Regional extension strategy for managing western flower thrips and tomato spotted wilt virus in the Sydney Region

Dr Leigh Pilkington
Department of Primary Industries

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Final Report

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(31 August 2011)

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Submitted 31st August 2011

Purpose of this report:

A report on the effectiveness of an IPM research and extension project conducted by NSW DPI and collaborators to address the problems caused by western flower thrips (WFT), tomato spotted wilt virus (TSWV) and other significant pests and diseases affecting vegetable industries in the Sydney Region.

Funding Source:

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Contents

Media Summary

Integrated Pest Management (IPM) surveys, research trials and on-farm grower workshops were conducted by the NSW Department of Primary Industries (NSW DPI) and commercial collaborators; to provide IPM information and develop support service capabilities. Demonstration farms were established on leading grower farms to trial new strategies, products (including biological control options) and provide the opportunity for growers to learn about alternative IPM control strategies. The project increased the capabilities of IPM service providers in the region and a series of industry workshops, field days and training courses communicated the information to growers.

Benchmarking surveys conducted at the start, during and at the end of the project showed that growers are now better informed on insect vector/virus threats to vegetables crops, are accessing more IPM technical support and are better able to manage western flower thrips (WFT), aphids and other insect vectors and their associated diseases. The increased adoption of IPM strategies by vegetable growers in the region has improved the industry's ability to manage threats to the Sydney's fresh vegetable supply.

Vegetable growers in the Sydney Region have access to new strategies, skills and services to better control new pests and diseases. Outbreaks of WFT and aphid species in the region over the recent decade have caused significant crop losses, spread plant diseases and reduced the supply of local fresh food. A project by NSW DPI has delivered new IPM tools and services to vegetable growers for managing these problems.

WFT and aphids insects cause crop damage and are vectors of plant diseases such as tomato spotted wilt virus. Significant outbreaks of WFT and aphids in the past decade have caused substantial losses to grower incomes and threatened Sydney's local fresh food supply. The new pest species quickly developed resistance to pesticides registered for their control. New strategies using IPM were required to understand the pest and disease dynamics and provide new support services to help growers manage their pests and diseases.

The most important finding to come from this project is that the adoption of integrated pest management strategies by greenhouse growers in the Sydney Basin has increased during the course of the project. A barrier to further adoption of these techniques includes a reluctance to employ an integrated pest management consultant to assist in either the transition to this method of pest management, or to continue an effective program.

To maintain a consistent IPM support service informed by the latest research and to ensure growers are able to respond to new pest or disease outbreaks, there needs to be IPM extension officers available to provide IPM extension. This can also be balanced with support of commercial integrated pest management consultants. Along with these resources, access to appropriate IPM resources and services is also a key challenge for growers from a non-English speaking background as their first language. The cultural diversity of vegetable growers (especially in areas such as the Sydney Region) requires the use of bi-lingual officer to work in conjunction with IPM officers and consultants. The benchmarking survey results for Asian vegetable growers in this project are a clear indication of the necessity for this support service.

Further research into biological control options for IPM in hydroponic lettuce and Asian vegetable growing crops and systems would reduce the current high reliance on pesticides, lower the incidence of pesticide resistance development by pest species, and, in turn, improve chemical use strategies and minimise food safety issues. Research should be conducted into consumer tolerance of insect presence in leafy greens.

Technical Summary

Outbreaks of *Frankliniella occidentalis* (western flower thrips, WFT), aphid species and other insect vectors of virus diseases over the recent decade have caused significant crop losses, spread plant diseases and reduced the supply of local fresh food across the Sydney Region. In response to calls from growers to develop new solutions to these problems, the NSW Department of Primary Industries (NSW DPI) has delivered new integrated pest management (IPM) tools and services to growers. Vegetable growers in the Sydney Region now have access to new strategies, skills and services to better control outbreaks of pests and diseases using IPM approaches.

WFT and aphids insects cause crop damage and are vectors of plant diseases such as tomato spotted wilt virus (TSWV). Significant outbreaks of WFT and aphids in the past decade have caused substantial losses to grower incomes and threatened Sydney's local fresh food supply. When WFT arrived in Australia and subsequently in Sydney, it quickly developed resistance to pesticides (Colomer *et al*, 2011) registered for their control. New strategies using IPM were required to deal with the pest and disease dynamics and a need was identified to provide new support services to help growers manage their pests and diseases.

A Project Steering Committee comprising of the Project Leader, Appointed Project Industry Liaison Officer, NSW Vegetable Industry Development Officer, Horticulture Australia Limited (HAL) and growers representing key vegetable grower groups from the Greater Sydney Region was established early in the project. The Steering Committee conducted regular project reviews through which the strategies employed throughout the project were determined and adjusted. The steering committee assisted the project team in maintaining a focus that was relevant to industry and the needs that were developing during the course of the project. The committee also served as a means to capture the feeling of the broader industry about the progress that was being achieved to date.

Initially growers were highly supported through the project, which included regular farm visits, surveys of crop, pest and disease status and soil condition, IPM planning and familiarisation for the grower. Group training and workshops were used to deal with industry-wide issues, such as hygiene improvements, crop waste and weed management. Within each target group a key IPM spokesperson was identified and trained to assist other growers on basic IPM issues, such as suitable chemical use or where to go for more help. The spokesperson additionally acted as language assistants in the field where necessary. As a group, training needs were identified and training was staged accordingly *via* many on-farm workshops, field days or training events.

In addition to the support services, demonstration farms were established on leading grower farms to trial new strategies, products (including biological control options) and provide the opportunity for growers to learn about alternative IPM control strategies. The project increased the capabilities of IPM service providers in the region which gave growers far greater support for the implantation of IPM strategies than the project team could have achieved. A series of industry workshops, field days and training courses communicated the information to growers including the introduction of the IPM service providers.

Benchmarking surveys conducted at the start, during and at the end of the project showed that growers are now better informed on insect vector/virus threats to vegetables crops, are accessing more IPM technical support and are better able to manage WFT, aphids and other insect vectors and their associated diseases. The availability of IPM consultants in the Sydney Region has increased over the life of the project but most importantly, growers are more open to IPM and are utilising the techniques at an accelerated rate as was demonstrated by the benchmarking survey.

The project focused on the Greater Sydney Region but the extension methodology developed can be transferred to other major vegetable growing districts such as the Riverina and North Coast, or interstate.

To maintain a consistent IPM support service informed by the latest research and to ensure growers are able to respond to new pest or disease outbreaks, there needs to be IPM extension officers available to provide IPM extension. This can also be balanced with support of commercial integrated pest management consultants. Along with these resources, access to appropriate IPM resources and services is also a key challenge for growers from a non-English speaking background as their first language. The cultural diversity of vegetable growers (especially in areas such as the Sydney Region) requires the use of bi-lingual officer to work in conjunction with IPM officers and consultants. The benchmarking survey results for Asian vegetable growers in this project are a clear indication of the necessity for this support service.

Further research into biological control options for IPM in hydroponic lettuce and Asian vegetable growing crops and systems would reduce the current high reliance on pesticides, lower the incidence of pesticide resistance development by pest species, and, in turn, improve chemical use strategies and minimise food safety issues. Research should be conducted into consumer tolerance of insect presence in leafy greens.

Introduction

Industry profile

Vegetable production in the Greater Sydney Region is valued at over $220M. Major crops include hydroponic lettuce ($21.5M), greenhouse cucumbers ($38.5M), greenhouse tomatoes ($53M) and Asian vegetables ($33M). Other market gardening in a diverse range of fresh vegetables and herbs account for greater than $70M. The Sydney Region growers experience significant problems with insect vectors, such as thrips and aphids, insects that cause damage to produce and spread crop virus diseases. A wide range of vegetable crops grown in the region are affected by thrips and aphids, primarily lettuce, capsicum, cucumber, zucchini, and eggplant.

The vegetable farming community in the region is comprised of people from diverse cultural backgrounds. There are approximately 700-900 Maltese and Italian, 230 Chinese, 200 Arabic, 70 Cambodian, and 40 Vietnamese farmers in the region. Numbers are difficult to verify, but these are considered conservative estimates. It is also estimated that 90% of the vegetable industry workforce is also from non-English speaking backgrounds (NESB). The ethnic groups tend to grow a variety of commodities and English is often their second language and communication difficulties may be encountered. Historically this has resulted in slow technology uptake and implementation of new pest management strategies and practices.

It was common for grower communities established grower associations in the 1990s which provided a voice for grower concerns and an access point for government agencies to consult with association representatives to seek advice on how to communicate better with the growers. Increasing industry and government pressure on growers to demonstrate good chemical use practices, food safety management, nutrient run-off reduction and Occupational Health and Safety (OH&S) on farm has led to new communication lines with the farmers.

Grower associations have organised their members to obtain language support and translated resources for workplace training courses such as farm chemical user (SmartTrain, ChemCert), food safety (Freshcare), fertiliser management and other business risk management training (e.g. OH&S, accounting, etc.). NSW DPI staff actively supported the establishment of the grower associations and their initiatives. However, none of these initiatives specifically focussed on the problem of crop damage and the spread of virus diseases such as tomato spotted wilt virus (TSWV) caused by insect vectors such as western flower thrips (WFT). This project aimed to address this gap and provide this support and knowledge.

In the summer season of 2002-03, the insect pest WFT and the associated disease TSWV severely affected vegetable crops in the Greater Sydney Region, leading to an industry call for assistance and urgent action. The WFT/TSWV problems during this time revealed the poor information flow and understanding amongst growers of how to effectively manage such pest species. Many growers did not understand the fundamental relationships between their practices, the insect vectors and the viruses.

The NSW Department of Primary Industries (NSW DPI) has significant research expertise in IPM and had developed improved strategies and practices for the control of these insect vectors. Although NSW DPI maintained a network of research and extension officers in the region, there was no specialist program to engage in the complex communication strategy needed to bridge the communication and skills gaps that would be necessary to address the damage being done by these pests.

In response, a project proposal was submitted and funded, with a Vegetable Industry Liaison Officer (IPM) appointed through the project for the Greater Sydney Region. Their role was to develop and deliver specific on-farm extension services addressing WFT/TSWV management for vegetable growers. Once this position had been established it was extended to include other insect vectors and viruses that could be similarly addressed in an IPM program.

A broad range of field vegetable crops are produced in Sydney Region, generally on a small scale with successive weekly plantings on a seasonal basis for crops such as eggplant, capsicum, zucchini, lettuce, brassicas and sweet corn. The increased adoption of IPM in the Sydney Basin as a result of this project will likely result in significantly lower pesticide breaches in produce and reduce the incidence of pesticide resistance in common pests. Growers, while still in need of continuing support, will have a greater self reliance when it comes to managing pest and disease problems in their crops.

Key vegetable insect pests and diseases

Key insect pests and the diseases they transmit (the insect as vector of the diseases) that affect the productivity and sustainability of vegetable growers in the Sydney Region were the focus of this project. They are briefly described in the following section, to provide background information to the IPM research, surveys and extension activities conducted by this project.

Western Flower Thrips

Frankliniella occidentalis originates from the western USA and was first found in Western Australia in 1993. It has spread to all states and most production areas since.

WFT is a significant pest because it is a vector of TSWV that affects key vegetable crops grown in the Sydney Region, such as tomatoes, lettuce, cucumbers, potatoes, and capsicum.

WFT is more of a problem than other thrips species because it develops resistance to pesticides easily, hence there are few chemical options to control it.

WFT eggs are laid into soft plant tissue. Within a few days eggs hatch into a wingless juvenile or larval stage. Immature thrips are pale yellow, thin, wingless and up to 1 mm in length.

Thrips have two feeding larval stages followed by non-feeding pre-pupal and then pupal stages that tend to hide in soil crevices or within foliage. Winged adults emerge from the pupae to mate and feed. Adults are also thin, with yellowish head and darker abdomen. They are about 1.5-2 mm in length, with two feathery wings. The length of the life cycle and life expectancy of the adults depend on temperature and food quality. At 30°C the life cycle is approximately 12 days while at 20°C it is 19 days. WFT breeds on a wide range of flowering plants including weeds, vegetable crops and fruit trees.

WFT larvae must feed on a tomato spotted wilt virus TSWV-infected plant to acquire TSWV. Once a larva has acquired the virus, TSWV will multiply within the larva. When an infected larva reaches adulthood it can fly to a new plant, transmitting the virus as it pierces the plant cells and sucks the contents. The virus does not pass through the egg stage so each succeeding generation of WFT must re-acquire the virus as larvae feeding on TSWV-infected plants. Uninfected adult thrips cannot acquire the virus.

WFT feeding can cause scarring and deformation on leaves and fruit, with seedlings and soft tissue particularly prone to feeding damage. Products particularly susceptible to scarring include capsicums, cucumbers and beans.

Tomato Spotted Wilt Virus

TSWV is a tospovirus that has become one of the most wide-spread and damaging viruses affecting vegetable crops in Australia. TSWV was first described in Australia in 1915 and has been a sporadic problem since. The arrival of the very efficient vector WFT has seen an increase in the seriousness of the disease, particularly in hydroponic and covered systems.

TSWV is also transmitted in vegetables by tomato thrips (*Franklienella schultzei*) and onion thrips (*Thrips tabaci*). Melon thrips (*Thrips palmi*) is also a vector of TSWV but is not widespread in NSW. Plague thrips and other non-host thrips cannot acquire the virus, nor can other insects such as aphids. TSWV is not spread in seed or via mechanical damage although it can be spread through cuttings used for plant propagation. Once a plant is infected with TSWV it cannot be cured, so prevention or use of tolerant varieties, if available, are the only management options.

Many hundreds of plants (>900) are TSWV hosts, most being in the Solanaceae, Asteraceae or Fabaceae. Some show symptoms and some do not. TSWV causes significant damage to solanaceous vegetables such as tomatoes, potatoes and capsicums, but also to lettuce and a wide range of herbs and ornamental crops, whereas cucumber infections are symptomless.

Common weed hosts of TSWV (and WFT) include amaranth, cape weed, pigweed, mallows, blue heliotrope, fat hen, purple top, shepherd's purse, nightshades, Scotch thistle and sow thistle. Not all plants that are infected by TSWV will show symptoms. Crops that are susceptible will tend to show symptoms on the new developing foliage after infection.

Some varieties of capsicums and tomatoes are resistant to TSWV although strains of TSWV that break the resistance can develop in areas of high TSWV pressure. For resistant varieties it is still important to reduce the virus pressure through weed management and other sanitation measures.

Aphids

Aphids (Homoptera: Aphididae) are small (about 2 mm long), soft-bodied insects with characteristic tubular extensions to the abdomen. They feed on plant sap using their sucking mouthparts and have complex life cycles. Adults can be winged or un-winged and females can reproduce with or without mating. Aphids can build up large populations within a short period of time.

Aphids are responsible for spreading mosaic viruses and transmit the disease in a non-persistent manner, meaning they are only infective for a few hours at a time (Hausbeck, 2002). The aphid sucks on affected leaves, distorting plant tissues and moving around spreading disease to healthy plant tissue as it probes or feeds. Transmission may occur within a few minutes of feeding on a healthy host, making chemical control an unreliable management option.

Contact insecticides may reduce the population of aphids by stopping breeding in the crop; however that may not prevent the virus, as the insect only needs to feed for a short time to transmit the virus (Commens, 2004).

Aphids may simultaneously be a vector for more than one type of virus. Crop protection from aphids is best managed through an IPM program that includes good farm hygiene, the use of resistant varieties, removal of crop residues, control of aphids in alternate hosts, introduction and preservation of beneficial insects as well as ‘soft chemistry’ insecticide applications when most necessary (Llewellyn, 2002).

Alternative hosts, which act as a virus reservoir, include broadleaf weeds such as mallow and amaranth (Coutts, 2006) as well as asteraceous and solanaceous plants.

Fungus Gnats

Fungus gnats (*Bradysia sp.* Sciaridae) are a common problem in greenhouse crops, as they like high levels of organic matter and moisture. Adult fungus gnats can be found sitting on the surface of plastics and media, and flying around the bottom of plants. They are small (5 mm) black flies with long legs and antennae, with a single pair of wings. Under a microscope, a Y-shaped pattern can be seen in the veins on the end of the wings.

Larval fungus gnats are clear to white worms about 5–8 mm long and have a small black head. They can be found near the surface of potting media, feeding on seedling stems and roots, soil fungi, algae and other organic matter.

Fungus gnats worsen in cool wet weather, and where greenhouses have poor drainage and excess fertiliser. Fungus gnats prefer media like compost mix, cocopeat and sawdust that is high in organic matter, rather than inorganic media such as rock wool and perlite. Repeated use of media for a number of crops worsens the situation, as the level of organic matter held in the media increases crop by crop.

Controlling fungus gnats also helps control Pythium and Fusarium diseases that worsen in crops with high fungus gnat populations. This is because adult fungus gnats can carry Fusarium spores from stem to stem, and larval fungus gnats feeding on the roots provide an entry point for disease spores to infect. If there are no fungus gnats, root diseases can still cause damage, however the losses will not be as severe.

There are four commercial products available to manage fungus gnats. Use of these along with improvements to crop hygiene, drainage and nutrition will achieve best results.

Whitefly

Greenhouse whitefly (GWF) *Trialeurodes vaporariorum* and silverleaf whitefly (SLWF) *Bemisia tabaci* Biotype B (also known as *Bemisia argentifolii*) are potentially major pests in greenhouse crops in the summer months or under dry warm conditions.

Whiteflies are more commonly found in hot spots of greenhouses as higher temperatures suit their breeding cycle.

Whiteflies suck the sap from plants. Affected plants may wilt, turn yellow, shed leaves and display reduced growth rates if infestations are severe. Whiteflies produce honeydew, encouraging sooty mould growth, which reduces photosynthesis and decreases plant vigour. Feeding by whiteflies can also cause deformed fruit and discoloration of tomatoes, through uneven ripening. Whiteflies can be vectors of plant viruses such as tomato yellow leaf curl virus (TYLCV), beet pseudo yellows virus (BPYV) and tomato torrado virus (ToTV).

GWF and SLWF are major pests in tomatoes (*Lycopersicon esculentum*) and cucumbers (*Cucumis sativus*) and minor pests in other cucurbits and Solanaceae crops such as eggplant.

Their weed hosts for GWF include verbena, mallow and sowthistle and milk thistle for SLWF.

Two-spotted mite

Two-spotted mite (TSM), *Tetranychus urticae* Koch is a pest of many vegetable crops. Feeding by all life stages of the mite from the under surface of the leaves can cause white or greyish spots on the leaves making leafy green crops unmarketable and reducing overall health in other crops.

TSM is often an ‘induced’ or ‘secondary’ pest, which is a pest that is encouraged by insecticide sprays. This is because it can rapidly develop resistance to insecticides and the predators of TSM, like ladybird beetles, are killed by the insecticides, leading to TSM outbreaks. Routine insecticide applications can therefore assist TSM.

Two-spotted mites are not insects but are related to spiders. Common insecticides used to control other insect pests are not effective in controlling them. For efficient control of two-spotted mites, miticides like Vertimec® need to be used.

The females are oval shaped, about 0.5 mm long, and just visible to the naked eye. Usually females are far more numerous than the males in a colony. Males are slightly smaller and more elongated. The adults are pale green or yellowish with a dark spot on each side of the body. The spots are more prominent in the females. Females can lay up to 100 translucent spherical eggs individually on the underside of the leaves, usually under webbing.

The life cycle from egg to adult occupies about 7–14 days depending on the temperature (shorter in warmer weather). Therefore in warmer weather populations can build up rapidly.

Spider mites feed by piercing the surface tissues of the leaves and sucking up the sap. The first sign of injury is the appearance of greyish spots peppered over the leaves. These spots soon coalesce and the leaves become grey all over. Under heavy infestations the under surface of the leaf will be covered with webbing and mites and the leaf surface will appear bronzed. Besides crawling from plant to plant, the mites may be spread from infested crop to healthy crop on clothing of people working in the farm or they could be blown on the wind.

The Chilean predatory mite *Phytoseiulus persimilis* is the most common commercially available predatory mite growers can use. The predatory mites feed on all the stages of the two-spotted mites and do not feed on the plants.

Psyllid

Psyllids are sap sucking insects like aphids that feed by inserting stylets into the plant, sucking sap and excreting the excess water and sugar as honey dew. In Australia, psyllids are commonly seen on wattles and eucalypt trees.

Until recently psyllids have not been known to infest or attack vegetable crops in Australia. In 2007 a yet-to-be formally identified psyllid belonging to an Australian genus called *Acizzia* sp. was found feeding on eggplants in the Sydney Region. The host plants of this psyllid genus are usually species of *Acacia* or wattles. We are not sure why the psyllid has switched host species but a number of insect species are capable of having multiple hosts of completely different plant types at different times of the year.

The *Acizzia* psyllid has been found two years running in a western Sydney backyard vegetable garden. Both times the psyllids were only noticed in late summer and early autumn. The variety of eggplant grown in 2007 was a ‘Long Tom’ variety, while in 2008 both ‘Long Tom’ and more traditional ‘Black Beauty’ were affected.

The adult *Acizzia* psyllids (Figure 1) are small - roughly the same size as green peach aphids. The adult males have a black and green body with a black head and bright red eyes. The wings are held tent-wise over the body, a bit like a small cicada.

Figure 1. Adult male psyllid (left) and nymphs (right) - images courtesy of Deborah Kent

The adult females start out with an all green body and head but later darken to the same colour as the male. Eggs are laid directly onto the underside of leaf surface and are attached by a thin stalk. The newly emerged nymphs are clear to white in colour with numerous spiky hairs (Figure 24) and unlike young aphids are relatively flat in shape. Both adults and nymphs are found on leaves mainly on the under surface of the leaves or near new growing tips.

At this stage the only Solanaceous vegetable infested in the Sydney Region is the eggplant *Solanum melongena*. Tomatoes and capsicums that have been exposed to the psyllids both in a garden situation and in a laboratory greenhouse have not become infested.

Damage to the eggplant seems to be confined to the new leaves at the growing tips and flowers (Figure 2). Severe feeding damage has caused the death of growing tips and the premature loss of flowers (Figure 2). This psyllid has a unique method of disposing of excess plant sap, i.e. honeydew. Both the adults and the nymphs package the honeydew within a plastic-like sac that can be seen as silvery globules or threads adhering to the leaves. When a large number of psyllids are present the affected leaves can take on a silvery sheen but eventually develop black sooty mould.

Figure 2. Infested eggplant (left) and dead shoots with sooty mould on upper surface - images courtesy of Deborah Kent

In the garden situation general native predators such as hover fly larvae and adult and larval ladybeetles were observed to actively feed on psyllid nymphs. A small parasitic wasp was found parasitizing large nymphs late in the 2007 season (Figure 3) and this supports the belief that the psyllid is a native species rather than an exotic.

Figure 3. Undescribed parasitic wasp (left) and parasitised psyllid nymph (left) - images courtesy of Deborah Kent

Materials and Methods

Demonstration farms

Adoption of integrated pest management (IPM) in field, hydroponics and greenhouse vegetable production has been relatively slow in the Sydney Region. Major vegetable growing regions interstate and overseas have made significant progress with success, for example diamond back moth IPM in Australian brassicas and greenhouse IPM in Europe and North America. One of the objectives of the Vegetable IPM Project was to improve this rate of uptake. Through providing the experience of IPM support and capitalising on the benefits, the growers could understand the value to their production systems that IPM expertise can bring. Incorporating IPM into their risk management could provide greater confidence for overcoming their significant pest and disease challenges.

The direct IPM technology transfer approach for this project was to establish demonstration farms and assist the participating growers with developing site-specific monitoring protocols and support their IPM implementation through weekly site visits and monitoring result consultations. The on-ground support was provided by the IPM Project Officer or the grower's IPM consultant who were, in turn, supported by NSW Department of Primary Industries Research Entomologists and diagnostic services.

The provision of weekly support, particularly during times of high pest and disease pressure, provided growers with a valuable information resource, assistance with management decisions and ready access to diagnostics services. This ensured the accurate diagnosis of crop problems and access to solutions that did not necessarily involve chemical applications. While the initial focus was on WFT and tomato spotted wilt virus (TSWV), management of other insect vectors became part of the overall IPM approach developed for each demonstration farm and grower visits.

IPM programs were planned in summer 04/05 and after several months of evaluating farm suitability for the project objectives and developing relationships with the key growers, a number of demonstration farms were identified in early 2005. The demonstration farms covered the variety of key vegetable crop types and their production systems, including:

- seedling propagator - Leppington
- field vegetables – Camden, Shanes Park, Richmond, Freemans Reach
- hydroponic lettuce – Glenorie
- low technology greenhouse – Rossmore
- high technology greenhouse - Rossmore

Selection of the demonstration farms in each key area was followed by an initial benchmarking exercise to record pest and disease management practices at the commencement of the project period. Weekly farm visits were established to provide pest and disease monitoring and provide IPM recommendations when pest and disease pressure was observed. Examples of site monitoring sheets are in Appendix 1.

The following examples describe how the monitoring was conducted and management responses for the hydroponic lettuce and low and high technology greenhouse demonstration farms.

Field vegetables

Regular pest and disease monitoring of lettuce, brassicas, potatoes, artichokes and radishes throughout the cooler months of 2005 was conducted on two field sites. The Hawkesbury demonstration site was monitored with agronomists from Elders Limited, as part of a pre-existing relationship between the two enterprises. The role of the IPM Project Officer was to provide technical support and an avenue for early diagnosis of pest and disease issues.

The Hawkesbury demonstration site followed currant lettuce aphid control practices during the 2005 mid-year planting, by drenching seedlings with imidacloprid (e.g. Confidor®). The presence of natural predators and parasites on the farm that used imidacloprid were far fewer, despite following an otherwise almost identical chemical usage pattern to the Camden grower demonstration farm. The Camden grower weighed the risk of not successfully managing lettuce aphid, in anticipation of its arrival in the Sydney Region, by relying on beneficial insects alone. They would have to resort to chemical control if the pest arrived, in order to maintain interstate market access.

Unfortunately for the project, over the summer of 05/06 the Hawkesbury region demonstration farm shifted to melon and sweet corn production, prompting a change in project activities.

The weekly IPM service provider for the Camden district demonstration farm was one of the commercial partners of the project, and the IPM Project Officer acted as technical support to this service provider. This farm produces lettuce and brassica crops for the supermarkets. An incidence of high TSWV on this farm had prompted a study into the movement of various thrips species into the crop from adjacent crops, and the possible over-seasoning of the virus in weed reservoirs. This work was undertaken with the cooperation of the IPM consultant Andy Ryland from IPMC (formerly known as Beneficial Bug Co.). The grower and the project team developed a strategy for field-grown lettuce and TSWV on this farm.

On the Shanes Park demonstration farm regular monitoring with sticky traps plus crop pest and disease scouting had been undertaken since December 2004 on zucchini, capsicum and eggplant crops.

WFT and plague thrips were present in zucchini and eggplant flowers over the summer of 04/05, but little fruit scarring was found. Capsicum crops on this farm had minor losses to TSWV, losing only one plant per fortnight. Preliminary virus surveying in eggplant had identified a phytoplasma that is known to be transmitted by brown leaf hoppers. Of the nine farms surveyed for zucchini viruses over the summer period of 04/05, five were also producing eggplant and all five had a small number of plants with the phytoplasma disease - little leaf. This was confirmed by sectioned leaf material examined by electron microscopy. The sticky trap records show brown leaf hoppers to have been regularly present in the eggplant crop, consistent with this disease diagnosis.

Hydroponic lettuce

The hydroponic lettuce farm has a semi-protected crop with plastic roof and open sides, as a barrier to climate extremes rather that pests and diseases. The method of production is not popular around the world hence little research into IPM of hydroponic lettuce is available to extend to the growers. Aspects of IPM were to be drawn from field lettuce and greenhouse vegetables in order to develop a practical approach for hydroponic lettuce production.

The production area is made up of seven houses, each with 30-35 18m long hydroponic tables over an area of 2 ha. Turnover of crops is fast at 4-6 weeks, and monitoring of the area was conducted in an oval fashion across the whole farm. Three tables from each house were monitored (10%) each week.

