Horticulture Innovation Australia

# Final Report

## New in-field treatment solutions to control Fruit Fly (2)

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Vegetable (R&D Levy)

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VG13042

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# Summary

This project has focused on two previously untested methods for managing and monitoring fruit fly in vegetable crops; Netting and repellents, and attraction with UV light.

Floating row covers were both a visual and physical barrier. Netting that was draped over crops and secured with soil effectively excluded fruit flies from capsicum and chilli crops. Even though the large mesh size of Vent Net allowed flies to crawl through, this material still significantly reduced entry of flies into the crop, cutting fruit infestation by 98%. Aphid Net reduced infestation by 99% but other pests inside the crop increased. VegeNet proved both lightweight and effective at blocking flies. No infested fruit was found under this material while it remained intact and sealed to the ground.

Floating row covers improved yield and quality of capsicum fruit. Netting increased marketable yield by 10 to 80%, while the number of fruit scored as grade 1 increased by 24 to 55%. The biggest gains were observed for crop covered by 18gsm fleece, where the number of grade 1 fruit was more than doubled. Unfortunately this single-use material proved relatively fragile, so is unlikely to provide good protection from fruit flies.

These effects were not repeated with chillies. Yield and quality of chilli crops in Sydney and Bundaberg were unaffected by various netting materials, even though the plants were larger and appeared healthier.

Field trials also tested Surround® kaolin clay applied to chilli plants. Despite issues with application and permanence after rain, no infested fruit were found on Surround® treated plants. This promising result deserves further examination in a more commercial setting.

Laboratory and field cage trials examined the attractiveness of white, green and UV light. Green light was attractive during the day, while white light was repellent. UV light was most attractive at dusk, when flies are mating, and captured equal numbers of male and female flies in field cage tests. Trials in a large net house demonstrated that a UV light placed against a dark background was extremely attractive to flies. However, the same light in the open was not attractive, and even repellent. A small field trial was conducted using a prototype UV light trap. The number of flies captured on yellow sticky traps was doubled in the presence of the UV light, with more females captured than males.

A combination of UV light with another attractant, such as protein bait or odour lure, could provide better results than either method used alone. However, it will be important to clarify how to locate any such device for best effect.

Outputs from the project include a series of five x three minute videos for growers. These detail the fruit fly lifecycle, monitoring, protein baiting, use of MAT and female traps, and finally barriers and hygiene.

The video material is expanded in greater detail in an accompanying 32pp A4 booklet; "Fruit fly management for vegetable growers". This will be printed for distribution to growers at field days and conferences, such as Hort Connections 2017.

For the first time, this booklet brings existing information and knowledge about fruit flies into a single resource, and presents it in a form suitable for growers to use.

# Keywords

Fruit fly, Bactrocera, Barrier, Netting, Kaolin, Capsicum, Chilli, Light trap, UV

# Introduction

Fruit flies are recognised as one of the world's most serious pests for horticulture. They can breed rapidly, disperse widely and successfully infest most fruit and fruiting vegetables. The larvae not only destroy infested fruit, but are a major quarantine issue for both domestic and international markets.

In-field treatment solutions are needed to not only meet domestic and export market requirements, but also to ensure that there is product worth selling. Until August 2011, cover sprays of dimethoate and/or fenthion insecticides were commonly used to meet both production and market access requirements. Following suspension of these chemicals from most use patterns, vegetable farmers have had to find other ways to control fruit fly.

*Bactrocera tryoni* – Queensland fruit fly (Qfly) – is the most economically important horticultural pest of fruit and fruiting vegetables on Australia's eastern and northern coasts. Where the pest is endemic, access to domestic and international markets is reduced, while production costs increase due to pest control, yield reduction, and postharvest treatment expenses.

An estimated $128 million was spent on fruit fly related activities between 2003-2008 (PHA, 2008). This included surveillance activities, control, postharvest treatments and research. While the majority of this expenditure was on Qfly, other species are also significant. For example, cucumber fly (*B. cucurbitae*) is a pest of cucurbit species such as zucchini, pumpkins and squash. Moreover, although WA is Qfly free, medfly (*Ceratitus capitata*) is a significant barrier to domestic trade in vegetables between the east and west coasts.

As new chemistry is unlikely to solve this issue, growers will need to combine a range of fruit fly control measures in a "systems approach". There is a range of tools potentially available, including chemical, physical, genetic and biological methods. Improved understanding of fly ecology as well as expanding control on an area wide basis may further enhance effectiveness of such tools.

