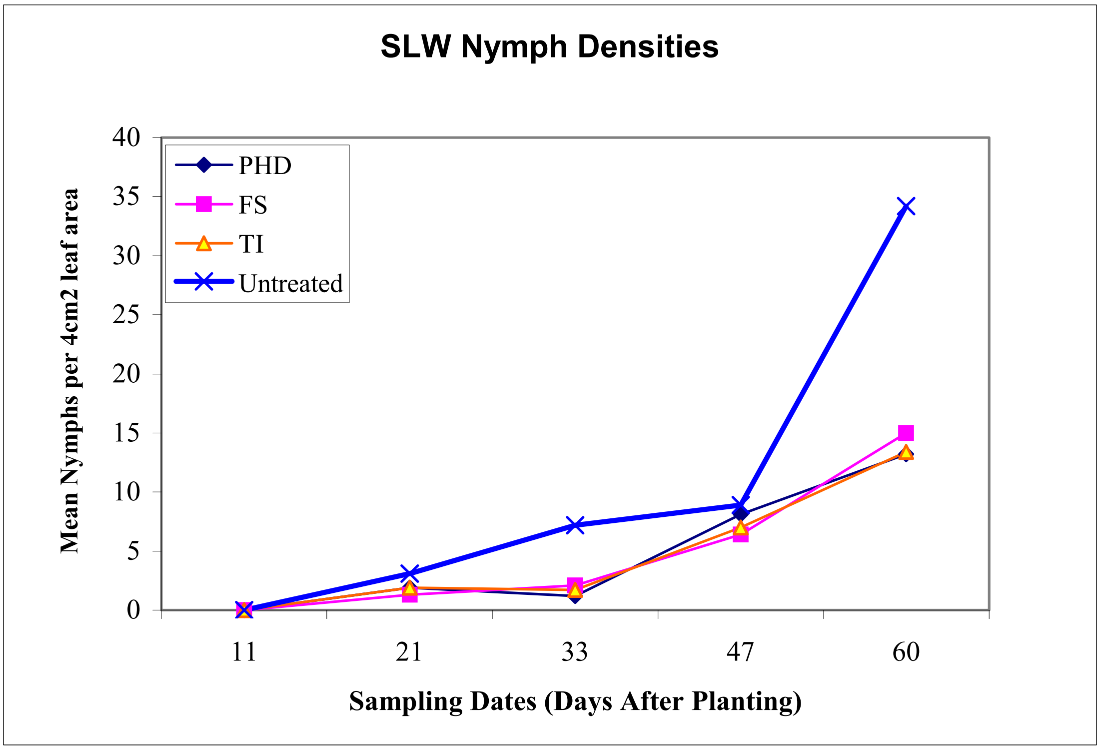


Fig 3.3. Effect of imidacloprid soil application methods on whitefly nymph (small and large) densities

Table 3.4. Effect of Imidacloprid Soil Application Methods on Whitefly Nymph Densities on Zucchini - August to November, 2002

Treatments	Days After Planting (DAP)				
	11	21	33	47	60
	Mean Small Nymphs / 4 cm^2 leaf area				
PHD	0.0	1.9 a	1.2 b	3.6 a	6.4 a
Furrow Spray	0.0	1.3 a	2.1 b	3.2 a	8.3 a
Trickle Injection	0.0	1.9 a	1.7 b	4.9 a	8.3 a
Untreated Control	0.0	3.1 a	7.0 a	4.3 a	14.6 a
	Mean Large Nymphs / 4 cm^2 leaf area				
PHD	0.0	0.0	0.0	4.5 a	6.8 b
Furrow Spray	0.0	0.0	0.0	3.2 a	6.7 b
Trickle Injection	0.0	0.0	0.0	2.1 a	5.1 b
Control	0.0	0.0	0.2	4.6 a	19.6 a
	Mean Overall Nymphs / 4 cm^2 leaf area				
PHD	0.0	1.9 a	1.2 b	8.1 a	13.2 b
Furrow Spray	0.0	1.3 a	2.1 b	6.4 a	15.0 b
Trickle Injection	0.0	1.9 a	1.7 b	7.0 a	13.4 b
Control	0.0	3.1 a	7.2 a	8.9 a	34.2 a

Means within column followed by the same letter did not differ significantly at $P > 0.05$

Effect on silvery symptom on leaves

The effects of imidacloprid treatments on leaf silvering symptoms are shown in Table 3.5. Silvering on leaves began to appear 20 DAP, but clear symptoms were recorded only on the second assessment date (28 DAP). The presence of nymph numbers on the plant (22 DAP) coincided with increasing silverleaf symptoms on the leaves.

Cumulative score for the extent of silverleaf symptoms were significantly lower for all imidacloprid treatments on the second and third assessment dates (29 and 37 DAP) compared to the untreated control. However, PHD and FS treatments had significantly lower silverleaf score than the TI treatment on the second assessment date (28 DAP).

The percentage of plants with severe silverleaf symptoms (cumulative score above 5) was much higher (86-100%) in the untreated control than in the PHD and FS treatments (16-35%) (Table 3.5).

Table 3.5. Effect of imidacloprid soil application methods on leaf silvering in zucchini

Imidacloprid application methods	Cumulative silverleaf score per plant		% Severe silverleaf symptom plant	
	29 DAP	37 DAP	29 DAP	37 DAP
PHD	1.73 c	5.75 b	16.6 b	33.3 b
FS	1.33 c	4.47 b	16.6 b	35.0 b
TI	3.27 b	7.70 b	36.6 b	60.0 b
Untreated control	11.57 a	33.1 a	86.6 a	100.0 a

Effect on fruit quality and marketable yield

The effect of imidacloprid soil application on the fruit quality and marketable yield are shown in Figure 3.4 and 3.5.

The number of unmarketable fruits due to reduced size and lighter colour were much higher in the untreated control plots. All three imidacloprid treatments had significantly higher number of marketable fruit (1.6 to 2.0 fold higher) than the untreated control. No significant differences in fruit numbers (combined harvest) were observed between imidacloprid treatments.

Higher average marketable yield resulted in the combined harvest for all imidacloprid treatments compared to the untreated control. Around 2 to 2.5 fold higher marketable yield was recorded in the imidacloprid treatments than in the control plots. The calculated marketable yield (based on the trial plot yield and spacing) was around 7.8 –8.5 t/ha in the imidacloprid treatments compared with 3.3 t/ ha in the untreated control.

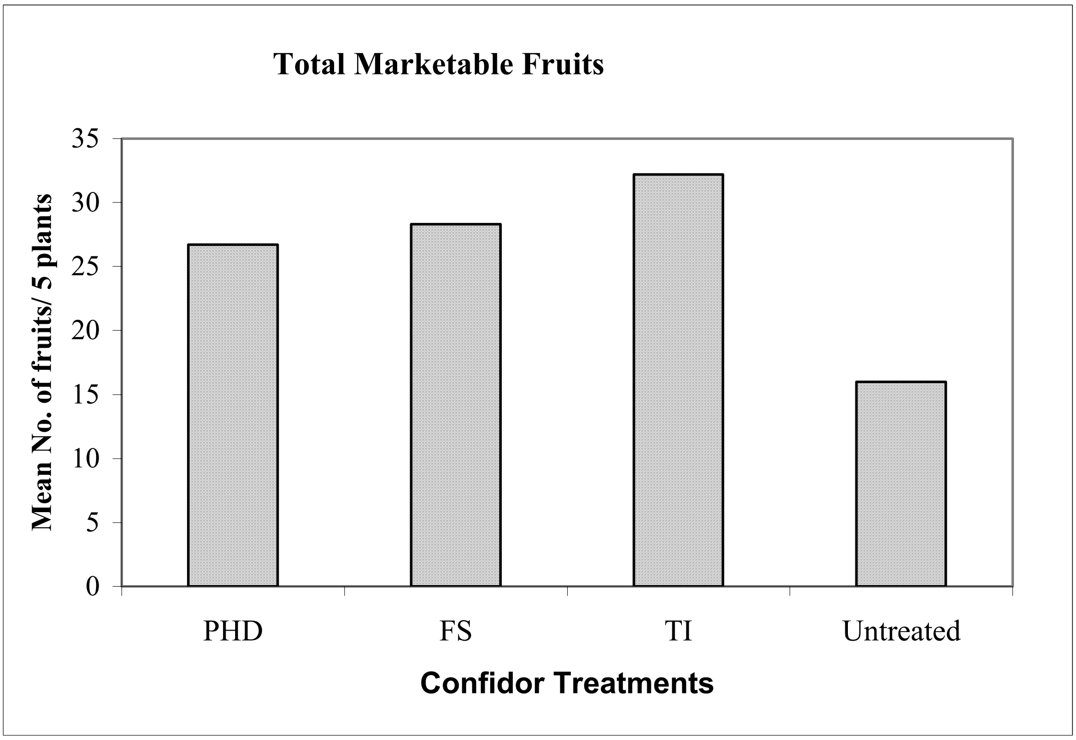


Fig 3.4. Effect of imidacloprid soil treatments on number of marketable fruits

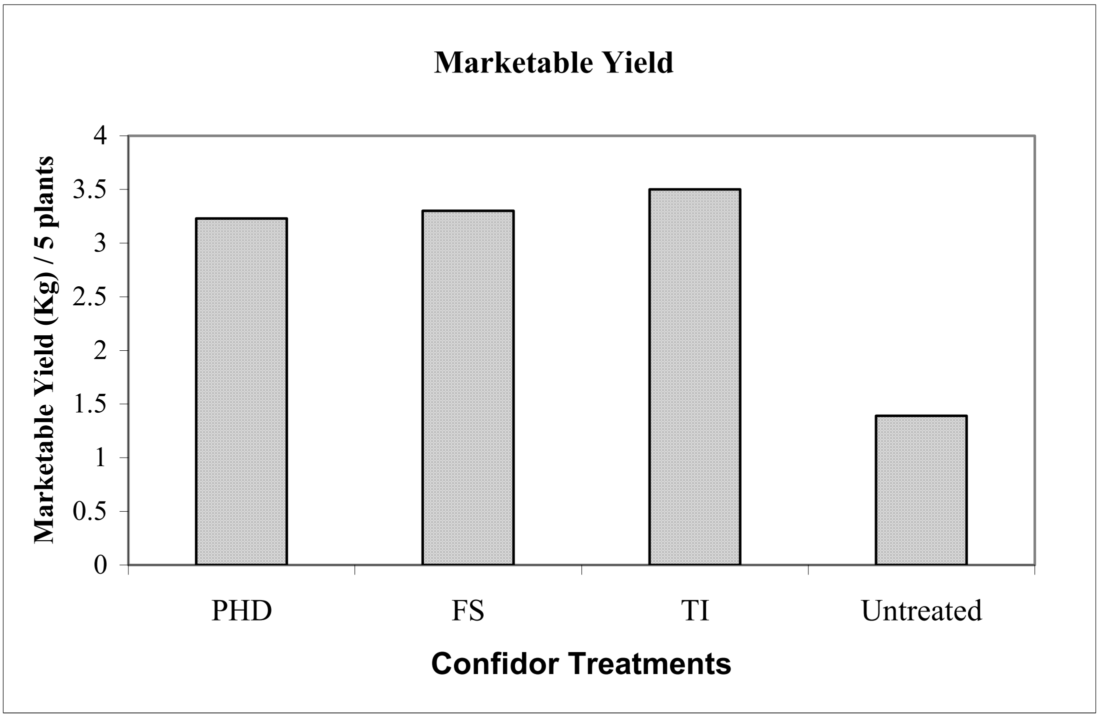


Fig 3.5. Effect of imidacloprid soil treatments on fruit marketable yield

Discussion

This study clearly shows that the soil application of imidacloprid is an effective method in the control of adult whiteflies and suppresses the development of immature stages. Reduction in immature colonisation following soil application showed a similar trend in all treatments.

All three imidacloprid treatments did not provide effective residual whitefly control for whole life of the crop. This may be due to insufficient chemical present in the leaves to provide adequate control, especially when the plants are growing rapidly. After the mid-crop stage (33 DAP), nymph numbers were still above the damage threshold level even though the population was significantly lower than the untreated control. Therefore supplementary insecticide sprays are required to provide adequate control until harvest.

In this study, trickle injection method was equally effective as the other two methods. In contrast, tomato and eggplant trial results show that PHD was superior to the trickle method. This may mean that crop root structure and growth factors also influence the effectiveness of the chemical treatment. The chemical dilution effect within the zucchini crop appeared to be faster than tomato and eggplant, possibly due to its fast growing nature. Trickle injection of imidacloprid is a more convenient and labour saving technique on a commercial scale. It is important to position the trickle emitters close to the root zone to optimise chemical uptake. However, it is difficult to align the emitters with the plant hole, especially in wider-spaced crops, so chemical wastage is high.

This study also prove that soil application imidacloprid at planting effectively reduce the silvering symptoms and subsequently increased marketable yields. The reduction in marketable yield was mainly due reduced fruit size and discolouration. Photosynthesis rate in completely silvered leaves was reported to be 30% lower than in green leaves (Burger et al 1988). Costa *et al* (1994) found a negative correlation between yield and silverleaf severity in zucchini.

In Zucchini, silverleaf symptom expression appeared to be associated with nymph density rather than adult numbers. Clear silverleaf symptoms were noticed at 28 DAP which was after the establishment of nymph populations on the plants. Silverleaf symptoms were not clearly seen during the first three week period even though high adult populations were recorded during that period.

In most parts of Queensland, late season crops (August to December) often experience high SLW pressure, mainly due to hot and dry weather and migration from adjacent crops. Soil application of imidacloprid at planting would be an effective control option for SLW under these higher risk conditions.

These application methods require validation on a commercial scale. However, it should be considered that prophylactic application of imidacloprid increases the potential for development of resistance in SLW and aphid populations.

Conclusion

This study clearly demonstrated the residual efficacy of soil applied imidacloprid against SLW colonisation in zucchini.

All three application methods gave effective residual control against colonising adults for up to 48 days while providing up to 33 days of protection against nymph stages.

This study demonstrates that imidacloprid applied via these three application techniques are equally effective in controlling SLW stages. The treatments that resulted reduced whitefly populations also resulted in low silverleaf symptoms and high marketable yields.

This study suggests that the amount of imidacloprid delivered at planting was only sufficient to provide adequate control against whitefly stages until mid-crop growth (4 to 5 weeks). To achieve a high marketable yield, an effective spray program should be supplemented with soil application of imidacloprid, especially during high pest pressure period.

References

Australian Bureau of Statistics (2002). Agricultural Industry in Australia _ QLD State Profile. http://www.abs.gov.au.

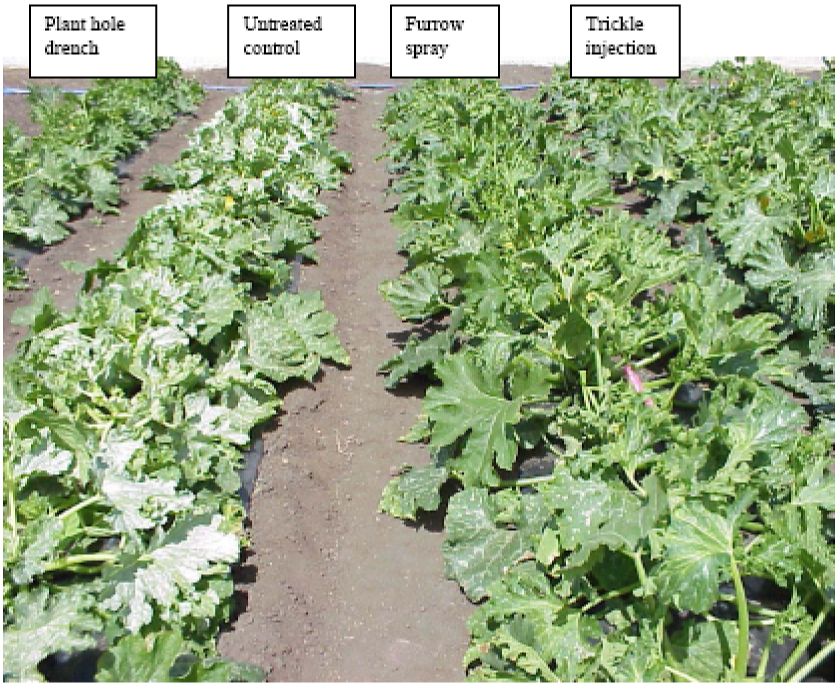
Burger, Y.A and Paris, H.S (1988). Physiological and anatomical features of the silvering disorder of Cucurbits . J. Hortic. Sci. 63: 635-640.

Costa, H.S; Ullman, D.E and Tabashnik, B.E (1994). Squash silverleaf symptoms induced by immature, but not adults, *Bemisia tabaci*. Phytopathology 83: 763-766.

Mullin, JW. 1993. Imidacloprid: a new nitoroguanidine insecticide, pp 184-198. *In* Pest control with environmental safety. American Chemical Society Symposium Series 524.

Schuster, D.J ; Kring, J.B, and Price, J.F.(1991). Association of the sweet potato whitefly with a silverleaf disorder squash. Hort Science 26: 155-156.

Siva Subramaniam (2000). Relationship between the silverleaf whitefly infestation and silverleaf symptom in zucchini. *Silverleaf Whitefly Research Project Milestone 3 report*. Submitted to Horticulture Australia July 2000.



Picture 3.1. Expression of silverleaf symptoms on imidacloprid treatments

Section 4

Effectiveness of Confidor® Soil Application Methods against Silverleaf Whitefly on Eggplant

Effectiveness of Confidor® Soil Application Methods against Silverleaf Whitefly on Eggplant

Introduction

Silverleaf whitefly (SLW), *Bemisia tabaci* Biotype B, also known as *Bemisia argentifolii*, is well established in most vegetable growing regions in Queensland. In the past few years, this insect has become a major pest on many vegetable crops including tomato, eggplant, cucurbits, melon, sweet potato, brassicas and lettuce. SLW has become a serious pest because of its high reproductive capability, wide host range, high rate of feeding and injection of toxic saliva into the plant and exudation of sticky honeydew.