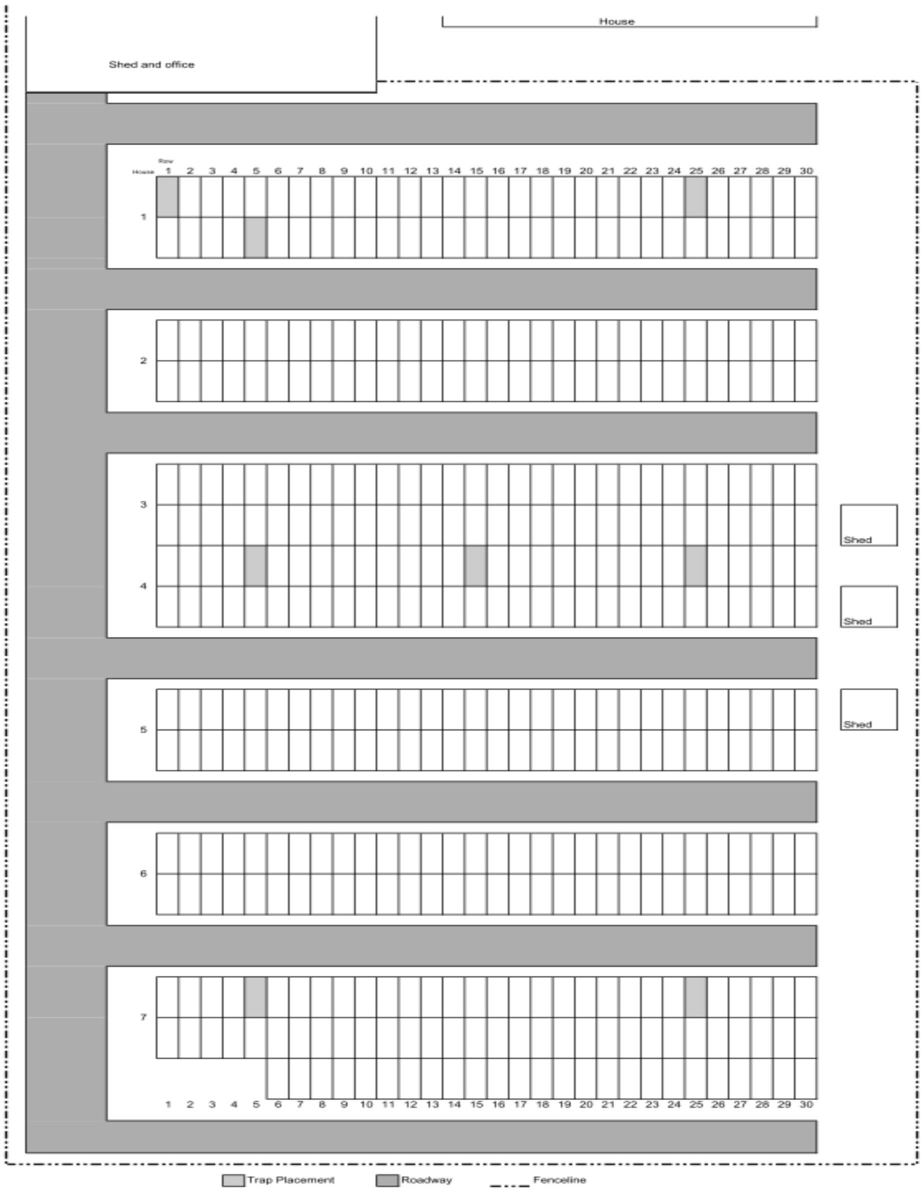
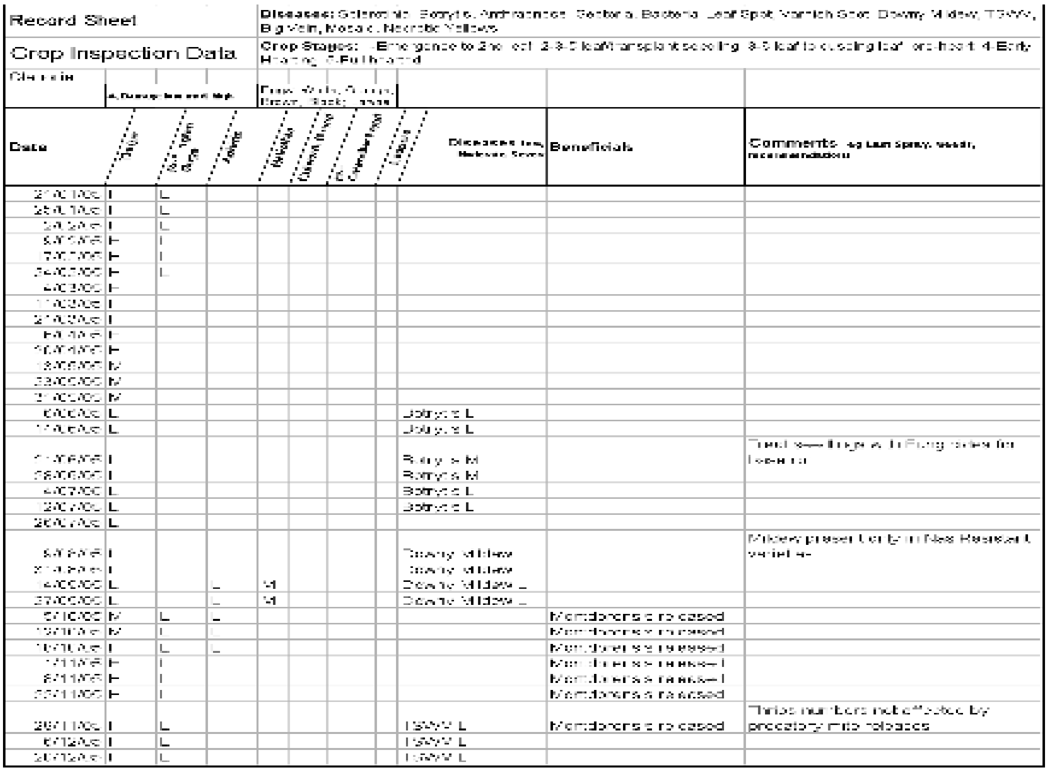


Figure 4. Hydroponic Lettuce Farm Map



Record Sheet — Crop Inspection Data

Diseases: Sclerotinia, Botrytis, Anthracnose, Septoria, Bacterial Leaf Spot, Varnish Spot, Downy Mildew, TSWV, Big Vein, Mosaic, Necrotic Yellows

Crop Stages: [illegible]

Date	Thrips	[illegible]	Aphids	[illegible]	[illegible]	[illegible]	[illegible]	Diseases	Beneficials	Comments
[illegible]	I	L								
[illegible]	I	L								
[illegible]	I	L								
[illegible]	H	I								
[illegible]	H	I								
[illegible]	H	L								
[illegible]	H									
[illegible]	I									
[illegible]	I									
[illegible]	H									
[illegible]	H									
[illegible]	M									
[illegible]	M									
[illegible]	M									
[illegible]	L							Botrytis L		
[illegible]	L							Botrytis L		
[illegible]	I							Botrytis M		[illegible]
[illegible]	I							Botrytis M		
[illegible]	L							Botrytis L		
[illegible]	L							Botrytis L		
[illegible]	L									
[illegible]	I							Downy Mildew		[illegible]
[illegible]	I							Downy Mildew		
[illegible]	L		L	M				Downy Mildew L		
[illegible]	L		L	M				Downy Mildew L		
[illegible]	M	L	L						Montdorensis released	
[illegible]	M	L	L						Montdorensis released	
[illegible]	I	L	L						Montdorensis released	
[illegible]	H	I							Montdorensis released	
[illegible]	H	I							Montdorensis released	
[illegible]	H	I							Montdorensis released	
[illegible]	I	L						TSWV L	Montdorensis released	Thrips numbers not affected by predatory mite releases
[illegible]	I	L						TSWV L		
[illegible]	I	L						TSWV L		

Figure 5. Crop Inspection data for hydroponic lettuce demonstration farm

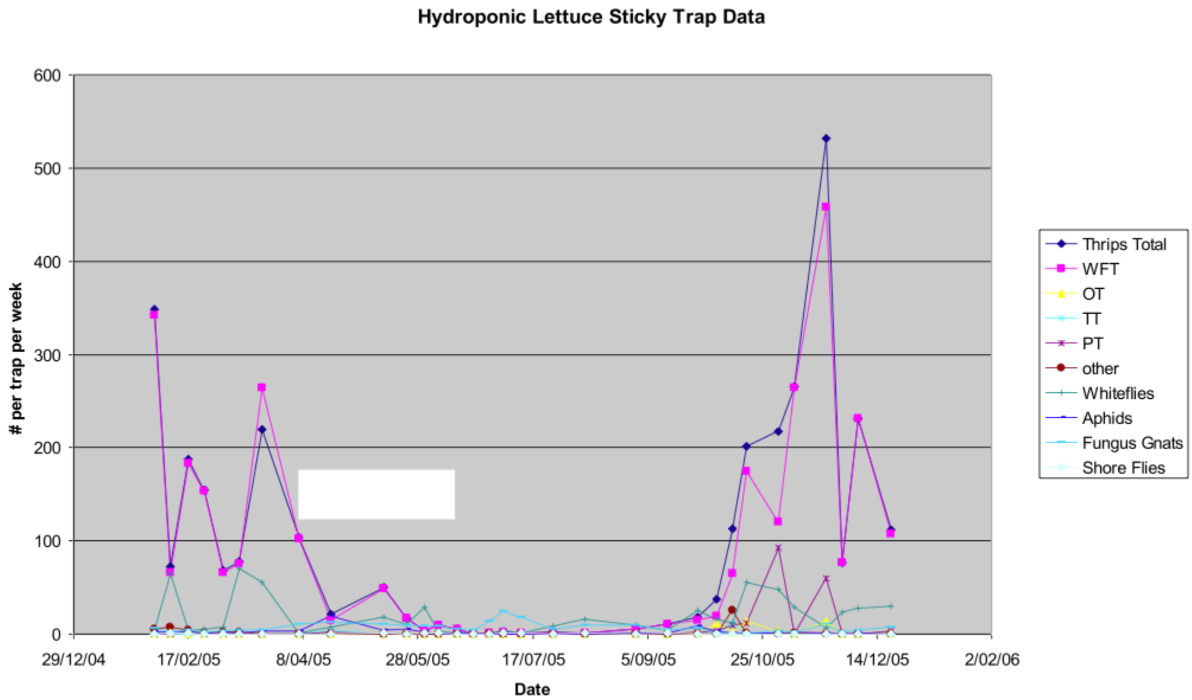


Figure 6. Mean trap counts per week for hydroponic lettuce demonstration farm

Figures 4 and 5 show the farm layout and an example monitoring worksheet. Figure 6 shows the sticky trap data for the year 2005 and the challenges for an IPM approach.

WFT were the most significant pest detected during 2005 monitoring and sticky trap evaluations. WFT numbers decreased significantly from the summer highs as temperatures declined into May. However, warm westerly winds in October and the rising mean daily temperatures saw a major influx of WFT to the site and sticky trap numbers continued to climb dramatically. Predatory mites were released but were unable to deal with the major influx of WFT. The grower had no choice but to re-introduce insecticides for WFT control in November, following six weeks of continued increases in WFT numbers and increasing crop damage. The first signs of TSWV infection in the crop coincided with the peak in WFT numbers in November.

The key pest and disease complex targeted on this farm was WFT/TSWV. The WFT pressure was moderate to high in 04/05, with hotspots and significant losses to TSWV. Hundreds of plants were lost in December 2004 to TSWV, and a number of exercises were undertaken in an effort to reduce thrips numbers in the crop.

As the initial visit at the commencement of the project coincided with 100% losses in one part of the farm, the objective had been to prevent a similar case from occurring in the 05/06 season. With a multi-faceted approach of hygiene, monitoring, biological control and pesticide management, virus losses did not exceed 5% in the known hotspot area to the end of the 05/06 period. Thrips feeding damage and numbers were still persistent, indicating the improvements in weed management and regular roguing of affected plants contributed to the reduction of TSWV affected plants. Biological control trials and other alternative methods of thrips management began over this peak summer season following the identification of an insecticide resistant population (spinosad).

Weekly monitoring has shown mid-summer Rutherglen bug infestations, late summer septoria leaf spot, and constant low greenhouse whitefly and aphid numbers. TSWV affected plants were confirmed with Agdia® Immuno-test strips. Pest and disease monitoring has also seen a reduction of winter crop losses, primarily due to botrytis crown rots from 30-35 plants per bench to 0-5 per bench due to early fungicide intervention.

The use of beneficial insects was restricted as it was a fast growing crop. Produce buyers in the market want <2% live insects in the produce specifications - including pests and beneficials. This area of Sydney also had strong WFT resistance to spinosad and moderate resistance to methomyl. As these were the only options at the time for hydroponic lettuce it became at losing battle for most, if not all, the hydroponic lettuce growers in the region. Methomyl was de-registered from use in hydroponic lettuce early in 2007, forcing growers to reassess their growing strategies.

Insecticides are applied by mister and the coverage was assessed using water-sensitive spray cards (Figure 7) positioned throughout the plants, bench and house. Coverage was seen to be adequate, and is not considered to be contributing to the high thrips numbers.

Figure 7. Common mister (left) used by hydroponic lettuce growers; water-sensitive spray card in a lettuce head for measuring coverage (middle) and TSWV damage in lettuce (right)

The IPM Project Officer and an IPM consultant recommended an investment in good farm hygiene practices to address the persistent populations of WFT and the persistence of TSWV. This recommendation was not acted upon until successive losses meant that the future of the business was at risk. A new chemical product from Bayer called Movento® also became available and was trialled at the farm in 2008-09. A major farm clean up was initiated and new hygiene practices transformed the results. Diseased plants were rogued (removed) on a daily basis and placed in a bin rather than, as previously, dropped on the floor below the benches. Previous practice allowed thrips to pupate on the dropped plants and maintained a source of virus contaminated material for young thrips to transfer back to healthy plants on the benches. This is called in IPM terms the ‘green bridge effect’.

Another strategy adopted during harvest was as plants are picked, sleeved and boxed on the bench, workers place the outer lettuce leaves straight into a bag lined wheelie bin. These practises dramatically reduced, if not eradicated the resident and persistent population of WFT. Pesticide applications had also been dramatically reduced as a result of the monitoring, clean up and modified practices program.

Chemicals used for thrips control are methomyl and spinosad. These chemical options should give good control, so usage patterns were modified to follow resistance management recommendations. The chemical management strategy for WFT involves three applications of a chemical or chemicals in the same activity group three days apart in summer (over 6 days). This targets all individuals in their vulnerable stages of the life cycle for a generation, leading to better control. Subsequent rounds of chemical applications should involve chemicals from different activity groups. This was undertaken with maldison, methomyl and spinosad bringing thrips numbers down significantly.

Data collected from weekly sticky trap counts and scouting show seasonal population dynamics to be dependent on temperature, rather than insecticide applications. The resistance results (see Appendix 3) indicated strong resistance to spinosad (24%) and moderate resistance to methomyl (89%) - these are the only chemical options for lettuce. Samples of the WFT population were forwarded to the NSW DPI Insecticide Resistance Management group led by Dr Grant Herron at Elizabeth Macarthur Agricultural Institute (EMAI) in Camden, to be assessed for resistance.

The implementation of IPM to hydroponic lettuce may be limited due to issues related to crop marketing. The hydroponic lettuce demonstration farm is a direct supplier to a major supermarket whose product specifications define the presence of live insects as a major defect. Physical presence of insects (live or dead) must not exceed 2% of product in any consignment. Hydroponic lettuce growers believe this limits the potential for IPM implementation to the level of introducing beneficial insects or conserving natural predators.

Low technology greenhouse

Cucumbers are generally produced in low tunnels or low multispan greenhouses throughout Western Sydney. The site selected as a cucumber demonstration farm had both of these structures on-site, allowing other growers to evaluate the success of IPM implementation in structures similar to their own.

Seven rows out of 35 were monitored in the multispan, with rotation between rows each week. Sticky traps were placed in six locations throughout the multispan, changed and counted weekly. 6 tunnel houses were monitored, each with two of four rows inspected weekly. 20 plants from each of 3 tunnels (6%) were inspected and two sticky traps per tunnel were placed, changed and counted weekly.

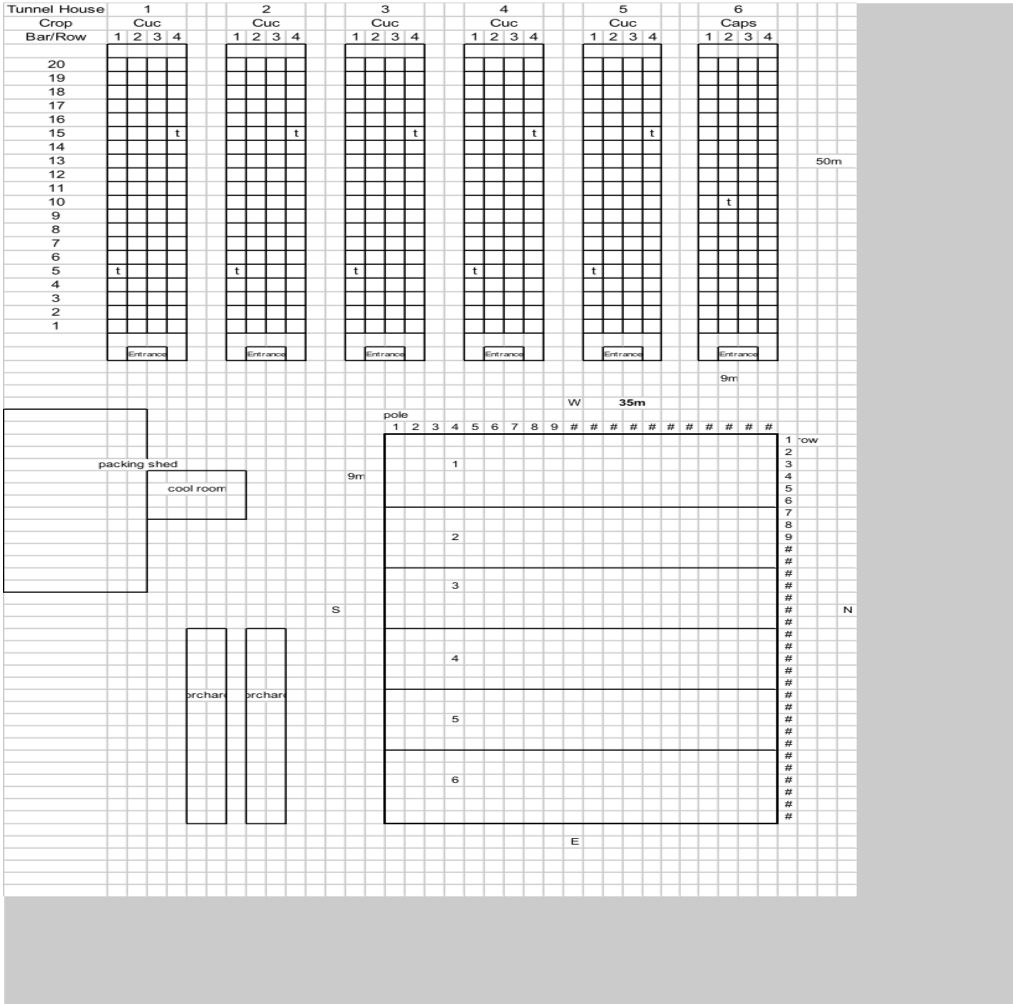


Figure 8. Greenhouse Cucumber Demonstration Farm Map

Crop Inspection Results

Grower Details	
GPS	
Crop	Cucumber
Planting Date	20/04/2006
Variety	
Est. harvest date	from 1/6/06
Planting Size	House 4: 120 x 4 plants; 9x 50m
Farm Size	

Pesticide Records (active, date, rate)

Plot Map

Monitoring Records

Insects, Pests Low, Moderate, Severe

Date	Crop Stage	Thrips	Whiteflies	Aphids	Spider mites	Fungus Gnats	Shore Flies	Loopers/ other grubs	Beneficials	
30/05/2006	1			Low on end						
10/05/2006	2	Low	Low	Low						
24/05/2006	3									
	4									

Diseases Low, Moderate, Severe

Date	Crop Stage	Root	Crown	Stem	Foliar					
30/05/2006	1	0	0	0	0					
10/05/2006	2	0	0	0	Low small amount of powdery					
	3									
	4									

Crop Stages: 1: Planting age/Emergence/Seedlings 2: Pre-flowering 3: Flowing/Early fruiting 4: Harvest age

Cucumber Diseases: Fungal (Pythium, Fusarium, Gummy Stem Blight, Botrytis, Powdery Mildew, Angular leaf Spot, Downy Mildew), Bacterial (Leaf Spot), Viral (Mosaic, Yellows)

Tomato Diseases: Fungal (Pythium, Fusarium, Botrytis, Powdery Mildew, Grey Leaf Spot), Bacterial (Canker, Wilt, Leaf Spot), Viral (TSWV, CMV, others)

Comments: Laboratory Test Results, Insect Identifications

new bags

Figure 9. Crop Inspection data for low technology demonstration farm

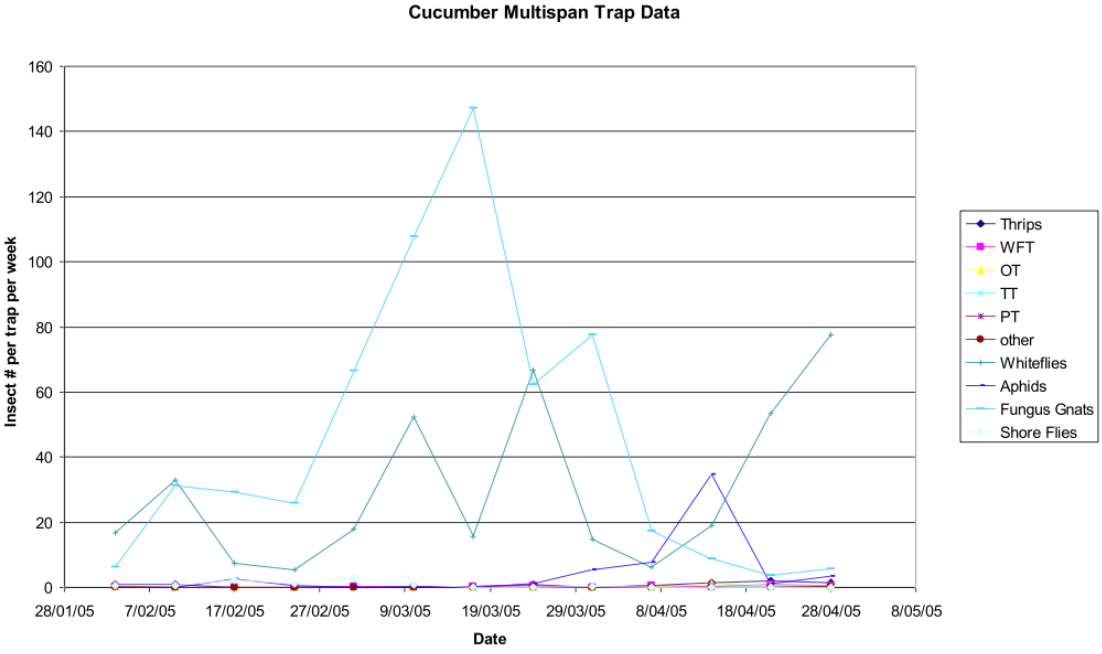


Figure 10. An example of mean trap counts per week in cucumber multispan house

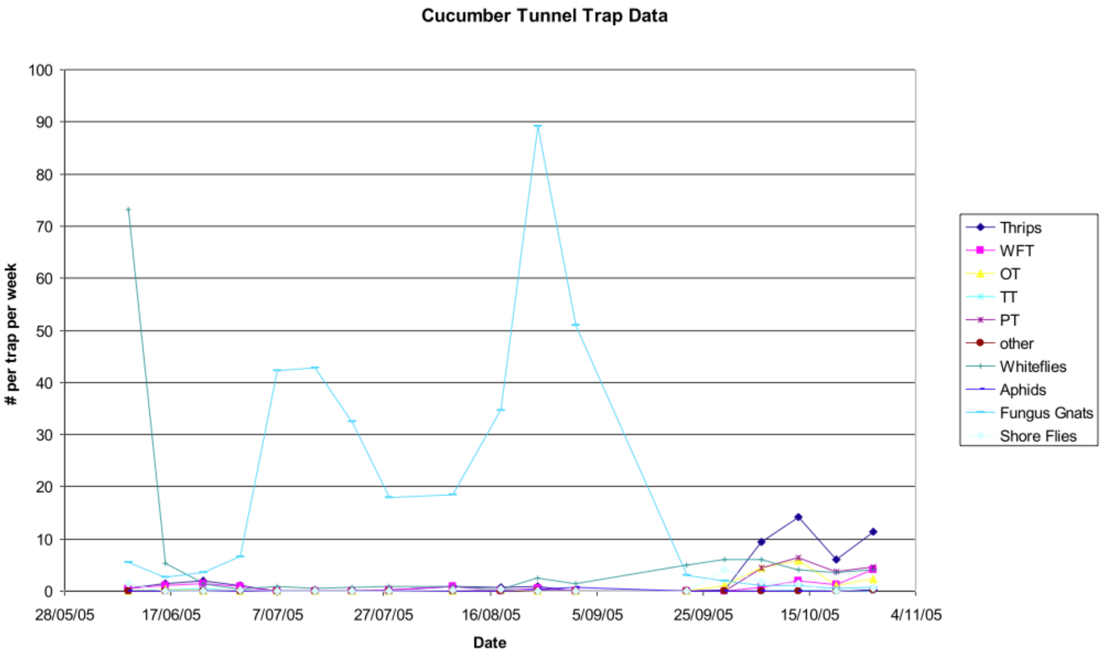


Figure 11. Mean trap counts per week in cucumber tunnel houses

Figures 8 and 9 show the farm layout and an example monitoring worksheet. Figures 10 and 11 show trap data from the year 2005 for the multispan and tunnel structures.

The results reflected in Figures 10 and 11 above are averages of the trap counts for each week. Whitefly counts are higher on the warmer north-west side of the multispan (Figure 12). Sciarid flies, or fungus gnat, counts are higher on traps closer to the ground. The decline in this pest seen in Figure 9 is attributed to fortnightly applications of entomopathogenic nematodes during March, released when trap counts exceeded 50 adult gnats per trap per week. Aphids peaked when weeds around the greenhouse were present and declined when they were cleared. The management of fungus gnats reflected in Figure 7 demonstrates the effectiveness of *Hypoaspis* predatory mites.

Figure 12. Low technology cucumber farm (left) and *Encarsia* biological control release (right)

Up until December 2004, the low technology greenhouse grower producing mini-cucumbers experienced WFT in excessive numbers that were unable to be chemically controlled, due to lack of registrations and withholding period (WHP) restraints. The grower acted on initial recommendations provided by the IPM Project Officer to control weeds to a 5m buffer zone around the greenhouse, along with removing old crop residues promptly.

Weekly scouting revealed few thrips in the summer of 04/05, with sticky traps averaging one thrips/trap, with a maximum of five WFT on one trap. No fruit has since been discarded due to thrips damage, whereas the grower reported up to 30% losses caused by thrips damage in previous crops.

The issue of a permit for spinosad on cucumbers with a one day WHP enabled the grower to have a chemical option if thrips numbers increased again. However, improved farm hygiene kept WFT numbers in check. Spinosad is now registered for use on greenhouse cucumbers but has a three day WHP.

A cropping cycle starting in late April 2005 continued with the use of biological controls such as nematodes for sciarid control, *Encarsia* wasps for whitefly control and predatory mites for two spotted mite (TSM) from early in the season. This was to limit the chance of infestation experienced with the previous crops. As the season progressed, thrips and other pest and disease issues were controlled with IPM compatible products where possible. The 04/05 summer crop had suffered from powdery mildew, TSM and climate related fruit losses. A phytotoxic effect caused by a chemical application for suspected angular leaf spot in that crop also emphasised the importance of correctly diagnosing problems rather than making assumptions and using inappropriate chemical control options.

The IPM crop was showcased as a farm walk demonstration in late May 2005, with early stage biological controls and sticky traps in use. Over 25 attendees participated with five growers showing strong interest in developing IPM programs (Figure 13). Subsequent visits to some of their farms diagnosed a number of aphid borne viruses in a range of crops, plus nutritional disorders the growers had mistaken for viruses. A follow-up farm day was planned for September 2005. Two additional cucumber farms including a Vietnamese family farm began the transition to IPM, improving crop hygiene and cultural controls and the reduction of chemical usage. Both farms were considering trialling the use of beneficial organisms.

Figure 13. IPM demonstration farm walk in May 2005

Screening can also be useful for both shade and pest exclusion. A range of greenhouse crop pests can be screened out with different hole sizes, or with optical additives to the screens that may repel certain pests and pesticide use can be significantly reduced. Considerations include cost, ventilation, ability to retrofit screens and the structure lifespan.

Types of screens that can be used include:

- OptiNet 40 and 50 mesh (Polysack)
- BioNet 50 mesh (Meteor)
- Antivirus net (Meteor)
- Spidernet (Meteor)
- Econet M (LS) / Econet T (LS)

Screens can be fitted to side walls, doors, vents or whole structures.

This low technology greenhouse cucumber farm fitted whitefly screen modifications to their tunnel houses (Figure 14). The grower reported that he had confidence in their effect in screening pests out but that the screens significantly reduced ventilation in the tunnel, making them too hot for his workers during the warmer months - so he removed them.

Figure 14. Tunnel greenhouse in Rossmore with roll up sides protected by whitefly grade insect screening

Biological control is successfully implemented as part of the IPM program on this farm. As spring and summer of 2005 approached, pest pressure was foreseen to increase. A beneficial population of biological controls had been established in conjunction with weekly pest and disease monitoring and spot-spraying of soft chemicals. The farm maintained weed control around the polyhouses plus weekly pest and disease monitoring of the crops throughout the summer of 2005/06. A combination of biological and chemical control was used throughout the year to maintain healthy crops, with the frequency of insecticide applications reduced from weekly to one or two applications per crop.

Biological control can be implemented in lower technology greenhouses, but implementing good crop hygiene practices and controlling weeds in areas surrounding the greenhouses achieves the most dramatic and sustained improvements. Pest incursions such as WFT will happen from time to time based on weather conditions and chemical controls may be needed. However, good farm hygiene underpins an IPM program that ensures persistent and chemically resistant populations of pests are not allowed to establish.

A second and nearby low-medium technology farm is a pivotal meeting place for one of the largest groups of greenhouse growers in the Sydney Region. Lebanese-background growers meet frequently at this farm, both for business and social occasions, and the grower provides his farm as a community space growers are comfortable with when attending workshops, field days, meetings and general business.

The interest of growers in implementing greenhouse IPM programs was verified with local producers attending the meetings. Their interest may be stimulated by financial incentives to minimise crop losses to pest and disease but this provides a good opportunity to advance IPM concepts with them. Following demonstration of results on this farm six additional growers agreed to cooperate and implement a similar IPM program on their farms. Each of the meetings involved a commercial partner and the six farms were represented. Other growers maintained contact with the IPM Project Officer and initiated IPM strategies with particular focus on fungus gnat control in substrate media.

This demonstration farm was a great place to exhibit the basics to IPM. Early in the project an immense effort was put into good farm hygiene practices (Figures 15 to 20 show ‘before’ and ‘after’ site photos). A backhoe was made available and used to clear pathways, reduce weeds, and remove accumulated waste from the property.

Figure 15. Side fence 'Before'

Figure 16. Side fence 'After'

Figure 17. Between houses 'Before'

Figure 18. Between houses 'After'

Figure 19. Front 'Before'

Figure 20. Front 'After'

High technology greenhouse

Although tomato growers do not contribute to the national vegetable levy, the farms with high technology greenhouses produce tomatoes in order to cover capital costs. As biological control programs are most effective in houses using newer technologies, this method of IPM was demonstrated on this demonstration farm.