The aim of this project was therefore to develop integrated pest management options for fruit fly. Trials have focused primarily on one of the key priorities identified in VG13040 – Barriers to infestation. These include netting, windbreaks and even sunscreen materials applied directly to the crop. Field trials in Bundaberg Qld and Silverdale in NSW have examined the effectiveness of different types of netting and fencing applied to capsicum and chilli crops, as well as application of kaolin.

In the early stages of this project it was discovered that both sexes of Queensland fruit fly are attracted to UV light. This has not previously been reported, and appeared a promising area for more research. A series of trials have therefore been conducted examining whether UV light could be adopted as part of a lure and kill strategy for fruit fly.

The outcomes of this project include a series of instructional videos for farmers, a guide to fruit fly management for fruit fly management in vegetable crops, and a series of presentations that have already been provided to growers in Bundaberg, Qld.

# Methodology

A summary of the trials conducted is shown in Table 1. More detailed descriptions of methodology, as well as results and discussion, are included in Appendices 1, 2 and 3 to this report.

## Field trials – Silverdale NSW

Trial crops of capsicums and chillies were grown at a commercial vegetable farm. No other host crops are grown on the property, which is remote from other horticultural producers. This meant that fruit flies could be released into the crop; although the area is endemic for fruit flies, populations are low.

An area 50m x 20m was used for the trials. In **year 1** capsicum plants were grown directly in the soil with overhead irrigation. Three replicate sections of floating row covers (VegeNet, NetPro) and 2m high fences lined with insecticide treated windbreak material (VentNet, Redpath) were installed in areas of the crop.

Fruit fly traps (Biotraps™) baited with cuelure wafers (FT Mallett-CL™) were placed under the netting and inside the fenced area, along with temperature and humidity loggers. Pupal release boxes were set up around the crop perimeter, with three releases conducted when mature capsicums were present.

**Figure 1. Trial 1 left to right: Installation of fruit fly trap inside one of the fenced areas; pupal release box with approx. 200 pupae, sugar cube and water; one of the 16 pupal release boxes placed around the crop perimeter.**

Unfortunately mortality from pupal release was extremely high due to high temperatures and predation by ants and other insects. In addition, weeds created major issues, increasing disease in the crop and making it difficult to detect infested fruit.

In **year 2** cayenne and birdseye chillies were grown instead of capsicums, to avoid issues with detecting larvae in fruit. Plastic weed mat was used to inhibit weed growth. Three types of floating row covers (Insect Net, VegeNet and VentNet) were installed over replicated sections of rows in the crop, with kaolin clay (Surround WP®) applied to other sections. The Biotraps and loggers were installed as previously.

**Figure 2. Netting and repellants tested in trial 2, clockwise from top left: Vent net, VegeNet, Surround® and Aphid Net.**

Once the fruit started to change colour mature adult Qflies were released directly into the crop. Nine fly releases were conducted between 27 January and 27 April. After the first two releases, most were at fortnightly intervals. Each release was of two cages (BugDorm 475 x 475 x 475mm) containing several thousand mixed sex Qflies. This ensured a high level of pest pressure on the different barriers being tested.

Efficacy was assessed by recording trap catches under netting or inside fenced enclosures compared to those in the unprotected crop, and by examining samples of fruit for infestation. Yield and quality of fruit was also recorded.

## Field trials – Bundaberg Qld

A series of field trials in Queensland were conducted using commercial crops of capsicums and chillies. Although no fruit flies could be released, there are significant natural populations in Bundaberg for much of the year. Most trial crops were subject to normal commercial practices including pesticide applications. However two trials were conducted on cayenne chilli crops where the area was left unsprayed, allowing fruit flies to naturally infest the crop.

Trials tested two types of row covers (VegeNet and Insect Net) on spring, summer and early autumn crops, as well as use of fleece materials during winter. Biotraps were installed under the materials as previously described, and temperature and humidity were monitored.

**Figure 3. Fleece (left) and VegeNet on capsicums in Bundaberg. A fruit fly trap is visible under the VegeNet.**

Efficacy was measured by recording trap catches under the netting or fleece materials as well as yield and quality of the harvested fruit. In addition, samples of unsprayed cayenne chillies, and 'normal practice' habanero chillies were examined for larvae (habaneros are very susceptible to fruit fly infestation).

## UV light as an attract and kill device – Macquarie University, Sydney

Trials at Macquarie university were primarily laboratory based, but also utilized a heated greenhouse during winter and large shade-house during summer.

Laboratory trials were conducted examining the attractiveness of UV light compared to green and white light wavelengths. Trials used a screen house containing artificial plants, which was divided into two with black plastic. The flies' attraction was tested using clear sheets of acetate suspended in front of the light sources, and replaced every two hours between 10am and 6pm.