In eggplant (*Solanum melongena* L.), SLW feeding can reduce yield directly due to removal of plant sap. Feeding damage by both nymphs and adults also results in the accumulation of honeydew on the leaves and fruits and subsequent growth of sooty mould. As eggplant has reasonable tolerance to SLW damage, light to moderate pest infestation did not show distinctive symptoms as a result of their feeding. However with heavy population the crop becomes unthrifty and less productive and the fruits are rendered unmarketable. Dark fruit colour varieties may also lose their glossy black colour.

SLW adults feed and oviposit on the lower surface of leaves therefore a large proportion of eggs and nymphs infesting the crops are protected from contact insecticide sprays. An effective systemic insecticide against the pest would therefore alleviate the coverage problem associated with SLW control in eggplant.

Imidacloprid (Confidor®, Bayer Crop Science Australia), a chloronicotyl insecticide, has systemic activity through soil application and controls sucking pests such aphids and whiteflies. Imidacloprid is relatively immobile in the soil and efficient root uptake is dependent on precise placement of the chemical within the root zone (Mullins 1993).

The objective of this study was to evaluate the efficacy of three imidacloprid soil application techniques on controlling SLW in eggplant.

Materials and Methods

Experimental details

The trial was established on a clay loam soil (light medium non-cracking clay, with cation exchange capacity 20 meq/ 100 g) at the QDPI research station, Bowen, Queensland. The experimental area consisted of polythene covered raised beds at 1.5 m row spacing. All experimental plots were grown with the trickle irrigation system (the commercial standard in Queensland) and irrigated at weekly intervals until final harvest. Commercial agronomic practices were followed to grow and maintain the experimental crops. Insecticides and fungicides to control other pests and diseases were carefully selected and only those known to have no significant impact on SLW were used so as not to confound the result.

Eggplant seedlings (variety Shiner) were transplanted 55 cm apart on 25 July 2002. Plots consisted of a single row 25m long with a 1m buffer row on both ends. Treatments were arranged in a randomised complete block design with three replicates (Appendix 1). The four treatments were plant hole drench (PHD), furrow spray (FS) and trickle injection (TI) and untreated control. A single soil application of imidacloprid (Confidor 200 SC, Bayer crop Science, Australia) was used during the planting time. Treatment details are summarised in Table 4.1.

Table 4.1. Confidor (200 SC) application methods, rate and application volume

Application Method	Rate used for 25m row		Water volume per 25 m row	Application time
	Product (ml)	Active ingredient (g)		
Plant Hole Drench (PHD)	6.3 ml (0.14ml/ plant)	1.26g (0.03g/ plant)	1.85 L (40 ml / plant)	1 DAP
Furrow Spray (FS)	9.3 ml	1.86g	3.5 L	1 DBP
Trickle Injection (TI)	6.25 ml	1.25g	15 L	5 DAP

DAP = Days after planting; DBP = Days before planting

Application methods

Trickle Injection – The treatment was applied 5 days after planting (DAP). Imidacloprid solution (15 L) was injected through the trickle irrigation system (emitter spaced at 30 cm and flow rate 1.0 L/hr) using a pressure pump operated at 15 psi. At the end of injection, 5 L of water was used to wash out the tubes.

Plant Hole Drench - Pre-mixed imidacloprid solution was drenched around the base of each plant. A motorised knapsack sprayer fitted with adjustable nozzle was calibrated to deliver 40 ml of imidacloprid solution per plant hole.

Furrow spray - Imidacloprid solution was applied into pre-moistened furrows (8-cm wide and 5 cm depth) one day before planting. The spray volume was equally distributed to the furrow using a motorised sprayer fitted with high flow nozzle (TP 80.06 VP). The raised bed was covered with the plastic mulch immediately after the application.

Sampling methods

Eggplant leaves were sampled for immature whitefly stages at 14-day intervals. Four mature lower leaves (from the 9^{th} or 10^{th} main stem node position down from the terminal leaf) and four young leaves (from the 4^{th} or 5^{th} main stem node position) were collected from four random plants in each plot. A total of eight leaves were assessed for each plot. Leaf samples were taken to the laboratory where four 1-cm^2 areas were selected on each leaf and immature stages were counted under the microscope. Immature stages on each leaf were classified as eggs, small nymphs (1^{st} and 2^{nd} instar), large nymphs (3^{rd} instar and red-eye pupae) and exuviae (enclosed pupal cases).

Whitefly adults were sampled from four random plants per plot using a modified vacuum sampling machine. The suction samples were taken from the top one-third of the plants.

Results

Effect on adult population

In all treatments whitefly adult colonisation of seedling started within a week of planting and increased gradually to a higher level towards the end of the trial. (Fig. 4.1). No significant differences in adult numbers were observed between treatments at the first sampling date, 7 DAP (Table 4.2).

PHD treatment maintained adult numbers at a significantly lower level than the untreated control at all sampling dates, and the reduction ranged from 51 to 85% However, the adult numbers increased to a higher level (above 100 adults per sample) at 61 DAP (Table 4.2).

TI and FS treatments did not provide early protection against adult colonisation. Significant reductions in adult numbers in FS and TI treatments were seen only by 42 and 61 DAP respectively. After 49 days, even though the adult numbers were significantly lower than the untreated control, adult numbers in all treatments had increased to higher levels (Table 4.2).

The adult numbers increased steadily on untreated plots after 49 days. This sudden increase was mainly due to the completion of generations within the crops. In the untreated plots, the plants were less attractive to adults due to high honeydew contamination, especially towards the end of the experiment. This may have increased adult movement from untreated plots to adjacent plots (Fig. 4.1)

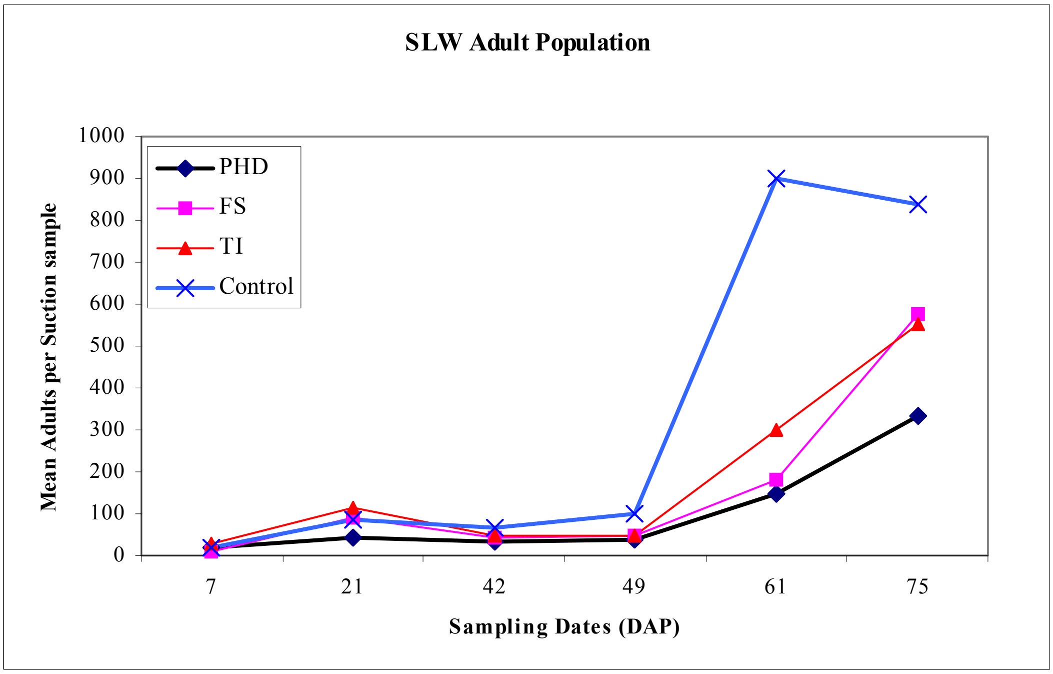


Fig. 4.1. Effect of imidacloprid soil applications on adult population on eggplant

Effect on oviposition

The effects of imidacloprid soil application on egg densities are shown in Table 4.3. At the first sampling date (12 DAP) only fresh eggs were detected in all treatments.

On the first sampling date (12 DAP) fewer eggs were recorded on the plants in PHD and FS treatments, whereas numbers on TI treatment plants were no different to the untreated control (Table 4.3).

In the PHD and FS treatments, the egg densities were significantly lower than in other treatments and the reduction persisted at successive sampling dates (Fig. 4.2). An increase in egg numbers occurred close to harvest (63 DAP), but numbers were still much lower than the untreated control (Table 4.3).

In the TI treatment, the mean egg densities were not significantly lower than untreated controls at most sampling dates.

Even though FS treated plants had moderate number of adults at the first two sampling dates, the treatment seems to have worked against egg laying females and significantly reduced the egg load on the leaves. However, PHD appeared to be superior to the FS treatments.

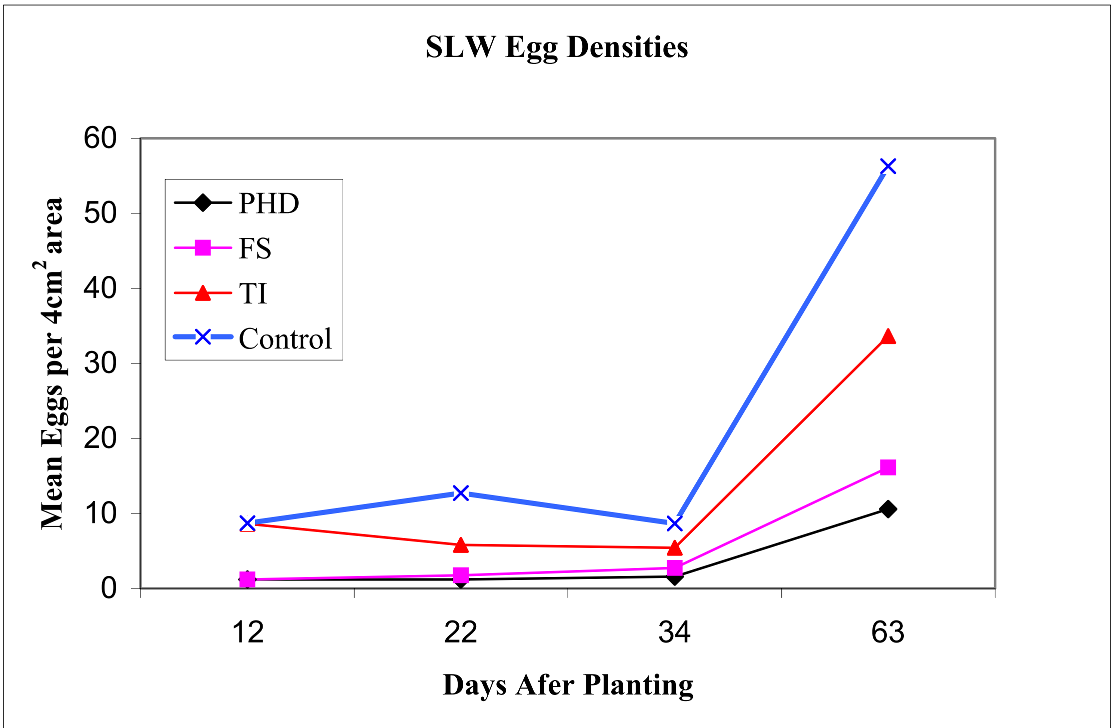


Fig 4.2. Effect of imidacloprid soil application methods on whitefly egg densities in eggplant

Effect on nymph population

Small nymph stage (1st and 2nd instar) establishment was detected from the second sampling date (22 DAP) and the initial infestation level was very high. All imidacloprid treatments had significantly lower number of small and large nymphs compared with the untreated control at third sampling date (34 DAP) (Table 4.4).

In the PHD treatment, the overall nymph numbers were significantly lower than in the untreated control at all sampling dates (Table 4.4). The overall nymph densities were around 3.5 nymphs/4 cm^2 at 48 DAP which was an acceptable level in eggplant (Table 4.4). The PHD provided higher reduction in nymph densities than all other treatments.

In the furrow spray treatment the mean nymph densities were significantly lower than in the untreated plots at the second and third sampling date (22 and 34 DAP), thereafter the overall nymph number increased to higher level of 6.6 nymphs/4 cm^2 (Table 4.4). Other studies indicated that a threshold exceeding 4 nymphs/4 cm^2 leaf area unmanageable and can cause high honeydew contamination on the fruits at harvest (Siva Subramaniam, unpublished).

TI treatment did not significantly reduce the nymph numbers at the second sampling date (22 DAP). Assessment of overall nymph numbers on leaves at 34 DAP showed that TI treatment reduced the nymph densities (Table 4.4). This could be due insufficient root development in the young plants to absorb and translocate the chemical to the leaves. It is often difficult to deliver the chemical accurately close to the root system via a trickle irrigation system because of the difficulties in aligning the emitters close to the root zone. Similarly, the nymph densities on trickle injected plants were lower than the untreated control at the fourth and fifth sampling dates (48 and 63 DAP), however the densities exceeded the threshold level (Table 4.4).

In the untreated control plots overall nymph numbers increased at an exponential rate and the densities increased from 12 nymphs/4 cm^2 at 22 DAP to 24.1 nymphs/4 cm^2 at 63 DAP (Table 4.4).

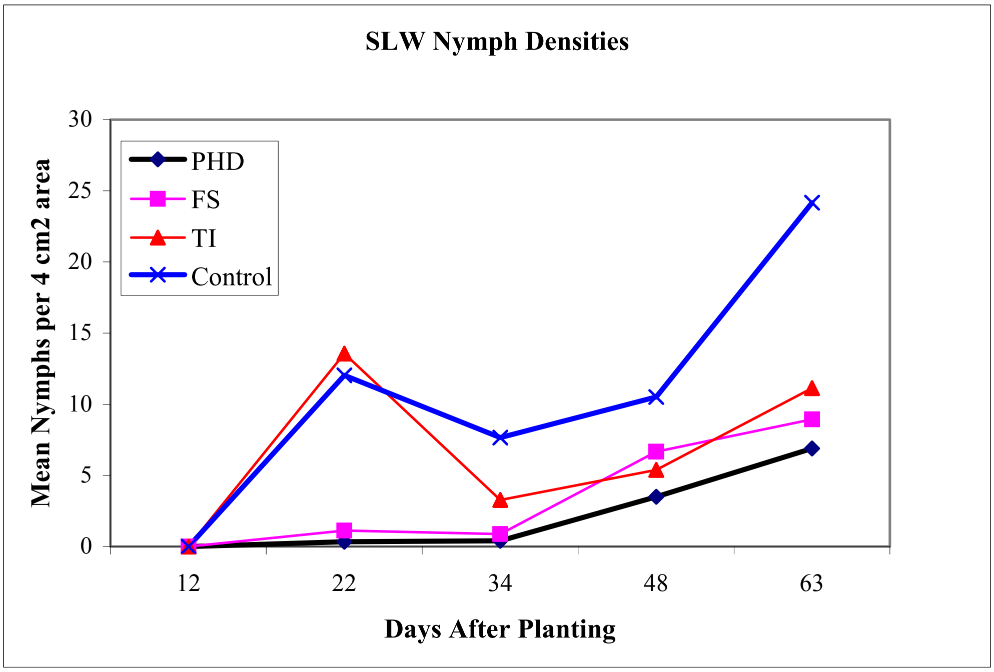


Fig 4.3. Effect of imidacloprid soil application methods on whitefly nymph (small and large) densities on eggplant leaves

Table 4.2. Effect of Imidacloprid Soil Application Methods on Whitefly Adult numbers in Eggplant - August to November, 2002

Treatments	Days After Planting (DAP)					
	7	21	42	49	61	75
	Mean number of Adults / suction sample					
PHD	20.7 a	42.3 b	32.3 b	36.0 b	145.7 c	355.7 b
Furrow Spray	15.0 a	90.0 a	41.7 b	49.3 a	183.0 b	574.0 a
Trickle Injection	26.3 a	112.0 a	50.0 ab	46.7 a	376.0 b	553.0 a
Untreated Control	18.7 a	84.7 a	68.5 a	101.0 a	898.0 a	839.0 a

Means within column followed by the same letter did not differ significantly at P > 0.05

Table 4.3. Effect of Imidacloprid Soil Application Methods on Whitefly Egg Densities in Eggplant - August to November, 2002

Treatments	Days After Planting (DAP)				
	12	22	34	48	63
	Mean Whitefly Eggs / 4 cm^2 leaf area				
PHD	1.20 b	1.20 b	1.58 b	N.A	10.57 b
Furrow Spray	1.20 b	1.73 b	2.75 a	N.A	16.15 b
Trickle Injection	8.60 a	5.79 a	5.42 a	N.A	33.63 a
Untreated Control	8.72 a	12.72 a	8.65 a	N.A	56.30 a

Means within column followed by the same letter did not differ significantly at P > 0.05
N.A = data not available for the sampling date

Table 4.4. Effect of Imidacloprid Soil Application Methods on Whitefly Nymph Densities in Eggplant - August to November, 2002

Treatments	Days After Planting (DAP)				
	12	22	34	48	63
	Mean Small Nymphs / 4 cm^2 leaf area				
PHD	0.0	0.33 b	0.41 a	0.90 a	4.10 a
Furrow Spray	0.0	1.13 b	0.87 a	1.53 a	4.11 a
Trickle Injection	0.0	13.57 a	1.96 a	1.10 a	7.60 a
Control	0.0	12.03 a	3.46 a	1.77 a	16.30 a
	Mean Large Nymphs / 4 cm^2 leaf area				
PHD	0.0	0.0	0.01 c	2.60 b	2.83 b
Furrow Spray	0.0	0.0	0.01 c	5.13 a	4.83 a
Trickle Injection	0.0	0.0	1.33 b	4.30 a	3.53 b
Control	0.0	0.0	4.21 a	8.73 a	7.97 a
	All Nymphs / 4 cm^2 leaf area				
PHD	0.0	0.33 b	0.41 b	3.50 b	6.93 b
Furrow Spray	0.0	1.13 b	0.87 b	6.66 a	8.94 b
Trickle Injection	0.0	13.57 a	3.29 b	5.40 a	11.14 a
Control	0.0	12.03 a	7.67 a	10.50 a	24.27 a

Means within column followed by the same letter did not differ significantly at P > 0.05

Effect on whitefly generation development

Exuviae (empty pupal cases) on the leaves were recorded to indirectly assess the treatment effect on adult emergence. The first set of exuviae was detected on plants only at the third sampling date (34 DAP) and the numbers gradually increased at 48 DAP.