The 6000 square metre multispan greenhouse was divided into quadrants for the purpose of crop inspections, and traps were placed in eight locations throughout the house. Traps were changed and counted and 30 plants (1%) in each was quadrant inspected weekly. The demonstration farm map is presented below in Figure 21.

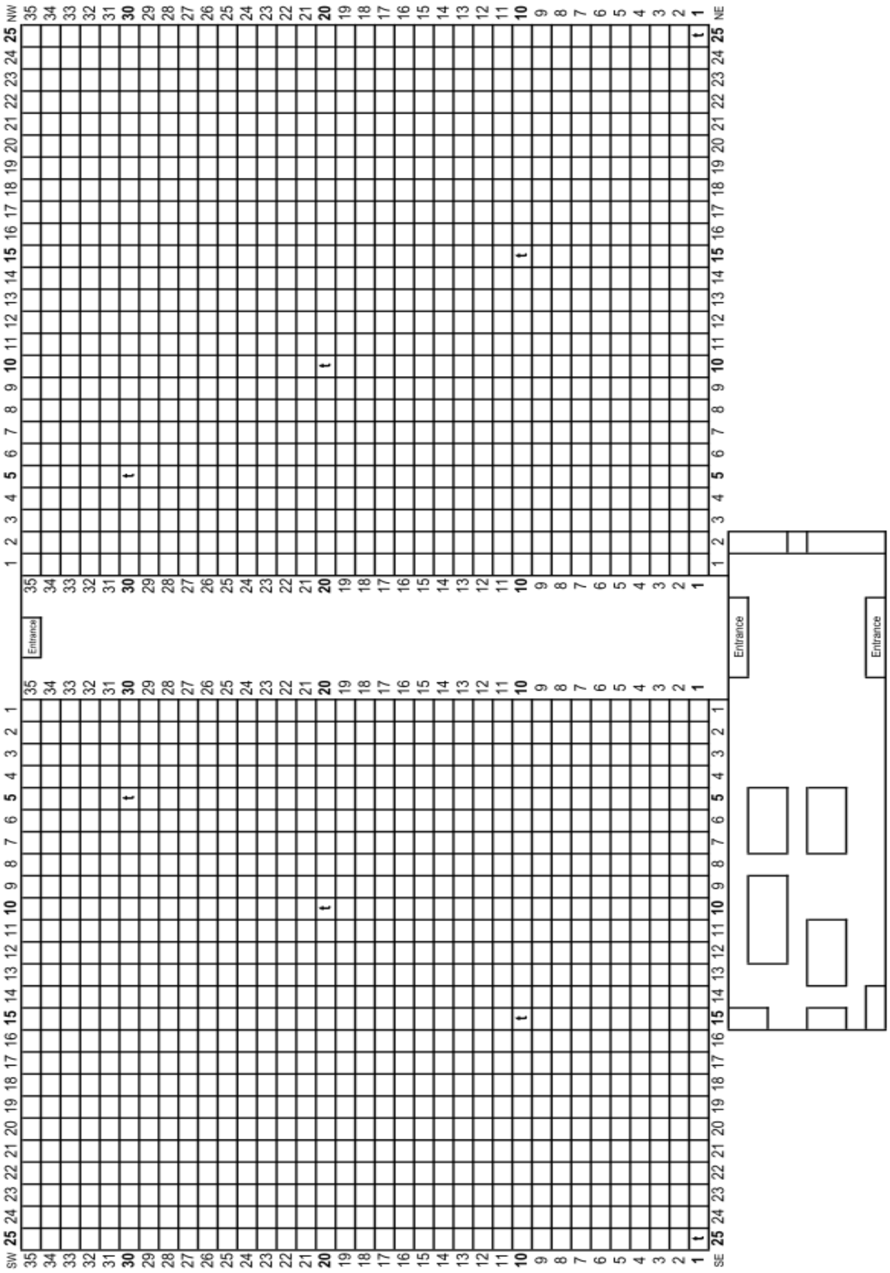


Figure 21. Greenhouse Tomato Demonstration Farm Map

Record Sheet

Diseases: Fungal (Pythium, Fusarium, Botrytis, Powdery Mildew, Grey Leaf Spot), Bacterial (Canker, Wilt, Leaf Spot), Virus (TSWV, CMV, others)

Crop Inspection Results

Crop Stages: 1: Establishment/Pre-fruiting 2: Early fruiting 3: Fruiting

		# pests, Damage low, mod or high?										
Date	**Crop Stage**	Thrips	Whiteflies	Aphids	Spider mites	Russet Mites	Fungus Gnats	Shore Flies	Heliothis/Loopers/ other grubs	**Diseases** Low, Moderate, Severe	**Beneficials:** #, Type Ef *Encarsia formosa*	**Comments** eg Last Spray, weeds, recommendations
15/09/2005	1							H				
22/09/2005	1							L				
29/09/2005	1						L	L				
6/10/2005	1	L					L					
13/10/2005	1	L					L			TSWV x 3		
20/10/2005	1	L					L		loopers L	TSWV x 1		Bt via mist
27/10/2005	1	L	L						loopers L	TSWV x 2, powdery mildew low	Ef H	BT spray, keep humidity low for mildew
3/11/2005	1	L	L						loopers larvae all sizes L			spray liquid sulfur and Bt
10/11/2005	2								loopers pupae L	PM moderate on east side, minimal Botrytis, TSWV x 4 (25-3, 33-10, 12-8, 4-22)		spray Bt and Bravo
17/11/2005	2								loopers 3-5mm L	PM mild on east side, TSWV x 4 (4-25, 3-15, 3-16, 29-15)	Ef M	spray Bt
24/11/2005	2										Ef L; other wasp with pink scale	sulfur on floor next week
1/12/2005	2	L	M				L			2 TSWV 31-6, 55-3 and 3 plants for testing 31-11, 39-1, 47-21, PM mild-moderate on east side	Ef L	Consult horticulturist: Row 2-34 wilted due to high EC 5 days ago. Roots damaged, expect fruit loss if plants survive
8/12/2005	3	L	H						heliothis in fruit L, loopers L	TSWV 3-7, 70-1, 72-1; powdery not on new growth, blossom still bad	Ef L	spray eco-oil and Bt for whitefly and grubs. in afternoon, repeat next week.

Figure 22. Crop Inspection data for high technology demonstration farm

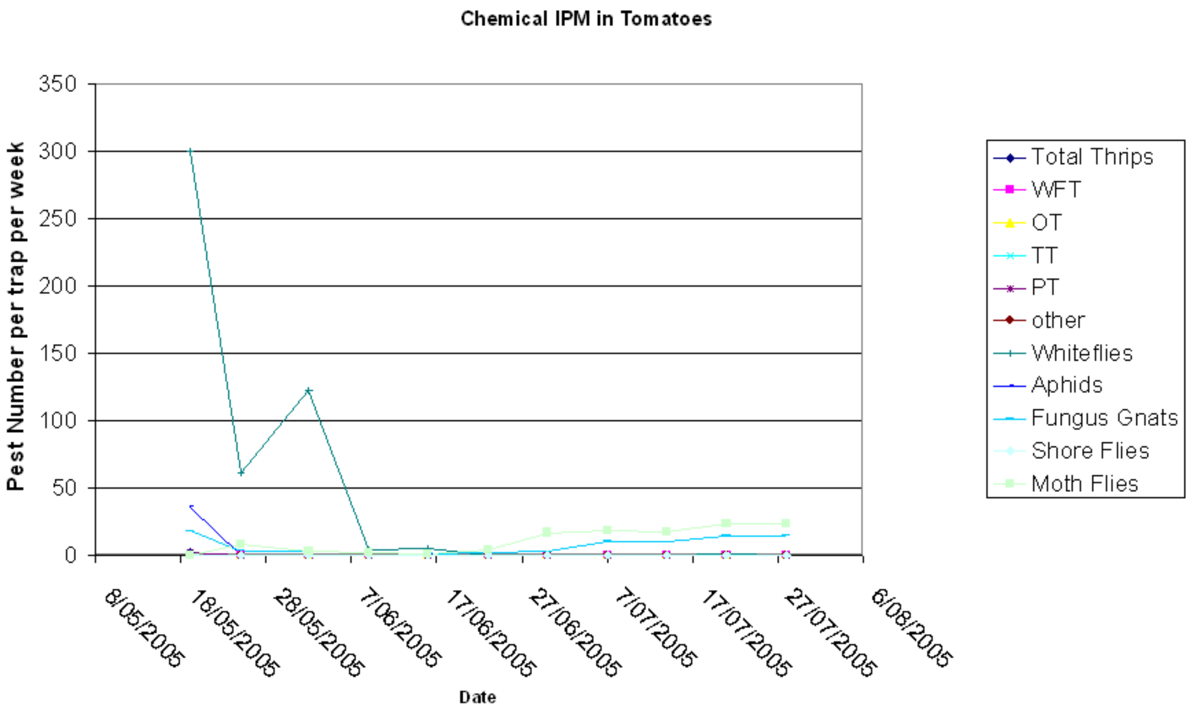


Figure 23. Mean trap counts per week in 2004-5 tomato crop using chemical IPM

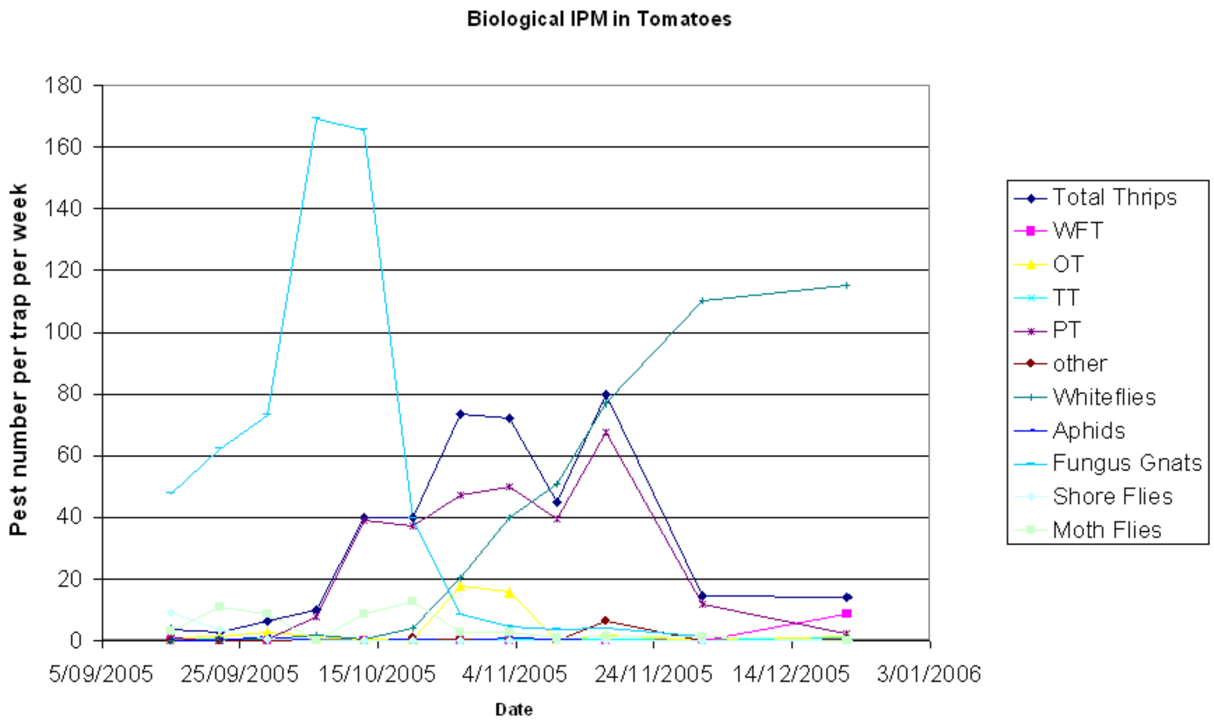


Figure 24. Mean trap counts per week in 2005-6 tomato crop using biological IPM

Figures 21 and 22 show the farm layout and an example monitoring worksheet. Figures 23 and 24 show trap data from the year 2005 for the chemical IPM and biological IPM strategies for tomato crops.

The drop in whitefly numbers in Figure 23 is attributed to both cooler conditions and foliar imidacloprid (Confidor®) applications.

The data presented in Figure 24 shows the crop establishment and fruiting for three months. Fungus gnats were managed with entomopathogenic nematodes in October and were maintained at low numbers with *Hypoaspis* predatory mites. Shore flies detected in the first fortnight on traps were introduced with the seedlings and thrips numbers were seasonally elevated with periods of warm winds through October to November. Whitefly became established once mean daily temperatures were above 35°C in the house and *Encarsia* were released at 2 per m^2 for their control.

A high technology farm in the Rossmore area also participated as a demonstration farm midway through the project. Farm hygiene levels were very high and various biological agents were trialled on this farm at the cost of the grower.

Encarsia, *montdorensis* mites, entomopathogenic nematodes and Vectobac® were used and showcased during a greenhouse cucumber farm walk in May of 2008. This grower persisted with biological controls but later reverted back to conventional pest management. Their reasons cited were quicker control of pest flare ups using systemic options such as Confidor® for whiteflies, and conscious that the greenhouse temperatures during summer months would be too high for the survival of beneficial insects. Despite this, demonstrations conducted at the farm were an ideal exhibition of good farm hygiene practices for many local growers.

A high technology greenhouse producing truss tomato varieties was also used as a demonstration farm (Figure 25). The initial IPM benchmarking survey results found the extent of IPM practice to include physical exclusion of pests and diseases, with double door entry, foot baths, gloves, and solid walls. Vents were not screened and pests such as two-spotted mite and diseases such as Botrytis are spot sprayed where possible. Methomyl was used to control thrips however weekly scouting generally found minimal thrips. Five TSWV affected plants (one isolated and one hot spot of four plants) were removed from December 2004 to March 2005 out of 18,900 plants. Sticky traps have less than one thrips per week over the whole house.

Figure 25. Truss tomato production (left) and TSWV ‘bronzing’ symptoms on leaf (right)

The structure itself ensures a very low pest and disease pressure; however an infestation gone unnoticed would have devastating consequences. 15% of the 2004 crop succumbed to Botrytis, favoured by cool, moist conditions. Bacterial canker (*Clavibacter michiganensis*) then affected most of the house in the second month of the 2004/05 growing season, resulting in the removal of the entire crop, disinfestation of the house, media bags, and equipment. This led to a late planting of a replacement tomato crop.

Entomopathogenic nematodes were introduced in the growing season of 2005 and aimed to reduce the level of sciarid fly larvae. During the 05/06 crop several biocontrol agents were demonstrated; *Encarsia* wasps for whitefly biocontrol, along with entomopathogenic nematodes for sciarid, Montdorensis mites for whitefly control and *Bacillus thuringiensis* was applied through the misters to control *Heliothis*.

As new plants (19 000) arrived in September 2005 for the 2006 crop it was decided that the greenhouse would follow a biological IPM program with strict hygiene and cultural conditions reducing the chance of pest infestation for this period. An on-farm workshop was conducted in November 2005 so that a targeted group of long-term crop truss tomato growers and their consultants could learn about transitioning to an IPM program.

Seedling producer

A further demonstration farm at a seedling producer provided the opportunity to focus on prevention of transmitting pests and disease to other farms. Seedling producers have an obligation to provide premium quality products to their clients and it is vital that seedlings are free from insects and diseases. Using beneficial insects can be a major challenge for these growers as clients demand insect free material and most of the time this includes beneficial insects also.

This grower became interested in IPM and farm improvement early in the project. Using beneficial insects may not have been something that was going to become part of the pest management program. However, the farm manager employed the services of an IPM scout for support in his pest and disease management process. During the initial process of IPM awareness farm hygiene became the main focus in combating any persistent pest/disease problems. Many of this supplier's clients request seedlings for organic, IPM and conventional farming systems, therefore, managing pests for different requirements has been a challenge. This grower is dedicated to maintaining good farm hygiene practices and using an IPM scout to lower pesticide application plus provide accurate pest and disease identification.

The IPM program for a vegetable seedling farm includes sticky trap monitoring and pest and disease scouting to provide opportunities for early intervention to minimise losses, and to identify the efficacy of chemicals. There is a need for seedling stock that has not been sprayed with chemicals that have residues harmful to natural enemies (field) and biocontrol agents (greenhouse). A significant proportion of production is in brassicas, and chemical usage in the nursery must reflect what the IPM growers will need on their farms.

The weekly vegetable seedling monitoring program was maintained in-house by the seedling propagator, with technical support offered by the IPM Project Officer, where necessary, throughout the course of the project.

Surveys

Zucchini Mosaic Viruses - 2005 – 2009

Zucchini (*Cucurbita pepo* [Cucurbitales: Cucurbitaceae]) is an important part of the summer crop rotation for many Sydney field vegetable growers. Zucchinis are planted after late frosts in August to February, with the last crops picked up to mid-April. One of the key pests is aphid and the key diseases are mosaic viruses (spread by aphids) and powdery mildew.

Throughout the summers of 2005 to 2009, virus incidence, variety performance, aphid incidence, product trials, alternate hosts and virus transmission within zucchinis was surveyed and trialled.

The term 'mosaic virus' in zucchini refers to diseases caused by papaya ring spot virus (PRSV), watermelon mosaic virus (WMV2), or zucchini yellow mosaic virus (ZYMV). Zucchini mosaic viruses dramatically reduce yields. The mosaic viruses cause chlorotic (yellowing) rings, mosaic patterns, mottling or colour break on foliage, flowers, fruits and stems. These diseases are associated with stunting of young plants, malformation in leaf, raised lumps along the fruit and stem (figure 26) and cause necrosis of various tissue and fruit drop (Agrios, 2005).

Figure 26. Distorted zucchini leaf (left) and fruit (right)

Other viruses

Other virus surveying was aimed mostly at TSWV in various vegetable crops, weeds and volunteer plants. Some samples were organised surveys whereas others were samples admitted into the NSW DPI plant health diagnostic lab at Elizabeth Macarthur Agricultural Institute, either by IPM consultants on behalf of their clients, *via* project team members or directly by vegetable farmers that were closely associated to the project. IPM consultants trained under the project were urged to use the diagnostic facility as a tool in accurate analysis of their client's pest and disease problems. Virus survey results can be seen in Appendix 2 - submissions highlighted in yellow were positive results for virus presence and submissions highlighted in orange were positive results and also unusual findings on that host plant.

Alternate host survey - Summer 2006-07

An evaluation of the common plants found on zucchini farms in the Sydney Region was conducted to identify the possible alternate hosts to zucchini mosaic potyviruses vectored by aphids. *Myzus persicae* and *Aphis gossypii* are known vectors of all three zucchini mosaic potyviruses. They have consistently been detected on zucchinis and alternate hosts during regular surveying over recent years in these crops in the Sydney region. These two aphid species were used to mimic an aphid flight into a crop to transmit the viruses from known infected zucchinis to the test hosts, as well as mechanical inoculation. A temporal assessment to monitor the time taken from initial virus transmission to symptom expression was conducted in a glasshouse situation. Host plants were also exposed to potential virus transmission in a field situation as sentinel plants.

New pest and disease detections

Papaya Ring Spot Virus

Surveys were conducted using an enzyme linked immuno-sorbent assay (ELISA) to detect the presence of papaya ring spot virus (PRSV) on a number of weed species

Currant Lettuce Aphid

A survey for the currant lettuce aphid (CLA) (*Nasonovia ribis-nigri*) was undertaken at growers' properties across the Sydney Basin while extension activities were being undertaken and during organised surveying visits. Plant material was visually inspected for the presence of the aphid and results recorded.

Psyllids

A single survey of a commercial eggplant grower in the western Sydney Region during spring 2007 found no psyllids. However, as the infestation in the suburban backyard did not appear until February 2008 and in April 2007 it is possible that commercial growers' may only have been affected late in the season. Adults and nymphs (Figure 30) were found in abundance in the residential area.

Growers should also be aware that an exotic psyllid from North America has recently become established in New Zealand. The potato/tomato psyllid, *Bactericera cockerelli*, was initially found in 2006 in an Auckland greenhouse tomato crop using IPM. The psyllid is now considered established in New Zealand. Its method of entry into New Zealand was undetermined. As its name implies the psyllid infests a range of Solanaceous species such as tomatoes, potatoes, eggplant and capsicum. A solid white deposit on the leaves called 'psyllid sugar', this species' particular method of excreting excess honeydew, characterizes plants infested by this psyllid.

In tomatoes, the potato/tomato psyllid feeding causes plants to produce numerous small fruit of poor quality or prevents fruit forming at all. In addition, the psyllid nymphs inject a toxin into the plants as the feed. The toxin results in conditions called 'psyllid yellow' and 'purple top' where the leaves become discoloured and distorted and the plant itself becomes stunted and new growth is retarded.

Figure 30. Adult (left) and nymph (right) - image courtesy of Shaun Bennet

Impatiens Necrotic Spot Virus

Early in 2010 NSW DPI plant diagnostics detected impatiens necrotic spot virus (INSV) in an ornamental crop after symptomatic plant material was submitted for testing.

Variety trials

December 2006

Five zucchini farms participated in demonstrations for virus resistant varieties. Seed companies offered lines with various levels of resistance. Seedlings were grown by Farm 13 and they were planted 23rd November 2005.

Of the 25 resistant varieties tested, 19 were dark green types (to compare with the industry standard Congo), 3 Lebanese types (for comparison with Martina or Clarita) and three gold types (to compare against the standard Sunline).

Plots of 50-100 plants were set up for each variety. Growers selected the variety they preferred to trial, and fortnightly virus testing was maintained throughout the growing season.

Variety trial - February-March 2006

Twelve zucchini varieties, including the susceptible industry standard Congo, were compared in a randomised complete block design (RCB) at farm 6. The trial varieties selected were: Congo Standard, Z52 Top Gun, HZU 4, 3463, 3465, Jaguar, 8572 Stinger, 8642 Hummer, Houdini, Shimmer, Midnight and ZU384. Five replicates of ten plants were planted for each of the 12 varieties on the 6th February 2006. Score: 0 - nil; 1 - leaf symptoms; 2 - leaf and fruit symptoms. Plants were monitored for aphid vector activity and leaf samples were collected fortnightly for virus testing.

Variety trial - Summer 2006-07

Trials were undertaken on a commercial vegetable farm in Freemans Reach (Farm 6) on the western escarpment of the Hawkesbury River near Richmond, and also at the University of Western Sydney Hawkesbury Campus (Farm 19) at Richmond.

Five varieties (including the susceptible Congo) were compared in an RCB design at two locations (Farm 6 and Farm 19). Six plots of 20 plants per variety were planted for each of the 5 varieties at Site A and 6 plots of 10 plants per variety were planted for each of the 5 varieties at Site. Each row represented one block. The trial plot was buffered by the standard variety, Congo. The trial varieties selected were: Congo Standard, Top Gun Z52, Hummer SPS 8642, Houdini and Midnight.

Random plants were monitored for aphid vector activity and scored for virus symptoms (Score: 0 - nil; 1 - leaf symptoms; 2 - leaf and fruit symptoms). Symptoms were scored and leaf samples were collected fortnightly from Week 4 for virus assessment, with weekly aphid monitoring and sampling.

Product trials

Product Trial 1 – Stress-Ex® and Flextend®

The use of anti-transpirant substances on zucchinis, such as Stress-Ex® and Flextend®, may enable growers to use susceptible varieties without the need for pesticide control of aphids (Azzopardi, 2006). Anti-transpirants contain beta-pinene polymers. Pinolene is a natural non-toxic product derived from pine resins and has been proven to protect pesticides from environmental degradation (Hurtt and Templeton, 1971). The properties of this polymer-based product may include a reduction in stylet penetration of sucking insects. Products such as Flextend® contain possible properties for preventing insect feeding as the polymer sets to create a film over the leaf surface. This product was initially designed as a sticking-extending agent to enhance the life of pesticides (Ekko, 2007). Due to its unique properties, current trials will determine their efficiency at preventing foliar stylet penetration.

These trials investigated the use of Stress-Ex® and Flextend® as anti-transpirants that may prevent aphid stylet penetration of zucchini plants and deter zucchini mosaic virus transmission.

The two products were trialled in various combinations and rates to evaluate their effectiveness at preventing virus transmission by aphid vectors. Host plants were all susceptible Congo, planted 14th February 2006 and the spray trial was initiated from the 21st February.

The product trial was set up as an RCB design at a single farm known as Farm 6. Seven treatments replicated over four rows were planted, with 15 plants per treatment per block. Each row was buffered by non-treated rows in order to prevent spray drift. Leaf samples were collected fortnightly for virus testing.

The product treatments were:

Treatment	Product
1	Stress-Ex® @ 0.5% at transplanting, + Flextend® @ 0.3% weekly
2	Stress-Ex® @ 0.5% at transplanting, + Flextend® @ 0.3% fortnightly
3	Stress-Ex® @ 1% at transplanting, + Flextend® @ 0.3% weekly
4	Stress-Ex® @ 1% at transplanting, + Flextend® @ 0.3% fortnightly
5	Flextend® @ 0.3 at transplanting and weekly
6	Flextend® @ 0.3 at transplanting and fortnightly
7	Control (water)

Product Trial 2 - Flextend®

In weeks 1 and 8 no aphids were found in the weekly random aphid sampling of the product trial for farm 6. Aphids were found in the random sampling, with the majority of those found to be the virus vector. Most of these aphids were winged.

In weeks 1 through to 3 no aphids were found in the weekly random aphid sampling of the product trial for Farm 19. In weeks 4 through to 8 aphids were found in the random sampling, with the majority of those found to be virus vectors. Most of the aphids in week 4 were winged aphids. From weeks 5 through to 8 the aphids found were winged and non-winged aphids.

For Farm 6 Flextend® product trial week 4 of the random sampling of zucchini leaf material for ELISA tests, all 3 treatments tested negative to PRSV, ZYMV and WMV2. In week 6 all 3 treatments tested negative to PRSV but positive to ZYMV and WMV2. In week 8 the water (control) treatment tested negative to PRSV and WMV2, the Flextend® 1.0% treatment tested negative to PRSV and positive to ZYMV and WMV2, and the Flextend® 1.5% treatment tested positive to all three zucchini mosaic viruses (PRSV, ZYMV and WMV2).

For Farm 19 Flextend® product trial weeks 4, 6 and 8 of the random sampling of zucchini leaf material for ELISA testing all 3 treatments tested negative to PRSV, ZYMV and WMV2.

Site B product on aphid numbers were not found to be significantly affected by the treatments ($P>0.05$) but significantly increased as time of the trial continued ($P<0.001$). Weekly data showed the 2 treatments were not different from the Control as shown in Appendix 4, Table 5.

The Farm 6 product trial on visible virus symptoms showed no effects of the treatments on percentage with plants presenting visual virus symptoms at week 8 ($P>0.05$) (Appendix 4, Table 7). No visible viral symptom was found in most plants for up to week 7.

Bioassays

Hosts were propagated from seed in an enclosed greenhouse to three true leaves. A series of weekly virus assessments were conducted to observe the incidence of virus infection in each host as well as the time taken from infection to symptom expression. Virus incidence was monitored by observing symptom expression and classifying symptoms into three categories, being non-host, local lesion host or systemic. ELISA testing was conducted several times throughout the trial period to support symptom observations and to document the rise in virus titre in host leaves.

Farm 1 is located in Horsely Park; Farm 2 in Orchard Hills; Farm 3 in Berkshire Park; Farms 4,6 and 7 are in Freemans Reach and Farm 5 is situated in Tennyson.

Mechanical inoculation

A range of hosts were tested for mosaic virus susceptibility via mechanical inoculation. Mechanical inoculation of each host with preserved material sourced from the field surveys. Hosts included broadbean, zucchini (Congo – susceptible variety), lupins and *Nicotinia glutinosa.*

5 positive plants were taken from the mechanical inoculation trial and used as mother plants or positive viral material for a further study of various suspect host plants. The plants included were broadbean, zucchini, dock, fleabane and various species of fennel.

Test hosts mosaic virus assessment – Cage trial in glasshouse with infective plants

Introduction of known vectors *M. persicae* and *A. gossypii* to positive material sourced from the field surveys. Newly infective vectors were transferred to the virus-free hosts in a cage environment. 5 different host plants were selected to test virus transmission with cotton aphids and green peach aphids. Those plants were zucchini, dock, fleabane, and 2 species of nicotinia. Each had 2 seedlings per pot. Visual virus symptoms were assessed on a weekly basis.

The protocol (from S.A Hill in *Methods in Plant Pathology Volume 1*) of two species of aphids were used: *Aphis gossypii* and *Mysuz persicae* and three virulent zucchini plant samples - one containing only PRSV, one containing all three zucchini viruses and one sample had only WMV2.

Fleabane *Conyza spp.* was inoculated by *Aphis gossypii* and *Mysuz persicae*. The host feeding material used was positive for PRSV and borderline positive with ZYMV and WMV2. *Aphis gossypii* inoculated fleabane showed symptoms fairly early, but all plants tested positive to zucchini viruses in the first ELISA conducted on the 12th of May 2009, including the control. Cotton aphids were observed, and the study was deemed contaminated. The plants were further observed and tested by ELISA again on the 17th of June 2009. The fleabane inoculated by *Mysuz persicae* and the control plants tested positive to all three zucchini viruses and cotton aphid inoculated fleabane tested positive to PRSV and WMV2.

Several zucchini plants were inoculated by *Aphis gossypii* and *Mysuz persicae*. Positive virus host material included PRSV and WMV2 individually and material that was positive to all three zucchini viruses. Zucchini plants that were showing visual symptoms of virus early on were sent to EM (electron microscope) mid-April 2009 where a potyvirus was detected. These zucchini plants were inoculated by *Aphis gossypii* using PRSV positive material, *Mysuz persicae* using WMV2 and *Aphis gossypii* using material positive to all three viruses. An ELISA was conducted on the 12th of May 2009 and all plants sampled tested positive to PRSV. These included *Aphis gossypii* inoculated PRSV positive material, *Aphis gossypii* inoculated using positive material that contained all three zucchini viruses and *Mysuz persicae* inoculated using PRSV positive host material.