The screen house was also used for tests examining whether white or UV light sources inhibited mating, or reduced oviposition, in exposed flies. Male and female flies sorted by sex immediately after emergence were released into the net house with / without the UV light. The number of mating pairs was counted every hour from 9am to 6pm. In the second set of trials, oviposition devices were introduced to mature flies in environments that were illuminated with UV light or left unlit.

The heated greenhouse trials examined the attraction of flies to reflected UV light. Initial trials used individual citrus trees sprayed with contact insecticide (Buldock 25 EC) at 2ml.$L^{-1}$ and lit, or not lit, with a large UV light. Dead flies were collected daily for up to six days.

**Figure 4. UV light trials at Macquarie University in the indoor field cage (left) and larger net house.**

Trials then scaled up to a large shade house (24m x 4m x 5m). The house was divided into two with a sheet of black building plastic suspended from the roof. Large potted citrus trees were placed inside the house to simulate a crop. Mature Qflies were released in the centre of the house and supplied with food and water. The trees at either end of the house were sprayed twice weekly with a contact insecticide (Buldock 25 EC). A UV light was shone on the tree at one end, this being alternated with each replication of the trial. Flies landing on the insecticide treated trees were collected on netting suspended under each plant and counted daily.

In addition, potted capsicum plants with maturing fruit were introduced into dark / UV lit sides of the house during the trials. After 3 days the fruit were collected and incubated to allow any larvae to develop and pupate.

## Field test of UV light

A small trial was conducted testing a prototype UV light trap. The trap was constructed using black corflute and strips of UV LED lights. The lights were run for three hours each day at dusk using a small solar panel mounted on the roof of the unit. The unit was deployed in the Sydney chilli crop also used for the netting and kaolin trials. Attraction to the UV light was monitored using yellow sticky traps, with additional "control" sticky traps located approximately 30m away in an unlit part of the crop. Fruit flies were regularly released into the crop as previously described.

**Figure 5. Prototype UV light trap installed in the chilli crop.**

**Table 1. Summary of trials conducted**

| | Crop and status | Treatments | Date | Location QLD | Location NSW |
|---|---|---|---|---|---|
| PHYSICAL BARRIERS AND REPELLENTS | Capsicums. Non-commercial crop with pupal release of Qfly | Fences with insecticide treated windbreak material, VegeNet floating cover over 4 row block | December 2014–May 2015 | | X |
| | Capsicums – commercial crop | VegeNet floating cover and Insect Net on hoops, individual rows | March 2015 – May 2015 | X | |
| | Capsicums – commercial crop | VegeNet floating cover | May 2015 – July 2015 | X | |
| | Capsicums – commercial crop | Fleece 18gsm, 30gsm and 50gsm applied after planting; 30gsm fleece applied 1 month before harvest | July 2015 – November 2015 | X | |
| | Capsicums – commercial crop | VegeNet floating covers applied to young plants pre-flowering, plants with developing fruit and plants 3 weeks before harvest. | November 2015 – January 2016 | X | |
| | Cayenne and birdseye chillies. Non commercial crop with adult release of Qfly | Floating covers of Vent Net, VegeNet and Insect Net, application of Surround WP® kaolin clay. | December 2015 – May 2016 | | X |
| | Cayenne chillies – commercial crop but with trial section left unsprayed | VegeNet and 18GSM fleece floating covers applied 2 or 3 weeks after transplanting | February 2016 – March 2016 | X | |
| | Habanero chillies – commercial crop | VegeNet floating covers | January 2016 – February 2016 | X | |
| | Cayenne chillies – commercial crop but with trial section left unsprayed | VegeNet floating covers | March 2016 – June 2016 | X | |
| | Capsicums – pot trial | Fruit flies allowed to oviposit into developing fruit, observed to see if fruit detached | February – March 2016 | | X |
| UV LIGHT ATTRACTION | Potted citrus | Attraction to UV light in glasshouse | July 2014 – September 2014 | | X |
| | Potted citrus and capsicum plants | Attraction to UV light in a divided outdoor net house | November 2014 – April 2015 | | X |
| | N/A | Comparison of UV with white and green light | June 2016 – November 2016 | | X |
| | N/A | UV light and Qfly mating and oviposition | June 2016 – November 2016 | | X |
| | Cayenne chillies. Non commercial crop with adult release of Qfly | Field test of prototype UV light trap | February 2016 – May 2016 | | X |

# Outputs

This project has produced a number of significant resources for growers. These are believed to be unique, not just for vegetables, but for all Australian fruit fly affected industries. For example, although some State Government Departments have produced Fact Sheets on fruit fly management, the resources from this project provide more detailed information, include additional options not previously described (eg netting) and contain new, high resolution images.