All three imidacloprid treatments had significantly lower numbers of exuviae than the untreated control at 3rd and 4th sampling dates (34 and 48DAP). Mean exuviae densities were much lower in PHD treatments (0.13/4 cm^2) than in other treatments (Fig. 4.4)

A gradual increase in adult numbers was noticed in the crop for the first 21 days indicating continued colonisation by adults from outside sources. During the experimental period the SLW appeared to complete two generations within the crop. This can be seen by a distinct peaks in adult numbers at 61 DAP (Table 4.2) and the presence of exuviae during that period. The first generation of adults possibly emerged from the first set of eggs detected on the leaves 12 DAP. This shows that it took around 20 days to complete the first generation (from egg to adult).

Imidacloprid applied at planting as PHD and FS effectively controlled both first and second generation development. However, trickle injection only provided moderate level of control for the second generation.

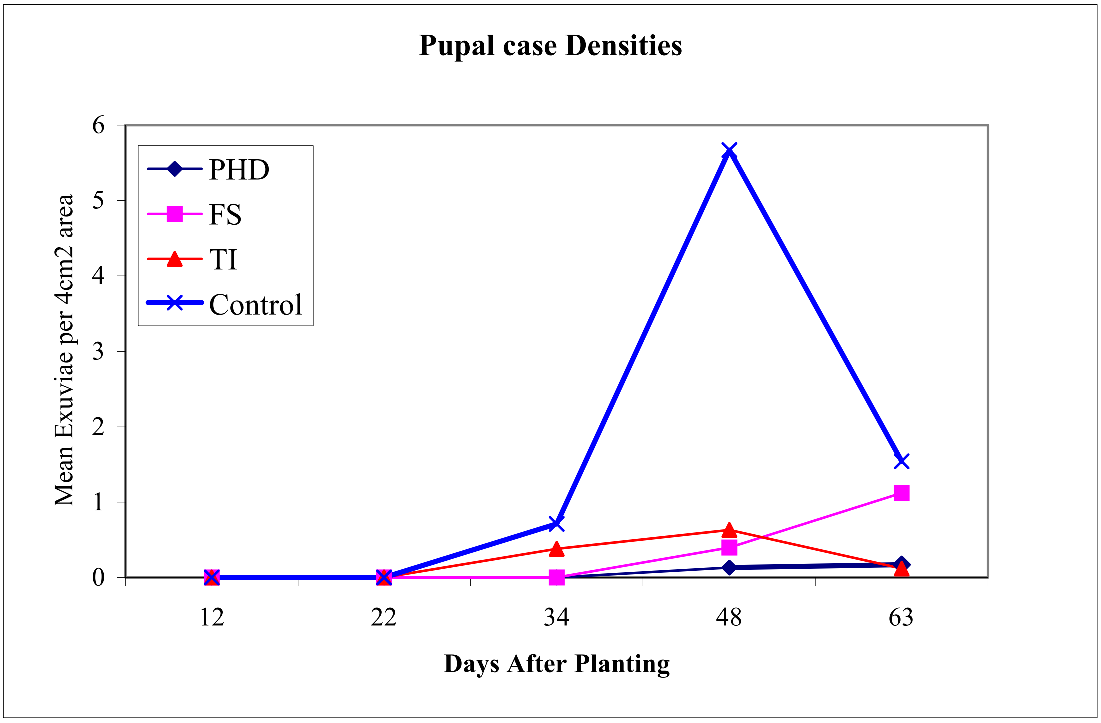


Fig 4.4. Effect of imidacloprid soil application methods on adult whitefly emergence (assessed as empty pupal cases on leaves)

Discussion

This study clearly shows that the soil application of imidacloprid is an effective method in the control of adult whiteflies and suppresses the development of immature stages. Reduction in immature colonisation following soil application showed a similar trend in all treatments, but the efficacy level and length of residual control varied with application techniques.

The PHD method has provided high level protection against SLW adult and immature stages for up to 7 weeks and prevented the population build-up in the later part of crop. The lower numbers of eggs and nymph stages in the PHD treated plants throughout the experiment indicates that the required rate of imidacloprid should be delivered within the root zone to achieve good SLW control. The PHD technique effectively places the chemical around the root zone, therefore the amount of chemical available to the plants is much higher than in the FS and TI treatments. Palumbo *et al* (1996) reported that soil placement of imidacloprid below 7.5 cm was not effectively taken up by the lettuce plants and did not prevent SLW colonisation.

FS treatment provided good protection against SLW for up to 5 weeks, thereafter did not give significant level of control. After the mid-crop stage (34 DAP), nymph numbers were still above the damage threshold level even though the population was significantly lower than the untreated control. Therefore supplementary insecticide sprays are required to provide adequate control until harvest. Westwood et al (1998) reported that imidacloprid is persistent in the soil for up to 97 days. The optimum imidacloprid rate required to provide adequate SLW control, especially in mature plants, is not clearly known.

TI treatments did not provide consistent level of residual control against SLW immature stages. This may be due to insufficient chemical present in the leaves to provide adequate control, especially when the plants are growing rapidly. Eggplants do have a relatively large root system that is much larger than a capsicum but not as large as tomatoes. They do have more secondary roots than tomatoes but their initial root development also is not as rapid as tomatoes (N. Meurant, personal communication). This may possibly explain why trickle injection did not give sufficient control against nymph and adult stages at early crop growth stage but provided some level of control three weeks after planting.

In the FS and TI methods the same amount of imidacloprid as in the PHD method was distributed across the entire row and therefore only a small proportion of the applied chemical would have been present in the active root zone and thus available to the plant. Trickle injection of imidacloprid is a more convenient and labour saving technique on a commercial scale. It is important to position the trickle emitters close to the root zone to optimise chemical uptake. However, it is difficult to align the emitters with the plant hole, especially in wider-spaced crops, so chemical wastage is high.

In most parts of Queensland, late season crops (August to December) often experience high SLW pressure, mainly due to hot and dry weather and migration from adjacent crops. Under dry and hot conditions, SLW developed significantly faster on eggplant than on tomato and cucurbits. Female flies reared on eggplant laid an average of 224 eggs, two to three times the average laid by females on other crops (Tsai, 1996). Soil application of imidacloprid, with optimal application methods, at planting would be an effective control option for SLW under these higher risk conditions.

These application methods require validation on a commercial scale. However, it should be considered that prophylactic application of imidacloprid increases the potential for development of resistance in SLW and aphid populations.

Conclusion

This study clearly demonstrated the long residual efficacy of soil applied imidacloprid against SLW colonisation in eggplant. PHD of imidacloprid provided the most effective whitefly control, with significant reduction in adult, egg and nymph numbers throughout the trial period.

Imidacloprid applied as a PHD at the time of planting provided a high level of protection against SLW stages for up to 7 weeks, even during the high pest pressure period. This single PHD can maintain SLW populations at a very low level from seedling to early fruiting stage in eggplant.

This study suggests that the amount of imidacloprid delivered through FS method was only sufficient to provide adequate control against whitefly stages for up to 5 weeks. To achieve a high marketable yield, an effective spray program should be supplemented with furrow treatments, especially during high pest pressure period.

Trickle injection of imidacloprid applied 5 DAP did not give consistent level of control against SLW stages. The TI treatment was ineffective in reducing egg and nymphs numbers at the early growth stage in eggplant.

Soil applied imidacloprid should be used when SLW populations are beginning to build or be applied at planting as a preventive measure during the high risk period. For example, in North Queensland crops planted from mid-July to September are often at higher risk, therefore soil application of imidacloprid is more appropriate during this period.

References

Mullin, JW. 1993. Imidacloprid: a new nitoroguanidine insecticide, pp 184-198. *In* Pest control with environmental safety. American Chemical Society Symposium Series 524.

Palumbo, JC; Kerns, DL; Engle, CE and Wilcox, M (1996). Imidacloprid formulation and soil placement effects on colonisation by sweet potato whitefly: Head size and incidence of chlorosis in lettuce. Journal of Economic Entomology. 89 (3): 735-742.

Tsai, J.H and Wang, K (1996) Development and reproduction of *Bemisia argentifolii* on five host plants. Environmental Entomology 25, 810-816.

Westwood, FK; Bean, KM and Chamberlain, K (1998). Movement and persistence of [C14] imidacloprid in sugar-beet plants following application to pelleted sugar-beet seed. Pesticide Science . 52: 92-103.

Picture 4.2. Honeydew and sooty mould contamination on leaves of eggplant

Picture 4.3. Silverleaf whitefly adults and nymphs on an eggplant leaf

Section 5

Effectiveness of Confidor® Soil Applications against Silverleaf Whitefly on Capsicum

Effectiveness of Confidor® Soil Application Methods against Silverleaf Whitefly on Capsicum

Introduction

Silverleaf whitefly (SLW), *Bemisia tabaci* Biotype B, also known as *Bemisia argentifolii*, is well established in most vegetable growing regions in Queensland. In the past few years, this insect has become a major pest on many vegetable crops including tomato, eggplant, cucurbits, melon, sweet potato, brassicas and lettuce. SLW has become a serious pest because of its high reproductive capability, wide host range, high rate of feeding and injection of toxic saliva into the plant and exudation of sticky honeydew.

SLW infestation on capsicum (*Capsicum annum*) and its subsequent damage to the crop not clearly understood. Our observation in commercial crops indicated that capsicum is a less attractive host crop to silverleaf whitefly. However, overseas studies indicated that SLW can cause damage to capsicum by sucking plant sap and covering plants with sticky honeydew. Black sooty mould grows over the honeydew, lowering the photosynthetic capacity of the plant (Bentley *et al* 2000)..

SLW adults feed and oviposit on the lower surface of leaves therefore a large proportion of eggs and nymphs infesting the crops are protected from contact insecticide sprays. An effective systemic insecticide against the pest would therefore alleviate the coverage problem associated with SLW control in capsicum.

Imidacloprid (Confidor®, Bayer Crop Science Australia), a chloronicotyl insecticide, has systemic activity through soil application and controls sucking pests such aphids and whiteflies. Imidacloprid is relatively immobile in the soil and efficient root uptake is dependent on precise placement of the chemical within the root zone (Mullins 1993).

The objective of this study was to evaluate the efficacy of three imidacloprid soil application techniques on controlling SLW in capsicum.

Materials and Methods

Experimental details

The trial was established on a clay loam soil (light medium non-cracking clay, with cation exchange capacity 20 meq/100 g) at the QDPI research station, Bowen, Queensland. The experimental area consisted of polythene covered raised beds at 1.5 m row spacing. All experimental plots were grown with the trickle irrigation system (the commercial standard in Queensland) and irrigated at weekly intervals until final harvest. Commercial agronomic practices were followed to grow and maintain the experimental crops. Insecticides and fungicides to control other pests and diseases were carefully selected and only those known to have no significant impact on SLW were used so as not to confound the result.

Capsicum seedlings (variety Merlin) were transplanted 30 cm apart on 25 July 2002. Plots consisted of a single row 25m long with a 1m buffer row on both ends. Treatments were arranged in a randomised complete block design with three replicates (Appendix 1). The four treatments were plant hole drench (PHD), furrow spray (FS) and trickle injection (TI) and untreated control. A single soil application of imidacloprid (Confidor 200 SC, Bayer crop Science, Australia) was used during the planting time. Treatment details are summarised in Table 5.1.

Table 5.1. Confidor (200 SC) application methods, rate and application volume

Application method	Rate used for 25m row		Water volume per 25 m row	Application time
	Product (ml)	Active ingredient (g)		
Plant Hole Drench (PHD)	6.3 ml (0.07ml/ plant)	1.26g (0.014g/ plant)	3.3 L (38 ml / plant)	1 DAP
Furrow Spray (FS)	8.8 ml	1.76g	3 L	1 DBP
Trickle Injection (TI)	6.25 ml	1.25g	15 L	5 DAP

DAP = Days after planting; DBP = Days before planting

Application methods

Trickle Injection – The treatment was applied 5 days after planting (DAP). Imidacloprid solution (15 L) was injected through the trickle irrigation system (emitter spaced at 30 cm and flow rate 1.0 L/hr) using a pressure pump operated at 15 psi. At the end of injection, 5 L of water was used to wash out the tubes.

Plant Hole Drench - Pre-mixed imidacloprid solution was drenched around the base of each plant. A motorised knapsack sprayer fitted with adjustable nozzle was calibrated to deliver 38 ml of imidacloprid solution per plant .

Furrow spray - Imidacloprid solution was applied into pre-moistened furrows (8-cm wide and 5 cm depth) one day before planting. The spray volume was equally distributed to the furrow using a motorised sprayer fitted with high flow nozzle (TP 80.06 VP). The raised bed was covered with the plastic mulch immediately after the application.

Sampling methods

Capsicum plants were sampled for immature whitefly stages at 14-day intervals. Four mature base leaves (from the 7th or 8th main stem node position down from the terminal leaf) and four young leaves (from the 3rd or 4th main stem node position) were collected from four random plants in each plot. Leaf samples were taken to the laboratory where whole leaf area was assessed for immature stages under the microscope. Immature stages on each leaflet were classified as eggs, small nymphs (1st and 2nd instar), large nymphs (3rd instar and red-eye pupae) and exuviae (enclosed pupal cases).

Whitefly adults were sampled from four random plants per plot using a modified vacuum sampling machine. The suction samples were taken from the top one-third of the plants.

Results and Discussion

Effect on adult population

SLW adult infestation on capsicum seedling was very low throughout the trial period. Even though the trial was conducted during the high whitefly pressure period, SLW adult colonisation on the capsicum crop was at very lower level. The adjacent experimental crops, tomato and zucchini had very high level of adult population than capsicum.

No significant differences in adult numbers were observed between treatments at all sampling date (Table 5.2). The adult numbers recorded at first and second sampling dates were not sufficient enough (< 3 adults/ suction sample) to do meaningful statistical analysis. Adult numbers on the crop increased to moderate level (12 to 85 adults/ sample) at later sampling dates, but there were no significant differences between the treatments. In all treatments, a sudden increase in adult numbers at final sampling date (61DAP) was recorded and this was mainly due to the migration of adults from the adjacent declining crops (Fig 5.1). However, this adult population did not cause any noticeable damage to the crop.

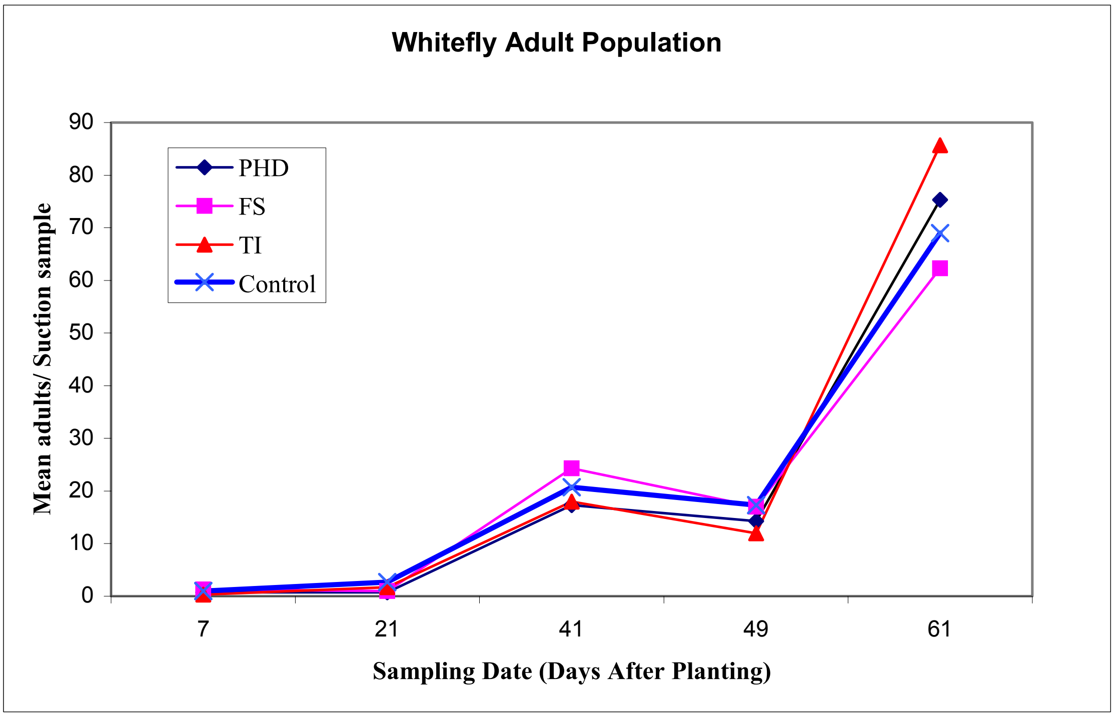


Fig 5.1. Imidacloprid soil applications on whitefly adult populations on capsicum

Table 5.2. Effect of Imidacloprid Soil Application Methods on Whitefly Adult numbers on Capsicum - August to November, 2002

Treatments	Days After Planting (DAP)				
	7	21	41	49	61
	Mean number of Adults / suction sample				
PHD	0.7	0.7	17.3 a	14.3 a	75.3 a
Furrow Spray	1.3	1.0	24.3 a	17.0 a	62.3 a
Trickle Injection	0.3	1.7	18.0 a	12.0 a	85.7 a
Untreated Control	1.0	2.7	20.7 a	17.3 a	69.0 a

Means within column followed by the same letter did not differ significantly at $P > 0.05$

Effect on oviposition and nymph development

The eggs and small nymphs (crawlers) recorded on the leaves at different sampling dates are shown in Table 5.3. In this study, the whole leaf area was assessed to count the egg and nymph numbers because of very low and uneven distribution of the stages on the leaves.