Test host aphid assessment – Pot trial in situ with sentinel plants

Introduction of non-caged potted virus-free host plants in the field as sentinels to assess natural infection. Sentinel plants were assessed for vector presence in addition to the virus symptoms and ELISA testing. The surrounding zucchini crop was also assessed for vectors, virus symptoms and ELISA testing.

Three farms were selected for in situ pot trial with sentinel plants. Many of the plants perished in the field or performed poorly due to lack of nutrients and water. However 4 plants managed to thrive and were tested by ELISA, only Farm 1 at Horsley Park came back positive for PRSV.

Field Lettuce Trials

Efficacy of Silwet® for thrips management in field lettuce

Silwet L-77 (Silwet®) has been found to be efficacious against thrips in table grapes (Tipping *et al.*, 2003). Preliminary evaluation of the silicone-based product among other bio-rational insecticides on lettuce crops was conducted in 2005. Silwet® applied twice weekly was found to reduce thrips larvae at a range of rates. With these results and an evaluation of phytotoxicity on fancy lettuce varieties in the glasshouse, Silwet® was tested for efficacy in the field on iceberg lettuce for thrips control.

Thrips species that transmit TSWV are considered to be the key pest of lettuce, both field and hydroponically grown in the Sydney Region. The most common species in these crops is WFT (*Frankliniella occidentalis*). Other thrips known to vector this virus in the region are onion thrips (Thrips tabaci) and tomato thrips (*Frankliniella schultzei*). Plague thrips (*Thrips imaginis*), among other species, is also often found in lettuce crops but is not a vector of TSWV.

A farm (15) with field lettuce in Southwest Sydney was consistently suffering from TSWV during summer months for two consecutive years. With the objective to improve thrips management and in turn gain a reduction in virus incidence in Sydney lettuce crops, virus and vector pressure was monitored through a commercial consultant during early summer. Virus incidence and pest presence escalated and the Silwet® field trial began 15th January 2007.

Plants were treated with a twice-per-week spray application after transplanting (from 15th January) for the trial period of 8 weeks. The trial block was not treated with any other insecticides during this time.

Treatments (50 plants per plot, 3 treatments (150 plants) per row, 6 rows) were randomised over the trial block in 2 Latin square designs to give balanced replicates both in row direction and column direction. This design (Table 1) will give equal probability for the treatment plots exposed to the untreated plots from both directions.

Table 1. Treatment and application design

1	**Water Control**	**50 plants x 6 rows (300 plants per treatment)**
2	**0.02% Silwet®**	**50 plants x 6 rows (300 plants per treatment)**
3	**0.05% Silwet®**	**50 plants x 6 rows (300 plants per treatment)**
Buffer	**Buffer**	**untreated**

	Row 1	Row 2	Row 3	Row 4	Row 5	Row 6	
50 plants	3	1	2	1	3	2	
50 plants	2	3	1	2	1	3	
50 plants	1	2	3	3	2	1	

Plants were designated a number according to their row, treatment and position in the plot (e.g. the 38^{th} plant positioned in the fourth row, in treatment 3 is numbered 4-3-38).

TSWV affected plants were scored visually each week for the level of symptom expression, from '0%' with no virus symptoms through to '25%', '50%' and '75%' to evaluate the effectiveness of Silwet® on virus incidence and severity. Plants were consistently rogued throughout the assessment period if, at the time of assessment, the plant expressed virus symptoms in >75% of the leaves. Rogued plants were then scored as 100%. While a lettuce with TSWV will not recover from the virus, and symptoms will progressively worsen over time until plant death, the removal method used was aimed to simulate the standard disease management practices on-farm. Roguing of virus-affected plants is recommended in an integrated virus management program and will reduce the number of virus vectors in a crop.

A second priority was the monitoring of adult thrips movement in the crop with yellow sticky traps. It is assumed that highly mobile adults are responsible for virus transmission. Weekly trap counts provided data on the movement on adult thrips, and enable species identification. Traps were placed in each treatment plot to assist in capturing data on the effectiveness of Silwet®. A total of 18 sticky traps were placed weekly at canopy height between plants 25 and 26 in each treatment.

In order to assess early thrips activity, visual inspections were conducted *in-situ*. 4 plants were randomly inspected in each treatment with a total of 72 plants each week for the first three weeks from transplanting. Random numbers were generated for each treatment, with numbers corresponding to individual plants within each treatment for each week, allowing for a five-plant buffer between treatments. Nymphs and adults were counted and recorded for each plant.

A final thrips population assessment was conducted prior to harvest to provide data for Silwet® efficacy on the pest. Destructive sampling with leaf washes of 10 random plants per treatment, a total of 180 plants (<20%), was conducted during Week 8. Random numbers were again generated for each treatment, with numbers corresponding to individual plants within each treatment for each week, allowing for a five-plant buffer between treatments. Plants were harvested and transported to the laboratory in sealed plastic bags for processing. Nymphs and adults were collected in 70% ethanol, counted and recorded.

Hydroponic lettuce trials

Evaluation of foliar treatments in hydroponics lettuce

In a recent trial on a commercial hydroponic lettuce farm (Farm 10) it was noted that while treatments for TSWV within the trial area were not effective, incidence of TSWV in these beds was substantially lower than in adjacent grower beds. Two possible factors contributing to this reduced incidence are:

(i) in order to reduce TSWV spread, we removed plants once 25% of leaves showed symptoms of TSWV, and

(ii) wet sprays, regardless of content, might have impacted on WFT establishment.

Overhead irrigation is known to reduce thrips populations and fruit damage in strawberries. Water and other reduced risk pesticides were trialled at Gosford on hydroponic lettuce to clarify whether water and also other reduced risk pesticide treatments might have an impact on WFT populations.

Trial 1. - Two greenhouse units each $18m^2$ covered with reinforced polypropylene plastic were set up with lettuce seedlings of the cultivar Green Oak Kristine on 29 June 2006. In each unit there were eight growing channels 12 cm wide and 3 m long, with 15 holes per channel, on a recirculated nutrient system. There were four treatments applied as foliar sprays to wet.

Treatments were:

No	Treatment
1	No treatment
2	0.1% Silwet® L-77 as a surfactant applied twice weekly
3	0.5% Eco-Oil® applied weekly
4	DPI 9 (*Beauveria bassiana* Gosford-collected strain) at 22g spores plus 500mL oil and surfactant/100L, applied weekly

The four treatments were assigned randomly within blocks two channels wide and half a channel long, with six plants in each half channel, and two centre holes and one or two at each end left empty. This resulted in eight replicates per treatment in total. Adult WFT were released from a laboratory culture late afternoon on 4 July and again on 21 July by spreading vermiculite containing the thrips on the concrete floor below the benches holding the channels (~2000 thrips/unit on each occasion). Pesticide treatments were initiated the morning of 5 July. Approximately 300-400mL in total was applied for each material at each treatment date, increasing with greater leaf area.

After four weeks, on 31 July, an assessment of thrips damage was made by grading leaf damage on each of the four centre plants per plot on the scale 0 = no damage, 1 = very slight damage, 2 = 1-2 leaves damaged, 3 = >2 leaves damaged. These plants were then removed, minus roots, and bagged individually. Each plant was weighed and then washed through to assess thrips numbers. Counts were made separately of adult and immature (larval + pupal) thrips collected by washing through a screen (112μm hole size).

Trial 2. - The two greenhouse units were set up in a similar way. The cultivar was Green Sun, a green type with somewhat more horizontal leaves. There were eight treatments with four replicates of seven plants (two replicates in each Bay) per treatment, arranged in a randomised block design. The plants were set out as seedlings 29 September 2006 and adult WFT released 3 October 06 (~1500 per greenhouse unit) by sprinkling thrips in vermiculite under the channels. Treatments were applied 4 October 06 as sprays to wet.

Treatments were:

No	Treatment	No	Treatment
1	No treatment (control)	5	0.02% Silwet® L-77 twice weekly
2	water only twice weekly	6	0.1% Agral® twice weekly
3	0.1% Silwet® L-77 twice weekly	7	DPI 9 (*Beauveria bassiana* Gosford-collected strain) at 22g spores plus 500mL oil and surfactant/100L, applied weekly
4	0.05% Silwet® L-77 twice weekly	8	DPI 9 (*Beauveria bassiana* Gosford-collected strain) at 22g spores plus 500mL oil and surfactant/100L, applied twice weekly

Plants reached marketable size and were harvested 27 October 2006. The five centre plants in each replicate were weighed individually and bulked for extraction of thrips as previously. Analysis of variance of the plant weights and log transformed thrips counts was conducted (Appendix 4).

Results

Demonstration Farms

The above examples of data and integrated pest management (IPM) strategies for dealing with pest and disease at demonstration farms were presented at a series of demonstration farm workshops, field days/farm walks and grower meetings (see Technology Transfer). They provide good illustration of the active monitoring required to assess the impact of a pest or disease and the IPM strategies that might be employed as alternatives to chemical controls.

Demonstration farm field days showed growers the monitoring systems, data captured about pest and disease and the results of control options implemented. By taking growers through the processes in farming examples they could relate to they were able to understand the benefits they could capture for their businesses. Demonstration also had the benefit of showing the benefits before growers took part in what they perceived to be a risky management system. Some of the key benefits they could see were the reduction in chemical use, chemical costs and a reduction in the costs associated with lost production or crop failure. This does not include other indirect benefits such as worker health risk reduction and environmental impacts of chemical use.

Surveys

Zucchini Mosaic Viruses - 2005 - 2009

Initial survey results conducted in the summer months of 04/05 showed up to 100% crop infection, causing widespread disease problems and severe economic losses to zucchini growers. The prevalence of the mosaic viruses, despite regular insecticide applications, prompted further fieldwork and surveys in the following zucchini seasons.

Trials conducted during 05/06 summer demonstrated and evaluated resistant varieties and potential anti-virus products. Summer 06/07 trials investigated alternative virus management options to regular insecticide use.

Standard management practices for mosaic virus in the Sydney Region is regular crop spraying with insecticides to control aphids. Insecticides used include dimethoate and pirimicarb. Management with insecticides may not prevent the incidence of viruses, as aphid incursions only require minutes to transmit the disease from nearby weed reservoirs or unmanaged crops. An integrated approach to virus and vector management is more successful in reducing the losses to this disease.

In 2005 nine zucchini farms were surveyed for viruses. As leaf samples were collected for enzyme linked immuno-sorbent assay (ELISA) testing, each crop was assessed for the proportion of plants affected by mosaic virus, and disease severity was scored. Mild leaf symptoms are defined as yellowing, mosaic and mottle patterns. Strong symptoms include yellowing, mosaic and mottle with distorted leaf shape. Fruit symptoms are the characteristic raised lumps along the fruit seen on affected plants.

The youngest fully expanded leaf was collected from at least 5 plants from each variety or block and tested by ELISA for the three potyviruses known to cause mosaic – zucchini yellows mosaic virus (ZYMV), papaya ring spot virus (PRSV) and watermelon mosaic virus (WMV2). Laboratory tests were conducted by the Plant Health Diagnostic Service at Elizabeth Macarthur Agricultural Institute (EMAI).

The most prominent of the three aphid-borne mosaic potyviruses is WMV2, found on seven of the nine farms and ranging from 5 to 100% crop infection. The most popular variety of zucchini is Congo, selected by growers over other varieties promoted as virus tolerant, due to the cost of seed and the shape, colour and yields of fruit.

Seed trial crops included in the survey highlighted the need for more extensive virus testing in new zucchini varieties on the market. Seeds marketed on claims of virus tolerance and resistance undergo limited, small-scale trialling on Sydney farms, with no virus diagnostics to verify the claims. Seed company representatives expressed interest in testing virus levels for the 05/06 season's crops, and agreed that larger scale trials will provide more conclusive results.

Mosaic virus in zucchinis appears to be best managed by tolerant variety selection rather than reactive pest management. Infection may occur at any stage, but scouting has shown aphid activity to be more prominent on very young plants.

Aphids [Homoptera: Aphididae] are responsible for spreading mosaic viruses. They transmit the disease in a non-persistent manner, meaning they are only infective for a few hours at a time (Hausbeck, 2002). Contact insecticides may reduce the population of aphids by stopping breeding in the crop; however that may not prevent the virus, as the insect only needs to feed for a short time to transmit the virus (Commens, 2004).

The five key aphid species that transmit zucchini mosaic virus include:

- green peach aphid (*Myzus persicae* Sulzer)
- cotton/melon aphid (*Aphis gossypii* Glover)
- cowpea aphid (*Aphis craccivora* Koch)
- pea aphid (*Acyrthosiphon pisum* Harris)
- brown sow thistle aphid (*Uroleucon sonchi* Linnaeus) (Fletcher and Herman, 2000).

Virus detection may be conducted using a variety of diagnostic test, including electron microscopy, bioassays, ELISA and reverse transcription polymerase chain reaction (RT-PCR). Serological tests such as ELISA are more economical and more specific in determining which of the mosaic viruses are present in the zucchini crop (Agdia, 2007).

Virus prevention in zucchini crops is best managed through an IPM program that includes good farm hygiene, the use of resistant varieties, introduction and preservation of beneficial insects as well as 'soft chemistry' insecticide applications when most necessary (Llewellyn, 2002). Using 'soft chemistry' sprays also preserves many beneficial insects in the crop, such as the parasitic wasp *Aphidius colemani* and predator green lacewing *Mallada signata* (Llewellyn, 2002).

Alternative virus and aphid hosts are an important aspect of understanding IPM. All three of the zucchini mosaic viruses also infect other cucurbits including melons, pumpkins, cucumber and squash (Horlock and Persley, 2007). Alternative weed hosts that are non-cucurbitaceous, act as a virus reservoir. These include broadleaf weeds such as mallow and amaranth (Coutts, 2006) as well as asteraceous and solanaceous plants. Some of the aphids that transmit zucchini mosaic viruses are also responsible for the transmission of other plant viruses. The green peach aphid is a highly efficient vector with hosts ranging from potatoes, peppers, beans, beets and tobacco. The turnip aphid is also a vector of cucumber mosaic virus (CMV) and turnip mosaic virus (TuMV), and their hosts include cruciferous weeds and crops. Weeds and other crops can act as a host for virus and their vectors for zucchini crops (DiFonzo, 2005).

A survey was conducted on seven farms in the Sydney Region for ZYMV and vector incidence during summer 08/09, for multiple hosts. Following positive results of composite ELISA testing, a secondary assessment on each site positive for viruses was conducted, particularly targeting the site that had all three mosaic viruses present. During the secondary sampling, plants were tagged and tested individually in order to source material for transmission and inoculation.

ZYMV incidence on farm was detected by bulk sampling and ELISA testing. The results were then analysed and an estimate percentage established (Moran et al. 1983) and upper and lower confidence limits to 95% were found (Rolf and Sokal 1969). Four ELISA tests were run for farm bulk sampling, this occurred between one to three times on any given farm.

Four growing area's were surveyed in the Sydney Region, including Horsley Park, Orchard Hills, Berkshire Park and Freemans Reach (extensively). Berkshire Park had a clean bill of health and no zucchini viruses were detected in the first ELISA so no further surveying was done on this farm - this was attributed to good farm hygiene practices.

On Farm 1 virus incidence was fairly low in the middle of the growing season, by the end of the season in May PRSV was at 100%, WMV2 and ZYMV had decreased in incidence. This trend was repeated over most farms, with ZYMV and WMV2 incidence higher in the middle of the growing season (Feb-Mar) and later decreasing as the season drew to a close, and PRSV increasing through to the end of the season. This can be seen in ELISA tests conducted and estimate percentages of the population infected. These results are apparent for Farm 1 (Appendix 4, table 8.), Farm 2 (Appendix 4, table 9.), Farm 4 (Appendix 4, table 10.) and Farm 5 (Appendix 4, table 11.).

These results indicate that ZYMV and WMV2 are prevalent early in the growing season and PRSV later in the season

Gal-On (2007) states that the most successful control for disease in plants is the use of resistant cultivars. David Commens (2004) also comments that with the use of resistant varieties and a regular spray program for insects, can extend the life of the crop significantly, thus broadening the economic picking time frame. Conventional cross-protection can only be achieved between closely related viral strains. A mild viral strain is used for commercial crop protection (Gal-On, 2007). Desbiez and Lecoq (1997) also consider cross-protection with a mild strain is effective against most ZYMV isolates. Genetic tolerance is partially transferred from *Cucurbita moschata to C. pepo* to create a resistant cultivar (Gal-On, 2007). Resistance to ZYMV within *C. moschata* is decided by a single dominant gene *Zym* (Paris *et al.,* 1988), therefore making the *Zym* gene the major resistance gene (Pierpoint and Shewry, 1996).

Fortnightly assessments of weeds for virus were conducted in order to investigate the possible virus reservoir on and around zucchini farms. Weeds from plant families known to host one or more of the mosaic viruses were targeted.

Other viruses

The most interesting find on a one day TSWV survey in hydroponic lettuce in the Northwest region of Sydney in April of 2009 found high levels of wilt virus on the farms visited; this was largely due to failure to rogue diseased plants and also a lack of weed control. On one farm many weed species tested positive to TSWV using Agdia® immuno-test strips (See table 2). These weeds were all discovered underneath a single hydroponic table, it was strongly recommended at the time to eradicate weeds around the farm as swiftly as possible to reduce any further produce loss and decrease virus incidence on farm.

Table 2. TSWV results in alternate hosts

Date	Site	Host	Common name	Sample	Virus	Outcome
21/04/2009	JV	Crop	**Endive**	**Cichorium endivia**	**TSWV**	**Positive**
21/04/2009	JV	Weed	**Mallow**	**Malva parviflora**	**TSWV**	**Positive**
21/04/2009	JV	Weed	**Sowthistle**	**Sonchus oleraceus**	**TSWV**	**Positive**
21/04/2009	JV	Weed	**Nightshade**	**Solanum nigrum**	**TSWV**	**Positive**
21/04/2009	JV	Weed	**Farmer's friend**	**Bidens pilosa**	**TSWV**	**Positive**
21/04/2009	JV	Weed	**The holy herb**	**Siegesbeckia orientalis**	**TSWV**	**Positive**
21/04/2009	JV	Weed	**Persian speedwell**	**Veronica persica**	**TSWV**	**Positive**
21/04/2009	JV	Weed	Potato weed	Galinsoga parviflora	TSWV	Negative
21/04/2009	JV	Weed	Pig weed	Portulaca oleracea	TSWV	Negative
21/04/2009	JV	Weed	Burr medic	Medicago polymorpha	TSWV	Negative
21/04/2009	JV	Weed	Cut-leafed Daisy	Brachycome	TSWV	Negative
21/04/2009	JV	Weed	Unknown	Unknown	TSWV	Negative
21/04/2009	JD	Crop	**Red coral lettuce**	**Lactuca sativa**	**TSWV**	**Positive**

This type of discovery immediately reinforces that practicing good farm hygiene is fundamental in lowering disease pressure and essential in decreasing economic losses. Even when pest pressure is high, following such measures can make an impact without having to resort to chemical controls.

Summer 2006-07

The alternative hosts survey for aphids on weeds and other vegetation on Farm 6 found *M. persicae* (virus vector) in week 4 on silverbeet and in week 7 on eggplant. The alternative host survey for aphids conducted at Farm 19 on weeds and other vegetation found no aphids. No viruses were detected in the alternative hosts survey conducted at Farm 19 prior to planting in the zucchini trial or in weeks 4 through to 8.

No viruses were detected in the alternative hosts survey conducted at Farm 6 prior to planting in the zucchini trials or in weeks 6 and 8. Virus was found in weeds and other vegetation on farm 6 in week 4 as shown in Table 3. Amaranth (weed) and sow thistle (weed) tested positive to PRSV, artichoke (crop) tested positive to PRSV and ZYMV and a zucchini plant (Congo- buffer plant) not within the experimental area tested positive to WMV2.

Table 3. Alternative host plants tested for zucchini mosaic viruses

DATE	COMMON NAME	PLANT	PRSV	ZYMV	WMV2
6/03/2007	Dock	Rumex spp.	Negative	Negative	Negative
Week 4	Mallow	Malva parviflora	Negative	Negative	Negative
	Amaranth	Amaranthus spp.	Positive	Negative	Negative
	Strawberry Weed	Modiola caroliniana	Negative	Negative	Negative
	Sow thistle	Sonchus oleraceus	Positive	Negative	Negative
	Pig Weed	Portulaca oleracea	Negative	Negative	Negative
	Fleabane	Conyza spp	Negative	Negative	Negative
	Fat Hen	Chenopodium album	Negative	Negative	Negative
	Silverbeet	Beta vulgaris	Negative	Negative	Negative
	Artichoke	Cynara scolymus	Positive	Positive	Negative
	Zucchini Congo variety (buffer row)	Cucurbita pepo	Negative	Negative	Positive

New Pest and Disease Detections

Papaya Ring Spot Virus

Of the species sampled, *Conyza* sp. (fleabane) and *Sonchus* sp. (sow thistle) both tested positive for the presence of PRSV and were confirmed using RT-PCR techniques. These results indicate a new host record for PRSV and provide some information for growers to take into account when managing weeds around their property with respect to crop health and hygiene.

ELISA also detected the presence of PRSV in samples of *Cynara* sp. (artichoke) and *Amaranthus* sp. (amaranth) but these were not able to be confirmed using RT-PCR. The *Cynara* sp. returned a positive result, using RT-PCR, for both WMV2 and zucchini yellow mosaic virus and, as such, is a notable contradiction to the ELISA results. The *Amaranthus* sp. samples were not tested using RT-PCR. These results indicate that these two species are considered unconfirmed plant hosts and need to be viewed with an amount of caution.

Currant Lettuce Aphid

The detection of the currant-lettuce aphid (CLA) (*Nasonovia ribis-nigri*) was confirmed in NSW on a number of commercial lettuce production properties. The initial detection was on a hydroponic lettuce farm in Austral, south-west Sydney and the sample was collected as part of routine surveillance by NSW DPI.

Inspections in the Sydney Region and regional lettuce growing areas of NSW had not detected any CLA until early February 2006.

There had been over 100 inspections across NSW lettuce producing regions and markets and 370 insect identifications reported between 25 February 2005 and the end of January 2006 prior to the positive detection.

CLA feeds on lettuce, endive, chicory and some weeds, and can be found both on the leaves and in the heart of the lettuce. When monitoring crops for the aphid, it is important to check the leaves through to the heart. CLA hides in the heart away from insecticide sprays, allowing them to breed through to harvest.

CLA management trials were conducted in Tasmania and Victoria has shown the most effective methods to be:

- seedling treatments with Confidor®
- biological IPM
- NAS Resistant varieties

Biological IPM programs are unsuccessful if Confidor® drenches are used. Confidor® has been shown to affect the populations of natural predators such as lacewings and ladybeetles. The use of resistant varieties provides growers with the ability to reduce insecticide applications, including Confidor® drenches.

CLA was confirmed in Tasmania (the first time in Australia) in March 2004 but difficult to control aphids were observed from late January 2004. The aphid is thought to have come to Tasmania from New Zealand on an easterly weather stream. It is considered endemic in Melbourne metropolitan area following its detection in May 2005. It is now also being considered as endemic in most states of Australia.

Psyllids

A single survey of a commercial eggplant grower in the western Sydney Region during spring 2007 found no psyllids. An infestation in a suburban backyard appeared in February 2008 and in April 2007 it is possible that commercial growers' may only have been affected late in the season. Adults and nymphs (Figure 31) were found in abundance in the residential area.

Growers should also be aware that an exotic psyllid from North America has recently become established in New Zealand. The potato/tomato psyllid, *Bactericera cockerelli*, was initially found in 2006 in an Auckland greenhouse tomato crop using IPM. The psyllid is now considered established in New Zealand. Its method of entry into New Zealand was undetermined. As its name implies the psyllid infests a range of Solanaceous species such as tomatoes, potatoes, eggplant and capsicum. A solid white deposit on the leaves called 'psyllid sugar', this species' particular method of excreting excess honeydew, characterizes plants infested by this psyllid.

In tomatoes, the potato/tomato psyllid feeding causes plants to produce numerous small fruit of poor quality or prevents fruit forming at all. In addition, the psyllid nymphs inject a toxin into the plants as the feed. The toxin results in conditions called 'psyllid yellow' and 'purple top' where the leaves become discoloured and distorted and the plant itself becomes stunted and new growth is retarded.

Figure 31. Adult (left) and nymph (right) - image courtesy of Shaun Bennet

Impatiens Necrotic Spot Virus

Early in 2010 NSW DPI plant diagnostics detected impatiens necrotic spot virus (INSV) in an ornamental crop. INSV is a tospovirus much the same as tomato spotted wilt virus (TSWV). They are vectored by thrips, namely WFT, and have similar symptoms and plant hosts. Although INSV mainly affects ornamental or flowering crops there are some weed and vegetable crops that are susceptible. This is important to vegetable growers as it increases the risk of potential virus infection on-farm. Although a full eradication plan was undertaken at the property to contain the spread of the virus and neighbouring nurseries/farms were surveyed for the virus, and all results came back negative, there is still the minor chance that INSV may be latent in neighbouring crops or weeds. INSV has not been found in any vegetable crops in Australia as yet.

Figure 32. INSV symptoms on begonias.

The vegetables and herbs that are known to host INSV include: basil, bean, broccoli, cauliflower, celery, coriander, cucumber, lettuce, parsley, pea, pepper, spinach and tomato. The symptoms are very much the same as TSWV with plants developing necrotic spots, streaking, ring spots, sometimes with double ring spotting, stunting and wilting. Once again this highlights the importance of farm hygiene and the necessity to remove plants that appear to be affected with the virus, as leaving virus-infected plants amongst crops creates a reservoir for thrips to spread the virus throughout the crop.

Variety trials

December 2006

- The aphids collected from the sites during December included:

Scientific Name	# Detected	Common Name
Aphis craccivora	2	Cowpea aphid
Lipaphis pseudobrassicae	2	Turnip aphid
Rhopalosiphum padi	1	Oat aphid
Brachycaudus heliochrysi,	1	Leaf-curling plum aphid
Tetraneura nigriabdominalis	1	Oriental grass root aphid

- Turnip aphid and cowpea aphid are known vectors of mosaic virus.
- By the final assessment, all varieties across all farms had some plants test positive for WMV2 with the exception of Gold Coast, however one site had low overall

infection (5% symptoms) across all varieties. ZYMV was detected in only the standard Lebanese variety Clarita.

- All varieties tested through to harvest had some plants test positive for WMV2, with the exception of Gold Coast, however the variety had low overall infection (5% symptoms).
    - These included Congo Standard Sunline Standard, Martina Standard and test varieties:

Disco SPS 0692	Stinger SPS 8572	Disco SPS 0692
HZU-4	HZU-12	Ramis EX 681
Jaguar	ZUC 3463 CLX 29758	ZUC 3465Amanda Blackadder
ZU 392	Green Express Z18	
Sungold	Yellow Gold EX 472	
Columbia SPS 5223	SPS 6093	

- ZYMV was detected in only the standard Lebanese variety Clarita at site RC
- Hummer, Beara (Lebanese), Top Gun Z52, Houdini, Midnight, Shimmer and ZU 384 were not included in the December trial

Variety trial - February-March 2006

There were significant varietal effects on the presence of mild symptom recorded on 14/03/06 and strong symptom recorded on 21/03/06 (Appendix 4, Table 1).

Among the lowest infected plants observed on 14/03/06 were HZU4, ZU384, Jaguar, Midnight, Z52 Topgun and Houdini. Mid range to high infection were 8642 Hummer, 8572 Stinger, Shimmer, 3463 and 3465. Congo standard had the higher rate of plant with symptom.

For observations made on 21/03/06, HZU 4 remained the lowest on the infection rate, followed by Z52 Topgun, Houdini, ZU384, Midnight, Jaguar and 3463. Shimmer, Hummer and Stinger were among the higher range and Congo standard was the highest infection rate.

- Aphids were present on all varieties, predominantly cotton aphid. The aphids collected from the site during February-March included:
    - *Aphis gossypii* Cotton Aphid
    - *Lipaphis pseudobrassicae* Turnip aphid
    - *Tetraneura nigriabdominalis* Oriental grass root aphid
- There were significant varietal effects on the presence of mild symptoms and strong symptoms
- The best performers at Week 5 were: HZU4, ZU384, Jaguar, Midnight, Z52 Topgun and Houdini
- Varieties with mid to high infection were: 8642 Hummer, 8572 Stinger, Shimmer, 3463 and 3465
- Congo had the higher rate of plants with symptoms

- At week 6, observed on 21/03/06, HZU 4 remained the lowest on the infection rate. HZU-4 was followed by Z52 Topgun, Houdini, ZU384, Midnight, Jaguar and Lefroy 3463
- Shimmer, Hummer and Stinger were among the higher infection range and Congo standard was again the highest infection rate
- Aphids, predominantly cotton aphid were present on all varieties. The aphids collected from the site during February-March included cotton aphid, turnip aphid and oriental grass root aphid

Variety trial - Summer 2006-07

In weeks 1, 4 and 8 no aphids were found in the weekly random aphid sampling of the zucchini variety trial for farm 6. In weeks 2, 5, 6 and 7 aphids were found in the random sampling, with the majority of those found to be the virus vector. Most of these aphids were winged aphids (colonising aphids).

In weeks 1 through to 3 no aphids were found in the weekly random aphid sampling of the zucchini variety trial for Farm 19. In weeks 4 through to 8 aphids were found in the random sampling, with all of those found to be virus vectors. Most of the aphids in week 4 were winged aphids from weeks 5 through to 8 the aphids found were winged and non-winged (non-colonising) aphids.