## Presentations

- Bundaberg grower workshop – 21st November 2014
- Bundaberg agronomists meeting – 28th May 2015
- Bundaberg grower workshop – 9th December 2015
- International Symposia on Tropical and Temperature Horticulture, Cairns, November 2016. Presentation titled "Low cost protected cropping for capsicum crops".

## Printed materials

*"Fruit fly management for vegetable growers"*

Booklet, A4, 32pp. Includes descriptions of different fruit fly species and detail with pictures and diagrams about fruit fly lifecycles. How to sections, including "Best Practice" pullout panels on monitoring, protein baits, male annihilation, female biased traps, physical protection and hygiene.

Guide has been approved by HIA and 1,000 copies printed for distribution at field days and events, particularly the 2017 Horticulture Convention in Adelaide. Only a few days after printing, more than 100 guides have been distributed at the request of industry members.

A pdf of this document is included as Appendix 4 of this report.


**Figure 6. Screenshots of the Fruit fly management guide for vegetable growers booklet**

## Videos

A series of five x 3 minute videos has been professionally filmed and edited. These are now available on You-Tube through the AHR website. The videos are as follows;

Controlling Fruit Fly in Vegetables: (1) Targeted Control
https://youtu.be/HQgvrbTULTw

Controlling Fruit Flies in Vegetables: (2) Monitoring
https://youtu.be/APaY6hUwLz4

Controlling Fruit Fly in Vegetables: (3) Food Based Baits
https://youtu.be/sVwzz9sMrTA

Controlling Fruit Fly in Vegetables: (4) Male Annihilation and Female Biased Traps
https://youtu.be/YsdNlodhJiQ

Controlling Fruit Fly in Vegetables: (5) Netting, Repellant and Field Hygiene
https://youtu.be/hzZYhH5CC0Y

The videos will also be distributed on USB sticks (100 made), to accompany the guidebook.

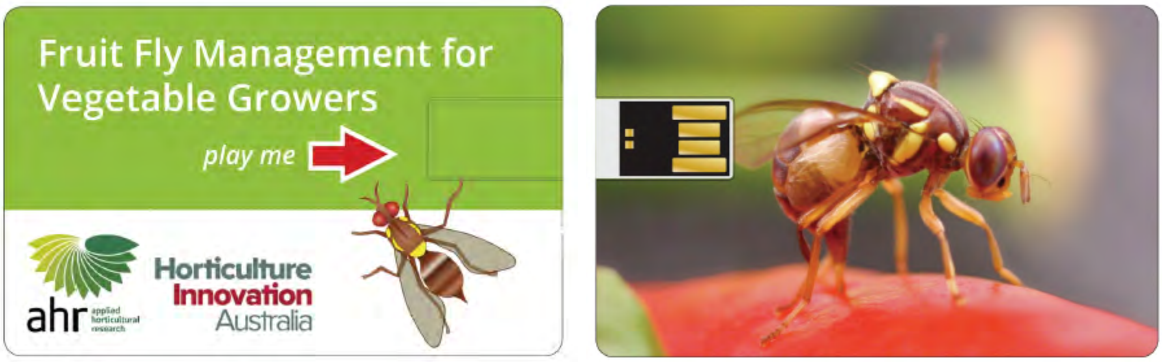


**Figure 7. USB "wafer" design for distribution of fruit fly videos and guide.**

## Articles

*Paper submitted to ISHS;* Goldwater A., Ekman JH, Rogers G. 2016. The effects of floating row covers on yield and quality of field-grown capsicum (*Capsicum annuum* L.). In Press.

**NB.** The report on the UV light trials will be submitted to the Journal of Pest Science (Impact factor 3.103). The work will be divided into two separate articles, one on the laboratory work, the other on the results from the field cage trials. The first in done, the second requires some additional tests to check whether there was a tree effect in the net house trials.

It is further planned to write up the work on netting for the Journal of Economic Entomology (Impact factor 1.6). This will be the first time work has been published on the use of floating row covers for management of fruit flies.

*Article submitted to Vegetables Australia magazine* "Net benefits for fruit flies" Included as Appendix 5.

# Outcomes

## Field trials – Silverdale NSW

These trials have demonstrated that floating row covers block fruit flies from entering a crop, and reduce infestation rates to close to zero.

In trial 1, VegeNet was very successful at excluding flies, although its effectiveness was reduced once weeds started to push up the edges of the netting. In contrast, the insecticide treated fences failed to block fruit flies from entering the capsicum crop. While yield was the same from netted and uncovered plants, the percentage of marketable fruit was slightly increased under the netting.