There were no significance differences in egg and nymph densities found among the treatments at the first four sampling dates. This was mainly due poor establishment of whitefly immature stages on the plants. At last sampling date (67 DAP), the mean egg and small nymph densities on PHD and FS treated plants were lower than in untreated controls. However, the nymph (first instar) numbers on the untreated plants did not cause significant damage to the crop.

A small proportion of eggs were able to reach the first instar stage on the capsicum leaves, but no survival was observed after the first instar stage in all treatments, (including untreated control). The absence of larger nymphs (2^{nd} and 3^{rd} instars and red-eye pupae) indicates that the nutrition in the capsicum leaves may not be suitable for the development of SLW nymphs.

Another study also showed that capsicum (pepper) varieties are poor reproductive host for *Bemisia argentifolii* (Nava-Camberos 2001). However, our observations show that two capsicum varieties (Seinor, Matrix) become infested by this pest, especially when they are planted in close proximity to declining crops (Siva Subramaniam, 2002)

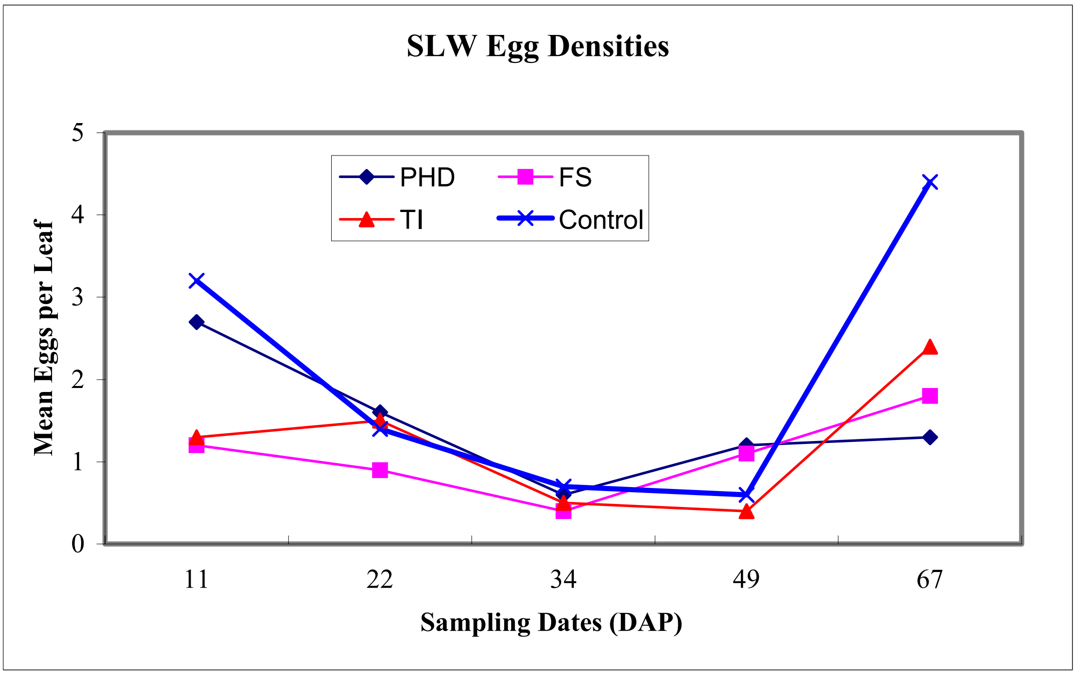


Fig 5.2. Effect of imidacloprid soil application methods on whitefly egg densities

Table 5.3. Effect of Imidacloprid Soil Application Methods on Whitefly Egg and Nymph Densities on Capsicum - August to November, 2002

	Days After Planting (DAP)				
	11	22	34	49	67
Treatments	Mean Whitefly Eggs / leaf				
PHD	2.7	1.6	0.6	1.2	1.3 a
Furrow Spray	1.2	0.9	0.4	1.1	1.8 a
Trickle Injection	1.3	1.5	0.5	0.4	2.4 a
Untreated Control	3.2	1.4	0.7	0.6	4.4 a
	Mean Small Nymphs / leaf				
PHD	0.0	0.1	0.0	0.3	0.4 a
Furrow Spray	0.0	0.9	0.3	1.0	2.1 a
Trickle Injection	0.0	1.9	0.1	1.2	3.2 a
Control	0.0	2.0	0.3	0.5	3.8 a

Statistical analysis was carried out only for the last sampling data. Means within column followed by the same letter did not differ significantly at P > 0.05

Whitefly generation development on host plant

The suitability of a host can be judged by the size of the progenies developed on them. The number of pupal cases (exuviae) which remain attached to the leaf surface would, therefore, be a reliable criterion to categorise the status of the host plant.

No empty pupal cases on the leaves were recorded throughout the sampling period in any of the treatments, including untreated controls. The absence of large nymphs, red-eye pupae and exuviae on the leaf samples clearly indicate that whitefly did not complete generations within the crop. A sudden increase in adult numbers at the last sampling date (61DAP) was mainly due to the migration of adults from adjacent declining crops.

The continuous leaf sampling throughout the trial period did not find any pupal cases on the leaf which clearly shows that this capsicum variety is not a suitable breeding host for whitefly.

Conclusion

SLW adults laid eggs on the leaves and small proportion of eggs hatched and produced first instar nymphs. Only the first instar nymphs were able to survive on the leaves. No nymph development past the first instar occurred on the capsicum plant

The absence of large nymph stages (2^{nd} and 3^{rd} instars and red-eye pupae) and empty pupal cases on the leaves suggests that SLW could not complete a generation in the capsicum crop.

This result indicates that capsicum, particularly the popular commercial variety Merlin, could not be a suitable host for silverleaf whitefly reproduction. Therefore, the preventive soil application of imidacloprid at planting is not required for SLW control in capsicum.

In most parts of Queensland, late season crops (August to December) often experience high SLW pressure, mainly due to hot and dry weather and migration from adjacent crops. In such a high pest pressure situation, the capsicum crops may require foliar sprays to control colonising adult population.

References

Bentley, W.J (2000). University of California pest management guidelines: peppers. UC website, http://www.ipm.ucdavis.edu.

Mullin, JW. 1993. Imidacloprid: a new nitoroguanidine insecticide, pp 184-198. *In* Pest control with environmental safety. American Chemical Society Symposium Series 524.

Nava-beros, U; Ridley, D.G and Harris, M.K (2001). Temperature and host plant effects on development, survival, and fecundity of *Bemisia argentifolii*. Environmental Entomology 30 (1): 55-63.

Siva Subramaniam and Paul De Barro (2002). Best management strategies for silverleaf whitefly in vegetable crops. Extension publication, DPI, 23 pp.

Section 6

Evaluating Insecticide Strategies Against Silverleaf Whitefly on Melons

Evaluating Insecticide Strategies against Silverleaf Whitefly on Melons

Introduction

Silverleaf whitefly, *Bemisia tabaci* (Gennadius) biotype B, is a serious pest of many crops, including melons (De Barro 1995).

A range of insecticides, applied in various ways, are used to manage the pest. On cucurbits, APVMA permits have allowed the use of foliar sprays of imidacloprid, D-C-Tron and bifenthrin and imidacloprid applied through the trickle system for some time. Recently, new insecticides such as pymetrozine and pyriproxyfen have become available for use against silverleaf whitefly, while new soil application methods for imidacloprid have been investigated.

In this trial we tested several insecticide strategies using the new insecticides and application methods to manage silverleaf whitefly on rockmelons.

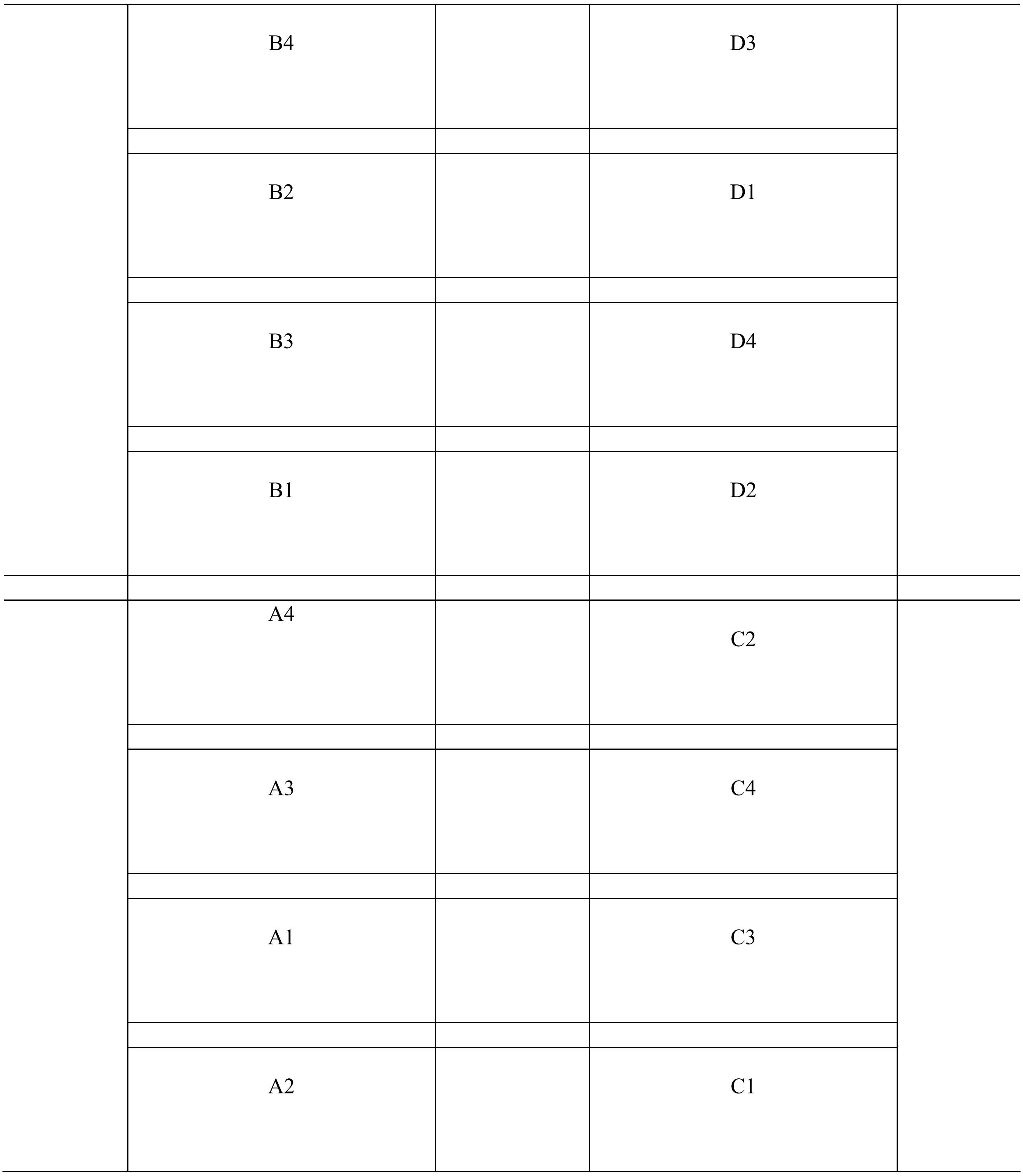
Materials and Methods

The trial was conducted at Bundaberg Research Station from September to December 2004.

Rockmelon seedlings, variety Dubloon, were planted in the field on 23rd September on black plastic mulch over trickle irrigation tubing. Seedlings were planted 0.5m apart in rows 1.5m apart. The crop was grown using standard irrigation and fertiliser practices, and was sprayed as necessary for disease control using chlorothalonil (Bravo) early in the crop (well before D-C-Tron was used), and then mancozeb, azoxystobin (Amistar), and fenarimol (Rubigan) as necessary.

The trial was a randomised replicated block design with four treatments and four replicates (Figure 6.1). Each plot consisted of 10m of row (20 plants) by four rows, and plots along a row

Figure 6.1. Trial design



Treatment 1: Confidor plant hole drench
Treatment 2: Admiral Early
Treatment 3: Admiral Late
Treatment 4: Standard

were separated by 2m without plants, and between rows by 3m of bare soil. The four treatments were called Confidor plant-hole drench (PHD), Admiral Early, Admiral Late, and Standard. There was no untreated check treatment because we were concerned that silverleaf whitefly numbers would increase rapidly in untreated plots, spread through the trial area, and confound and overwhelm the effects of the other treatments. Information on the insecticides used is given in Table 6.1.

Table 6.1. Insecticide products, active ingredients and formulations used

Trade Name	Active ingredient	Formulation
Admiral	Pyriproxyfen	100 g/L emulsifiable concentrate
Brella	Paraffinic mineral oil	791 g/L spray oil
Chess	Pymetrozine	500 g/kg wettable powder
Confidor 200SC	Imidacloprid	200 g/L suspension concentrate
D-C-Tron Plus	Petroleum oil	782 g/L emulsifiable spray oil
Enervate	Piperonyl butoxide	800 g/L
Talstar	Bifenthrin	100 g/L emulsifiable concentrate

In the Confidor plant-hole drench treatment, Confidor was applied at 0.02 g ai (= 0.2 ml product) in 40 ml of water per plant around the base of each plant at six days after planting. Other insecticides applications were made as necessary, based on whitefly numbers exceeding thresholds as shown in Table 5.2.

In the Admiral Early treatment, Admiral was applied to be within two weeks of planting when adults and eggs were present, and other insecticides were to be applied as necessary, based on whitefly numbers exceeding thresholds as shown in Table 6.2.

In the Admiral Late treatment, Admiral was to be applied later in the crop (3-4 weeks after planting) when nymphs were present. Other insecticides were to be applied as necessary, based on whitefly numbers exceeding thresholds as shown in Table 6.2.

In the Standard treatment, foliar sprays of Confidor, Talstar, or DC-Tron were to be applied when adults were present (Table 6.2).

The plant-hole drench was applied at the base of each plant using an Echo motorised knapsack sprayer with a lance and a nozzle, operated at low pressure, and calibrated to deliver 40ml of insecticide mixture in a given time.

Foliar insecticides were applied using either a knapsack sprayer or a tractor-mounted boom. The knapsack sprayer was an Echo motorised sprayer with a 1m boom fitted with four Albuz brown hollow cone nozzles, and operated at 480 kPa. Small plants were sprayed with the equivalent of 250 L/ha of water, while 500 L/ha was used on larger plants. A tractor-mounted boom sprayer fitted with Teejet twin flat spray tip nozzles operated at 480 kPa was used to apply the insecticides in approximately 830 L/ha of water once the plants had grown to fill the plot area.

Table 6.2. Planned treatments and thresholds

Treatments	First application (1-2 weeks post-plant)		Second application (3-4 weeks post-plant)		Third application (5-6 weeks post-plant)		After fruit set
	Threshold	Chemical	Threshold	Chemical	Threshold	Chemical	Thresh/chem.
Plant-hole drench	-	Confidor (soil)	-	Not required	3-4 adults/leaf	Brella	If high adult numbers use Talstar plus Enervate
Admiral Early	1-3 adults/leaf + 3-4 eggs/4cm^2	Admiral	1-3 adults/leaf	Brella	3-4 adults/leaf	Brella	
			>4 adults	Chess			
Admiral Late	1-3 adults/leaf	Brella	1-2 small nymphs/4cm^2	Admiral	3-4 adults/leaf	Brella	
	>4 adults/leaf	Chess			>5 adults/leaf	Chess	
Standard	>4 adults/leaf	Confidor (foliar); Talstar	>4 adults/leaf	D-C-Tron; Talstar	>4 adults/leaf	Confidor (foliar)	Talstar

The actual insecticides that were applied to each treatment, the rates of application, and the application methods used are detailed in Table 6.3.

Silverleaf whitefly sampling

All sampling was done in the middle two rows of the plots, leaving a 1m buffer at each end.

Numbers of adults were counted each week. Sampling was done early in the morning before the adults became too active. The second or third leaf back from the tip of a main runner was carefully turned over and the adults on the underside counted. Adults were counted on 10 leaves/plot (five from each row) for the first five weeks and then on five leaves/plot (2 and 3 from each row). The number of adults on the 10 or five leaves were totalled, and the mean number per leaf calculated. Analyses of variance were done on the mean numbers per leaf after square root (x + 0.5) transformation on each sample date.

The numbers of eggs and nymphs were counted on leaves 5 or 6 and on leaves 9 to 13 (usually leaf 12) back from the tip on main runners. Five leaves from each row were collected into a paper bag, and taken to the laboratory where numbers of eggs and nymphs in two 1cm^2 squares on each side of the mid vein (i.e. in four 1cm^2 squares for each leaf) on the underside of each leaf were counted under a stereo microscope at 10-15 times magnification. Nymphs were counted as nymphs or red-eye final instars, and empty cases were counted. Rain interrupted the collection of leaf 5-6 in Sample 3, on 19th October, and only two replicates were sampled. The mean numbers per 4cm^2 were calculated, and analyses of variance done on these numbers of eggs and nymphs following square root (x + 0.5) transformation.

Table 6.3. Insecticide applications made to each treatment

Date (2004)	Chemical, rate of product, and method of application* used on each date on each treatment			
	Plant-hole drench	Admiral Early	Admiral Late	Standard
29 Sept.	Confidor; 0.2 mL/plant; KN	-	-	-
7 Oct.	-	Admiral; 500 mL/ha; KN	Chess; 200 g/ha; KN	Talstar; 40 mL/ha; KN
12 Oct.	-	Chess; 200 g/ha; KN	-	Confidor; 300mL/ha; KN
22 Oct.	-	-	Admiral; 500mL/ha; KN	-
28 Oct.	-	-	-	D-C-Tron; 0.5%; T
3 Nov.	-	-	Brella; 0.5%; T	Confidor; 375mL/ha; T
12 Nov.	Talstar + Enervate; 600mL/ha + 250mL/ha; T	Talstar + Enervate; 600mL/ha + 250mL/ha; T	Talstar + Enervate; 600mL/ha + 250mL/ha; T	Talstar; 600mL/ha;T
18 Nov.	Talstar + Enervate; 600mL/ha + 250mL/ha; T	Talstar + Enervate; 600mL/ha + 250mL/ha; T	Talstar + Enervate; 600mL/ha + 250mL/ha; T	Talstar; 600mL/ha;T
26 Nov.	Talstar + Enervate; 600mL/ha + 250mL/ha; T	Talstar + Enervate; 600mL/ha + 250mL/ha; T	Talstar + Enervate; 600mL/ha + 250mL/ha; T	Talstar; 600mL/ha;T

*Application method: KN = knapsack; T = tractor.