On Farm 6 zucchini variety trial weeks 4 and 6 of the random sampling of zucchini leaf material for ELISA testing all 5 zucchini varieties tested negative to PRSV, ZYMV and WMV2. In week 8 of the random sampling of zucchini leaf material for ELISA testing, the variety Houdini tested negative to PRSV and WMV2, but had an inconclusive reading for ZYMV, meaning that one or a few of the plants in the random Houdini sample may have been positive to ZYMV. The varieties Hummer, Midnight and Top Gun both tested negative to PRSV, inconclusively to WMV2 and tested positive to ZYMV. The variety Congo tested positive to all three zucchini mosaic viruses (PRSV, ZYMV and WMV2).

For Farm 19 zucchini variety trial weeks 4, 6 and 8 of the random sampling of zucchini leaf material for ELISA testing all 5 zucchini varieties tested negative to PRSV, ZYMV and WMV2.

Farm 19 variety results showed no differences between varieties on aphid infestation ($P>0.05$). The numbers increased and time of trial continued to week 8 ($P<0.001$). There was no interaction between variety and time effects ($P>0.05$). Appendix 4 Table 6 presents log (means) and retransformed means of aphid counts for the 5 varieties.

Product trials

Product Trial 1 – Stress-Ex® and Flextend®

The products were found to have no significant effect on virus transmission, based on the number of plants with symptoms in controls compared to other treatments. This was found in both assessments, on the 14th and 21st March 2006 (Appendix 4, Table 3).

Leaf samples from the product trials tested positive for WMV2 after 5 weeks. Symptom assessments in individual plants are analysed in Appendix 4, Table 4.

Product Trial 2 - Flextend®

In weeks 1 and 8 no aphids were found in the weekly random aphid sampling of the product trial for farm 6. Aphids were found in the random sampling, with the majority of those found to be the virus vector. Most of these aphids were winged.

In weeks 1 through to 3 no aphids were found in the weekly random aphid sampling of the product trial for Farm 19. In weeks 4 through to 8 aphids were found in the random sampling, with the majority of those found to be virus vectors. Most of the aphids in week 4 were winged aphids. From weeks 5 through to 8 the aphids found were winged and non-winged aphids.

For Farm 6 Flextend® product trial week 4 of the random sampling of zucchini leaf material for ELISA tests, all 3 treatments tested negative to PRSV, ZYMV and WMV2. In week 6 all 3 treatments tested negative to PRSV but positive to ZYMV and WMV2. In week 8 the water (control) treatment tested negative to PRSV and WMV2, the Flextend® 1.0% treatment tested negative to PRSV and positive to ZYMV and WMV2, and the Flextend® 1.5% treatment tested positive to all three zucchini mosaic viruses (PRSV, ZYMV and WMV2).

For Farm 19 Flextend® product trial weeks 4, 6 and 8 of the random sampling of zucchini leaf material for ELISA testing all 3 treatments tested negative to PRSV, ZYMV and WMV2.

Site B product on aphid numbers were not found to be significantly affected by the treatments ($P>0.05$) but significantly increased as time of the trial continued ($P<0.001$). Weekly data showed the 2 treatments were not different from the Control as shown in Appendix 4, Table 5.

The Farm 6 product trial on visible virus symptoms showed no effects of the treatments on percentage with plants presenting visual virus symptoms at week 8 ($P>0.05$) (Appendix 4, Table 7). No visible viral symptom was found in most plants for up to week 7.

Bioassays

No symptoms were observed in the dock or *N. benthamiana. N. glutinosa* did appear to have some visual symptoms, EM results proved negative for virus particles.

On-farm variety trial plots were set up in December 2005 to demonstrate to growers the benefits of using virus-resistant varieties. Five farms across Sydney have been trialling new varieties and comparing them to their standard varieties. Laboratory results indicated that the key virus during summer 2005-6 in Sydney zucchinis was WMV2.

A further trial conducted through February-March 2006 included a selection of resistant zucchinis to be compared with the susceptible variety Congo for mosaic virus resistance on a single property with a known mosaic virus reservoir. An assessment of the crop revealed HZU 4 to have the lowest infection rate, followed by Z52 Topgun, Houdini, ZU384, Midnight, Jaguar and 3463. The industry standard variety, Congo, had the highest infection rate followed by Shimmer, Hummer and Stinger. The current trial will now focus on the better performing resistant commercial varieties, which have also been accepted by the growers for their yield and fruit quality.

Field Lettuce Trials

Efficacy of Silwet® for thrips management in field lettuce

Insect count data were averaged per plant analysed using linear mixed model with spatial (row by column) variance structure of first order autocorrelation. A residual maximum likelihood (REML) technique was used to estimate all parameters and Fisher's F protected least significant difference at 5% level was used to test pair-wise treatment comparisons.

F-test shows that the three treatments had no significant difference on insect populations ($P>0.05$) (Appendix 4, table 12). No further tests on pair-wise treatment differences were conducted.

Hydroponic lettuce trials

Evaluation of foliar treatments in hydroponics lettuce

Trial 1. - Leaf damage was very minor in all treatments so was not assessed beyond noting that there was no apparent leaf damage in T1 and occasional minor damage on outside leaves in the other three treatments. Leaf damage in the form of brown edges on new leaves was apparent in T2, and plants were visibly smaller.

The mean head weight of lettuce in T2 (water plus Silwet®) was significantly lower than in T1, T3 and T4, which were not significantly different from each other (Appendix 4, table 13). The most likely explanation for this is that Silwet® was phytotoxic, borne out also by the brown tips to new leaves.

Adult thrips populations were significantly lower in T2 than in all other treatments, and T4 was significantly lower than T1, representing reductions of 97.2% (T2), 54.3% (T4), and 23.7% (T3). Larval thrips populations were reduced by all treatments, representing reductions of 95.2% (T2), 59.1% (T4), and 33.9% (T3). Thrips populations were relatively low which was partly due to a malfunction in temperature control providing low temperatures (12.8-23.7, mean 18.9^{o}C in Bay 1 and 8.0-23.7, mean 18.1^{o}C in Bay 2), and possibly due to a concrete floor which would have reduced survival of those larvae dropping to the ground to pupate because of the lack of shelter and low humidity (26.9-100%, mean 67% RH in Bay 1, and 23.1-98.8%, mean 64.8% RH in Bay 2). 50.6% of immature stages were pupae. The percentage of thrips in various growth stages varied between treatments (Appendix 4, Table 14).

For T2, there is a marked reduction in the percentage of thrips in the pupal stage, and a corresponding increase in those in the adult stage. One hypothesis is that the treatment interferes with successful pupation of the larvae. It is apparent in the other treatments that a high percentage of thrips pupated within the lettuce plants rather than dropping to the ground to pupate. A few may have pupated under the plant or in the media and these were not counted. It is suspected that relative humidity may influence the decision to drop to the ground, and that in a more humid environment the percentage leaving the plant might increase.

The substantial reduction in WFT populations by application of water plus Silwet® is very encouraging, but the influence of Silwet® needs to be separated from water alone and the experiment repeated with lower rates of Silwet® or an alternative wetter. No phytotoxicity was noted from application of 0.5% Eco Oil® weekly, but the reduction in thrips populations was not adequate. DPI 9 gave >50% control of WFT, which might be expected to improve with an increase in temperature and humidity.

Trial 2 - Tip burn, possibly caused by too high temperature and humidity, obscured any phytotoxicity due to treatment effect, except to note that plants treated with 0.1% Silwet®

were again visibly smaller. Assessment of thrips populations was more complex because three additional species were present: plague thrips, *Thrips imaginis*, onion thrips, *Thrips tabaci*, and tomato thrips, *Frankliniella schultzei*. Onion thrips and tomato thrips are of interest because they may carry TSWV. Many of the plague thrips were shrunken and it is suspected that they do not survive on lettuce. Larval thrips could not be separated as to species. There were small numbers of orange larvae that were probably those of the darker *F. schultzei*.

Mean temperature over the four week period was ~21.0^{o}C (Appendix 4, table15). Mean relative humidity was ~80-85% in the first two weeks and ~90% in the second period. Higher day temperatures equated to lower humidity. Because of less night heating and a rainy period the relative humidity was much higher and the temperature a little higher than in the previous trial.

An outbreak of lettuce aphid, *Nasonovia ribisnigri*, necessitated a foliar application of Pirimor to all plants mid-crop. Many dead thrips were noted after application, but as Pirimor is not known to affect onion thrips or WFT, it is suspected that these may have been *Thrips imaginis*, possibly affected by Pirimor but more likely dying anyway from being on a non-host plant.

Differences in head weight were not significantly different statistically (Appendix 4, table 16). Thrips counts were analysed by comparing thrips immature stages and adults of the four species separately. For adult WFT, means for all treatments ranged from 4.25 to 14.4 per head, but there were no significant differences between treatments. For thrips larvae, means ranged from 6.35 to 33.05 per head with significant difference between treatments (Appendix 4, table 16). Silwet® at the two higher rates were the only treatments significantly different from the check. Major differences between replicates obscured treatment differences. For example, adult *Thrips tabaci* counts were higher in T2, T6 and T8 of Block 2, and T8 of Block 4, with higher larval counts also, indicating that at least some of the larvae may have been those of *T. tabaci* rather than WFT. Adult counts of WFT were much higher in Block 4, T3, less so in T6 and T8, with notably higher larval numbers in T3 and T8 but not T6. Whether there was an uneven distribution of WFT or just a peculiarity of the greenhouse set-up is not known, but the high local adult population may have lowered the apparent efficacy of T3, T6 and T8 against WFT, and T2, T6 and T8 against *T. tabaci*. Mean numbers of *Thrips imaginis* per treatment varied between 17.57 and 34.14 per head, but because of the difficulty of discerning whether they were dead or alive when collected, statistical analysis of the data was not performed.

The percentage of thrips in the pupal stage relative to the larval stage is much lower in this trial than in the previous one. One possibility is that more thrips late-stage larvae left the plant to pupate because of the more favourable relative humidity of the surrounding air, but this is contrary to experience in cucumbers, where more larvae remained on leaves at higher relative humidity. Differences in plant structure may also have played a part, but the question of what influences thrips larvae to stay or leave the plant to pupate is an interesting one and has a bearing of control strategies.

The cultivar used in this trial was a green variety but leaves were displayed horizontally making underleaf spray coverage poor, probably explaining the lower efficacy of 0.1% Silwet® compared with the first trial. The increased adult WFT numbers in this treatment compared with the unsprayed control contrasted sharply with the very low numbers recorded in the first trial. Overall, Silwet® provided the best control of WFT (Figure 33), with the lower two rates preferable to minimize the possibility of phytotoxicity.

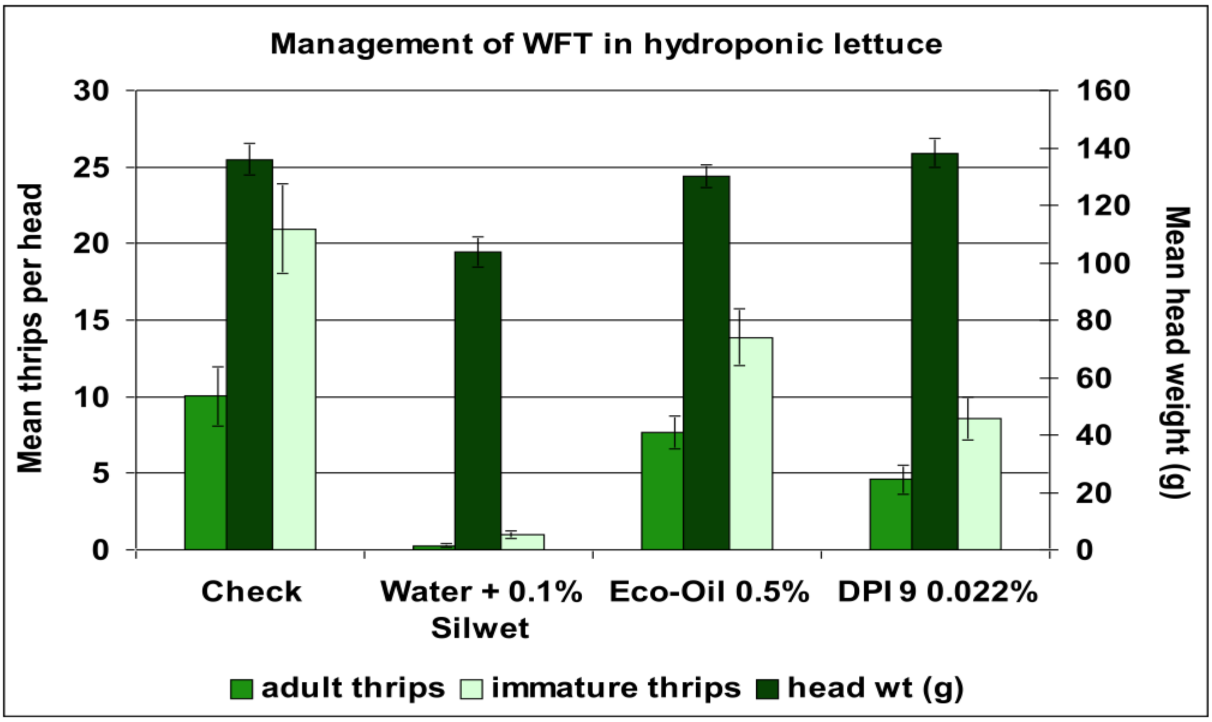


Figure 33. Efficacy of 4 treatments against WFT in hydroponic lettuce

Discussion

Integrated management of mosaic viruses in zucchinis is thought to be more effective through the use of resistant varieties and improved farm hygiene, rather than relying on chemical control of aphid vectors alone.

There are many aphids that are known to spread the mosaic viruses. Over thirty species are documented, including green peach aphid, cotton aphid and turnip aphid (Fletcher and Herman, 2000). Since so many aphids are known to spread the disease, it is almost safe to assume that any aphid found on or near a susceptible zucchini crop is a threat and should be managed.

Aphids responsible for spreading mosaic viruses transmit the disease in a non-persistent manner, meaning they are only infective for a few hours at a time. The aphid sucks on affected leaves, and moves around spreading the disease to healthy plants as it feeds. Transmission may occur within a few minutes of feeding on a healthy host (Gal-On A, 2007).

Many weeds are reservoirs for mosaic viruses and can also express symptoms, just like the zucchinis. It is important to control the weeds around the farm before planting zucchinis and throughout the summer to keep aphid numbers down. Also a break from growing cucurbit crops mid season is an option to be considered if pest pressure is high.

Crops residue and waste should be removed as soon as picking finishes, particularly if there was virus present. It is most important to monitor the crop for the signs of mosaic virus, and those first affected plants must be removed. It is important that vegetable growers are aware that once the plants have a virus, they cannot be cured, no matter how much they are sprayed. Virus management therefore must focus on preventing crop infection.

Regular and effective application of contact insecticides may reduce the population of aphids by stopping breeding in the crop. By targeting susceptible lifestages, the pest is no longer able to increase in population size and an overall reduction may be observed. However, that will not prevent the virus, as the insect only needs to feed for a short time to infect the plant with the virus. Anti-transpirant products were trialled over a few seasons. These products are suggested to create a film over the leaf, and for it to be effective against the aphids, the film must also coat the underside of the leaf as is the case for effective use of contact pesticides.

Lower rates of Ekko's Stress-Ex® and Flextend® trialled in summer 2005-6 did not show any difference between treated and untreated zucchinis and virus results.

In the summer of 2006-07 Flextend® was trialled to evaluate the effect of this anti-transpirant on inducing resistance to aphid stylet penetration, thereby controlling mosaic virus transmission. Results showed it was ineffective. There is also potential for further studies (possibly lab based) to discover as to why aphid numbers were higher in the treatments rather than the control, in the results for Site B product trial. This is an indication that Flextend® may have properties that are an aphid attractant, and could be the reason for the treatments in the product trial on Site A having a higher visual virus rate than the control.

There is a broad range of resistant zucchini varieties offered by the seed companies. Demonstration plots were set up and independently assessed for virus throughout 2005-2007. This enabled Sydney growers to make their own decision for variety selection for the next season.

The resistance offered in current varieties is 'Intermediate Resistance' and not complete. The plant is said to be able to resist low aphid pressure, so must be used in an integrated system, with better crop planning, weed management and the use of chemical control.

In the summer of 2006-07 the zucchini resistant varieties trial on Site A, demonstrated the resistant variety Houdini, considered to show 'Intermediate Resistance' was the most effective variety against viruses. In previous years varieties suggested for use would be to start the season with Congo and once there is a low to medium pest pressure, then to move on to farming the resistant varieties such as Hummer, Top Gun and Midnight if the pest pressure becomes medium to high. Finally, if pressure becomes very high, plant the variety Houdini. Control may be improved by planting varieties with higher tolerance ZYMV and WMV2 earlier in the season, then have a break, then replant resistant varieties again to prevent the tolerance from being broken down. This is a different approach to previous advice which would have been to use the least tolerant varieties at the beginning of the season and then as the growing season progressed to switch the next planting to a higher tolerance variety. It still seems to be a good idea to have a break in planting altogether as to diminish the green bridge, or revert to this practice if virus incidence becomes high. This strategy will alleviate virus presence on the farm thus reducing spread to new cucurbit crops. This should be coupled with 'soft chemistry' aphicide spray application, when necessary. Using 'soft chemistry' sprays also preserves any beneficial insects in the crop, such as the parasitic wasp *Aphidius colemani* and the predatory green lacewing *Mallada signata.*

In the summer of 2008-09 a study observed the incidence of virus in the Sydney Region. Assessing weeds was also a crucial aspect of the study. The zucchini viruses weren't found in fennel *Foeniculum vulgare*, but WMV2 was found in fennel in New Zealand by Fletcher *et al*. in 1999 (Pearson et al. 2006) it is then seen as a potential host here in Australia. Area wide weed control on road sides is an important future activity and should be discussed with councils and revegetation groups.

At the start of the season alternate host numbers were low which could be a reason as to why papaya ring spot virus (PRSV) is very low in incidence if present at all.

All three zucchini viruses are mechanically transmitted according to plant viruses online (VIDE - http://www.agls.uidaho.edu/ebi/vdie//refs.htm) database. As Horsley Park used knives for harvesting fruit from plants and had higher incidence rate than most farms could be an indication of virus being transmitted from plant to plant not only by aphid infestation but also from farm workers picking and transferring virus from infected plant sap on knives. Further transmission studies would have been valuable for understanding mechanical inoculation, as well as surveying for squash mosaic virus (SqMV), as it has not been detected on the East coast of Australia.

As zucchini varieties were not the main focus of the study in the summer of 2008-09, it may be that the resistant (tolerant) varieties that were grown on the farms in the Sydney Region have a higher tolerance to PRSV, which could be a reason as to why it doesn't appear until later in the growing season when the resistance has been broken down.

Recent estimates show the number of vegetable farms in the Sydney Region to be at least 900 in total (Malcolm and Fahd, 2008). There are four distinct growing regions within the Sydney Region, being Liverpool, Camden, Hawkesbury the Hills districts. It was important to ensure that a balanced number of growers were surveyed across these regions. There are 6 commodity groups within these regions, being field vegetable, field Asian vegetable, greenhouse vegetable, hydroponic lettuce, and hydroponic Asian vegetable and seedling production nurseries.

Statistically, the number of growers is balanced between field and greenhouse groups; however we have surveyed more than half of the hydroponic lettuce grower population. There may be an equal number of Asian field vegetable farms to general field and greenhouse; however as most of the Asian vegetable crops are grown by growers that do not use English as their first language, the language barrier was a limitation. A bilingual officer delivered the survey to a smaller proportion of Asian growers than to other commodity groups.

We have surveyed growers that use a consultant, as well as those who do not (See Tables 1-3). There are a larger proportion of growers in the population that do not use an IPM consultant, and this is reflected in the number of growers that were surveyed in each category.

The survey participants were found from contact lists used for the dissemination of extension information, obtained from district horticulturists and industry development officers. 90 growers were contacted, and of these, 60 growers participated in the survey.

The growers were surveyed by telephone in most cases for time efficiency. This introduces the possibility of bias, as individual sites were not audited or inspected in person. Survey respondents may have been inclined to respond more favourably to certain questions in order to reflect positively on their management practices to the surveyors. A negative response from a grower when asked to participate in the survey may relate to the level of IPM adoption, or language barriers, however most cases were due to time constraints to answer questions.

The average grower score for those using a consultant may not necessarily be a fair estimate of consultant competency. Consultants may be providing the appropriate advice but the grower may not be following it, having a negative impact on the mean consultant scores. The group of clients that a consultant has may have some confounding effect which influences the IPM score. This may include commodity type, size of business, infrastructure, technology, management and staffing issues and market fluctuations. The frequency of consultant visits may also have an effect, as weekly advice would ensure a higher adoption level than monthly or seasonal consultant visits.

There is a difference in the IPM requirements across crop types. For example, there are limited biological control options for hydroponic lettuce growers at present. Current research projects aim to improve this, meaning the scores for this commodity group should be weighted accordingly when compared with mean scores from other commodity groups.

Hydroponic lettuce growers pay particular attention to variety selection, and those that use a consultant are more inclined to monitor for pests and diseases (See Appendix 1). Variety selection has been heavily influenced by the introduction of currant-lettuce aphid, *Nasonovia ribis-nigri* in March 2006. The increased adoption of variety selection as an IPM strategy in hydroponic lettuce can be seen in Figure 34. Hydroponic lettuce growers have limited access to biological control options. Their key pest, WFT cannot be effectively managed with biological control at present, so there is a heavier reliance on chemical management options integrated with improved farm hygiene and varieties.

Seedling production nurseries have a zero tolerance for pests and diseases on their products. This encourages them to rely on IPM consultants for monitoring and management advice. While they may use regular chemical applications, they cannot rely solely on biological control due to the rapid turn-around of product and zero pest tolerance from clients.

The three Asian vegetable growers surveyed, in both hydroponic and field groups, do not use IPM consultants. Hydroponic Asian vegetable growers have limited access to biological control as in hydroponic lettuce crops and the poor scores achieved highlight the need for bilingual support with IPM consultants to improve areas such as pest and disease monitoring, variety selection and general crop management.

A high proportion of greenhouse vegetable growers were surveyed from the Liverpool region. This is consistent with the number of farms located there. Most of the extension activities were centred in this region for this commodity group. There was a limited number of this group that used a consultant. The good adoption scores could be attributed to many farm visits from the project team, extension activities including farm walks, field days and workshops held during the project, rather than consultant use as in other commodity groups. The greenhouse vegetable growers rely mostly on chemical IPM strategies and variety selection as part of their IPM programs. They could improve their adoption rates with the use of IPM consultants, improvements to infrastructure and incorporation of biological control strategies.

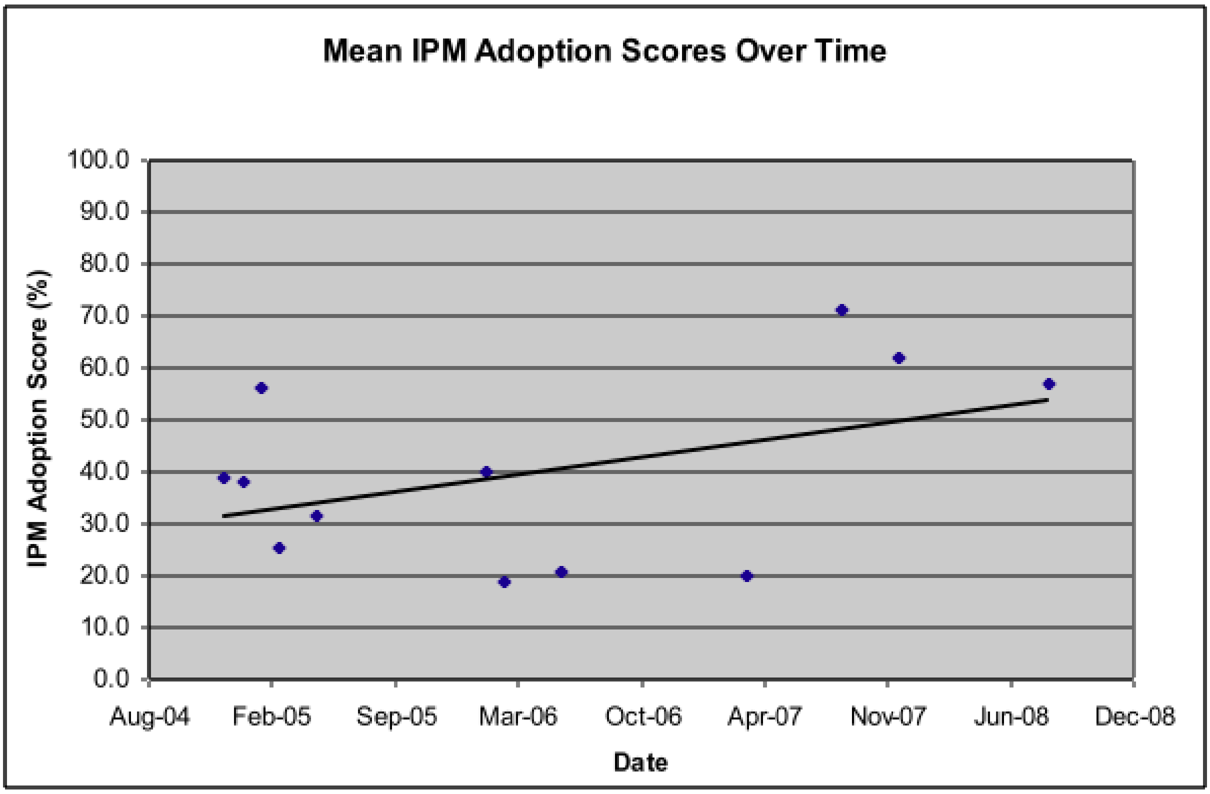


Figure 34. Mean IPM adoption increasing over time

Field vegetable growers have been receptive to the concept of IPM. They have been the most willing to use an IPM consultant, along with seedling producers. Field vegetables have attracted a lot of research and extension into IPM over recent years, particularly for brassicas, sweet corn and lettuce crops. The growers of these crops were familiar with the strategies required to adopt IPM. Field crops such as eggplant, zucchini and capsicum, widely grown in the Sydney Region, had received little attention prior to the current project. Work on these crops, plus reinforcing the IPM message for the other field crops was effective in improving adoption, with the cooperation of IPM consultants. Crop rotations and variety selection were popular strategies, and farm hygiene scores need improvement. Camden growers achieved the highest adoption scores, followed by the Hawkesbury. Camden field growers using a consultant achieved the highest scores of all groups (77%). This is most likely attributed to the strong association of the local growers with a highly competent consultant.

The reluctance of growers to use an IPM consultant is a barrier to IPM adoption. The mean score for growers with a consultant was 65.7% and without 41.12% (See Table 4). The overall score for Camden field vegetable growers (58%) was weighted significantly by the poor adoption scores of two non-consultant farms (mean 29%). The mean score of the three farms using an IPM consultant was 77%. This clearly demonstrates the value of growers using a consultant if their priority is to adopt IPM on their farm. The IPM extension activities held as part of the project over the last few years, including the participation of growers in field days and workshops have been a valuable strategy in improving overall IPM adoption, irrespective of whether a consultant was used. The mean IPM adoption score has increased over time (Figure 35).

The results from the survey validate the findings that a high proportion of growers in the Sydney Region have adopted IPM to some degree, though the vast majority fall short of the ideal biologically based IPM system. Most growers targeted the use of cultural control methods which included improved hygiene, varietal selections and using monitoring as an important tool in their spray management procedures.

This adoption of IPM is tempered with the observation by the growers that they received the greatest benefit from the use of an IPM consultant or visits by NSW DPI staff to help them through their decision processes. Whilst it is unsustainable for NSW DPI staff to continue the high visitation rates that the growers enjoyed through the course of the project, it does highlight that the greatest success in IPM adoption is to be seen through the support and setup of additional IPM consultants in the area. The greatest barrier to the successful evolution of highly valued IPM consultants for growers was the provision of what was perceived to be “free” assistance in the guise of project staff visiting growers.

The greatest improvement and perhaps the greatest achievement in growers was the practices of monitoring crops for pest and beneficial arthropods, a step critical in the development and success of any IPM program. This result needs future support through the provision of continued and additional training to growers in order to maintain current skills and develop extra skills in the event of new plant pests or changing climatic conditions. In recent times, the use of online microscopy has opened up many avenues for training and diagnostic services that would have otherwise been impossible to provide. The extension and growth of this technology would be greatly beneficial to the growing community.

The shortfall in the use of monitoring was the reported lack of record keeping when it came to pest and beneficial arthropods in their crop. Without the extended and highly contextual records that should be collected for each farm, the use of monitoring effectiveness is reduced. Future projects have a need to focus on the development, training and use of monitoring tools that make the process easy and provide a tool for growers to collect this information easily. The identification of trends and management procedures that succeeded, or failed, needs to be worked into all growers’ management practices.

The growers surveyed did indicate that the project was successful with achieving the perceived outcomes and delivering important knowledge and training to growers in the area. The training provided was identified as a valuable component of the project and nearly all the growers indicated that they would undertake more training if it was offered to them in the future. The indication of support for future training should be met with the provision of this training. Many of the growers surveyed indicated that the large learning curve to move into IPM was a major barrier preventing the adoption of biologically based IPM. This can only be addressed by providing the necessary training to support growers as they make the transition to more effective pest management practices.

Technology Transfer

The IPM Project Officer conducted significant informal extension work through regular contact with key growers participating in the demonstration farms and their grower networks. Significant follow-up on inquiries or troubleshooting was completed when pest and disease issues arose through project contact with growers.

The project also completed a significant number of structured extension activities in the form of workshops, field days/farm walks and training courses and conference presentations. These provided the opportunity to share learning from the demonstration farms, surveys and research trials, conducted by the project and other relevant information. Workshops were well attended and many opportunities for further knowledge and skills development came from these.

Ten IPM newsletters (Appendix 7) were written and distributed to growers throughout the Sydney Basin, NSW and in other states. The newsletters were a vehicle for communicating new information on techniques, dangers and threats, as well as a means to recognise growers adopting IPM.