Trial 2 further explored the use of different netting types, and added Surround® (kaolin clay) application. Chillies, rather than capsicums, were grown in trial 2 to ensure that larvae could be readily detected in infested fruit. VegeNet and Aphid Net were both effective at excluding flies. Even though the mesh size of Vent Net was large enough to allow flies to enter, it still greatly reduced the number of flies caught under the netting, and reduced infestation rates almost as low as the finer mesh sizes. Kaolin application also proved surprisingly effective, with no infested fruit recovered from these plants.

These results demonstrate that visual barriers, as well as physical ones, can prevent fruit flies from finding host fruit.

Yield and quality were not improved in chilli crops protected by netting, unlike previously observed for capsicums. Moreover, large populations of aphids developed under the aphid net. As the crop was not treated with any insecticides during the trial, this suggests that natural predators were keeping aphids in check in the remainder of the crop but were unable to penetrate the finer mesh of the aphid net.

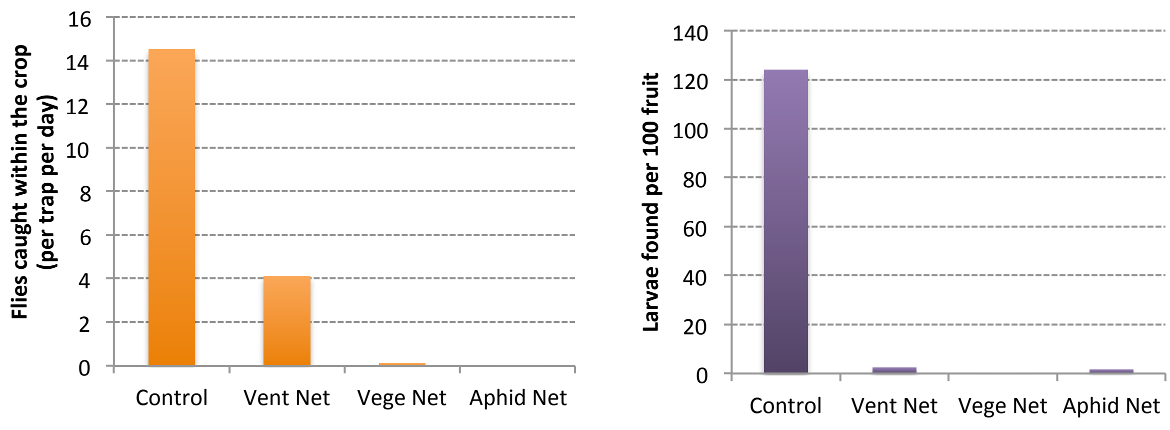


**Figure 8. Flies caught and larvae found in a chilli crop protected by different types of floating row cover netting or left as an uncovered control. Data from 2015-2016 field trial in Sydney.**

## Field trials – Bundaberg Qld

Floating row covers of netting were shown to improve yield and quality of capsicums, as well as reduce the number of fruit flies entering the crop.

Four trials were conducted on commercial capsicum crops in Bundaberg, grown at all times of year. While yield was improved, the most significant results were on fruit quality. For example, total yield under VegeNet or fleece floating row covers was increased by 10 to 42% compared to the uncovered controls. Yield of marketable fruit was 12 to 82% higher than the uncovered controls. The largest effect was observed in the crop grown during winter – grade 1 fruit per plant increased from 556g/plant in the uncovered crop to 1.24kg/plant in the plots covered with 18gsm fleece.