Fruit assessments

Slipped and half-slipped fruit from the centre two rows of each plot were harvested on four occasions over a 10 day period from 22nd November to 2nd December. Fruit were counted and each fruit was weighed separately. We attempted to rate fruit for the amount of sooty mould on the surface where 0 = no visible sign of sooty mould; 1 = <5% of the surface area with light sooty mould; 2 = 6 – 20% of the surface area with light sooty mould; 3 = 21 – 40% with light to moderate sooty mould; 5 = >40% with sooty mould, with heavy patches. However it was difficult to determine sooty mould ratings, especially on several harvest days when fruit were wet from rain when picked, so the rating results are considered unreliable.

On each harvest date, except the second when few fruit were picked, five marketable fruit were selected from those harvested from each plot and analysed for sweetness using Brix testing. The whole flesh method as described by Martin *et al.* (2004) was used. Each melon was placed with ground spot downwards and a core from skin to seed cavity taken from each side. The skin and seed remnants were trimmed off, and the remaining flesh crushed. The Brix of the juice from the crushed flesh was measured using a Leica OE 200 temperature compensated refractometer.

Analyses of variance were done on number and weight of fruit and mean Brix value on each harvest date, and on the combined harvest data.

Results

There were numerically fewer adults on leaves in the PHD treatment than in the other treatments from Sample 1 to Sample 5, and significantly ($P<0.05$) fewer in Samples 1, 4 and 5 (Table 6.4 and Figure 6. 2). Numbers in all treatments fell and were low in Sample 3 as there was a storm with heavy rain the previous night that clearly affected adults. Numbers in all treatments increased from Sample 5 to Sample 6. The plants were mature with few fresh leaves on major runners on Sample 7 so the results for that day should be treated with some caution.

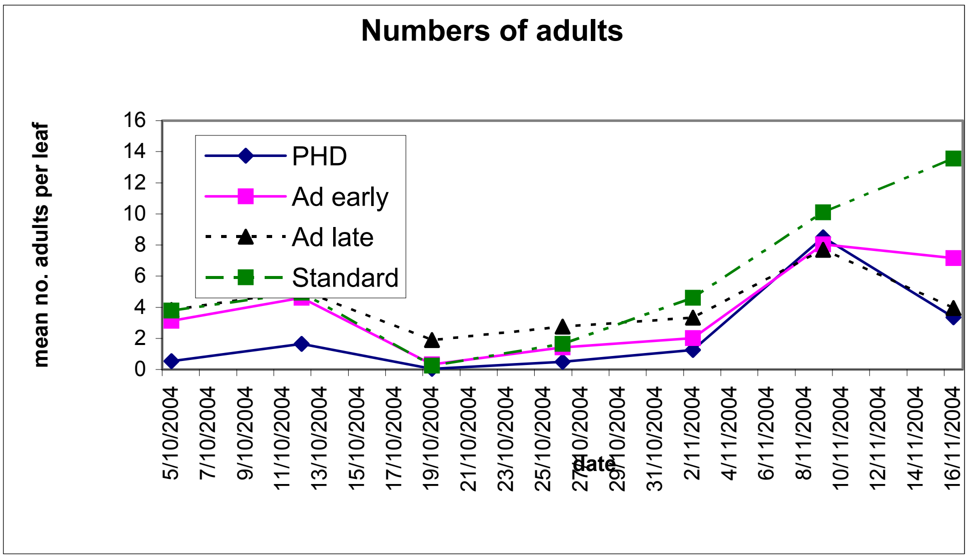


Fig. 6.2. The mean number of adults per leaf on each sample date

The PHD treatment was the most effective in controlling numbers of silverleaf whitefly on the plants. Adult numbers were lower, usually significantly so, in this treatment than in all the other treatments until early November when numbers increased throughout the trial. Numbers of eggs and nymphs on leaf 5-6 and on leaf 9-13 remained low until early November. These results indicate that the PHD treatment provided about five weeks protection to the plants. It may provide control for longer in a situation where a large area of crop was treated, keeping the total population low, so that it was not under continual pressure from whiteflies migrating from nearby source areas.

Table 6.4. Mean number of adults per leaf on each sampling date

Treatment	Mean number of adults per leaf on each sampling date * #						
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7
	5 Oct.	12 Oct.	19 Oct.	26 Oct.	2 Nov.	9 Nov.	16 Nov.
PHD	0.51 a	1.60 a	0.05 a	0.48 a	1.23 a	8.38 a	3.33 a
Admiral Early	3.09 b	4.30 a	0.30 a	1.39 b	2.01 b	7.68 a	6.78 ab
Admiral Late	3.62 b	4.43 a	1.81 b	2.65 c	3.25 c	7.12 a	3.91 a
Standard	3.67 b	4.52 a	0.24 a	1.64 b	4.51 d	9.36 a	12.58 b

* back-transformed means following square root (x + 0.5) transformation before analysis; # in each column means followed by the same letter are not significantly different at the 5% level.

On leaf 5-6 there were significantly fewer ($p<0.05$) eggs in the PHD treatment than in all the other treatments in Samples1, 2 and 5 (Table 6.5, Figure 6.3), and in Sample 3 there were many more eggs counted in the other three treatments compared to the PHD. In Samples 4 and 6 the PHD had fewer eggs than the other treatments, but not significantly ($p>0.05$) so from Admiral Early (Sample 4) or from the Standard (Sample 6). There were no significant differences ($p>0.05$) between treatments in Sample 7, although there were three to four times more eggs in the other treatments than in the PHD treatment.

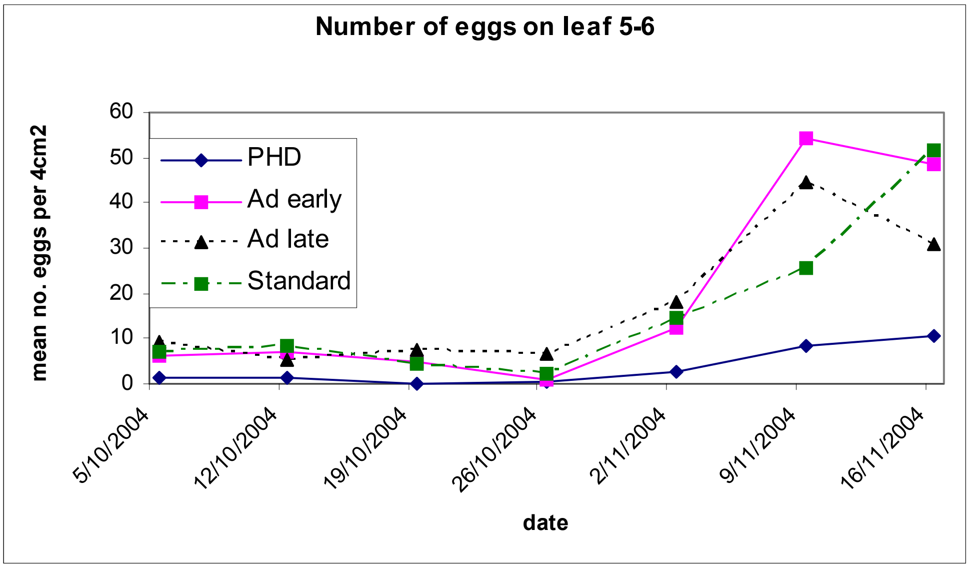


Fig. 6.3. The mean number of eggs per leaf on leaf 5-6 on each sample date

Very few nymphs were found on leaf 5-6 in any treatment on the first five sample dates (Table 6.5, Figure 6.4). In Sample 6 there were significantly fewer ($p<0.05$) nymphs in the PHD treatment than the other treatments, while in Sample 7 the Admiral Early treatment had significantly more ($p>0.05$) nymphs than the other treatments.

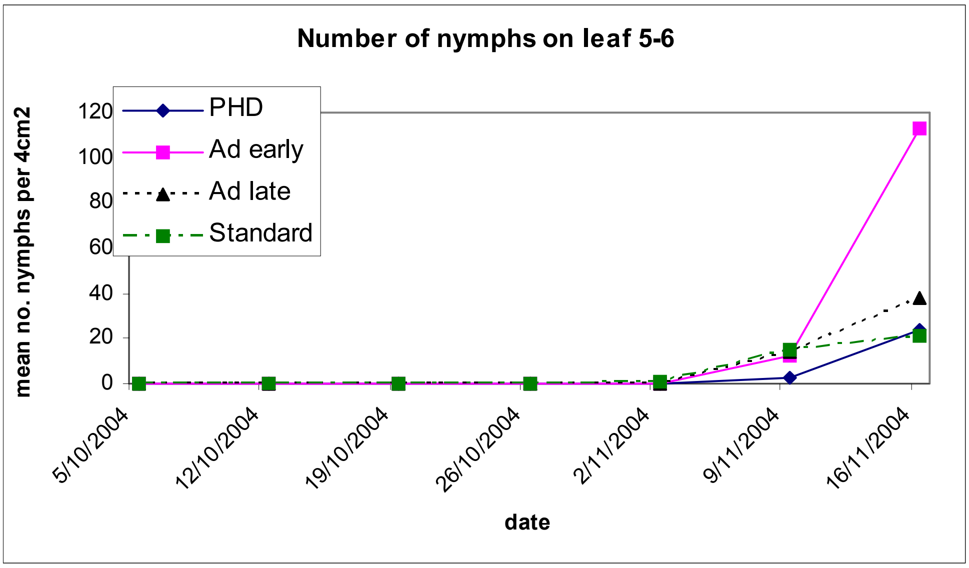


Fig. 6.4. The mean number of nymphs per leaf on leaf 5-6 on each sample date

The numbers of eggs and nymphs on leaf 9-13 are shown in Figures 5 and 6 and in Table 5.6. In general, on each sample date there were fewer eggs in the PHD treatment than in the other treatments, but not always significantly so. In Sample 3, both the PHD and Admiral Early treatments had significantly fewer nymphs than the other treatments, and while the number of nymphs in the PHD remained comparatively low, the numbers in the Admiral Early treatment increased to be significantly the same as, or higher than, those in the other treatments.

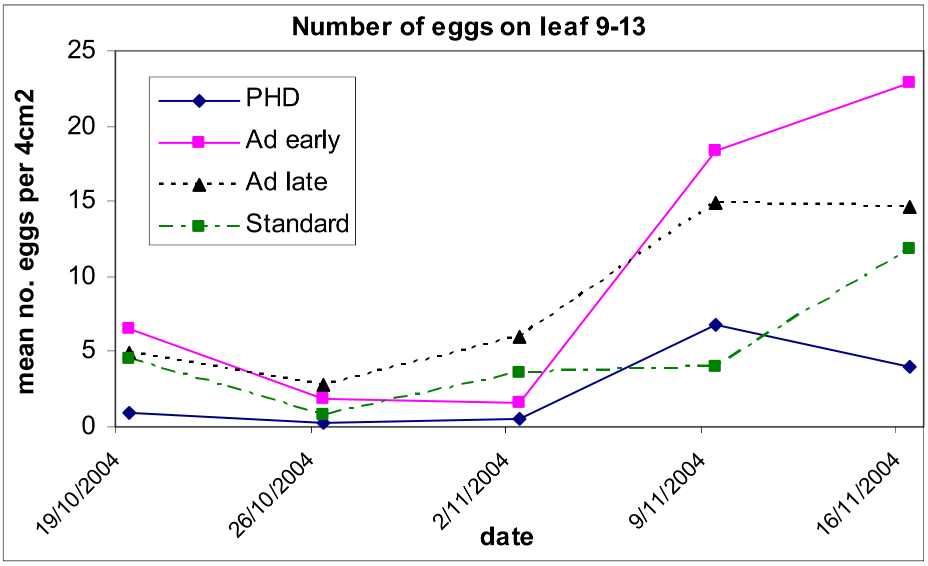


Fig. 6.5. The mean number of eggs per leaf on leaf 9-13 on each sample date

Some red-eye nymphs and very few empty 'pupal' cases were recorded in Sample 7 only. Too few empty cases were recorded to allow analysis. There were no significant differences ($p>0.5$) between the treatments in mean numbers of red-eye nymphs (PHD 0.24, Admiral Early 1.18, Admiral Late 1.10, Standard 0.70).

There were no significant differences ($p>0.5$) between treatments in numbers of fruit, fruit weight, or Brix levels on any harvest day or for the combined harvests (Table 7). The sooty mould rating results are considered unreliable because of difficulty in rating wet fruit, and so the results are not presented. However most sooty mould affected fruit were noted in block B (Figure 5.1), particularly in plots B2, B4 and B3, but fruit from the same treatments in other blocks generally were not contaminated by sooty mould, indicating a block effect rather than a treatment effect.

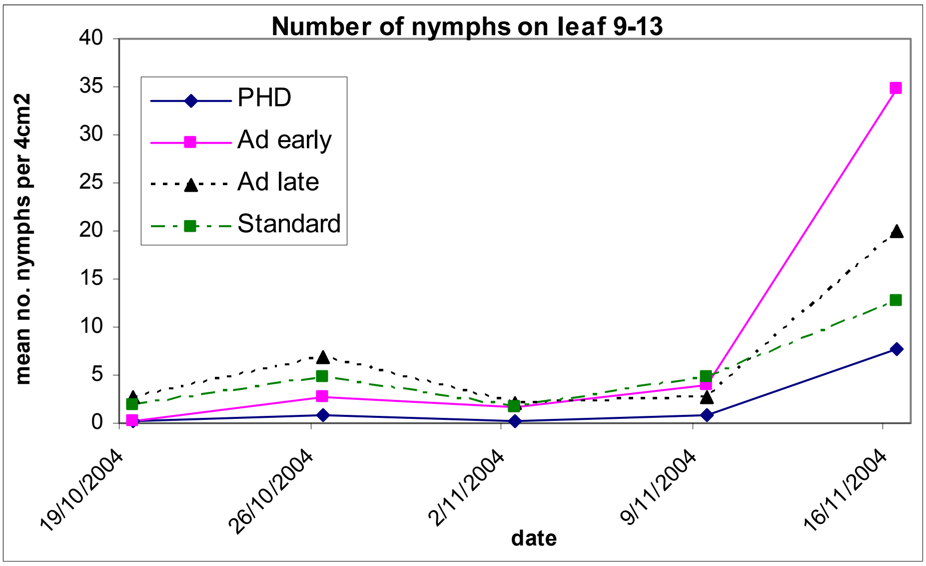


Fig. 6.6. The mean number of nymphs per leaf on leaf 9-13 on each sample date

Discussion

It is difficult to assess the true effectiveness of the treatments in the absence of an untreated check. However migration of silverleaf whiteflies between plots in the trial was evident, and this would undoubtedly have been worse if there had been untreated plots, justifying the decision not to have an untreated check. Comparisons between treatments still can be made. It could be argued that all the treatments provided acceptable control of silverleaf whitefly in that yields and Brix levels were high in all treatments, despite differences in whitefly numbers.

Table 6.5. Mean number of eggs and nymphs per sampling area on leaf 5-6 on each sampling date

Treatment	Mean number of eggs and nymphs per sampling area on each sampling date * #													
	Sample 1		Sample 2		Sample 3 ♦		Sample 4		Sample 5		Sample 6		Sample 7	
	5 Oct.		12 Oct.		19 Oct.		26 Oct.		2 Nov.		9 Nov.		16 Nov.	
	eggs	nymphs ♠	eggs	nymphs ♠	eggs	nymphs ♠	eggs	nymphs ♠	eggs	nymphs ♠	eggs	nymphs	eggs	nymphs
PHD	1.39 a	0	1.07 a	0	0.1	0	0.26 a	0	2.41 a	0	7.73 a	2.18 a	10.4 a	22.21 a
Admiral Early	5.15 b	0.03	6.74 b	0	4.8	0	0.96 ab	0.05	10.95 b	0.4	53.52 c	11.67 b	46.4 a	104.0 b
Admiral Late	8.72 b	0.05	5.14 b	0.08	7.5	0	6.68 c	0.15	17.47 b	0	38.80 bc	13.75 b	30.3 a	37.77 a
Standard	6.47 b	0.18	8.04 b	0	4.3	0.1	1.99 b	0	14.28 b	1.3	19.96 ab	13.40 b	40.0 a	19.91 a

** back-transformed means following square root (x + 0.5) transformation before analysis; # in each column means followed by the same letter are not significantly different at the 5% level; ♦ two replicates only sampled because of rain so analyses not done; ♠ analyses not possible because of many zero counts.*

Table 6.6. Mean number of eggs and nymphs per sampling area on leaf 9-13 on each sampling date

Treatment	**Mean number of eggs and nymphs per sampling area on each sampling date** * #									
	Sample 3		Sample 4		Sample 5		Sample 6		Sample 7	
	19 Oct.		26 Oct.		2 Nov.		9 Nov.		16 Nov.	
	eggs	nymphs	eggs	nymphs	eggs	nymphs	eggs	nymphs	eggs	nymphs
PHD	0.84 a	0.27 a	0.23 a	0.89 a	0.44 a	0.22 a	6.43 a	0.76 a	3.66 a	7.61 a
Admiral Early	6.36 b	0.28 a	1.69 bc	2.31 ab	1.55 ab	1.57 b	18.28 b	3.89 bc	22.09 c	34.10 c
Admiral Late	4.61 b	2.60 b	2.66 c	6.27 c	5.32 c	1.84 b	13.85 b	2.62 b	14.00 b	18.86 b
Standard	4.14 b	1.89 b	0.75 ab	4.23 bc	1.93 bc	1.51 b	3.90 a	4.54 c	11.06 b	12.33 ab

* back-transformed means following square root (x + 0.5) transformation before analysis; # in each column means followed by the same letter are not significantly different at the 5% level.