Workshops/Field Days

Date	Workshop topics	Attendance
26/05/2005 (Rossmore)	<u>Cucumber IPM Farm walk</u> • Looking at IPM in a cucumber crop • How do you manage thrips and whitefly on your farm? • Are you using the right chemicals? • How can you use IPM in your cucumbers? • Using ‘good bugs’ to control ‘bad bugs’ in your greenhouse	30
3/03/2006	<u>NSW Farmers Association Meeting</u> • Presented the findings of recent insecticide resistance testing with Grant Herron from the Insecticide Resistance Unit	20
30/03/2006 (Freemans Reach)	<u>Zucchini Mosaic Virus Farm Walk</u> • Inspection of trial plots of the latest mosaic resistant zucchini varieties and new anti-virus products	8
18/04/2006 (Leppington)	<u>Chinese Vegetable growers IPM Seminar</u> • Project introduction • IPM- Principles and practices • Common brassica pests and diseases • Farm walk	

27/04/2006 (Tahmoor)	Greenhouse IPM Picton Meeting • IPM in greenhouse vegetable crops • How do you manage thrips, whitefly and other pests? • Are you using the right chemicals? • How can you use IPM in your cucumbers, tomatoes and capsicums? • Biological control - Using 'good bugs' to control pests in your greenhouse	14
8/06/2006 (Rossmore)	Greenhouse IPM – 'Before' • IPM in greenhouse vegetable crops • How do you manage thrips, whitefly and other pests? • How can IPM be used on this farm? • How can you use IPM in your greenhouse vegetables? • Product launch – IPM card game	100+
21/06/2006 (Windsor)	Hydroponic Lettuce Growers Conference • Recognising key pests and diseases and monitoring • and TSWV • Root diseases in hydroponic lettuce – management strategies • Currant lettuce aphid – management strategies • Biologically based IPM, strategic chemical use and the minor use initiative	70
22/06/2006 (Rossmore)	Greenhouse IPM – 'After' • IPM in greenhouse vegetable crops • Designing your own IPM program • Commercial IPM consultants for greenhouse vegetable growers	100
22/08/2006 (Oakville)	Good Agricultural Practice – the key to successful IPM • Practices that help IPM to work in your greenhouse • Starting IPM	29
20/09/2006 (Tahmoor)	Greenhouse IPM • IPM in greenhouse vegetable crops	30
12/10/2006 (Werombi)	Field Lettuce IPM Demonstration (1/3) • Managing Currant Lettuce aphid (CLA) • Following a planting of resistant and susceptible varieties of lettuce V's confidor drenching	

27/10/2006 (Werombi)	Field Lettuce IPM Demonstration (2/3) • Following a planting of resistant and susceptible varieties of lettuce V's confidor drenching • Monitoring beneficial insect activity	
9/11/2006 (Werombi)	Field Lettuce IPM Demonstration (3/3) • Following a planting of resistant and susceptible varieties of lettuce V's confidor drenching • Monitoring beneficial insect activity	
15/11/2006 (Kemps Creek)	Greenhouse Growers Seminar • Becoming a better greenhouse grower	25
23/02/2007 (Richmond)	Hydroponic Lettuce Pesticide Management Workshop • Crop losses • Insecticide resistance • Pesticide residues	50
12/03/2007 (Rossmore)	Control Greenhouse Pests - With More Than Just Sprays • Insect screening • Simple greenhouse changes • Pest prevention through crop monitoring	35
3/04/2007 (Freemans Reach)	Zucchini Mosaic Virus Farm Walk • Zucchini variety trial inspection • Anti-virus product trial inspection • Cultural management practices • Avoiding calendar sprays of insecticides	12
19/06/2007 (Vineyard)	NSW Farmers Association – Hawkesbury Horticulture Branch • Pesticide use on hydroponic lettuce	23
4/09/2007 (Vineyard)	NSW Farmers Association – Hawkesbury Horticulture Branch • Project update	24
12/09/2007 (Rossmore)	APVMA CCC Meeting • Project update	40

28/11/2007 (Richmond)	Symposium & Workshop – Pest & Disease Management of Lettuce • Hydroponic lettuce root diseases • WFT status and coming options • IPM alternatives for WFT • CLA resistance management strategies • Crop health - IPM cycle, Insecticide resistance exercise, Disease recognition game, WFT/TSWV, Key insect pests – Aphids, Heliothis and other caterpillars	59
4/03/2008 (Vineyard)	NSW Farmers Association – Hawkesbury Horticulture Branch • Project update	24
2/05/2008 (Richmond)	Zucchini Field Day • Mosaic virus resistant varieties demonstration	40
20/05/2008 (Kemps Creek)	Greenhouse Cucumber Farm Walk • Cucumber and tomato pest and disease management • Best growing practices for greenhouse crops	40
30/05/2008 (Richmond)	Western Sydney Vegetable Demonstration Block – Grand Opening • Pest monitoring demonstration • IPM resources • Resistant varieties (lettuce/zucchini) demonstration	300+
28/07/2008\ (Rossmore)	NSW Greenhouse Vegetables Association Meeting • Project update	40
25/08/2008 (Rossmore)	NSW Greenhouse Vegetables Association Meeting • Project update	30
29/09/2008 (Rossmore)	NSW Greenhouse Vegetables Association Meeting • Project update	30
20/10/2008 (Richmond)	NSW Farmers Association – Cumberland Branch • Project update	
3/02/2009 (Vineyard)	NSW Farmers Association – Hawkesbury Horticulture Branch • Farm hygiene practices in hydroponic lettuce • How WFT spread TSWV	24
22/07/2009 (Menangle)	AHGA Conference Sydney Farm Tours • Presented to delegates on Zucchini virus work	90+

22/10/2009 (Werombi)	Lettuce Field Day • Following successive CLA susceptible plantings through • Demonstrating pest and beneficial insect activity and interaction • Revisiting correct spray application	25
5/11/2009 (Werombi)	Lettuce Diseases Focus Day • Following successive CLA susceptible plantings through • IPM in lettuce, a focus on disease • Information on IPM accreditation scheme	22

Training courses

Date	Training Topics	Attendance
6/04/2006 (Richmond-Londonderry)	IPM Training Workshop for Consultants & Agronomists – Day 1 • Approaches to IPM for vegetable crops • Greenhouse demonstration on practical IPM • Field IPM demonstration	15
7/04/2006 (Narara)	IPM Training Workshop for Consultants & Agronomists – Day 2 • Field vegetable monitoring, conservation of beneficial insects • Greenhouse vegetable monitoring, sticky trap use and pest identification, beneficial recognition and biological control, pesticide issues and compatibility • Disease recognition and diagnostics	15
27/09/2006 (Werombi-Rossmore)	IPM Training Workshop for Consultants & Agronomists • Recognising and managing common vegetable diseases • Scout for and discuss lettuce, brassicas and other field crops • Scout for and discuss diseases in greenhouse cucumbers and tomatoes	
8/8/2008 (Dural)	Nursery Industry IPM Training – Day 1 Recognising and monitoring pests	8
14/8/2008 (Dural)	Delivered Nursery Industry IPM Training – Day 2 Control and management of pests	8
28/08/2009 (Berkshire Park)	Certificate 3 in Agriculture (Chinese Market Gardeners) • Basics in IPM • Crop monitoring • Recognising and understanding beneficial insects • Insect pest identification	5
12/05/2010 (Menangle)	Nursery Industry IPM Training – Day 1 • Recognising and monitoring pests	12
19/05/2010 (Menangle)	Delivered Nursery Industry IPM Training – Day 2 • Control and management of pests	12
1/07/2010 (Tocal)	SMARTtrain AQF5 • Managing highly resistant insect pests: presentation and case study	25

21/07/2010 (Rossmore)	<u>Greenhouse IPM – Refresher Training</u> • Pest and disease recognition • Pest and disease monitoring • Pest and disease control – Chemical V's Biological • Basic farm hygiene	30

Conference presentations

Date	Conference	Information Presented	Presented by
2006	HFF Geelong	• Trade Booth • Goodwin, S. and Pilkington, L.J. (2006). The use of a Novel Reduced-Risk Chemical in the Control of Western Flower Thrips in Greenhouse Crops.	Stephen Goodwin and Leigh Pilkington
2007	AHGA Tasmania	• Trade Booth • Pilkington, L.J. (2007). Overuse of Synthetic Pesticides – How can Integrated Pest Management Help? • Pilkington, L.J., Kent, D. and Goodwin, S.(2007). Hacking the Heat? Greenhouse Screening to Manage Temperatures and Reduce Movement of Pests.	Leigh Pilkington
2008	ANZBC	• Pilkington, L.J. (2008) Current Research in Protected Cropping Biocontrol in Australia. • Pilkington, L.J. (2008). The State of Play in Biological Control in Australia – Where to now?	Leigh Pilkington
2009	AHGA Sydney	• Trade Booth • Pilkington, L. J. (2009) Good Bugs, Good Practices, Good Sense.	Leigh Pilkington

Project evaluation

IPM benchmarking survey

A benchmarking survey was completed in the early phase of the project with 15 growers across a range of vegetable commodity groups to generate baseline data on IPM practices amongst growers. This historical data was used to demonstrate changes in the level of IPM adoption on Sydney vegetable farms.

IPM adoption evaluation 2008

A survey was designed and conducted in August 2008 to identify the level of IPM adoption by vegetable growers in the Sydney Region and evaluate the effectiveness of project extension activities with the growers and their consultants. The IPM status of each farm was measured through grower completing a survey on their management practices, in the areas of pests, diseases and weeds, and the use of cultural, chemical and biological control options.

The survey was conducted in August 2008 with 60 vegetable growers (of 90 growers contacted) taking part. Growers were surveyed mostly by telephone, with some face-to-face and on-farm. The growers surveyed can be grouped into a number of categories, by growing region, commodity group or with and without IPM consultant (Table 4). The corresponding number of growers surveyed in each category is given below in the tables below.

Table 4. Number of growers surveyed in each commodity group in 2008

Commodity groups	# Surveyed	Consultant Use	
		No	Yes
Field Vegetables	18	14	4
Field Asian Vegetables	4	4	0
Greenhouse Vegetables	17	14	3
Hydroponic Lettuce	17	12	5
Hydroponic Asian Vegetables	2	2	0
Vegetable Seedlings	2	0	2

The survey aimed to reflect the benefits of working with a consultant across different regions in the Sydney Region (Table 5). It was hypothesised that those farms that had been working with a consultant to adopt IPM would achieve the highest scores. Those growers not with a consultant would conversely achieve the lowest scores.

Table 5. Number of growers surveyed in each growing region

Growing Regions	# Surveyed	Consultant Use	
		No	Yes
Hills	8	5	3
Hawkesbury	22	20	2
Liverpool	21	17	4
Camden	9	4	5

Reviewing the difference in scores from August 2008 surveys and those obtained in the initial benchmarking surveys in 2004-07 may assess the effectiveness of the vegetable IPM project on IPM adoption.

Patterns between groups may be used to highlight to the project team the areas of IPM adoption that are in need of further demonstrations and training. The difference in mean scores between farms using or not using consultants also highlights the need for greater promotion and access to growers for this type of service.

The survey results demonstrate that vegetable growers more successfully adopt IPM practices when they use a trained IPM consultant.

The adoption of IPM practices has increased during the course of the vegetable IPM project from 2004-08. Those using a consultant significantly improved their level of IPM adoption, while other growers made improvements in specific areas, such as variety selection and general crop management. Other strategies have fluctuated in their use (Figure 35).

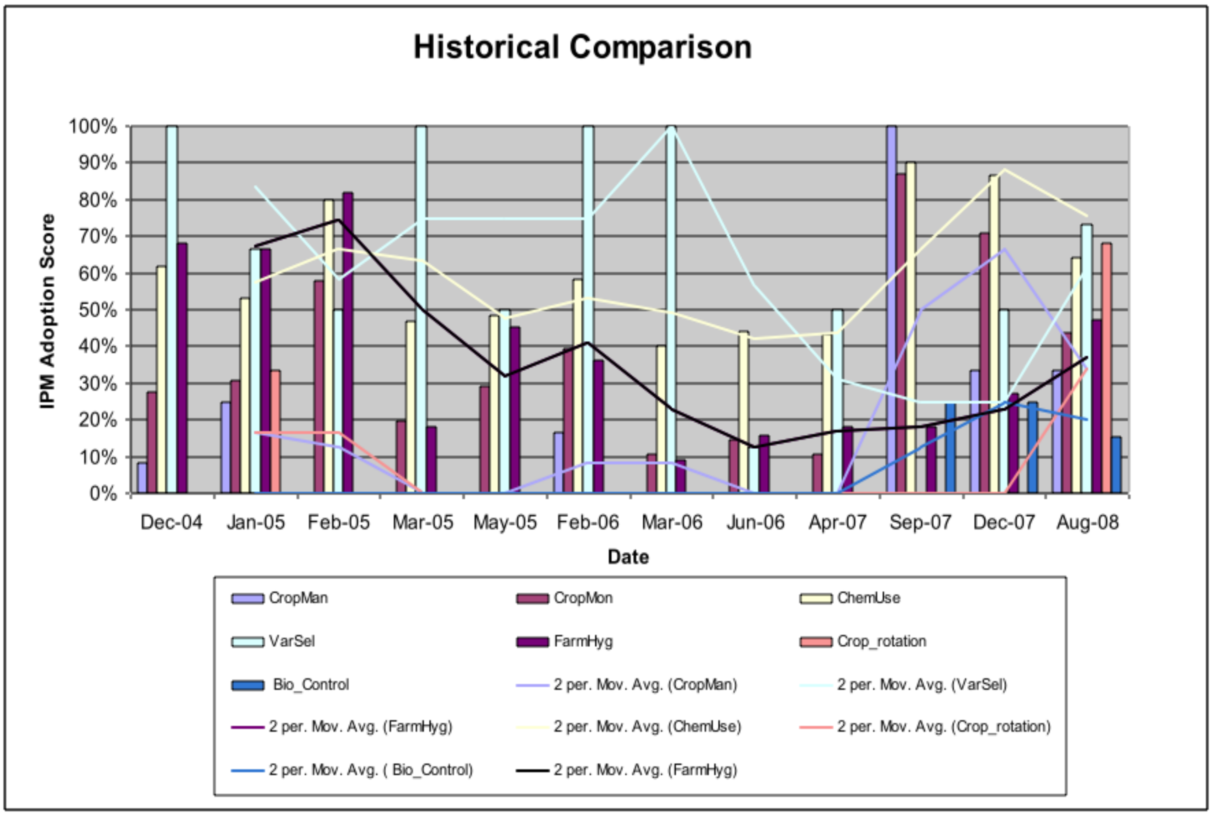


Figure 35. Historical comparison of the adoption of IPM strategies throughout the project.

Some farms were surveyed two or three times over the course of the project. Farms 1, 2, 3, 5 and 7 are great examples of the positive impact of working with a consultant to adopt IPM, as indicated in Table 5.

Table 5. Survey scores over time for farms surveyed more than once (percentage scores).

Survey Date	Farm Number														
	1	2	3	4	5	6	7	8	11	12	15	17	29	31	42
Dec-04						35						43			
Jan-05											44		39	32	
Feb-05									56						
Mar-05	26	25													
May-05										32					
Feb-06															40
Mar-06					19										
Jun-06			23			18	20	22							
Apr-07				20											
Sep-07								71							
Dec-07				62											
Aug-08	79	81	72	33	66	71	72	25	55	45	54	55	67	46	35

The change in levels of IPM adoption often reflects the importance of working with a consultant to maintain IPM programs, such as on Farm 8. This grower achieved a low score of 22% in 2006, worked closely with a consultant through to 2007 and achieved a high score of 71%. This was followed in 2008 with a low score of 25%, with a decision made by the grower to not use an IPM consultant. A similar pattern is seen with Farm 4. Farm 6 was surveyed on 3 occasions during the project, firstly scoring 35% in December 2004 then dropping to 18% adoption in June 2006, due to the lack of resistant varieties against currant-lettuce aphid, increased chemical use due to this issue as well as pesticide resistance to WFT.

Farms 12, 15, 29 and 31 have made considerable progress over the course of the project, have used consultants on a casual or seasonal basis, and have relied on the project team for technical support. They have participated in a number of workshops and field days, and have adopted better pest and disease management practices as a direct result of this interaction (Table 6).

Table 6. Number of growers surveyed with or without consultant use

Consultant use	# Surveyed	Mean Score
No	46	41.1%
Yes	14	65.7%

In the August 2008 survey, 60 farms were surveyed. The mean score for the 14 growers with a consultant scored 65.7%, and was significantly greater than the 46 growers without a consultant (See Table 7). The best performing region was Camden (9 surveyed) at 56.11%. The best performing commodity group were vegetable seedling producers (2 surveyed) at 60.5%; this is due to both farms employing an IPM consultant (Table 7).

Table 7. Survey scores for 60 growers, categorised according to consultant use, commodity groups and regions in 2008

Commodity groups	Region	Total		No consultant		Consultant	
		# surveyed	Mean score	# surveyed	Mean score	# surveyed	Mean score
Field vegetables	Camden	5	58	2	29	3	77.3
	Hawkesbury	10	47.2	9	45.2	1	65
	Hills	0	-	0	-	0	-
	Liverpool	3	38.5	3	38.5	0	-
Field Asian vegetables	Camden	0	-	0	-	0	-
	Hawkesbury	1	19	1	19	0	-
	Hills	0	-	0	-	0	-
	Liverpool	3	21	3	21	0	-
Greenhouse	Camden	1	57	1	57	0	-
	Hawkesbury	2	51.8	2	51.8	0	-
	Hills	2	57.3	2	57.3	0	-
	Liverpool	12	49.5	9	45.9	3	60.3
Hydroponic Asian vegetables	Camden	1	37	1	37	0	-
	Hawkesbury	0	-	0	-	0	-
	Hills	0	-	0	-	0	-
	Liverpool	1	32	1	32	0	-
Hydroponic lettuce	Camden	0	-	0	-	0	-
	Hawkesbury	9	40.6	8	39.4	1	50.5
	Hills	6	52.3	3	38.3	3	66.2
	Liverpool	2	57.3	1	42.5	1	72
Seedling production nursery	Camden	2	60.5	0	-	2	60.5
	Hawkesbury	0	-	0	-	0	-
	Hills	0	-	0	-	0	-
	Liverpool	0	-	0	-	0	-

The best performing group overall were the Camden field growers (3 surveyed) using a consultant with a score of 77.3%. The worst performing was the single Hawkesbury field Asian vegetable grower with a score of 19% (see table 7).

The data shows that for the 18 field vegetable growers surveyed across all regions in Sydney, 4 had an IPM consultant, 14 didn't. The mean survey score for field vegetable farms with consultants was 74.3%, without consultants 41.4%.

Hydroponic lettuce growers with consultants in the Liverpool (one grower) and Hills area (three growers) scored 72% and 66.17% respectively. This was a far greater score than their region counterparts without a consultant, scoring 42.5% in Liverpool and 38.33% in the Hills district.

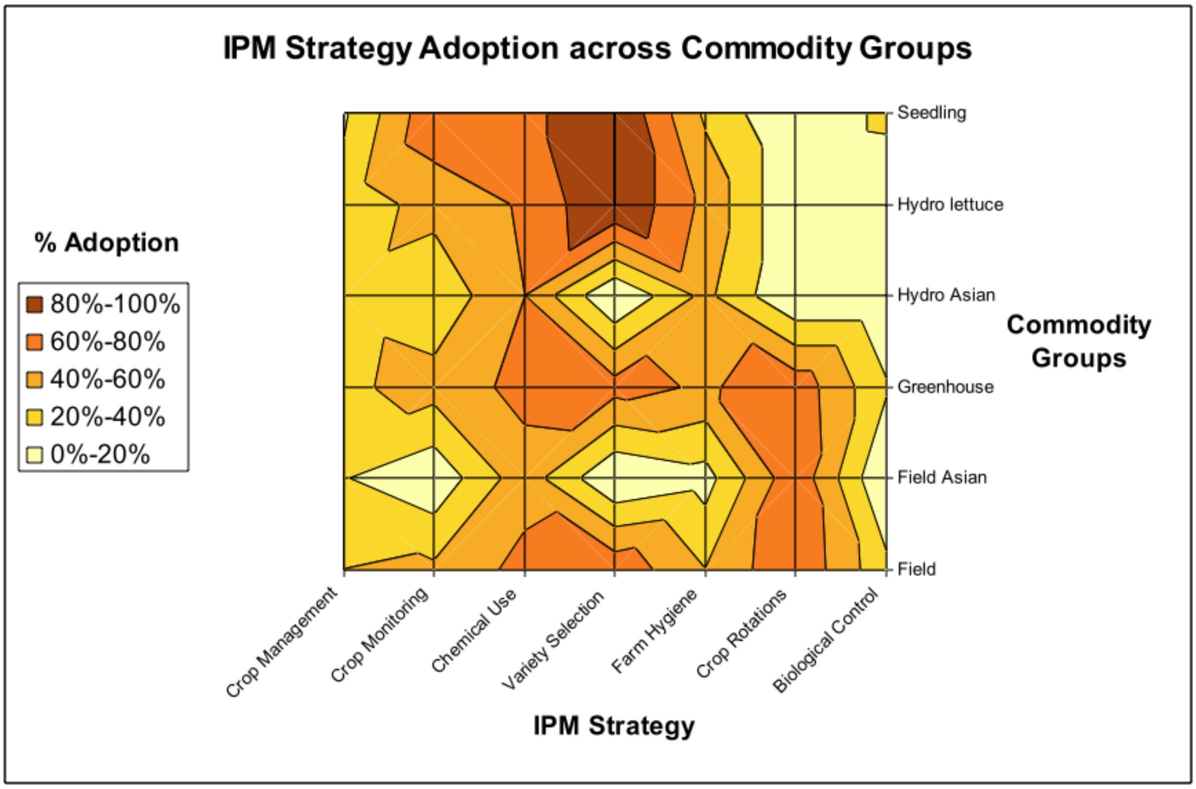


Figure 36. IPM strategy adoption across commodity groups

Figure 36 represents where each of the commodity groups are placed in relation to the various IPM adoption strategies. The higher adoption scores of 80-100% shown in this figure demonstrate that variety selection is of high priority to vegetable seedling producers and hydroponic lettuce growers, whilst the pale yellow segments, with low scores of 0-20% adoption show little to no importance for variety selection to field Asian and hydroponic Asian growers. This limited adoption can be due to the lack of varieties with pest or disease resistance available for cultivation.

Figure 36 also shows that seedling producers, hydroponic lettuce and hydroponic Asian growers who were surveyed do not rotate their crops, as to be expected in soil-less media, on raised benches and in protected cropping situations. Hydroponic lettuce and hydroponic Asian growers who were surveyed do not use use biological control options as a management strategy, although the seedling producers may encourage natural predators and use biologically based fungicides as they have 20-40% adoption.

A small percentage of field and greenhouse vegetable growers surveyed embrace biological control as a pest management option. There is a mid-range adoption of good chemical practices within hydroponic and field Asian vegetable growers and a higher adoption of 60-80% in good chemical use for all other commodities.

The yellow section following the crop management area indicates that most commodities scored low in crop management except for some field growers, and seedling producers scored a little less on this strategy as their clients request broad-spectrum fungicide applications and plant material to be completely free of pests prior to despatch.

IPM adoption evaluation 2010

In March 2010, a final survey was conducted that contained several in depth questions about farming practices which aimed to provide a detailed description of the position of the surveyed growers in relation to their practices and use of IPM. The aim of this survey was to evaluate if the objectives of the project were met and if growers found the process to be useful. It would also assess the level of IPM adoption.

47 growers were surveyed across the Sydney Region and were asked, through a series of multiple-choice questions, about their farming practices, adoption of IPM and reasons behind adoption or non-adoption. These data are presented separately to the earlier benchmarking surveys on account of the different questioning and the greater depth sought and was treated as a project evaluation. The commodity groups and numbers surveyed in each during this survey were highest in field vegetables, greenhouse vegetables and hydroponic lettuce but quite low in Asian vegetables and vegetable seedlings (Table 8).

Some growers identify themselves as being in more than one commodity group and this will be indicated in slightly higher numbers in total than were actually surveyed.

Table 8. Number of growers surveyed in each commodity group in 2010

Commodity groups	# Surveyed	Consultant Use	
		No	Yes
Field Vegetables	21	18	3
Asian Vegetables	3	3	0
Greenhouse Vegetables	11	10	1
Hydroponic Lettuce	16	14	2
Vegetable Seedlings	1	0	1

Growers from these groups were asked a series of 54 questions that were aimed at assessing the impact of the project and strategies that could have been adopted that the growers feel might have improved the project. Questions followed broad topics such as crop management, crop monitoring, chemical use, variety selection, farm hygiene, variety selections, crop rotations, biological control and project evaluation.

When asked to describe their approach to managing diseases in their crops, 47 growers indicated that they considered their approach to be “chemical IPM”. Hydroponic lettuce growers, greenhouse vegetable growers, field vegetable growers and nurseries had over 90% of responses in this category. Asian vegetable growers had a lower rate of IPM with two of the three respondents indicating they used calendar sprays. All grower groups indicated that their approach to pest management was considered to be “chemical IPM” with hydroponic lettuce growers, greenhouse vegetable growers, field vegetable growers and nurseries indicating at over 95% for their commodity group. Asian vegetable growers indicated that two of three growers used “chemical IPM”. In these chemical IPM schemes, growers were asked if they used targeted sprays in their crops. It was indicated that 47% of growers used targeted sprays with nurseries and Asian vegetable producers showing a 100% use of targeted sprays and greenhouse vegetable producers targeting at 55%. Of those that indicated a targeted spray regime, greenhouse and Asian vegetable producers selected conventional pesticides for their pest problem and hydroponic lettuce growers and nurseries focussed on the use of bio-rational pesticides.

Growers’ goals were broadly defined by increasing levels of IPM adoption (Table 9) with Asian vegetable growers focusing on improving farm hygiene. The most common aim for growers was to improve hygiene and the use of resistant varieties with 11 responses looking at including targeted sprays. At the higher end of IPM and the use of biological control, six growers indicated that this was their aim for on farm pest management strategies with five of those responses coming from field grown vegetables. Whilst chemical IPM was the target for the majority of growers, pesticide use was selected largely on efficacy with 43% or those questioned selecting products based on their kill rate. Specificity was a focus for 34% of growers, with compatibility for beneficial insects at 11%.

Table 9. Growers' goals for IPM adoption, based on commodity

		Are you a:				
		Hydroponic lettuce grower	Greenhouse vegetable grower	Field vegetable grower	Seedling producer	Asian vegetable grower
What is your goal for IPM?	N/A	6.7% (1)	0.0% (0)	0.0% (0)	0.0% (0)	0.0% (0)
	Focus on farm hygiene	26.7% (4)	18.2% (2)	9.5% (2)	0.0% (0)	**66.7% (2)**
	Focus on farm hygiene and use resistant varieties	**60.0% (9)**	**36.4% (4)**	**47.6% (10)**	0.0% (0)	0.0% (0)
	Focus on farm hygiene, resistant varieties and target sprays	6.7% (1)	**36.4% (4)**	19.0% (4)	**100.0% (1)**	33.3% (1)
	Focus on farm hygiene, resistant varieties, target sprays and BCA's	0.0% (0)	9.1% (1)	23.8% (5)	0.0% (0)	0.0% (0)

The majority of growers (79%) taking part in the survey indicated that they monitored their crops for pests and beneficial arthropods on a weekly basis - this was mostly conducted by the growers (83%) with only 13% using an IPM consultant. 81% of respondents indicated that they did not use a routine protocol and 73% did not keep records of pests within their crops. Similar trends were observed when growers discussed monitoring for diseases in their crops with the addition that 71% of respondents used a diagnostic service to identify the diseases in their crops.

Whilst over 95% of all growers were aware that weeds could provide a source of pathogens that could then bring disease into their crops, only 51% subsequently monitored for weeds that were known hosts for pests or reservoirs for pathogens.

Nutrient management and monitoring was undertaken by 57% of growers on a weekly basis and 79% of those growers used a routine protocol with 64% keeping long-term records. The selection of pesticides by growers was based largely to maximise the kill of the targeted pest with 43% of growers making their decisions on mortality of the pest, 34% on specificity of the pesticide and 11% selecting on reported impact on beneficials. Of concern was the 13% of growers that selected their pesticides based on the broadest possible effect on insects. Growers calibrated their spray equipment once or twice a season (79%) with 9% of growers calibrating weekly and 19% of growers using spray cards to evaluate the effective coverage of their applications. 79% of respondents indicated that the timing of their spray was based on pest pressure and 11% sprayed on a regular/calendar basis.

The use of Personal Protective Equipment (PPE) while spraying was based largely on label instructions (83%) and 96% of growers adhered to re-entry requirements indicated on the label. 19% of growers used chemicals from the synthetic pyrethroids group and 20% of growers used Schedule 7 chemicals.

The advice of IPM consultants was regarded highly as a source of information when using pesticides (Figure 37). Other growers and resellers were considered to be moderate sources of information and electronic resources were considered the least useful.