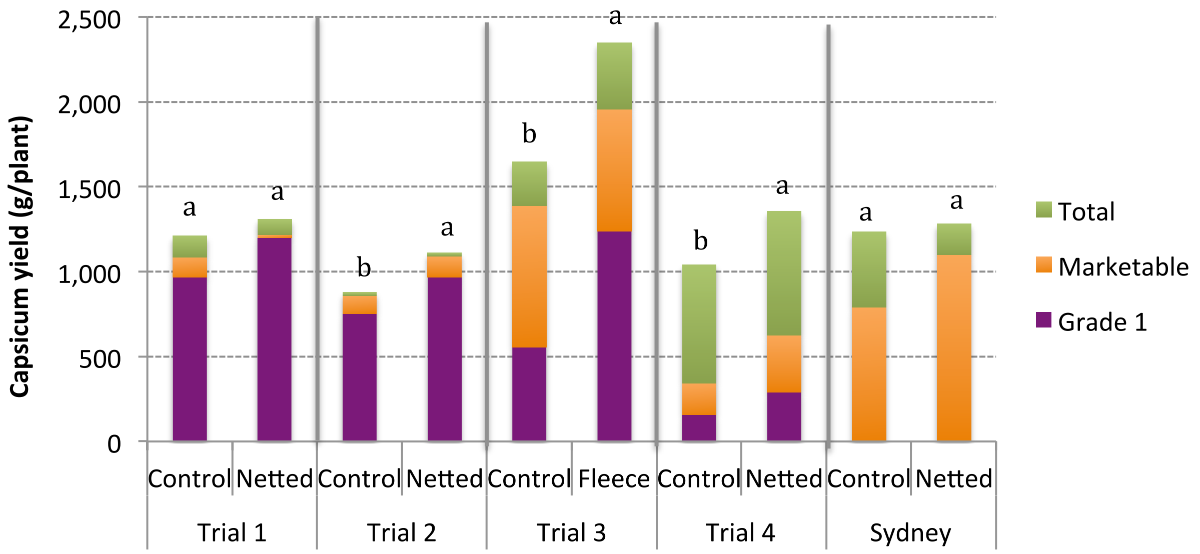


**Figure 9. Total, marketable and grade 1 yield of capsicum plants grown in four trials in Bundaberg and one trial in Sydney. Plants were protected with floating row covers of VegeNet / 18GSM fleece or left uncovered as controls. Data are mean values from 6 to 10 plants x 3 replications per trial, different letters indicate significant differences in total yield for each of the 5 trials ($p<0.05$).**

Although the plants grew vigorously under netting, the same improvements in yield and quality of fruit were not observed for cayenne chillies – which is consistent with the results from the NSW trial. However, the trials with an unsprayed cayenne chilli crop did confirm that the nets prevented fruit flies from entering the crop and reduced infestation of fruit to <1%.

Effectiveness was lost if the nets were not secured to the ground, as occurred after strong winds and once the chilli plants grew too large for the nets.

## UV light as an attract and kill device – Macquarie University, Sydney

UV light has been shown to attract both male and female Qflies. Male flies that were 10 days old showed the strongest response, whereas in females their responsiveness decreased as they aged. Attraction is greatest during the two hours immediately after dusk. It is hypothesized that attraction to UV light is based on mimicry of the conditions in the tree canopy where mating usually takes place. This could explain why males become more strongly attracted as they mature, but mated females are less attracted.

Green light was shown to attract flies during the middle of the day. Again, male flies were more strongly attracted than females, and there was a significant interaction with fly age. In contrast, reflected white light had a repellent effect, with significantly fewer flies caught on well-lit surfaces.

Neither UV light or white light affected mating, oviposition or the total number of eggs laid.

The glasshouse and large net house trials confirmed the significant attraction of flies to UV light in a more natural setting. In these trials male and female flies were equally attracted by UV light. However, the UV light was only effective in the large net house when it was located at the end that was shaded by overhanging foliage. When the light was placed at the open, un-shaded end, flies were not attracted, and more dead flies were collected from the unlit end of the cage.

Effectively, providing a UV light resulted in a seven-fold increase in the number of flies that settled in the dark location. However, illuminating a plant in a more open location with UV light halved the number of flies that settled there.