Table 6.7. Mean number, weight and Brix values of fruit in each harvest, and in total

Treatment	Mean number, weight and Brix values of fruit #														
	Harvest 1			Harvest 2			Harvest 3			Harvest 4			Total		
	No.	Wt (kg)	Brix	No.	Wt (kg)	Brix	No.	Wt (kg)	Brix	No.	Wt (kg)	Brix	No.	Wt (kg)	Brix
PHD	39.0 a	34.7 a	11.68 a	7.3 a	7.53 a	-	23.2 a	29.7 a	11.07 a	38.5 a	54.8 a	11.47 a	108.0 a	126.6 a	11.41 a
Admiral Early	41.2 a	36.8 a	12.08 a	5.3 a	5.32 a	-	18.5 a	22.3 a	10.20 a	35.8 a	47.0 a	9.97 a	100.8 a	111.5 a	10.75 a
Admiral Late	42.0 a	38.2 a	11.58 a	5.0 a	5.28 a	-	26.2 a	31.9 a	9.77 a	38.2 a	51.4 a	11.0 a	111.5 a	126.8 a	10.79 a
Standard	47.0 a	43.0 a	12.18 a	5.5 a	6.37 a	-	22.5 a	27.5 a	10.38 a	43.0 a	59.5 a	10.65 a	117.0 a	136.4 a	11.07 a

in each column means followed by the same letter are not significantly different at the 5% level.

The PHD treatment was the most effective in controlling numbers of silverleaf whitefly on the plants. Adult numbers were lower, usually significantly so, in this treatment than in all the other treatments until early November when numbers increased throughout the trial. Numbers of eggs and nymphs on leaf 5-6 and on leaf 9-13 remained low until early November. These results indicate that the PHD treatment provided about five weeks protection to the plants. It may provide control for longer in a situation where a large area of crop was treated, keeping the total population low, so that it was not under continual pressure from whiteflies migrating from nearby source areas.

In the Admiral Early treatment, the Admiral was applied within two weeks of planting, and Chess was applied five days later when adults exceeded the threshold. The results of adult counts, and egg and nymph numbers on leaves 5-6 and 9-13 indicated control equivalent to the standard until early November, but after that it was the worst treatment.

The Admiral Late treatment was the least successful of the treatments in controlling whitefly numbers. The application of Chess on 7th October appeared to result in a drop in egg numbers on leaf 5-6 on 12th October. The Admiral was applied on 22nd October, but it appeared to have little impact on numbers of eggs on leaves 5-6 or 9-13. There is some indication that numbers of nymphs on leaf 9-13 were lower than would be expected from previously recorded egg numbers, possibly demonstrating some effect from the treatment.

The Standard treatment, with applications of Talstar, Confidor as a foliar spray, and D-C-Tron, performed as well as or better than the Admiral treatments.

By mid November silverleaf whitefly numbers had increased to quite high levels all through the trial area. Movement of adults from nearby volunteer host plants was observed, and there probably was migration from further afield as there were high infestations in the general district, resulting in constant re-infestation of the trial area, particularly in blocks B and D. Adult numbers were clearly high enough each week to warrant spraying with Talstar or Talstar + Enervate. There is some indication from the adult counts on 16th November (Figure 2, Table 4) that the application of Talstar + Enervate on 12th November was more effective than Talstar alone (i.e. there were significantly fewer ($p<0.05$) adults in two of the other three treatments compared to Standard; and falls in adult numbers in the Talstar + Enervate treated plots compared to a rise in the plots treated with Talstar alone). The effects of the second and third applications of Talstar or Talstar + Enervate were not monitored as there were few suitable leaves available on which to sample adults due to the maturity of the plants and the effects of harvesting procedures.

The effect of heavy rain on silverleaf whitefly adults can be seen in the counts of adults on 19th October (Sample 3) and counts of eggs on 26th October following the storm on the night of 18th October. Adult numbers were much lower in all treatments the next day, while egg numbers on leaves 5-6 and 9-13 were generally lower in the following week's sample. Higher population levels may have developed in all treatments in the crop if adult numbers had not been reduced by this rainfall event.

Although silverleaf whitefly numbers increased to quite high levels by the end of the trial, there were no differences in fruit yield between the treatments, and Brix levels were uniformly high. The plants in the trial grew vigorously and rapidly, and presumably were not adversely affected by the numbers of whiteflies present.

References

De Barro, P. J. (1995) *Bemisia tabaci* biotype B: a review of its biology, distribution and control. CSIRO Division of Entomology Technical Paper No. 13.

Martin, E., Rogers, G. and Walsh, K. (2004) Variability in rockmelon Brix results highlights need for industry standards. Australian Melon Runner Magazine **18**: 5.

Section 7

Evaluation of insecticide strategies against silverleaf whitefly on tomato

Evaluation of insecticide strategies against silverleaf whitefly on tomatoes

Introduction

Silverleaf whitefly (SLW) has been the major pest of tomatoes in Queensland since 1998. This polyphagous pest causes severe damage to the crops through direct feeding, honeydew contamination of product and by injecting saliva into plants which leads physiological damage. The crop losses in the 2000 and 2001 years due to unmarketable fruits ranged between 10 to 40%.

SLW infestation of tomato plants is associated with irregular ripening in fruits. In some tomato varieties the external symptoms may not be obvious, but often internal damage is quite apparent and may lead to market rejection.

SLW adults feed and oviposit on the lower surface of leaves therefore a large proportion of eggs and nymphs infesting the crops are difficult to reach using contact insecticides. Effective insecticides with translaminar or systemic activities would alleviate the problems associated with poor coverage problem.

The objective of this study was to evaluate the effectiveness of best chemical rotations in combination with damage threshold levels and best spray practices against SLW on tomato.

Materials and Methods

The trial was conducted at the DPIF research station, Bowen, Queensland from March to July, 2002. The experimental area consisted of 16 (80m long) polythene covered raised beds at 1.5 m row spacing (approx. 2000 m2 area). Insecticides and fungicides to control other pests and diseases were carefully selected and only those known to have no significant impact on SLW were used so as not to confound the result.

Tomato seedlings (Guardian, a ground-grown determinate variety) were transplanted 75 cm apart on 21 March 2002. Plots consisted of three rows 10m long with a 1m buffer row on both ends. Treatments were arranged in a randomised complete block design with four replicates.

Treatments

Two Best Management Options (BMO) and two Standard Grower Practice (SGP) treatments were arranged in a randomised block designed with three replicates. The insecticide treatments and spray threshold details are summarised in Table 7.1 and 7.2.

The crops were sampled at weekly intervals to determine SLW adults and nymphs densities and to take decision on applying insecticide treatments. The insecticide applications were initiated when the whitefly threshold reached around 3-5 adults per leaf and 5 nymphs per leaflet. The first spray was started on 17 May 2002 (8 WAP) and the second and third sprays were at 7 -10 day intervals.

Petroleum oil or Ark soap were selected when the adult thresholds were around 3-4 adults/ leaf. When thresholds reached to 5-10 adults/ leaf, pymetrozine, bifenthrin or imidacloprid were selected for treatments. SP/OP mixtures were selected when the adult thresholds exceeded 10 adults/ leaf. The treatments were applied using a tractor mounted boom sprayer fitted with flat fan nozzles (Teejet DG80015).

Table 7.1. Details of BMO and SGP treatments used for SLW control in tomato, 2001

Control Options	First spray 17 May	Second Spray 27 May	Third Spray 4 Jun	Fourth Spray 14 Jun	Clean –up Spray at harvest 2 July
BMO- 1	Pyriproxyfen (50g ai /ha) Pymetrozine (100 g ai/ ha)	Bifenthrin (60g ai/ ha)	Petroleum Oil (0.5%)	Soap (1%)	SP mixture-1
BMO- 2	Pymetrozine (100 g ai/ ha)	Pyriproxyfen (50 g ai/ ha)	Pymetrozine (100 g ai/ ha)	Petroleum Oil (0.5%)	SP mixture- 1
SGP -1	Imidacloprid (50g ai/ ha)	Petroleum Oil (0.5%)	Imidacloprid (60g ai/ ha)	SPmixture-1	SP mixture- 2
SGP- 2	Bifenthrin (40g ai/ ha)	Imidacloprid (60g ai/ ha)	Bifenthrin (60g ai/ ha)	SP mixture-1	SP mixture- 2
Spray Thresholds	> 5 nymphs /leaflet + 3-5 adults/ leaf	> 5 nymphs /leaflet + 3-5 adults/ leaf	3 – 10 adults/ leaf	3 – 10 adults/ leaf	Exceeded 10 adults/ leaf

SP mixture 1 – Bifenthrin + Propagite , SP mixture 2 – Bifenthrin + Chlorpyrifos

Sampling Methods

The effects of the spray treatments were assessed on eggs and nymph populations by collecting leaf samples. Tomato plants were sampled for immature whitefly stages at 7-day intervals following each insecticide applications. Five mature base leaflets (from the 7th main stem node position down from the terminal leaf), five middle leaflets (from the 4th main stem node position) and five young leaflets (from the 2nd main stem node position) were collected from five random plants in each plot. A total of 15 leaflets/ plot were collected. On each leaflet immature stages were counted under the microscope. Immature stages were classified as eggs, small nymphs (1st and 2nd instar) and large nymphs (3rd instar and red-eye pupae).

Whitefly adult populations were assessed at 5 to 7 days intervals following each insecticide application. Adults were sampled from 8-10 random plants per plot using a modified vacuum sampling machine. The suction samples were taken from the top one-third of the plants, covering five leaves from each plant.

Table 7.2. Properties of the insecticides selected for SLW control

Trade Name	Active ingredient	Formulation	Chemical group/ MOA	Route of Entry	Effect on SLW stages
Admiral	Pyriproxyfen	100 g/ L EC	IGR, Juvenile Hormone mimic	Translaminar	Egg sterility Nymphs
Chess	Pymetrozine	500 g/ kg WG	Antifeedent Pyridine	Translaminar	Adults
Confidor	Imidacloprid	200 g/L SC	Chloronicotinyl Acetylcholine antagonistic	Systemic through roots	Adults Nymphs
DC-Tron Plus	Petroleum oil	782 g/L mineral oil	Physical Suffocation	Contact	Adults Nymphs
Ark soap	Potassium soap	800 g/L	Physical Suffocation	Contact	Nymphs
Talstar	Bifenthrin	100 g/L EC	Pyrethroid, block Na+ Channel	Contact	Adults

Fruit harvest and assessment

Tomato fruits were harvested on 3 July 2002. Around 35 mature green fruits were harvested from 10 plants in each plot and were placed in an ethylene gas room at 20 °C for ripening. Fully ripened fruits were assessed for external and internal irregular ripening using a 0 to 4 scoring system (Table 7.3).

Table 7.3. Scoring system used for the assessment of SLW damage on tomato fruit

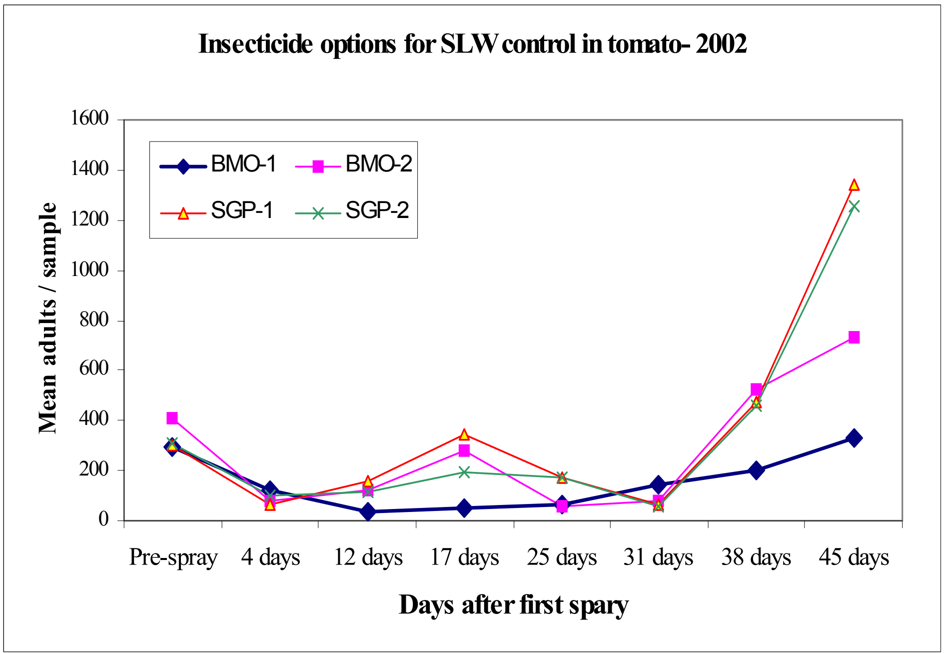
Score	External irregular ripening	Internal irregular ripening	Marketable grade
0	Full red colour	No white tissue inside	First grade
1	Slight blotches, but < 5% of fruit surface with uneven colour	< 5% internal area with slight white tissue	First grade
2	Moderate blotches, 6 to 20% of fruit surface with uneven colour	6 to 25% internal area with white or yellow tissue	Second grade
3	High uneven colours, 21 to 40% of fruit surface with uneven colour	26 to 50% internal area affected	Unmarketable
4	Over 40% fruit surface with uneven colour	> 50% internal area affected	Unmarketable

Results and Discussion

Effect on adult population

SLW adult infestation was low in the early part of the crop but increased to a higher level when the crop reached to early fruiting stage, 8 weeks after planting (Fig. 7.1). At pre-treatment sampling (16 May), the adult threshold level was 6-10 adults per leaf which warranted the insecticide applications. No significant differences in adult numbers were observed between treatments at the pre-treatment sampling date.

After the first spray, all the insecticide treatments had significantly fewer adults compared with pre-treatment samples. Among the treatments, pymetrozine and imidacloprid provided better adult control than bifenthrin (Table 7.4).



BMO-1 plots had significantly fewer adults than other three treatments at most sampling dates. GSP-1 and GSP-2 treatments provided shorter protection against adults than BMO-1 treatment (Table 7.4).

At harvest (01 July), adult numbers increased to high levels all through the trial area (Fig 8.1). The numbers were very high in the GSP-1 and GSP-2 treatments plots compared with the BMO treatments. This increase was mainly due to the mass emergence of adults from the eggs that were laid by the colonised adults at early part of treatments (3WAP). It took approximately five weeks to complete their generation. Movement of adults from the GSP plots to adjacent BMO plots was observed, and that some what masked the treatment effects in the later part of trial. Therefore, stronger products (SP mixtures, Table 7.1) were selected for the GSP 1 & 2 plots to control the adult populations.

GSP 1 & 2 were less effective in controlling adult population throughout the trial. Adult numbers were significantly higher ($P < 0.05$) in this treatment than in the BMO-1 treatment. In these treatments, foliar application of imidacloprid only provided short residual control. However the imidacloprid residual activity was much higher when it was applied close to the root system (see Section 2).

These results indicated that the BMO-1 (early pyriproxyfen + pymetrozine in rotation with oil & soap) provided consistent adult control in the later part of the crops. The pyriproxyfen does cause direct adult mortality, but a reduction in adult population was noticed 3- 4 weeks after the first application. This was mainly due its activity against eggs and nymphs and the subsequent reduction in adult emergence. This option may provide better control in a situation where a large area of crop was treated, so that it was not under continual pressure from whiteflies moving from other plots.

Table 7.4. Effect of insecticide treatments on whitefly adults in melon, 2002

Treatment Options	Mean number of adults per suction sample							
	Pre-spray	4 day after 1st spray	2 day after 2nd spray	7 day after 2nd spray	7 day after 3rd spray	4 day after 4th spray	11 day after 4th spray	18 day after 4th spray
	16 May	21 May	29 May	3 Jun	11 Jun	17 Jun	24 Jun	01 Jul
BMO 1	291 a	123 a	37 b	52 c	66 b	145 c	203 b	331 c
BMO 2	408 a	79 b	124 a	278 ab	59 b	76 c	524 a	734 b
GSP 1	303 a	61 b	158 a	346 a	175 a	68 b	470 a	1340 a
GSP 2	310 a	100 a	115 a	195 b	169 a	58 b	458 a	1259 a

Means within column followed by the same letter did not differ significantly at $P > 0.05$.

Effect on nymph populations

Nymph establishment was detected from the pre-treatment sampling date (16 May DAP) and the numbers gradually increased to a higher level at the end of the trial (Table 7.5).

The two BMOs and GPS-2 treatments had significantly lower numbers of nymphs than GSP-1 at last three sampling dates. The GSP-1 treatments had higher nymph densities (13 nymphs/ leaflet) at last sampling dates which were much higher than an acceptable level in tomatoes (Table 7.5).

In the BMO-1, nymph numbers were significantly lower than other treatments at most sampling dates. Pyriproxyfen in rotation with bifenthrin and petroleum oil gave significant reduction in nymph population throughout the trial period. This option resulted in fewer nymphs compared with other treatment combinations at 3rd, 4th, 5th and 6th sampling dates (Table 7.5). These nymph densities were around 3-4 nymphs / leaflet which is an acceptable level in mature tomato crop.

Pyriproxyfen, an insect growth regulator, has a completely different mode of action from other products used in tomatoes. Previous trials conducted in tomatoes showed that two applications of pyriproxyfen at 14 days intervals suppressed SLW population for up to 8 weeks.

Table 7.5 Effect of insecticide rotation on SLW nymphs, 2002

Treatment Options	Mean nymphs per leaflet and sampling dates					
	Pre-spray	12 Days after 1st Spray	11 Days after 2nd Spray	15 Days after 3rd Spray	13 Days after 4th Spray	19 Days after 4th spray
	16 May	29 May	7 Jun.	19 Jun.	26 Jun.	2 Jul.
BMO 1	8.9 a	13.5 a	3.7 b	2.3 c	4.1 b	2.4 c
BMO 2	9.6 a	8.8 a	11.6 a	6.2 b	4.7 b	6.3 b
GSP 1	7.1 a	14.4 a	11.4 a	13.6 a	14.7 a	13.3 a
GSP 2	8.6 a	12.5 a	11.2 a	5.2 b	7.2 b	6.4 b

Means within column followed by the same letter did not differ significantly at $P > 0.05$.