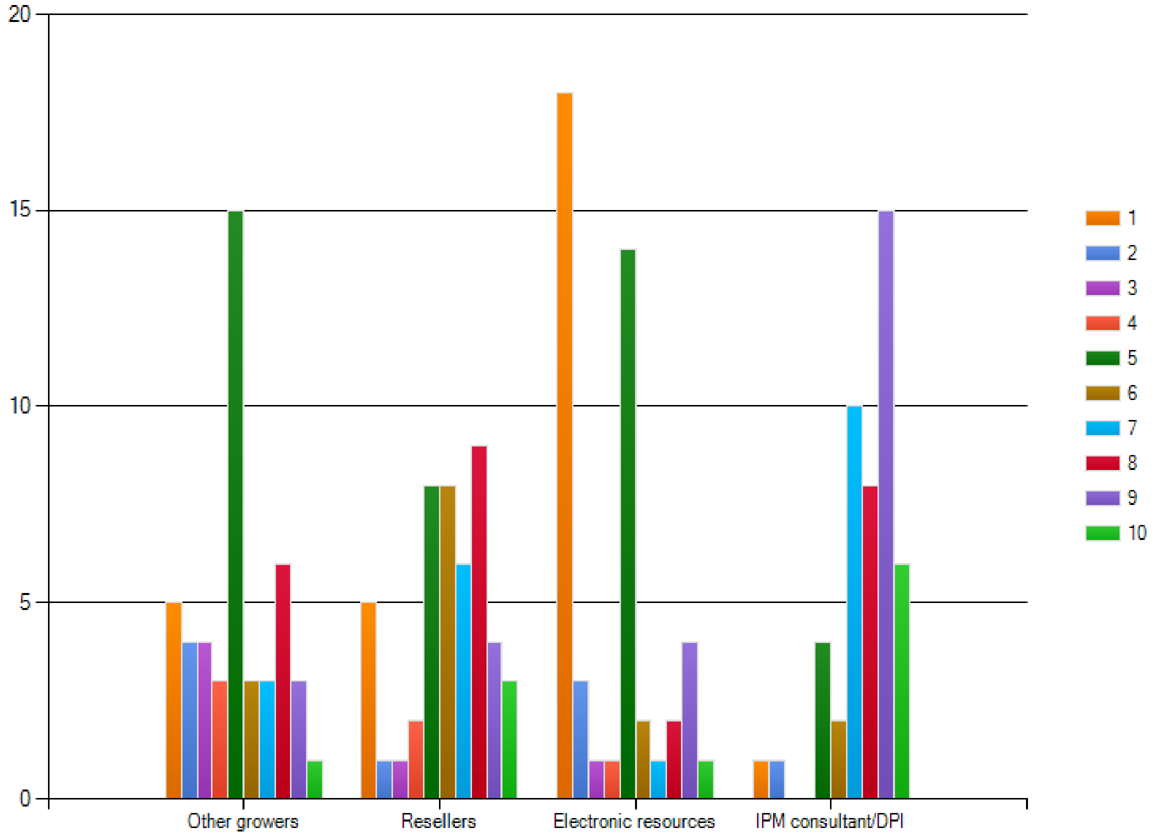


Figure 37. Growers' rating (1 lowest : 10 highest) of the value of advice and recommendations from various sources.

Variety selection was considered for pest and disease resistance by 79% and 81% of growers, respectively. 57% of growers rogue for diseased plants on a weekly basis and, when found, diseased plants are removed off site by 45% of growers and 53% of growers consider hygiene important and remove weeds from around the farm on a regular basis. 60% of growers indicated that their major source of pest or disease contamination was from neighbouring land, whether it was privately owned or council land and 49% of growers indicated that they removed their crop waste from their farm by disposing or burning the material.

Only 17% of growers released biological control agents in their crop and of those that did not release agents, 55% indicated that the major barrier to their use was the high learning adjustment that was needed to undertake the change. The growers that did use biological control agents did so to reduce pesticide residues in their crop and to reduce the exposure of pesticides to their workers. Despite the low commercial use of biological control agents in crops, 30% of growers were conscious of their role in the crop and 30% of growers had adjusted their growing practices to be compatible with the local populations of biological controls that might be present in their area and 49% actively monitor for beneficial insects and mites in their crops.

The project evaluation portion of the survey yielded results that showed that growers now considered IPM to be the use of an holistic approach to pest management combining cultural, chemical and biological techniques (64% of respondents). Singling out one method from other cultural practices, 49% agreed that IPM involved farm hygiene. When given a two-choice question on the aim of IPM, 83% regarded it as an educated and integrated approach to pest management rather than the use of biological control agents.

When asked specifically about the aims of the project, 76% felt that it was being funded to provide training and assistance to growers in the effective use of IPM. The greatest area of improvement, according to the growers, would have been an increase in the amount of one-on-one training to growers on their properties with 60% of growers indicating this would have been beneficial.

60% of growers felt that the project had met the objectives with 34% being unsure (Figure 38). The majority of growers were aware of the publications that were produced as part of this project and were satisfied with this output, both in print form and in workshops (Figure 38). The extension work that was conducted as part of this project would be used by 98% of growers (one response unsure) and that any further training offered would also be well patronised with 92% of growers attending this training, with the remaining 8% unsure.

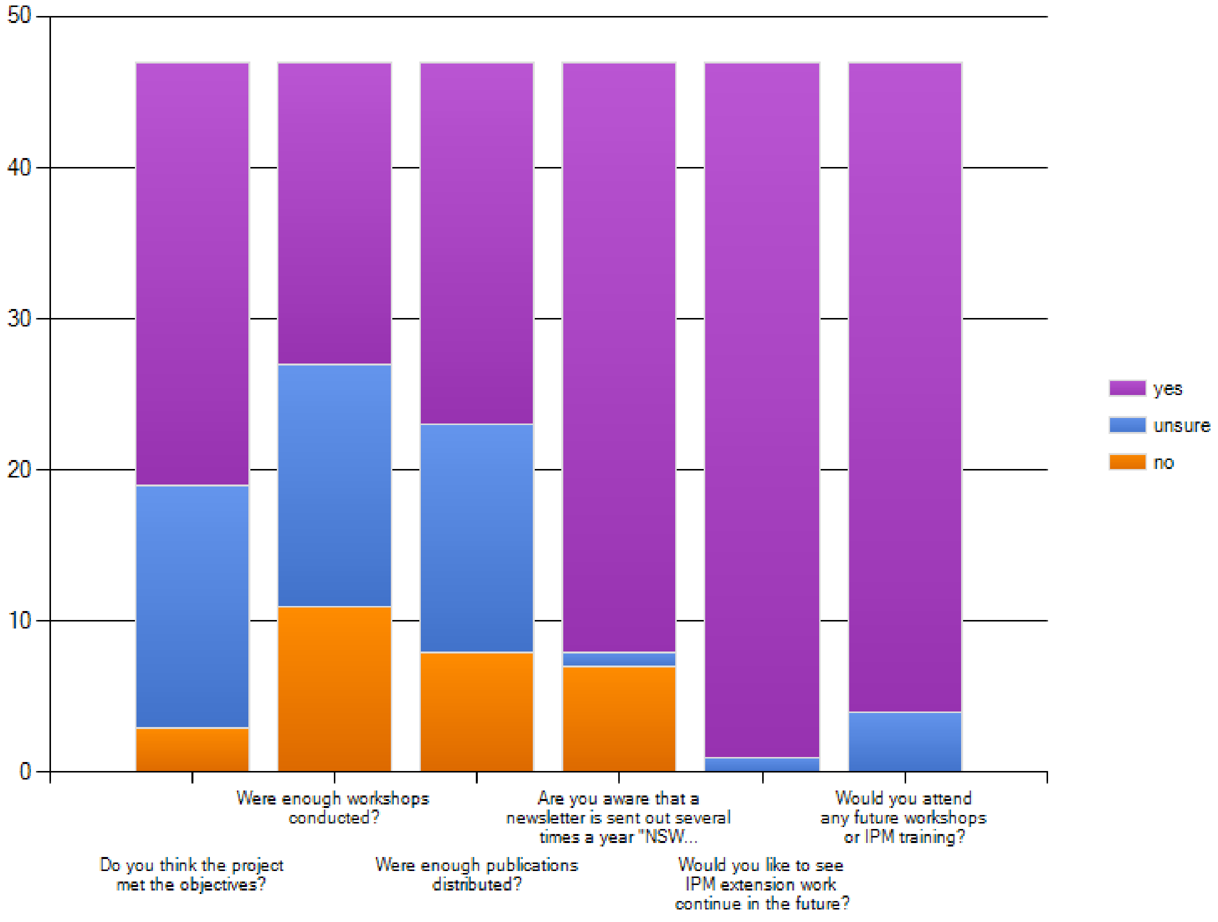


Fig. 38. Project evaluation – responses to project specific performance criteria.

Recommendations

To maintain a consistent IPM support service informed by the latest research and to ensure growers are able to respond to new pest or disease outbreaks, there needs to be IPM extension officers available to provide IPM extension. These officers would be able to provide technical support and extend research results to the IPM consultants and their grower clients.

Access to appropriate IPM resources and services is also a key challenge for growers from a non-English speaking background (NESB) as their first language. The cultural diversity of vegetable growers (especially in areas such as the Sydney Region) requires the use of bi-lingual officer to work in conjunction with IPM officers and consultants. The benchmarking survey results for Asian vegetable growers in this project are a clear indication of the necessity for this support service.

Further research into biological control options for IPM in hydroponic lettuce and Asian vegetable growing crops and systems would reduce the current high reliance on pesticides, lower the incidence of pesticide resistance development by pest species, and, in turn, improve chemical use strategies and minimise food safety issues.

Research should be conducted into consumer tolerance of insect presence in leafy greens. The product specification critical limit of a maximum of 2% of produce with insects present, determined by market surveys conducted by NSW DPI staff (unpublished), imposes a restriction on the use of biological controls and continued reliance on chemical controls.

Continued training and extension opportunities are required for new growers entering the industry and those seeking IPM information to transition from chemical control to diversified IPM control practices for pests and disease. Continued training of IPM consultants is also a high priority. Without access to IPM research, education and diagnostics services, the knowledge needed for this highly technical area will dissipate and the growers will lose access to the services experienced IPM consultants can provide.

Additional work looking at expansion of IPM consultancy services will be key to the successful adoption of IPM by vegetable growers. This project has shown that substantial improvements in controlling major vegetable pests and diseases can be achieved by using a holistic IPM approach to the problem, rather than relying on increasingly ineffective and costly chemical solutions. The project has also shown that to achieve greater practice change amongst growers, the IPM consultants need to work closely with growers to provide the support needed. Building such support networks will help provide growers with the on-ground knowledge, skills and confidence to successfully adopt IPM.

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Appendices

Appendix 1 - Survey forms

Record Sheet

Crop Inspection Data - Lettuce

Diseases: Sclerotinia, Botrytis, Anthracnose, Septoria, Bacterial Leaf Spot, Varnish Spot, Downy Mildew, TSWV, Big Vein, Mosaic, Necrotic Yellows

Crop Stages: 1-Emergence to 2nd leaf 2-3-5 leaf/transplant seedling 3-6 leaf to cusping leaf, pre-heart 4-Early Hearting 5-Full hearted

						#, Damage mild, mod, severe		Eggs: White, Orange, Brown, Black; Larvae									
Date	**Plot**	**Crop**	**Variety**	**Planting Date/Harvest Date/Stage**	**Plant Numbers**	***Thrips***	***Aphids***	***Heliothis***	***Cutworm (1 egg)***	***Cluster Caterpillar 1 egg)***	***Loopers***	**Diseases** Low, Moderate, Severe	**Beneficials**	**Comments** eg **Last Spray, weeds, recommendations**	**Forward to PHDS**	**Results**	**Ref #**

Record Sheet

Crop Inspection Results - Tomato

Diseases: Fungal (Pythium, Fusarium, Botrytis, Powdery Mildew, Grey Leaf Spot), Bacterial (Canker, Wilt, Leaf Spot), Virus (TSWV, CMV, others)

Crop Stages: 1: Establishment/Pre-fruiting 2: Early fruiting 3: Fruiting

							# pests, Damage mild, mod or severe?													
Date	**House**	**Row**	**Variety**	**Crop Stage**	**Number of plants in tunnel**	**Number of plants inspected**	***Thrips***	***Whiteflies***	***Aphids***	***Spider mites***	***Russet Mites***	***Fungus Gnats***	***Shore Flies***	***Heliothis/Loopers/ other grubs***	**Diseases** Low, Moderate, Severe	**Beneficials:** #, Type	**Comments** eg Last Spray, weeds, recommendations	**Forward to PHDS**	**Results**	**Ref #**

Record Sheet

Crop Inspection Results - Cucumber

Diseases: Fusarium, Gummy Stem Blight, Pythium, Botrytis, Powdery Mildew, Angular leaf Spot, Downy Mildew, Bacterial Leaf Spot, Mosaic Virus

Crop Stages: 1: Emergence to 2nd leaf 2: 3-5 leaf/transplant seedling 3: 6 leaf to flowering 4: Early fruiting 5: Mature

						# pests, Damage mild, mod or severe?													
Date	**Tunnel**	**Row**	**Variety**	**Crop Stage**	**Number of plants in tunnel**	**Number of plants inspected**	***Thrips***	***Whiteflies***	***Aphids***	***Spider mites***	***Fungus Gnats***	***Shore Flies***	***Loopers/ other grubs***	**Diseases** Low, Moderate, Severe	**Beneficials:** #, Type	**Comments** eg Last Spray, weeds, recommendations	**Forward to PHDS**	**Results**	**Ref #**

Record Sheet
Sticky Trap Data

WFT=Western Flower Thrips; OT=Onion Thrips; TT=Tomato Thrips; PT=Plague Thrips

Beneficials: B=Beetle, RB=Rove Beetle; MW=Micro-wasp, HLB=Hippodamia ladybeetle

Pests: MF=Moth Fly; BLH=Brown Leaf Hopper; 28SLB=28-Spotted Lady Beetle,

					Count numbers of each pest on sticky trap										
Trap Label	Grower	Date Collected	# days trap was up	Thrips						Whiteflies	Aphids	Fungus Gnats	Shore Flies	Beneficials	Comments/Others
				Total	WFT	OT	TT	PT	other						

Crop Inspection Results - Greenhouse

Grower Details	
GPS	
Crop	
Planting Date	
Variety	
Est. harvest date	
Planting Size	
Farm Size	

Pesticide Records (active, date, rate)

Plot Map

Monitoring Records

		Insects, Pests Low, Moderate, Severe								
Date	Crop Stage	Thrips	Whiteflies	Aphids	Spider mites	Fungus Gnats	Shore Flies	Loopers/ other grubs	Beneficials	
	1									
	2									
	3									
	4									

		Diseases Low, Moderate, Severe								
Date	Crop Stage									
	1									
	2									
	3									
	4									

Crop Stages: 1: Planting age/Emergence/Seedlings 2: Pre-flowering 3: Flowing/Early fruiting 4: Harvest age

Cucumber Diseases: Fungal (Pythium, Fusarium, Gummy Stem Blight, Botrytis, Powdery Mildew, Angular leaf Spot, Downy Mildew), Bacterial (Leaf Spot), Viral (Mosaic, Yellows)

Tomato Diseases: Fungal (Pythium, Fusarium, Botrytis, Powdery Mildew, Grey Leaf Spot), Bacterial (Canker, Wilt, Leaf Spot), Viral (TSWV, CMV, others)

Comments: Laboratory Test Results, Insect Identifications

Crop Inspection Results - Hydro Lettuce

Grower Details	
GPS	
Crop	
Planting Date	
Variety	
Est. harvest date	
Planting Size	
Farm Size	

Pesticide Records (active, date, rate)

Plot Map

Monitoring Records

Insects, Pests Low, Moderate, Severe

Date	Crop Stage	Thrips	Aphids	Rutherglen Bugs	Heliothis/ other grubs	Whiteflies	Fungus gnats	Leafminers (damage)	Beneficials	
	1									
	2									
	3									
	4									

Diseases Low, Moderate, Severe

Date	Crop Stage	Root Rot	Botrytis Crown Rot	Sclerotinia Crown Rot	Sclerotinia Crown Rot	Septoria leaf spot	Downy Mildew	Bacterial Leaf Spot	Tomato Spotted Wilt Virus	Mosaic Virus, Big vein
	1									
	2									
	3									
	4									

Crop Stages: 1: Planting age/Emergence/Seedlings 2: Pre-hearting 3: Early hearting 4: Harvest age

Comments: Laboratory Test Results, Insect Identifications

Crop Inspection Results - Field

Grower Details	
GPS	
Crop	
Planting Date	
Variety	
Est. harvest date	
Planting Size	
Farm Size	

Pesticide Records (active, date, rate)

Plot Map

Monitoring Records

		Insects, Pests Low, Moderate, Severe								
Date	Crop Stage	Thrips	Aphids	Caterpillars	Spider mites	Whiteflies	Rutherglen Bugs	Others: leafhoopers, leaf miner damage	Beneficials	
	1									
	2									
	3									
	4									

		Diseases Low, Moderate, Severe								
Date	Crop Stage									
	1									
	2									
	3									
	4									

Crop Stages: 1: Planting age/Emergence/Seedlings 2: Pre-flowering/Pre-hearting 3: Flowing/Early fruiting/ Early hearting 4: Harvest age

Lettuce Diseases: Fungal (Sclerotinia, Botrytis, Anthracnose, Septoria, Downy Mildew), Bacterial (Bacterial Leaf Spot, Varnish Spot), Viral (TSWV, Big Vein, Mosaic, Necrotic Yellows)

Brassica Diseases: Fungal (Sclerotinia, Rhizoctonia), Bacterial (Black Rot), Viral (Mosaic)

Cucurbit Diseases: Fungal (Powdery Mildew, Botrytis, Anthracnose, Alternaria, Root Rot), Bacterial (Bacterial Leaf Spot, Soft Rot), Viral (Mosaic Virus, Yellows)

Solanaceae Diseases: Fungal (Botrytis, Powdery or Downy Mildew, Root Rot), Bacterial (Bacterial Leaf Spot, Fruit speck, Canker), Viral (TSWV, Mosaic)

Stem & Stalk Crop Diseases: Fungal (Alternaria, Mildew, Anthracnose, Phytophthora), Bacterial (Bacterial Leaf Spot, Stalk Rot), Viral (TSWV, Mosaic, Ringspots)

Comments: Laboratory Test Results, Insect Identifications

Appendix 2 - Virus Survey Results

Date	Sample #	Sample No.	Site	Host	Sample	Virus	Outcome
8/05/2007	M07-03255	29	K	crop	Long White Raddish	TuMV	Positive
21/05/2007	M07-03581		MG	crop	Chinese cabbage	TuMV	Positive
31/05/2007	M07-03926		GX	crop	Broad Bean	BWV	Positive
9/07/2007	M07-04908		HL	crop	Tomato	PVX	Positive
17/07/2007	M07-05208		VM	crop	Lettuce	TSWV	Negative
17/07/2007	M07-05209		VM	crop	Lettuce	TSWV	Negative
4/07/2007	M07-04903		MV	crop	Broad Bean	BWV	Positive
4/07/2007	M07-04903		MV	crop	Broad Bean	TSWV	Negative
4/07/2007	M07-04903		MV	crop	Broad Bean	CMV	Negative
13/07/2007	M07-05211		JB	crop	Cabbage	TuMV (EM)	Positive
13/07/2007	M07-05206		JB	crop	Lettuce (cos)	LMV (EM)	Positive
13/07/2007	M07-05207		JB	crop	Lettuce (iceberg)	LMV (EM)	Positive
17/07/2007	M07-05212		VM	crop	Cauliflower	TuMV (EM)	Positive
21/07/2007	M07-04486		SG	crop	Rhubarb	unknown	Positive
7/08/2007	M07-05882		MA	crop	Cos lettuce	TSWV	Negative
7/08/2007	M07-05882		MA	crop	Cos lettuce	CMV (EM)	Positive
7/08/2007	M07-05883		MA	weed	slender celery	TSWV	Negative
7/08/2007	M07-05883		MA	weed	slender celery	Virus (EM)	Negative
7/08/2007	M07-05889	A	DB	crop	butter lettuce	CMV	Negative
7/08/2007	M07-05889	A	DB	crop	butter lettuce	TSWV	Negative
7/08/2007	M07-05889	A	DB	crop	butter lettuce	LBV (EM)	Positive
7/08/2007	M07-05889	B	DB	crop	butter lettuce	CMV	Negative
7/08/2007	M07-05889	B	DB	crop	butter lettuce	TSWV	Negative
7/08/2007	M07-05889	B	DB	crop	butter lettuce	LBV (EM)	Positive
7/08/2007	M07-05886		MA	crop	Cos lettuce (saxon)	TSWV	Negative
7/08/2007	M07-05886		MA	crop	Cos lettuce (saxon)	CMV	Positive
7/08/2007	M07-05887		MA	crop	Cos lettuce (saxon)	CMV	Negative
7/08/2007	M07-05887		MA	crop	Cos lettuce (saxon)	TSWV	Negative
7/08/2007	M07-05887		MA	crop	Cos lettuce (saxon)	LBV (EM)	Positive
8/08/2007	M07-05840		PTD	crop	Lettuce	LBV	Positive
7/08/2007	M07-05888		PG	crop	Lettuce patagonia	CMV (EM)	Positive
7/08/2007	M07-05890		PG	weed	sowthistle	TSWV	Negative
7/08/2007	M07-05890		PG	weed	sowthistle	Virus (EM)	Negative
7/08/2007	M07-05884	1	DB	weed	Bittercress	TSWV	Negative
7/08/2007	M07-05884	1	DB	weed	Bittercress	Virus (EM)	Negative
7/08/2007	M07-05884	2	DB	weed	Deadly Nightshade	TSWV	Negative
7/08/2007	M07-05884	2	DB	weed	Deadly Nightshade	Virus (EM)	Negative
7/08/2007	M07-05884	3	DB	weed	Mallow	TSWV	Negative
7/08/2007	M07-05884	3	DB	weed	Mallow	Virus (EM)	Negative
7/08/2007	M07-05884	4	DB	weed	sowthistle	TSWV	Negative
7/08/2007	M07-05884	4	DB	weed	sowthistle	Virus (EM)	Negative
7/08/2007	M07-05884	5	DB	weed	Chenopodium	TSWV	Negative
7/08/2007	M07-05884	5	DB	weed	Chenopodium	Virus (EM)	Negative
9/08/2007	M07-05883		MA	weed	slender celery	TSWV	Negative
9/08/2007	M07-05883		MA	weed	slender celery	Virus (EM)	Negative
9/08/2007	M07-05885		MA	weed	chickweed	TSWV	Negative
9/08/2007	M07-05885		MA	weed	chickweed	Virus (EM)	Negative
14/08/2007	M07-06109		CV	weed	Mallow	Potyvirus (EM)	positive

15/08/2007	M07-06108		VM	crop	Cos Lettuce	Virus (EM)	Negative
16/08/2007	M07-06112		CH	crop	**cucumber**	**Potyvirus (EM)**	**Positive**
16/08/2007	M07-06107		CH	weed	Mallow	CMV	Negative
16/08/2007	M07-06107		CH	weed	Mallow	TSWV	Negative
16/08/2007	M07-06106		CH	weed	**sowthistle**	**Potyvirus (EM)**	**Positive**
16/08/2007	M07-06104		DCH	crop	**cucumber**	**Potyvirus (EM)**	**Positive**
16/08/2007	M07-06152		GX	crop	**cabbage**	**Potyvirus (EM)**	**Positive**
21/08/2007	M07-06631		JD	weed	sowthistle	Virus (EM)	Negative
22/08/2007	M07-06714		RM	weed	**Mallow**	**Potyvirus (EM)**	**Positive**
22/08/2007	M07-06714		RM	weed	**Mallow**	**Caulimovirus (EM)**	**Positive**
24/08/2007	M07-06326		DCH	crop	Tomato	TYLCV	Negative
22/08/2007	M07-06717	#1	RM	crop	Lettuce	Virus (EM)	Negative
22/08/2007	M07-06717	#2	RM	crop	Lettuce	Virus (EM)	Negative
22/08/2007	M07-06717	#3	RM	crop	**Lettuce**	**LBV (EM)**	**Positive**
3/09/2007	M07-07205		GX	weed	Dock	CMV	Negative
3/09/2007	M07-07205		GX	weed	Dock	TSWV	Negative
3/09/2007	M07-07205		GX	weed	Dock	Virus (EM)	Negative
3/09/2007	M07-07205		GX	weed	sow thistle	Cmv	Negative
3/09/2007	M07-07205		GX	weed	sow thistle	TSWV	Negative
3/09/2007	M07-07205		GX	weed	sow thistle	Virus (EM)	Negative
11/09/2007	M07-07765		JV	weed	Cudweed	CMV	Negative
11/09/2007	M07-07765		JV	weed	Cudweed	TSWV	Negative
4/10/2007	M07-09545		P	crop	**Lettuce**	**LBV**	**Positive**
4/10/2007	M07-10052		GX	crop	Broad Bean	TSWV	Negative
10/10/2007	M07-10379		GX	crop	Zucchini (Tennyson)	Virus (EM)	Negative
9/10/2007	M07-10401		MC	crop	Tatsoi- chinese flat cabbage	Virus (EM)	Negative
17/10/2007	M07-11212		JB	crop	cucumber	Virus (EM)	Negative
17/10/2007	M07-11248		JB	crop	bean	Virus (EM)	Negative
17/10/2007	M07-11213		JB	weed	**wild radish**	**Potyvirus (EM)**	**Positive**
17/10/2007	M07-11213		JB	weed	**wild radish**	**TMV (PCR)**	**Positive**
17/10/2007	M07-11215		RH	crop	Tomato	Virus (EM)	Negative
17/10/2007	M07-11217		RH	crop	cucumber	Virus (EM)	Negative
17/10/2007	M07-11223		RH	crop	**cucumber**	**Potyvirus (EM)**	**Positive**
26/10/2007	M07-12529v1		PG	weed	sowthistle	Virus (EM)	Negative
26/10/2007	M07-12529v2		PG	weed	**sowthistle**	**AMV (EM)**	**Positive**
1/11/2007	M07-13295		JV	crop	**Tomato**	**Clavibacter (AT)**	**Positive**
7/12/2007	M07-19756	1	RH	crop	Tomato (leaves)	TSWV	Negative
7/12/2007	M07-19756	2	RH	crop	**Tomato (leaves/fruit)**	**TSWV**	**Positive**
7/12/2007	M07-19759		GX (T)	crop	Tomato	TSWV	Negative
7/12/2007	M07-19759		GX (T)	crop	Tomato	TYLCV (LFT)	Negative
7/12/2007	M07-19760		GX (FR)	crop	**Sweet Corn**	**Potyvirus (EM)**	**Positive**
7/12/2007	M07-19761	11	GX (FR)	crop	Purple beans	TSWV	Negative
7/12/2007	M07-19761	12	GX (FR)	crop	Purple beans	TSWV	Negative
7/12/2007	M07-19761	13	GX (FR)	crop	Broad Bean	TSWV	Negative
7/12/2007	M07-19761	14	GX (FR)	crop	Potato	TSWV	Negative
7/12/2007	M07-19761	15	GX (FR)	crop	Potato	TSWV	Negative
7/12/2007	M07-19761	17	GX (T)	crop	Capsicum	TSWV	Negative
7/12/2007	M07-19761	"17"	GX (T)	crop	Capsicum	TSWV	Negative
7/12/2007	M07-19761	17	GX (T)	crop	**Capsicum**	**CMV**	**Positive**
12/12/2007	M07-20294		SH	crop	Cherry Tomato	Virus (EM)	Negative
12/12/2007	M07-20294		SH	crop	Cherry Tomato	CMV	Negative

Date	Sample #	Sample No.	Site	Host	Sample	Virus	Outcome
18/01/2008	M08-02150		WAA	crop	Capsicum	TSWV	Negative
18/01/2008	M08-02150		WAA	crop	Capsicum	CMV	Negative
18/01/2008	M08-02150		WAA	crop	**Capsicum**	**Tobamovirus (EM)**	**Positive**
25/01/2008	M08-03914		GX (FR)	crop	**Long Capsicum**	**TSWV**	**Positive**
25/01/2008	M08-03914		GX (FR)	crop	Long Capsicum	CMV	Negative
29/01/2008	M08-04726		GX (FR)	crop	**Capsicum**	**TSWV**	**Positive**
29/01/2008	M08-04726		GX (FR)	crop	Capsicum	CMV	Negative
29/01/2008	M08-04746		MV	crop	Capsicum	**Potyvirus (EM)**	**Positive**
29/01/2008	M08-04746		MV	crop	Capsicum	CMV	Negative
29/01/2008	M08-04746		MV	crop	Capsicum	TSWV	Negative
18/04/2008	M08-12527		PG	crop	**Lettuce Patagonia**	**Potyvirus (EM)**	**Positive**
2/09/2008	MO8-16403	1	JD	crop	**Lettuce green salanova**	**Ophiovirus (EM)**	**Positive**
2/09/2008	MO8-16403	2	JD	crop	**Lettuce green salanova**	**Ophiovirus (EM)**	**Positive**
2/09/2008	MO8-16403	3	JD	crop	**Lettuce green oak**	**Ophiovirus (EM)**	**Positive**
2/09/2008	MO8-16403	4	JD	crop	**Lettuce red salanova**	**Ophiovirus (EM)**	**Positive**
2/09/2008	MO8-16458	1	TA	crop	**Cucumber**	**Potyvirus (EM)**	**Positive**
2/09/2008	MO8-16458	2	TA	crop	Cucumber	(EM)	Negative
2/09/2008	MO8-16458	1	TA	crop	Cucumber	CMV	Negative
2/09/2008	MO8-16458	2	TA	crop	Cucumber	CMV	Negative
10/09/2008	MO8-16642		JB	weed	Sowthistle	(EM)	Negative
10/09/2008	MO8-16642		JB	weed	Sowthistle	TSWV	Negative
10/09/2008	MO8-16645		EG	crop	**Broadbean**	**Potyvirus (EM)**	**Positive**
10/09/2008	MO8-16645		EG	crop	Broadbean	TSWV	Negative
11/09/2008	MO8-16692	2a	SC	crop	Zucchini	(EM)	Negative
11/09/2008	MO8-16692	2b	SC	crop	Zucchini	(EM)	Negative
11/09/2008	MO8-16692	2c	SC	crop	**Zucchini**	**Potyvirus (EM)**	**Positive**
11/09/2008	MO8-16696		SC	crop	Tomato	(EM)	Negative
11/09/2008	MO8-16696		SC	crop	Tomato	TYLCV	Negative
11/09/2008	MO8-16691		EA	crop	**Cucumber**	**Potyvirus (EM)**	**Positive**
11/09/2008	MO8-16699		TD	crop	Tomato	TSWV	Negative
11/09/2008	MO8-16699		TD	crop	Tomato	(EM)	Negative
15/10/2008	MO8-17718		GX (FR)	crop	Zucchini,Broadbean,Weed	CMV	Negative
15/10/2008	MO8-17718		GX (FR)	crop	Broadbean	CMV	Negative
15/10/2008	MO8-17718		GX (FR)	weed	weed	CMV	Negative
15/10/2008	MO8-17718		GX (FR)	crop	Zucchini	TSWV	Negative
15/10/2008	MO8-17718		GX (FR)	crop	Broadbean	TSWV	Negative
15/10/2008	MO8-17718		GX (FR)	weed	weed	TSWV	Negative
21/10/2008	MO8-17817		GX (FR)	crop	Rhubarb	CMV	Negative
21/10/2008	MO8-17817		GX (FR)	crop	**Rhubarb**	**TSWV**	**Positive**
21/10/2008	MO8-17853	Shed 1	P	crop	Basil	CMV	Negative
21/10/2008	MO8-17853	Shed 1	P	crop	Basil	TSWV	Negative
21/10/2008	MO8-17855	Shed 2	P	crop	Basil	CMV	Negative
21/10/2008	MO8-17855	shed 2	P	crop	Basil	TSWV	Negative
28/10/2008	MO8-18035		JF	crop	Cucumber	(EM)	Negative
28/10/2008	MO8-18035		JF	crop	Cucumber	TSWV	Negative
10/11/2008	MO8-18380		WA	crop	**Capsicum**	**TSWV**	**Positive**

Date	Sample #	Site	Host	Sample	Virus	Outcome
11/11/2009	M09-11288	RZ	Crop	Tomato	CMV	Negative
11/11/2009	M09-11288	RZ	Crop	Tomato	TSWV	Negative
11/11/2009	M09-11288	RZ	Crop	Tomato	(EM)	Negative
5/01/2010	M10-00076	CZ	Crop	**Iceberg Lettuce**	**TSWV**	**Positive**
5/01/2010	M10-00076	CZ	Crop	**Cos Lettuce**	**TSWV**	**Positive**

Appendix 3 - WFT resistance monitoring

Results table for WFT resistance monitoring (Mr D'Anastasi, Glenorie Hydroponics) RF = resistance factor; CI = confidence interval; % Mort = percentage mortality at the discriminating dose or percent susceptible.