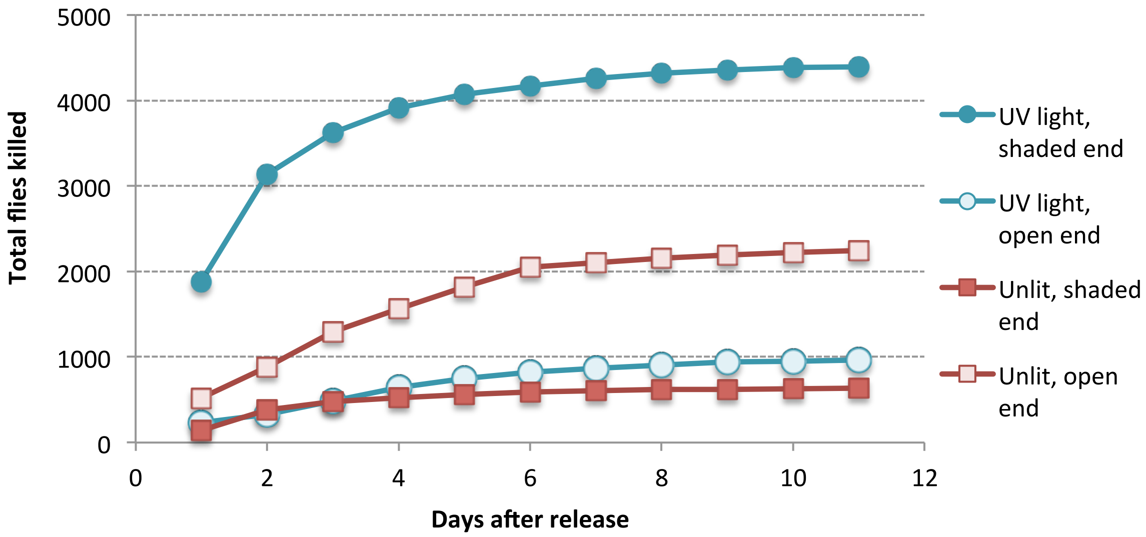


**Figure 10. Total flies killed on insecticide treated trees located at either end of a large net house. Trees were either lit with a UV light, or left unlit. Data shows cumulative totals of male and female flies from three replications.**

## Field test of UV light

Catches of fruit flies on yellow sticky traps were doubled in the presence of the UV light. In total 962 flies were caught next to the UV light compared to 425 on the non-lit controls.

A strong bias to female flies was observed, regardless of the presence or absence of UV light, suggesting they were generally more strongly attracted to the yellow traps than were male flies.

# Evaluation and Discussion

## Floating row covers

The use of physical barriers to manage fruit fly has not been previously studied for vegetable crops. However, netting (generally hail or shade net houses) is being more widely used by vegetable growers for production purposes. Netting can reduce sunburn and wind damage, improving quality and reducing irrigation needs.

Full exclusion netting has to be secured to the ground with no gaps and double door type entry systems, which creates issues for machinery movement. However, white is known to repel fruit flies, while netting which conceals the crop profile is a visual barrier for females searching for fruit to oviposit. Fruit flies travelling across an open area will fly quite close to the ground (<2 m high) (Dominiak pers. com.). As an arboreal pest, Qfly is unlikely to travel across open pasture without visual cues that represent food, shelter or oviposition sites. If flies encounter a barrier, they may be more likely to travel around it than attempt to fly over or even squeeze through the mesh

A HAL project (HG00018)[1] evaluated exclusion netting of fruit trees against Queensland fruit fly. No infested fruit were found during the two years of the study, and colour development and fruit quality was improved. The use of physical barriers was therefore identified in VG13040 as a recommended area for further research.

Compared to net houses, floating row covers offer a low cost option for vegtable crops. They can simply be placed over a crop temporarily, secured using shovelfuls of soil, then moved elsewhere as required. Netting can be cleaned and re-used many times. Alternatively, single use frost protection 'fleece' could also provide a barrier to fruit fly.

The results from the Sydney trials demonstrated that netting is an effective method to exclude fruit flies from fruiting vegetable crops. Even the Vent Net, which had mesh large enough that flies could readily climb through, reduced infestation by 98% compared to the uncovered controls. The fine Aphid Net reduced infestation by 99% while no infested fruit were found underneath VegeNet.

Trials in Bundaberg on capsicums were focused primarily on determining how these same treatments would affect yield and quality. Three trials examined the effect of netting on capsicum quality, with a fourth trial testing the use of fleece. Marketable yield was significantly increased in three of the four trials. The number of grade 1 fruit was likewise increased. Covered plants grew larger, and appeared healthier than those left uncovered. Such improvements in yield and quality could help defray the cost of the netting. Moreover, netting could reduce the need for insecticides to control other insect pests. It is also likely to reduce irrigation requirements – a factor not evaluated in the current trial, but likely to be significant.

The fleece provided excellent benefits in terms of marketable yield, but was less effective as a barrier to fruit fly. Fleece tears easily under windy conditions. Draped over upright capsicum plants it became quite torn and damaged, with sections blown off the crop. This would clearly have allowed fruit flies to enter. Fleece is normally used for low growing plants such as lettuces and baby-leaf crops. It may

[1] Lloyd A. 2003. Exclusion canopy netting of fruit crops for economically sustainable production and non-chemical interstate/export market access protocols. HAL final Report HG00018.

therefore be suitable for protecting crops such as pumpkins or even zucchini. Even though it can offer agronomic advantages, fleece cannot be recommended for protecting upright crops – such as capsicums, eggplant or chillies – from fruit fly.

Finally, trials in Bundaberg on unsprayed chilli plants confirmed the effectiveness of netting at excluding fruit fly, at least while the edges of the net remained secured to the ground. Interestingly, yield and quality were not improved by netting chilli plants in either Sydney or Bundaberg. Chilli plants have smaller leaves and denser foliage than capsicums, and the fruit is smaller and less fleshy. This may help protect them from sun, wind and rain, factors that reduced marketable yield of unprotected capsicums.