In the BMO-2, the nymph densities were significantly lower than the GSP-1 in the last three samplings. However, nymph numbers were much higher than in the BMO-1 samples. In BMO-2, pyriproxyfen was applied 10 days later and appeared less effective than the early application.

It is important to apply the pyriproxyfen in the early part of the crop to optimise chemical uptake and to allow sufficient time for the product work against SLW eggs and nymphs.

In GSP-2, foliar application of imidacloprid in rotation with two bifenthrin sprays provided better control than two imidacloprid sprays (GSP-1) in rotation with petroleum oil.

Effect on fruit quality and marketable yield

Fruits harvested from the plots treated with BMO-1 had a lower level of irregular ripening damage than the fruits from other treatments. Around 76% of the fruits with little or no irregular ripening damage were harvested from BMO-1 treatments where the crop was protected from SLW infestations (Fig 7.2).

The percentage of internally damaged fruit (white tissue) was high in the GSP-1 treatment where around 44% of fruits were unmarketable.

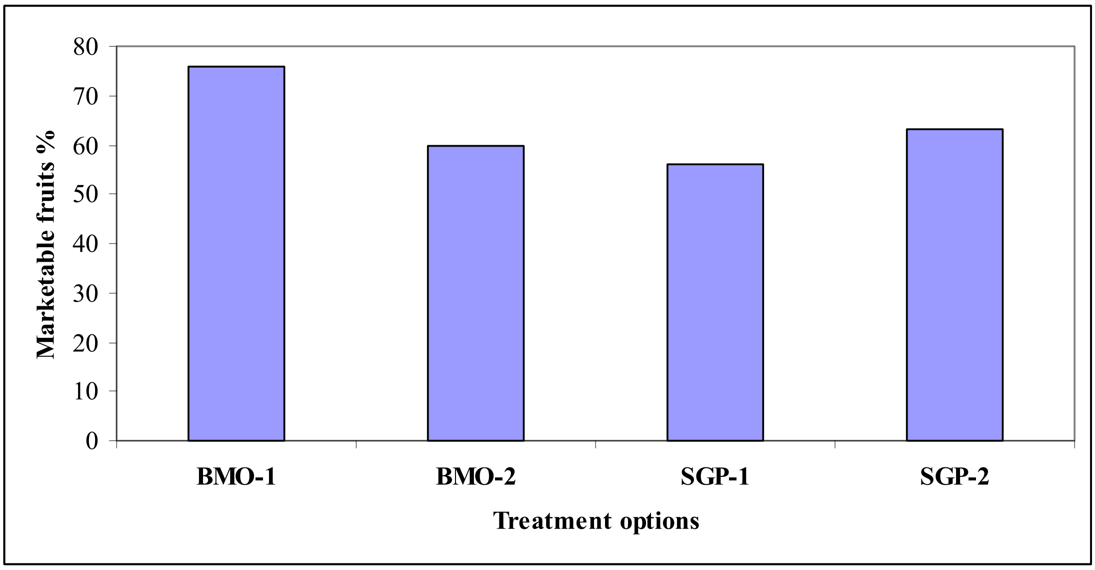


Fig 7.2 Effect of insecticide rotations on fruit quality and marketable fruits

In commercial packing houses field-harvested tomato fruit are sorted based on external colour. There is no reliable non-destructive method available to detect internal damage. Undetected internal damage can cause consumer dissatisfaction and potentially risk loss of sales. Therefore, an effective SLW control in the field is very important in tomatoes.

Conclusion

The IGR pyriproxyfen and pymetrozine, in rotation with bifenthrin, petroleum oil and soap provided high levels of whitefly control and high quality marketable fruit. This should be integrated with a better sampling plan, application timing and spray thresholds.

These new chemistries are low toxic to beneficial insects such parasitoids and predators which are naturally occurring in the field. The products would be an appropriate choice during early part of the crop where beneficial insect populations could be established. Highly toxic chemicals such as bifenthrin and mixture should be used in the later part of crop.

Imidacloprid foliar application has the limited potential for SLW management in tomatoes. However, approval for soil application of imidacloprid has recently been granted for SLW in some vegetables crops.

Without the new chemistry it is anticipated that insecticide resistance will lead to increasing difficulties in managing silverleaf whitefly. An area-wide insecticide resistance management strategy is seen as essential in protecting the new products.

Section - 8

Technology Transfer and Extension

Technology Transfer and Extension

Industry Meetings

2003 Information sessions and grower meetings

Four early season silverleaf whitefly information meetings, each of 3 to 4 hrs duration, were held in the major vegetable production regions of Queensland The subject areas covered at these meetings included insecticide permits, best chemical use strategies, information on new chemistry, crop monitoring, spray threshold, resistance management, parasitoids and best farm practices. Late in the season, we collaborated with the Bowen District Growers Association and the Gumlu Local Producer Association to conduct an information forum on the tomato leaf curl virus (in response to the TLCV outbreak at Mossman).

The meetings were well attended by industry and the participants included vegetable growers, crop consultants, chemical company representatives, resellers, researchers and extension officers. Presentation notes, permit information, handouts (Best use of IGRs against SLW in vegetable crops, DPI Note on Tomato leaf curl virus) and sample spray programs were distributed to participants. Meetings were coordinated, publicised and facilitated by local DPI&F staff with assistance from local producer organisations.

Details of these five meetings are as follows:

1. **Bundaberg – 19 Feb 2003, facilitated by Iain Kay , DPI&F, Bundaberg.**
   Number of participants - 36.
   Presenters:
   - Garry Webb –Sumitomo Chemical, Insect Growth Regulators (IGR) – Admiral
   - Geoff Messer – Dow Agro Science, IGR – Applaud
   - Peter Holmes – Syngenta – Anti-feedent – Chess
   - Rob Vitelli – Bayer Crop Science – Confidor Soil Application
   - Siva Subramaniam – QDPI, Bowen – Permits, Effective chemicals & Best Management Strategies
   - Paul De Barro – CSIRO, Brisbane – Parasitoids & Resistance management

2. **Bowen – 19 March 2003,** facilitated by Sue Heisswolf, DPI&F, Bowen.
   Number of participants - 40
   Presenters:
   - Garry Webb –Sumitomo Chemical, Insect Growth Regulators (IGR) – Admiral
   - Geoff Messer – Dow Agro Science, IGR – Applaud
   - Pat English – Bayer Crop Science – Confidor Soil Application
   - Siva Subramaniam – QDPI, Bowen – Permits, Effective Chemicals & Best Management Strategies
   - Discussion – SLW resistance management strategy

3. **Ayr** – **20 March 2003,** facilitated by Frank Covolo, Burdekin Growers Assoc.
   Number of participants - 24
   Presenters:
   - Patrick Press – Sumitomo Chemical, Insect Growth Regulators (IGR) – Admiral

- Wayne Favier – Dow Agro Science, IGR – Applaud
- Pat English – Bayer Crop Science – Confidor Soil Application
- Siva Subramaniam – QDPI, Bowen – Permits, Effective Chemicals & Best Management Strategies
- Discussion – SLW resistance management strategy

4. **Gatton – 21 August 2003,** facilitated by Bronwyn Walsh, DPI&F, Gatton**.**
   Number of participants - 70
   Presenters:
   - Siva Subramaniam – QDPI, Bowen- Permits, Effective Chemicals & IPM Strategies
   - Garry Webb – Sumitomo Chemical, Insect Growth Regulators (IGR),- Admiral
   - Geoff Messer – Dow Agro Science- IGR, Applaud
   - Rob Vitelli– Bayer Crop Science - Confidor Soil Application
   - Peter Walsh - Syngenta – Anti-feedent, Chess

5. **Bowen TLCV information forum** - 30 Sep 2003,
   Presenters**:**
   - Dale Williams, President, Bowen District Growers Assoc. – potential impact of TLCV on crops in the Bowen and Gumlu districts
   - Roger Winton, Plant Health Services, DPI&F Townsville – distribution of the virus in North Qld and role of Plant Health Services in dealing with the virus
   - Janine Clark, Growcom – role of Growcom in dealing with the virus
   - Paul De Barro, CSIRO Brisbane – HAL & ACIAR project outcomes to date, biological control options, TLCV plant resistance work
   - Siva Subramaniam, DPI&F Bowen – SLW management options, minor use permit situation.

2004 Information sessions and grower meetings

Two SLW information workshops were conducted in North Queensland early in 2004 to deliver project outcomes to the Vegetable Industry. The workshop at Ayr on 31 March attracted 25 participants, the Bowen workshop on 1 April attracted 15 participants. Gowers, resellers, chemical companies, crop consultants, industry representatives and researchers took part in the workshops. Meetings were coordinated, publicised and facilitated by local DPI&F staff. The workshop program was as follows:

- Patrick Press, Sumitomo – Effective use of IGRs
- David Johnson, Caltex – Making the most of petroleum oil products
- Siva Subramaniam, DPI&F Bowen – updates on IPM strategies for tomato, melons and cucurbits including
  - Selection of suitable crop varieties during peak SLW activity periods
  - SLW monitoring and sampling techniques, identification of SLW life stages
  - Best farm practices such as weed management, clean-up strategies
  - New chemistries mode of action, efficacy against SLW, chemical safety information
  - Best chemical use strategies including timing of applications, spray threshold levels, Confidor soil application techniques for different crops, chemical rotation
- Group discussion to get feed-back on industry issues – what control strategies worked, what did not work and how to improve strategies for next season. – facilitated by Dale

Abbott, Bowen Crop Monitoring Services at the Bowen workshop and Sue Heisswolf at the Ayr workshop
- Group discussion on the proposed Insecticide Resistance Management Strategy for SLW – facilitated by Sue Heisswolf

The following SLW notes were distributed at each workshop:
- A proposed Insecticide Resistance Management Strategy for SLW in vegetables for the Bowen-Gumlu-Burdekin region. This document explains insecticide resistance mechanisms, strategies for managing the risks of resistance developing in new chemicals and measures that can help to manage these risks. It includes guidelines for reducing the pressure on chemicals within an IPM context and a list of non-crop host plants for SLW.
- Guidelines for managing silverleaf whitefly in tomato crops
- Sample spray programs for tomatoes, melons and pumpkin, which includes selecting right chemicals, spray thresh levels and spray volumes.
- Insecticide permit table and copies of permits

2005 Information sessions and grower meetings

A total of six industry meetings were held the major production districts of Queensland in the final year of the project. Three industry meetings for Bowen, Gumlu and Ayr districts were conducted in collaboration with the Western Flower Thrips project team in March 2005. Two combined SLW / WFT meeting were conducted in the Bundaberg district in May 2005 and in Mareeba we conducted a SLW meeting for pumpkin and zucchini growers in June 2005. Growers, resellers, chemical company staff, crop consultants, agronomists, industry representatives and researchers took part in these activities. Meetings were coordinated by local DPI&F staff in collaboration with local producer organisations and agribusiness staff. Details of the meetings are as follows:

1. **Gumlu** on 15 March 2005, 20 participants; **Ayr** on 16 March 2005, 17 participants; **Bowen** on 17 March 2005, 8 participants - facilitated by Sue Heisswolf. The silverleaf whitefly component included:
   - Sue Heisswolf - review the 2004 season leading into a discussion on how to improve SLW management in 2005
   - Siva Subramaniam - updates on management programs and permits for main crops
   - Group discussion on progress with insecticide resistance management strategy for SLW and ways to improve the strategy
   - Tim Murphy, Bayer – Confidor Guard

   Information distributed at these meetings included updated sample spray programs for SLW control in ground grown tomato, trellis tomato, melons and pumpkin, an updated permit table, a "chemical selector" decision tool, guidelines for end of crop clean-up strategies, and free copies of an insect pest ute guide for North Queensland vegetable crops written by John Brown, DPI&F Ayr.

   After checking with key resellers, chemical company staff and consultants, an improved colour version of the SLW insecticide resistance strategy was mailed out or emailed to 220 growers, agribusiness personnel and researchers in June 2005 (a copy of the Bowen strategy is attached in Appendix 1).

2. **Bundaberg** on 24 May 2005 at the DPI&F Research Station and on 25 May at the CPH Fresh Packing Shed – facilitated by Iain Kay, DPI&F Bundaberg. The silverleaf whitefly program was similar to that for North Queensland.

3. **Mareeba** on 21 Jun 2005 at the DPI&F Research station – coordinated by Peter Holt TGT Agriculture.

   Siva Subramaniam, DPI&F Bowen – information on SLW and management strategies for melons and cucurbits including

   - SLW monitoring and sampling techniques, identification of SLW life stages
   - Selection of suitable crop varieties during peak SLW activity periods
   - Best farm practices such as weed management, clean-up strategies
   - New chemistries mode of action, efficacy against SLW, chemical safety information
   - Best chemical use strategies including timing of applications, spray threshold levels, Confidor soil application techniques for different crops, chemical rotation
   - Field visit 22 Jun – to demonstrate SLW monitoring techniques and identification of life stages.

4. **Melon Field day at Ayr on 14 Sep 2005** – organised display on SLW and other pests

Publications, Handbooks, Information Leaflets

1. Goolsby JA, De Barro PJ, Kirk AA, Sutherst R, Canas L, Ciomperlik M, Ellsworth P, Gould J, Hartley D, Hoelmer KA, Naranjo SJ, Rose M, Roltsch B, Ruiz R, Pickett C, Vacek D (2005) Post-release evaluation of the biological control of *Bemisia tabaci* biotype "B" in the USA and the development of predictive tools to guide introductions for other countries. *Biological Control*, 32, 70-77.

2. The key to controlling silverleaf whitefly. April 2005. Australian Vegetable Review 2005.

3. The Million Dollar Pest. Vegetables Australia, volume 1.3, Nov/Dec 2005.

4. Guide to choosing insecticides for Silverleaf Whitefly control in vegetables. Mar 2005. Distributed to vegetable growers in Queensland.

5. Silverleaf whitefly management in melon - June 2004
   Distributed to melon growers via Australian Melon Industry Association.

6. SLW resistance management strategy – June 2004 QFVG's (Growcom) Fruit &Vegetable News

7. Best use of IGR's against SLW in vegetables. March 2004. Distributed at Bowen & Ayr growers meetings.

8. Insecticide resistance management strategy for SLW in vegetables. March 2004. Distributed at Bowen & Ayr growers meetings

9. Sample spray programs and spray threshold levels tomato, melons and pumpkin crops. April 2004. Distributed to vegetable growers in North Queensland and Bundaberg.

10. IGR's for managing SLW in melons – Nov 2003. Published in Australian Melon Runner.

11. Guideline for managing SLW in Tomatoes. Sep 2003. Posted to Bowen and Bundaberg Tomato growers.

12. Best management strategies for silverleaf whitefly in vegetable crops handbook – Siva Subramaniam, Paul De Barro and Alison Shield – Oct 2003 version.

Articles and Media Releases

Newspapers, magazines and electronic media

Melon E-News December 2005
Rural Leader, Bowen Independent September 2005
Bowen Independent September 2005
Good Fruit and Vegetables May 2005
Rural Weekly insert April 2005
North Queensland Fruit and Vegetable Grower March/April 2005
The Rural Leader, Bowen Independent March 2005
Good Fruit and Vegetables March 2005
Australia Grain March 2005
Queensland Country Life March 2005
Bundaberg News Mail March 2005
Farming Ahead February 2005
North Queensland Fruit and Vegetable Grower Jan/Feb 2005
Outlooks on Pest Management February 2005
Cottongrower February 2005
Countryman November 2004
Bowen Independent November 2004
Geelong Advertiser November 2004
Bendigo Advertiser November 2004
http://www.scienceblog.com/community/article4635.html
Mid-Coast Observer November 2004
Stanthorpe border Post November 2004
The Land November 2004
Oakey Champion November 2004
Bundaberg News Mail October 2004
Bowen Independent August 2004
The Gatton, Lockyer and Brisbane Valley Star August 2003
The Gatton, Lockyer and Brisbane Valley Star August 2003
Bowen Independent March 2003
Bowen Independent October 2002
Bowen Independent December 2002

In addition, there has extensive coverage through Growcom.

Radio and television

ABC Qld Regional Radio Queensland Country Hour 29 March 2005
Townsville TV State Television News 29 March 2005
ABC Tropical Queensland Radio News 28 March 2005
Bathurst 2BS Radio News November 2004
ABC Central Queensland Radio News November 2004
ABC Radio Tasmania Trevor Jackson November 2004
ABC Mid North Coast NSW November 2004

Section 9

Project Outcomes

Project Outcomes

Establishment of an effective biological control agent

In seven months of releases *Eretmocerus hayati* has been recovered from field release sites in Bundaberg, Childers, Lockyer and Fassifern Valleys and the Emerald Irrigation Area. This suggests that the parasitoid has established although it is uncertain how well the parasitoid will persist over winter. The shortfall in funds due to the non-payment of voluntary levee funds and the failure to provide further funding of the project has prevented both the wider release of the parasitoid in areas of interest to vegetable producers and the collection of impact data.

Adoption of Softer Insecticides

Insecticide Use-Pattern for SLW in the Bowen district (2002 to 2004)

Insecticide sale data was collected for the 2002, 2003 and 2004 seasons by interviewing chemical distributors in the Bowen district. The objective of this exercise was to obtain and indication of how the vegetable industry was using the new chemistries for SLW control in the region. The volumes of the products of interest distributed in each season are shown in Figs 9.1 and 9.2.