Active constituent		Lettuce G NSW
abamectin	RF	
	CI	
	% Mort	
acephate	RF	
	CI	
	% Mort	
dichlorvos	RF	•
	CI	•
	% Mort	84
dimethoate	RF	
	CI	
	% Mort	
fipronil	RF	1.79
	CI	0.518-6.21
	% Mort	98.9
malathion	RF	•
	CI	•
	% Mort	96
methamidophos	RF	
	CI	
	% Mort	
methidathion	RF	
	CI	
	% Mort	
methomyl	RF	•
	CI	•
	% Mort	93
pyrazophos	RF	
	CI	
	% Mort	

Active constituent		Lettuce G NSW
spinosad	RF	39.7
	CI	18.64-85
	% Mort	24

- Discriminating Dose (DD) test only, other data not available.

Appendix 4 - Statistical analyses

February-March 2006 Trials

Score measurement recorded on 14/03/06 of the variety trial were actually binary data and most scores recorded on 21/03/06 were alternately zeros between scores 0 and 1, and hence, can be pooled to form binary data.

Score data for the product trial were binary for the 14/3/06 observation and multinomial for the 21/03/06 observation. Data of 21/03/06 were reclassified to form binary data by merging scores 0 and 1 for one analysis as well merging scores 1 and 2 for another analysis.

The binary data were fitted with a generalized linear mixed model where the experimental structure such as blocks and rows were assumed random and the treatment assumed fixed. Logit function was used to link the data to the model parameters. Least significant difference (LSD) test was used to compare the treatment effects. The analysis was conducted using the statistical software package ASReml (Gilmour et. al. 2005).

Results

There were significant varietal effects on the presence of mild symptom recorded on 14/03/06 and strong symptom recorded 0n 21/03/06 (Table 1).

Among the lowest infected plants observed on 14/03/06 were HZU4, ZU384, Jaguar, Midnight, Z52 top gun and Houdini.

Mid range to high infection were 8642 Hummer, 8572 Stinger, Shimmer, 3463 and 3465.

Congo standard had the higher rate of plant with symptom.

Observed on 21/03/06 HZU 4 remained the lowest on the infection rate, followed by Z52topgun, Houdini, ZU384, Midnight, Jaguar and 3463. Shimmer, Hummer and Stinger were among the higher range and Congo standard was the highest infection rate.

The product effects were all not significant at both observation times (Table 3). The symptom rates are presented in Table 4.

References

Gilmour, A.R., Cullis, B.R., Harding, S.A. and Thompson, R. (2005). ASReml Update: What's new in Release 2. VSN International Ltd, Hemel Hempstead HP1 1ES, UK.

Table 1. Analysis of Variance – Plant disease: Leaf symptoms

	14.03.06		21.03.06	
Linear Mixed Model Term	**F-statistic Mild symptom**	**Variance component**	**F-statistic Strong symptom**	**Variance component**
Block		0.186		0
Rows		0.154		0.027
Block.Row.*units*				
Variety	9.37***		4.61***	
residual		0.260		0.311

Note: *** denotes significant at P<0.001

Table 2. Predicted Means for Varieties – Plant disease

	Mild symptom 14.03.06		Strong symptom 21.03.06	
Varieties	Logit value	Prop (Mild symptom)	Logit value	Prop (Strong symptom)
Congo Standard	3.0443d †	0.9545	10.9883f †	1
Z52 Top Gun	-1.4097ab	0.1963	-0.4172b	0.3972
HZU 4	-2.3289a	0.0888	-2.9410a	0.0502
3463	0.9984c	0.7307	0.7398bcd	0.677
3465	1.1734c	0.7638	2.3136e	0.91
Jaguar	-1.6086a	0.1668	0.3536bcd	0.5875
8572 Stinger	0.4879c	0.6196	1.8620de	0.8655
8642 Hummer	-0.0536bc	0.4866	1.7053de	0.8462
Houdini	-1.2912ab	0.2156	-0.3232b	0.4199
Shimmer	0.5282c	0.6291	1.5361cde	0.8229
Midnight	-1.5792a	0.1709	0.3482bcd	0.5862
ZU384	-2.0033a	0.1189	0.0610bc	0.5152
Average SED	0.719		0.757	
Average LSD 5%	1.460		1.537	

† different letters indicate significant at 5% level; prop = proportion

Table 3. Analysis of Variance – Plant disease: Leaf symptoms

	14.03.06		21.03.06			
Linear Mixed Model Term	**F-statistic Mild symptom**	**Variance component**	**F-statistic (Strong symptom)**	**Variance component**	**F-statistic (Mild+Strong symptom)**	**Variance component**
Block		0		0.142		0
Block.*units*						
Product	1.38 NS		0.69 NS		0.06 NS	
residual		1.00		0.560		1.073

Note: NS denotes not significant at P=0.05

Table 4. Predicted Means for Products – Plant disease

	Mild symptom 14.03.06		Strong symptom 21.03.06		Mild + Strong symptom 21.03.06	
Products	Logit value	Prop (symptom)*	Logit value	Prop (symptom)*	Logit value	Prop (symptom)*
1	-1.3863a †	0.2	0.3196a†	0.5792	1.5779a †	0.8289
2	-2.1972a	0.1	-0.0341a	0.4915	1.1762a	0.7643
3	-2.3273a	0.0889	-0.1156a	0.4711	1.4418a	0.8087
4	-2.1001a	0.1091	-0.4758a	0.3833	1.5144a	0.8197
5	-2.3979a	0.0833	-0.1346a	0.4664	1.4a	0.8022
6	-1.9253a	0.1273	0.5633a	0.6372	1.3596a	0.7957
7	-3.3673a	0.0333	-0.5102a	0.3752	1.1773a	0.7645
Average SED	0.6876		0.6734		0.8962	
Average LSD 5%	1.3477		1.4209		1.8910	

† different letters indicate significant at 5% level

Summer 2006-07

Generalised linear mixed model was fitted to insect counts for the weeks with insects present on the following model:

Count = fixed (Treatment + Week + Interaction) + Random (Block + Plot + Block*Week + error)

The errors were assumed to follow a super-Poisson and logarithmic function was used to link the observed values and the parameters to be estimated. A residual maximum likelihood (REML) technique was used to estimate al the parameters. Least significant difference at 5% level was calculated on the transformed estimates of parameters.

Because visual virus infection was not present in all trials except in Site A product trial at week 8. Therefore, only week 8 viral infection data were analysed. Virus infected plant proportion was analysed using a similar analysis as above except that data were assumed to follow a binomial distribution. Logit link function was used in parameter estimation.

Table 5. Treatment effects on aphid counts from Site B product trial, standard error of difference and least significant difference value at 5% level

	Week 5		Week 6		Week 7		Week 8		Week 5-8	
Treatment	Logmean	Mean	Logmean	Mean	Logmean	Mean	Logmean	Mean	Logmean	Mean
Control	1.182	3.26	2.784	16.18	3.894	49.09	3.455	31.66	2.829	16.92
1.00%	1.233	3.43	3.14	23.1	3.345	28.35	3.549	34.78	2.817	16.72
1.50%	2.638	13.98	3.485	32.61	3.246	25.68	3.58	35.85	3.237	25.45
sed	0.542		0.542		0.542		0.542		0.36	
lsd5%	1.084		1.084		1.084		1.084		0.72	

Table 6. Varietal effects on aphid counts from Site B variety trial, standard error of difference and least significant difference value at 5% level

	Week 4		Week 5		Week 6	
Varieties	Logmean	Mean	Logmean	Mean	Logmean	Mean
Congo	1.975	7.2	3.474	32.26	3.679	39.59
Top Gun	1.567	4.79	2.84	17.11	4.125	61.84
Hummer	2.439	11.46	2.47	11.82	2.913	18.41
Houdini	2.511	12.31	3.071	21.57	3.686	39.89
Midnight	2.173	8.78	3.06	21.33	3.6	36.58
sed	0.545		0.545		0.545	
lsd5%	1.09		1.09		1.09	

	Week 7		Week 8		Week 4-8	
Varieties	Logmean	Mean	Logmean	Mean	Logmean	Mean
Congo	4.541	93.78	4.169	64.68	3.568	35.43
Top Gun	4.093	59.94	4.537	93.45	3.432	30.95
Hummer	4.214	67.64	4.025	55.96	3.212	24.83
Houdini	3.949	51.88	3.869	47.9	3.417	30.48
Midnight	4.293	73.15	4.286	72.68	3.482	32.53
sed	0.545		0.545		0.294	
lsd5%	1.09		1.09		0.588	

Table 7. Treatment effects on visually infected plants from Site A product trial, standard error of difference and least significant difference value at 5% level for Week 8 only

Treatment	**logit(p)**	**%infected**
Control	-0.4226	39.59
1.00%	0.0016	50.04
1.50%	0.2114	55.27
sed	0.653	
lsd5%	1.28	

Summer 2008-09 Mosaic virus transmission and over-wintering in zucchini in the Sydney Region - Survey for viruses and vectors on 7 farms

Table 8

Farm 1 Horsley Park			
ELISA #	09/100	09/138	09/214-219
Date	Feb-09	Mar-09	May-09
Total estimate % of population infected	**2.836**	**12.945**	**100**
Lower %	0.904	6.86	19.4
Upper %	6.536	21.684	100
ZYMV estimate % of population infected	**1.612**	**1.048**	**0**
Lower %	0.326	0.125	0
Upper %	4.657	3.741	0
WMV2 estimate % of population infected	**2.836**	**5.803**	**2.622**
Lower %	0.904	2.586	1.039
Upper %	6.536	10.904	5.349
PRSV estimate % of population infected	**1.612**	**8.756**	**100**
Lower %	0.326	4.372	19.4
Upper %	4.657	15.257	100

Table 9

Farm 2 Orchard Hills		
ELISA #	09/100	09-138
Date	Feb-09	Mar-09
Total estimate % of population infected	**100**	**20.567**
Lower %	N/A	10.853
Upper %	N/A	35.532
ZYMV estimate % of population infected	**100**	**0**
Lower %	N/A	0
Upper %	N/A	0
WMV2 estimate % of population infected	**100**	**0.512**
Lower %	N/A	0.013
Upper %	N/A	2.816
PRSV estimate % of population infected	**0**	**17.28**
Lower %	0	9.239
Upper %	0	29.099

Table 10

Farm 4 Freemans Reach		
ELISA #	09/106	09/214-219
Date	Feb-Mar 09	May-09
Total estimate % of population infected	**11.343**	**6.093**
Lower %	5.942	3.279
Upper %	19.173	10.137
ZYMV estimate % of population infected	**7.675**	**0**
Lower %	3.716	0
Upper %	13.649	0
WMV2 estimate % of population infected	**8.756**	**3.504**
Lower %	4.372	1.581
Upper %	15.257	6.585
PRSV estimate % of population infected	**0.512**	**5.522**
Lower %	0.013	2.896
Upper %	2.816	9.357

Table 11

Farm 5 Tennyson		
ELISA #	09/106	09/214-219
Date	Feb-Mar 09	May-09
Total estimate % of population infected	**25.887**	**6.093**
Lower %	12.997	3.279
Upper %	48.549	10.137
ZYMV estimate % of population infected	**17.28**	**1.421**
Lower %	9.239	0.384
Upper %	29.099	3.606
WMV2 estimate % of population infected	**25.887**	**3.504**
Lower %	12.997	1.581
Upper %	48.549	6.585
PRSV estimate % of population infected	**0**	**0.688**
Lower %	0	0.082
Upper %	0	2.465

Field Lettuce

Efficacy of Silwet L-77 for thrips management in field lettuce

Table 12: Treatment means of thrips counts per plant at Week 3, nymphs, WFT, OT and TT per plant at week 8, standard error of difference (sed), least significant difference (lsd) critical value at 5% level and F-probabilities (fprob)

	Week 3 in-situ		Week 8 wash counts		
Treatment	Thrips counts	Nymphs	WFT	OT	TT
1	0.1102	30.07	0.0344	1.3626	0.5564
2	0.5020	45.83	0.3552	1.4234	0.5172
3	0.4992	47.40	0.3770	1.0481	0.7930
sed	0.1929	7.927	0.2338	0.3813	0.2169
lsd5%	0.3858	15.854	0.4676	0.7626	0.4338
Fprob	0.136	0.091	0.205	0.623	0.464

Hydroponic Lettuce

Evaluation of foliar treatments against WFT in hydroponics lettuce

Table 13. Weight of hydroponic lettuce heads and WFT populations after treatment with Silwet, Eco-Oil or DPI 9. (n = 32). Means followed by the same letter are not significantly different (P = 0.05)

	Head weight (g)	Adult thrips/head	Immature thrips/head
T1 (Control)	130.38b	10.03 b	20.97 c
T2 (water + 0.1% Silwet)	98.27 a	0.28 a	1.00 a
T3 (0.5% Eco Oil®)	124.58 b	7.65 b	13.87 bc
T4 (0.022% DPI 9)	132.52 b	4.58 b	8.58 b

Table14. Percentage of total WFT population in various growth stages in four treatments, Trial 1

	Adult female	Adult male	Larva	Pre pupa	Pupa
T1 (Control)	7.32 ± 1.15 c	9.43 ± 1.55 c	43.42 ± 5.64 a	5.09 ± 1.19 a	34.74 ± 6.79 a
T2 (0.1% Silwet)	35.82 ± 7.64a	16.42 ± 4.78 ab	34.33 ± 11.46 a	0.00 b	13.43 ± 5.25 b
T3 (0.5% Eco Oil®)	10.24 ± 1.47 b	11.15 ± 1.90 bc	35.28 ± 5.44 a	6.95 ± 1.76 a	36.38 ± 5.10 a
T4 (0.022% DPI 9)	9.02 ± 1.52 bc	18.31± 3.22 a	34.15 ± 5.17 a	7.38 ± 2.20 a	31.15 ± 6.95 a

Table15. Temperature and relative humidity means and ranges during trials evaluating reduced risk pesticides on thrips in hydroponic lettuce

Period	Temperature °C				Relative humidity %			
(2006)	Mean		Range		Mean		Range	
	Bay 1	Bay 2	Bay 1	Bay 2	Bay 1	Bay 2	Bay 1	Bay 2
29/6-1/8 (Trial 1)	18.9	18.1	12.8-23.7	8.0-23.7	67.0	64.8	26.9-100	23.1-98.8
28/9-19/10 (Trial 2)	21.0	20.6	15.4-29.4	12.0-28.3	79.8	84.9	36.4-100	35.4-100
19/10-27/10 (Trial 2)	21.0	21.0	15.4-27.6	15.4-27.2	90.6	92.1	55.0-100	54.31-100

*Table 16. Thrips populations on lettuce after treatment with Silwet, Agral and DPI 9 (*Beauveria bassiana*). (n = 32) and head weight. Means followed by the same letter are not significantly different (P = 0.05)*

Treatment	Head weight (g)	Adult WFT/ head	Adult *T. tabaci*/ head	Adult *F. schultzei*/ head	Immature thrips/ head
Control	109.7 a	11.25a	11.15a	1.1a	18.15cd
Water 2x weekly	109.66 a	14.2a	10.9a	1.6a	33.05d
0.1% Silwet 2x weekly	104.33a	13.3a	5.8a	1.15a	6.35a
0.05% Silwet 2x weekly	113.82 a	7.6a	9.65a	1.2a	6.95ab
0.02% Silwet 2x weekly	112.65a	4.25a	8.85a	1.35a	7.35abc
0.1%Agral 2x weekly	111.33a	9.8a	13.65a	1.05a	12.5abc
0.022% DPI-9 weekly	110.04a	8.4a	8.3a	0.7a	10.5abc
0.022% DPI-9 2x weekly	113.6a	14.4a	12.3a	1.75a	14.8bcd

Table 17. Percentage of total WFT population in various growth stages in four treatments, Trial 2

	Adult female	Adult male	Larva	Pre pupa	Pupa
T1 (Control)	22.5	11.03	52.31	1.79	12.37
T2 (water)	20.47	8.6	64.89	2.76	3.28
T3 (0.1% Silwet)	42.33	18.54	24.49	4.58	10.07
T4 (0.05% Silwet)	29.15	18.5	36.36	7.21	8.78
T5 (0.02% Silwet)	20.89	8.22	45.21	5.14	20.55
T6 (0.1% Agral)	25.96	15.74	49.57	3.62	5.11
T7 (0.022% DPI 9) weekly	25.06	12.2	45.23	1.33	16.19
T8 (0.022% DPI-9) 2x weekly	28.46	14.91	39.61	4.97	12.05

Appendix 5 - Survey questionnaire and scores

Total Score %	**100**
1. Crop Management	**6**
a) What crop management strategy do you use for diseases?	3
b) What crop management strategy do you use for pests?	3
For chemical strategies, do you use targeted spraying and if yes, how do you target? For biological strategies, do you use bio-rational chemicals and release beneficials?	
2. Crop Monitoring	**38**
a) Do you monitor your crops for pests?	3
If yes do you monitor:	3
Use a routine protocol?	1
Keep monitoring records?	1
Use Sticky Traps?	1
b) Do you monitor for beneficial insects	3
c) Do you monitor for diseases	3
If yes do you monitor:	3
Use a routine protocol?	1
Keep monitoring records?	1
Do you use a diagnostic service?	2
d) Do you monitor for weeds that are known to host viruses and their insect vectors?	3
If yes do you monitor:	3
Keep monitoring records?	1
e) Do you monitor nutrient levels?	3
If yes do you monitor:	3
Use a routine protocol?	1
Keep monitoring records?	1
Use a field identification guide?	1
3. Chemical Use	**30**
a) What factors are important for your choice of pesticide?	2
What best describes your spray rig?	
b) Do you calibrate your sprayer or change nozzles?	3
c) Do you use spray cards?	1
d) What time of day do you spray?	1
e) How often do you spray?	2
f) Do you read the label?	1
g) Do you use any off-label chemicals?	1
h) Do you keep chemical records/spray diaries?	1

i) Do you follow label instructions for with-holding periods?	1
j) Do you follow label instructions for re-entry periods?	1
k) Do you use chemicals from the Synthetic Pyrethroids group?	1
l) Do use Schedule 7 chemicals, labelled 'Dangerous Poison'?	1
m) What level of PPE do you use while using chemicals?	2
n) Have you got a certificate for chemical handling and usage (eg. SMARTrain, ChemCert courses)	3
o) Do you use biopesticides such as Bt (e.g. Dipel®, Vectobac®, Xentari®) or NPVs (e.g. Gemstar® or Vivus®)?	3
p) Do you use soft pesticides in your chemical rotation, e.g. Success®, Avatar®, Prodigy® or Proclaim®?	3
q) Where do you get your chemical advice and recommendations from?	3
4. Variety selection	**2**
a) Is insect resistance a key factor in choosing the vegetable variety to be planted?	1
b) Is disease resistance a key factor in choosing the vegetable variety to be planted?	1
5. Farm Hygiene	**11**
a) Do you chip out virus infected plants?	3
If yes what do you do with the affected plants?	
b) Do you control weeds around your field/shed?	3
What are the key reasons why you control weeds?	
c) What is the nearest pest/disease contamination source? Crop waste?	2
d) If greenhouse grown, are the houses screened?	3
6. Crop Rotations	**1**
a) Do you rotate your crops?	1
If yes, is this for:	
7. Biological Control	**12**
a) Do you release beneficial insects?	3
b) Do you plant crops to attract beneficial insects?	3
c) Do you modify your spray practices because of beneficial insects?	3
d) Do you modify your planting/harvesting or management of your crop because of beneficial insects?	3

Survey results for August 2008, listed as means by crop, region, consultant and IPM strategies.

Crop	Region	Consultant	Strategy						
			Crop Mgmt	Crop Monitor-ing	Chemi-cal Use	Variety Select-ion	Farm Hygiene	Crop Rotat-ions	Bio Control
Field	Camden	No	17%	14%	65%	25%	23%	0%	0%
Field	Camden	Yes	78%	89%	93%	83%	45%	33%	33%
Field	Hawkesbury	No	36%	37%	60%	78%	43%	100%	31%
Field	Hawkesbury	Yes	67%	58%	77%	100%	36%	100%	75%
Field	Hills	No							
Field	Hills	Yes							
Field	Liverpool	No	22%	38%	53%	83%	38%	100%	0%
Field	Liverpool	Yes							
Field Asian	Camden	No							
Field Asian	Camden	Yes							
Field Asian	Hawkesbury	No	17%	3%	50%	0%	9%	100%	0%
Field Asian	Hawkesbury	Yes							
Field Asian	Hills	No							
Field Asian	Hills	Yes							
Field Asian	Liverpool	No	22%	5%	52%	0%	12%	67%	0%
Field Asian	Liverpool	Yes							
Greenhouse	Camden	No	33%	53%	83%	50%	82%	0%	0%
Greenhouse	Camden	Yes							
Greenhouse	Hawkesbury	No	33%	51%	72%	50%	41%	50%	25%
Greenhouse	Hawkesbury	Yes							
Greenhouse	Hills	No	75%	44%	68%	75%	68%	50%	50%
Greenhouse	Hills	Yes							
Greenhouse	Liverpool	No	27%	43%	61%	72%	55%	100%	11%
Greenhouse	Liverpool	Yes	39%	63%	68%	67%	59%	67%	42%
Hydro Asian	Camden	No	33%	32%	60%	0%	45%		0%
Hydro Asian	Camden	Yes							
Hydro Asian	Hawkesbury	No							
Hydro Asian	Hawkesbury	Yes							
Hydro Asian	Hills	No							
Hydro Asian	Hills	Yes							
Hydro Asian	Liverpool	No	33%	18%	60%	0%	45%		0%
Hydro Asian	Liverpool	Yes							
Hydro lettuce	Camden	No							
Hydro lettuce	Camden	Yes							
Hydro lettuce	Hawkesbury	No	26%	34%	58%	100%	50%		0%

Hydro lettuce	Hawkesbury	Yes	33%	66%	48%	100%	64%		0%
Hydro lettuce	Hills	No	33%	26%	60%	100%	58%		0%
Hydro lettuce	Hills	Yes	28%	83%	75%	100%	67%		8%
Hydro lettuce	Liverpool	No	33%	37%	65%	100%	45%		0%
Hydro lettuce	Liverpool	Yes	33%	92%	80%	100%	55%		25%
Seedling	Camden	No							
Seedling	Camden	Yes	17%	75%	73%	100%	36%	0%	25%
Seedling	Hawkesbury	No							
Seedling	Hawkesbury	Yes							
Seedling	Hills	No							
Seedling	Hills	Yes							
Seedling	Liverpool	No							
Seedling	Liverpool	Yes							

Appendix 6 - Crop Monitoring Protocol

Crop Monitoring and/or scouting are an essential process to ensure pest activity and plant disease onset is observed early enough to make pest management decisions that reduce economic crop losses. This can be achieved by knowing the key insect pests and diseases associated with the crop, nutritional disorders and learning monitoring and recording techniques and how to interpret the results.

Knowledge ➔ Monitor ➔ Action

Knowledge

Growers, farm managers or horticultural consultants should collate as much information about the crop as possible, before monitoring. Important information includes:

- optimal growing conditions
- nutritional disorders the species suffers from
- seasonal insect pests and plant diseases
- best farming practices guides

Useful tools in this process include field identification guides and growing manuals.

Monitor

Monitoring a crop is a physical observation and indicates what is happening within the crop and what pests and diseases are present or absent. It is advised to monitor the crop weekly as well as recording the observations. This will assist in seeing patterns, whether it is seasonal or cultural. Records can also be a good reference point in looking back into previous crops, seasons and crop stages to foresee potential problems in preparedness for the pending crop. It is also a good indicator in assessing the controls prescribed, this can draw attention to potential pesticide resistance, correct spray application techniques, accurate biological control application rates and also an occasion that can be used to detect any other general maintenance issues that come to light.

Monitoring techniques include walking through the crop surveying plants for signs of pest, pest damage, nutritional disorders and apparent plant diseases. It is impossible to check every plant, so the best method is to choose a few plants in each row, or if is a large farm, every few rows. Then check the chosen plants thoroughly, from the shoot tips to the roots, turning leaves over looking for insect nymphs, adults, eggs, and fungal/viral/bacterial symptoms. This can be done using a 10x magnified hand lens or headband. It may not give you an accurate scope for species identification in thrips for instance but it can give you a close enough view to identify thrips and their larvae.

For further accurate identification simply collect some live insects in a vial and dispatch for identification or, if it is a suspected disease, pick leaves or remove entire plants and package for dispatch to a diagnostic laboratory. If you are aware of an area on the farm or greenhouse that is a problem area or hot spot, it is best to always inspect that area weekly as it is already a known problem area and can provide critical information in reducing spread through out the crop via early intervention. See Appendix 1 for examples of useful monitoring sheets.

Another important monitoring tool is the use of sticky traps. These can be place outside of greenhouses to see what insect movement is occurring, inside entry points of greenhouses to see what insects have entered, hot spots within greenhouses that are known flare up sites and several random locations within the crop (always note where you have placed them, as once the crop grows it becomes harder to find the traps amongst the crop). Do not place too many out as this may deter you from changing them or inspecting them fully as it becomes a time consuming task. Traps should be changed weekly in peak pest pressure and in the cooler months can be dropped back to fortnightly inspections. Sticky traps can also be used outdoors, but can easily be covered in dust and weather much quicker. Sticky traps aren't used as a form of pest control only as an indicator of insect activity. Appendix 1 has an example of sticky trap counting forms that can be useful in data collecting and recording.

Sticky Trap Assessments

Sticky traps are generally assessed from top left to bottom right, both sides being counted. Traps are generally placed in the same location each week. Where there is a week that has been missed, the counts are averaged in Excel over the fortnight to give the 7-day counts.

Record numbers for each of the following insects per trap, record on spreadsheet for each farm:

WFT	Western flower thrips *Frankliniella occidentalis*
OT	Onion thrips *Thrips tabaci*
TT	Tomato thrips *Frankliniella shultzei*
PT	Plague thrips *Thrips imaginis*
Whitefly	Assumed to be greenhouse whitefly *Trialeurodes vaporariorum*
Aphid	
Fungus gnat	
Shore fly	
(Moth Fly)	
Beneficials	e.g. Microwasps (W), Hippodamia lady beetles (HLB), transverse lady beetles (TLB)
Comments	e.g. Other pests present e.g. moth flies (MF), leaf hoppers / jassids (LH), general notes from traps.

Trap Labels

Each trap location has a different notation. The date written on each trap is the placement date, where the date written on the spreadsheet or notebook is the collection date. The number of days placed is recorded.

e.g.

JBH1R1 28/6/05 Joe Blogs: House 1, Row 1 → This trap was placed 28/6/05

CS H1B5R1 Citizen Smith: House/tunnel 1, Bar 5, Row 1

MainSt R10N-15 Bob Jones, 1 Main Street: Row 10, North side, bracket #15

Where insects are observed and identification to the required level is not confident, traps should be plastic wrapped with lunch cling film with the target marked for a second opinion.

Action

Action thresholds differ from farm to farm. Some farms can have a low-grade resident population of a particular pest that may not pose a threat. If insecticide resistance for a pest is known in an area, actioning a low-grade infestation would also be a futile task.

However, the same low-grade pest influx on another farm may be considered a direct threat and actionable immediately, either through a chemical spray application or biological control dispersal.

Site specific action thresholds should be determined by a trained IPM consultant or by a competent grower that is familiar with the property's microclimate and other contexts.

There are trained IPM consultants, horticultural consultants and agronomists that can conduct these tasks and prescribe recommendations in the form of clean up, chemical application or biological control dispersal.

Appendix 7 - IPM Newsletters