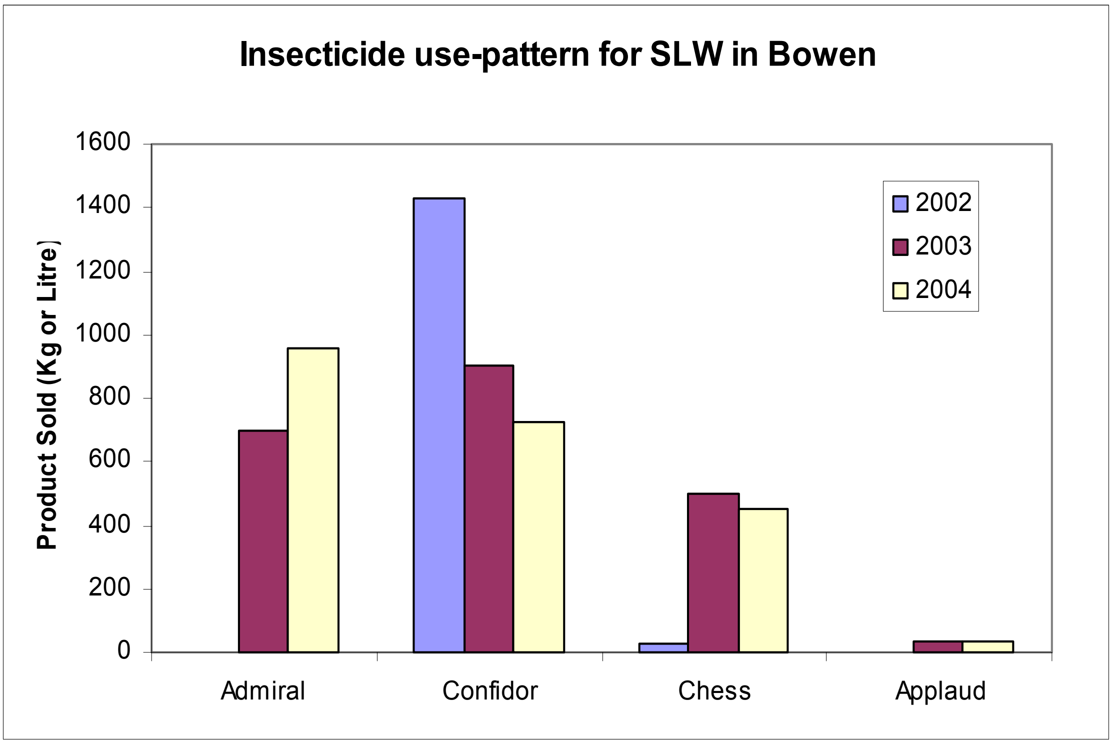


Fig 9.1. Volume of new chemistry products distributed during the 2002, 2003 and 2004 seasons in Bowen

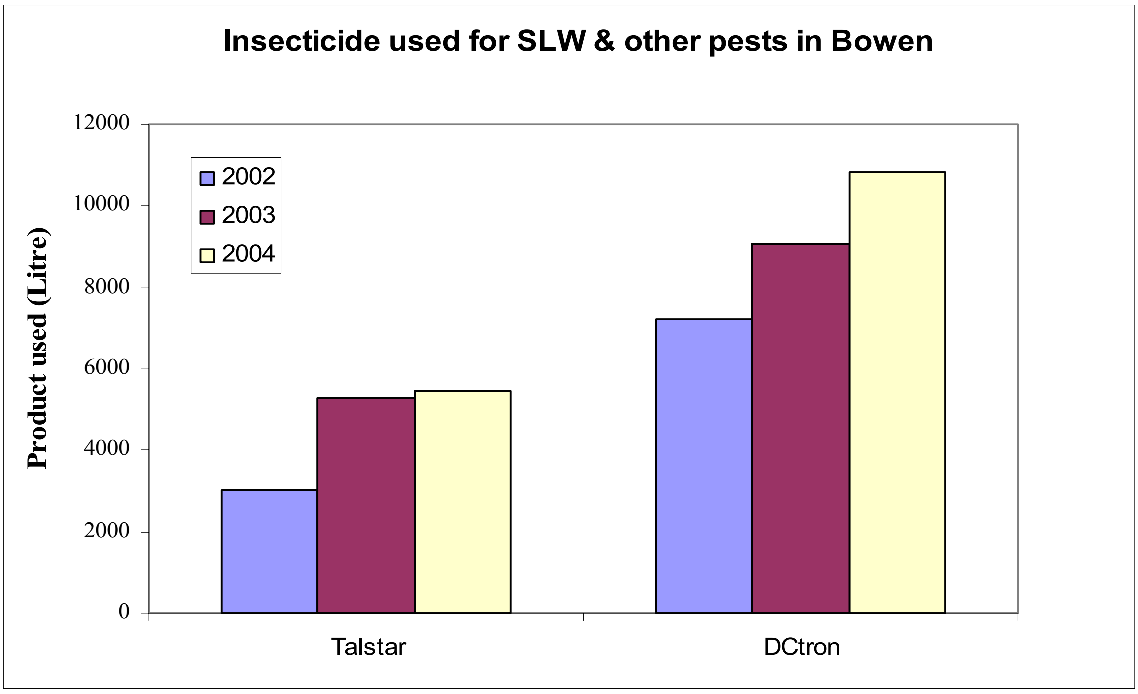


Fig 9.2. The volumes of Talstar and DC-Tron distributed during the 2002, 2003 and 2004 seasons in Bowen

The key points are summarised below:

- In 2002, three insecticides - Confidor (imidalcoprid), Talstar (bifenthrin) and DC-Tron (mineral oil) - were available for SLW control. Confidor was mainly used as foliar spray.

- In 2003, three more products became available - Chess (pymetrozine) and the IGRs Admiral (pyriproxyfen) and Applaud (buprofezin). Confidor was approved as soil application on temporary permit for some vegetable crops.

- Admiral (IGR) was widely used in the district for SLW control, mainly in tomato and cucurbit crops. Around 1400 ha of crop was treated with this product in 2003 with Admiral use increasing by 38 % in the 2004 season. It is likely that information made available to the industry, the support provided by the Sumitomo Company as well as the effectiveness of the product are the reasons for the successful adoption of this relatively ‘soft chemical’ in vegetable crops.

- Approximately 1400 L of Confidor was used in vegetables in 2002 season. Confidor use declined by 34 and 49 % in 2003 and 2004 season respectively. The reasons for this decline may be due the availability of other options (the three new chemistries) that are effective and can be rotated in the spray programs.

- Chess was mainly used for SLW control, but a small proportion was also used to control aphids. In 2004, the Chess formulation 250 gi ai/kg was replaced with the 500 g ai/kg formulation, so converting volumes used to hectares treated, in 2003 Chess was applied to 1200 ha of tomato and cucurbit crops.

- Only small volume of Applaud (30L) was used in 2003 and 2004, probably because it does not provide sufficient control against SLW in vegetable at the current label rate.

There was also a lack of information available on how to best use the product in vegetables and this project (VX02016) did not give priority to this product as the company was not interested in registering the product in vegetables.

- DC-Tron (petroleum oil) has been widely adopted by the industry. In 2002 over 7000 L of product was used in the district (we estimate that 20% of this volume was used for mango scale). Use of this ‘softer option’ has increased steadily in the district as illustrated by the by 25 and 49 % increase in volume during the 2003 and 2004 seasons respectively. Some is used also for thrips control.

- Talstar (Bifenthrin) is still more popular than the new chemistries and use increased in 2003 but seems to have stabilised in 2004. As a broad-spectrum product, it has been widely used for SLW, mites, heliothis and aphid control in the region.

Growers still prefer to use cheaper (broad-spectrum) chemicals, but are prepared to pay and use more narrow spectrum including soft options such as oils, IGR and Confidor to ensure they get effective control of the pest, but perhaps also to rotate chemistries to protect them against resistance.

Registration of Insecticides and approval permits

Confidor Registration

Full registration for Confidor soil application for SLW has been granted by APVMA in Jan 2005. This registration covers three application methods (furrow spray, trickle injection and plant hole drench) for tomato, eggplant and capsicum. Furrow spray and trickle injection were approved for sweet potato and cucurbit crops. This was good outcome for the vegetable industry to manage SLW in area-wide basis. Project staff collaborated with Bayer to achieve the registration and delivering recommendation to the industry (see details in Section 2 to 5).

SLW insecticide permits

Following permits were granted by APVMA for silverleaf whitefly control in vegetables. Growcom, DPI&F and Ausveg (Agware Consulting Ltd) have worked together in obtaining the permits (Table 9.1).

Table 9.1. Insecticide permits for silverleaf whitefly control in Queensland, 2005

Product	Active ingredient	Chemical Group	**Crops**	Rate (product)	WHP days	Expiry Date
DC-Tron	Petroleum Oil (839 g/L)		Capsicum, Eggplant, Tomato, Okra, Cucurbits	500ml/ 100 L	1	30/03/10
Talstar	Bifenthrin (100 g/L)	Pyrethroids (3A)	Cucumber, Melons Pumpkin, Squash, Zucchini,	40 – 60 ml / 100L or 600ml/ ha	3	31/03/06
			Beans,		2	
Confidor Soil application	Confidor 200 SC (200g/ L)	Chloronicotinyl (4A)	Cucurbits, Tomato, Eggplant Brassicas, Okra, Common Bean	25 ml/ 100 m Row More details in permit label		31/03/06
	Confidor Guard (350g/ L)			14 ml/ 100m row (Registered – see product label)		
Chess	Pymetrozine 500 g/L	Feeding inhibitor (9A)	Tomato, Cucurbits, Eggplant	200 g/ ha	3	31/03/06
Admiral	Pyriproxyfen 100 g/L	Juvenile hormone mimic (7C)	Tomato, Cucurbits, Eggplant	500 ml/ha	1	31/03/06
Applaud	Buprofezin 400 g/L	Chitin inhibitor (17A)	Cucumber, Zucchini, Tomato, Eggplant	30 to 60 ml/ 100L	3	31/03/06

Note: Above information is a guide only, must read the permit label before intended use.

Recommendations

1. In all there were less than 7 months available to release the parasitoid and as a consequence there has been insufficient time to evaluate the releases in terms of establishment and impact. At this stage the parasitoid is showing promise, but how well it will eventually establish and how grower practice needs to be modified in order to enable them to make the best use of the parasitoid has yet to be developed. It is possible that a landscape approach to managing a region will enable parasitoids to persist more effectively and so effect earlier control of whitefly numbers. It is desirable that further releases be made to ensure the parasitoid establishes in all parts of Australia affected by SLW. Further, it is desirable that the impact of the parasitoid be measured in terms of benefits to growers.
2. Currently, vegetable growers are obtaining reasonable control of SLW with new chemistries used in conjunction with various IPM strategies, depending on the grower and the crop. Inappropriate use of, and over reliance on these insecticides will no doubt lead to insecticide resistance.
3. Development of insecticide resistance is a particular concern with SLW, especially when the new products are applied repeatedly. There are five products (pyriproxyfen, buprofezin, imidacloprid, pymetrozine and petroleum oils) now available to control SLW in vegetable crops. Prolonged effectiveness of these products depends on how these products are managed within the vegetable production system.
4. SLW movement across commodities was considered as a major issue at the industry meetings in Ayr and Bowen. The mass migration of whiteflies from adjacent crops hindered control measures adopted in the region. Movement of adults from older crops and crop residues is the primary source of infestation for young crops. Workable and practical SLW dispersal control strategies are needed to tackle this issue. These could be combined with our existing "clean-up strategy" for the North Queensland vegetable growers, which has been critical for containing SLW migration within farms.
5. Industry adoption process - To be workable and cost effective, IPM programs for SLW need to be implemented on an area-wide basis. IPM components identified in this project include judicious use of pesticides within an insecticide resistance management strategy, crop monitoring, crop hygiene practices, use of tolerant varieties (when available); and conservation of beneficial insects. These components will be more effective when adopted on an area-wide basis. Individual growers can also adopt them but the benefits may be diminished by whiteflies invading from nearby crops
6. Confidor soil application has been broadly adopted by industry for SLW control in vegetable crops. Application technique is critical in achieving good control. Trickle injection method was very popular among the growers because of convenient to apply within the existing irrigation system. However, Confidor soil application did not work well for pumpkin growers as the majority of use flood irrigation.
7. The IGR, pyriproxyfen is an effective 'softer' tool for SLW IPM in vegetables. However, timing of application and effective crop monitoring are essential components to get the most out of this tool. Therefore, grower education and training still plays an important role.

Acknowledgements

The research team acknowledge the following organisations and individuals who have contributed to the project and its outcomes.

- Horticulture Australia, the Bundaberg Fruit and Vegetable Growers, Growcom and Sumitomo Chemical Australia Pty Ltd provided fund to the project.

- The following CSIRO and DPI&F staff provided support and assistance in various way to this project:
  Shama Khan, CSIRO Entomology, Brisbane
  Veronica Brancatini, CSIRO Entomology, Brisbane
  Peter Hart, CSIRO Entomology, Canberra
  Bob William, Science Leader, DPI&F South Johnson
  John Duff and Bronwyn Walsh, Entomologist, DPI&F Gatton
  Ross Wright, Senior Horticulturist, DPI&F Bowen
  Des McGrath, Senior Horticulturist, DPI&F Bowen
  Iain Walker, Senior Experimentalist, DPI&F, Bowen
  Reg Andison, Facility Manager, DPI&F, Bowen
  Ron Holt, Farm Supervisor, DPI&F, Bowen
  Jo Collison, Farm staff, DPI&F, Bowen
  Farm staff at DPI&F, Bundaberg
  Brande Hunter (casual technician) DPI&F, Bundaberg

- Sumitomo Chemical provided continuous support for Admiral field trials, residue trials and permit applications

- Bayer Crop Science provided support for Confidor field trails and permit applications.

- Nufarm Australia, DowAgro Science, Syngenta , Caltex provided support to the project.

- Thanks to chemical resellers in Bowen - Bartec, Landmark and Primac Elders - for providing chemical data.

- Thanks to Bowen vegetable growers for providing trial sites.

- Thanks to Lloyd and Judy Greensill and the Bundaberg, Childers and Lockyer Valley tomato, melon and vegetable growers for providing release sites.

- Thanks to Mat Dent, Growcom, for helping CSIRO find release sites and to release *E. hayati*.

APPENDIX 1

Insecticide Resistance Management Strategy for silverleaf whitefly in vegetable crops

Bowen - 2005 season

Area wide management strategy for silverleaf whitefly (SLW)

Bowen district

This strategy is an area-wide guideline. It is voluntary and flexible and should be seen as an ideal to aim for.

If you need to go outside the strategy to control a SLW outbreak, please return to the strategy once you have overcome the problem.

1. Use an integrated approach

- Summer production break and non-host cover crops (eg sorghum)
- Control broadleaf weed hosts and volunteer crops
- Improve farm planning – consider wind direction when planting, avoid planting young crops next to old crops, talk with your neighbours about their plans for the season
- Check transplants before planting out
- Avoid sensitive cucurbit varieties during peak whitefly periods (July to September plantings)
- Monitor crops regularly and spray on thresholds
- Ensure the spray rig is achieving good crop coverage
  - calibrate regularly, check water volumes used and chemical rates applied
- Timely spray out of finished crops before slashing to reduce mass migration of SLW into young crops

2. Rotate use of insecticides according to your local strategy
(see the diagram on the next page)

Window I – Autumn

- Use Admiral or Applaud - one spray/ crop in the early part of crop growth
- Use Chess – 1 or 2 sprays based on adult threshold levels
- Rotate with DC tron oils if required – use as a clean up spray after harvest if needed

Window II – Winter

- Do not use Admiral or Applaud
- Use Confidor Guard as a soil application at planting if you expect high migration of SLW adults from adjacent crops
- Use bifenthrin (Talstar or equivalent) to control adults. In cucurbit crops, consider impact on bees when spraying.
- Use DC-Tron oils if required - use as a clean up spray after harvest if needed

Window III - Spring

- Stop using Confidor Guard soil applications by the end of September
- Use Admiral or Applaud – 1 or 2 sprays per crop. If two sprays are required use Admiral first, then Applaud two weeks later
- Use Chess to control adults in the early part of crop growth
- Use bifenthrin mixtures to clean up crops after harvest if high SLW populations are present. For low populations, use 1% DC tron.

Summer window

- Vegetable crop production break
- bifenthrin for adult knockdown in seedling nurseries

3. Supporting best practices for managing insecticide resistance

- Avoid using OP's and SP's early in the crop's growth, as they are broad-spectrum insecticides that reduce natural enemy numbers, reduce pollination and increase the chance pest outbreaks.
- Avoid continuous use of an insecticide from any one chemical group
- Any one product should not be used more than twice within a window period
- Do not to respray with an SP if you suspect that a SP spray has failed
- If established whitefly populations are present, avoid using OP chemicals to control other pests as this can lead to whitefly flare-ups.

Insecticide Resistance Management Strategy for silverleaf whitefly in vegetable crops

Bowen - 2005 season

Comments and suggestions welcome – please contact Siva Subramaniam or Sue Heisswolf at Bowen DPI&F on 4761 4000

<table>
<tr><th>Summer</th><th>Window I
Mid February to May</th><th>Window II
June to mid August</th><th colspan="3">Window III
Mid August to mid December</th><th>Summer</th></tr>
<tr><td rowspan="4">Summer break

Field:
Recommend crop free period</td><td>IGR's – Admiral, Applaud</td><td>IGR's free period</td><td colspan="2">IGR's – Admiral, Applaud</td><td>No IGR's</td><td rowspan="5">Summer break

Put in place recommended cultural practices</td></tr>
<tr><td colspan="5">Petroleum oils (DC Tron Plus)</td></tr>
<tr><td>No Confidor</td><td colspan="2">Confidor Guard soil application</td><td colspan="2">No Confidor</td></tr>
<tr><td>Chess</td><td>No Chess</td><td colspan="3">Chess</td></tr>
<tr><td>bifenthrin *
Seedling nurseries only</td><td>No bifenthrin*</td><td>bifenthrin*</td><td colspan="3">bifenthrin* mixtures for field clean up</td></tr>
</table>

*bifenthrin - Talstar or equivalent
a synthetic pyrethroid (SP)

Change over times between windows dependent on prevailing temperature and pest pressure

Disclaimer: Information in this leaflet is based on the current best information available and is provided solely on the basis that the reader will be responsible for making his/her own assessment of the content and seek professional advice as needed. Chemical registrations and APVMA permits for silverleaf whitefly control do not apply to all vegetable crops.