## Kaolin clay

The results with Surround® kaolin clay is a standout result from the trials. Kaolin has previously been shown to reduce infestation on fruit crops. For example, kaolin provided similar or better results than trichlorfon and fenthion in protecting satsumas and summer fruit from infestation by Medfly[2]. Similar results have been reported for apples, nectarines and persimmons[3].

Even though spray application was far from ideal, and overhead irrigation and rain further reduced coverage on the plants, no infested fruit were found on the kaolin treated chilli plants.

While this result appears extremely promising, questions remain. Kaolin treated plants were next to non-treated ones –flies may try harder to find host fruit if they do not have an alternative so readily available. Whether postharvest washing and brushing can remove the material is a key concern. White residue on vegetables will not be acceptable to customers. Cost may also be an issue, as Surround® is relatively expensive, and quite a large amount needs to be applied to get good coverage.

## UV light

Attraction of insects to light is nothing new. Light traps have been used to capture a range of insect pests, including mosquitos[4], midges[5] and weevils[6]. However, this is the first evidence that UV light is attractive to fruit flies.

The trials have identified that UV light is most attractive at dusk and immediately afterwards, times associated with mating. This was in contrast to green light, which was attractive during the day, and white light, which was repellent. However, field cage tests consistently indicated that UV light only attracted fruit flies when it was in a shaded location. This may be due to the increased contrast between the light and the illuminated foliage at dusk.

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[2] D'Aquino S, Cocco A, Ortu S, Schirra M. 2011. Effects of kaolin-based particle film to control *Ceratitis capitata* (Diptera:Tephritidae) infestations and postharvest decay in citrus and stone fruit. Crop Prot. 30:1079-1086.
[3] Mazor M, Erez A. 2004. Processed kaolin protects fruits from Mediterranean fruit fly infestations. Crop Prot. 23:47-51.
[4] Burkett DA, Butler JF. 2005. Laboratory evaluation of coloured light as an attractant for female *Aedes aegypti, Aedes albopictus, Anopheles quadrimaculatus* and *Culex nigripalpus.* Florida Entomol. 88:383-389
[5] Bishop AL et al. 2006. Ight trapping of biting midges *Culicoides* spp. With green light emitting diodes. Austral. Entomol. 45:202-205.
[6] Duehl AJ et al. 2011. Evaluating light attraction to increase trap efficiency for *Tribolium castaneum*. J. Economic. Entomol. 104:1430-1435.

As a practical tool for monitoring, or for lure-and-kill, attraction to UV light may be most effective if combined with other strategies. Flies attracted to the UV light at dusk are likely to remain nearby overnight. The morning is when flies most actively forage for protein and are responsive to cuelure. If protein, a para-pheromone or an odour based lure is co-located with the UV light then this could potentially increase the efficacy of both methods. Similarly, visual lures such as the Ladd trap normally operate only during daylight hours. Adding a UV light could potentially both extend activity and increase attraction of such devices.

# Recommendations

## Repellents

Surround® was a standout result from these trials and worthy of further investigation in a commercial environment. However, trials were small scale, treating individual sections on rows, and the material was only applied to cayenne chilli plants. Moreover other sunscreen materials are now available, such as Parasol® which is composed of calcium carbonate, and carnauba wax combined with other clay materials.

Trials should therefore examine;

- Use on other fruiting vegetable crops eg pumpkin, eggplant, squash, capsicum
- Effect of application on a larger scale, thus removing easy access for flies to untreated host fruit, on infestation rates in fruit
- Timing of application
- Removal of these materials using normal commercial washing facilities
- Cost of materials
- Effect on product quality especially sunburn

## Netting

During this project a single trial was conducted examining the effect of timing of netting application on capsicums. Unfortunately this crop was severely rain affected, which reduced the value of the results. Also, this trial utilized a normally treated commercial crop, limiting the value of trap catch and infestation rate data. If growers only needed to apply nets two weeks before harvest, this could represent a major cost saving and make logistics of crop management much easier. A project examining this specific issue – the relative value of netting crops early compared to just before harvest – could address this issue.

## UV light

The effectiveness of UV light when combined with other attractants eg protein lures, para-pheromones and odour volatiles requires further examination. In particular, trials should examine whether such combination systems could be used for monitoring fruit fly populations. This would provide an alternative to normal monitoring traps baited with para-pheromone lures; results from these can be unreliable at sites where MAT is in place.

The results of the net house trials are difficult to understand. While it would be reasonable if the UV light had no effect when in the open end of the cage, the finding that it reduced captures appears surprising, especially given the strong positive result for UV light in the more shaded position. For any UV light trap to work it will be necessary to understand this effect – otherwise the device could be not only ineffective, but actually a negative, if used incorrectly.

## Fruit fly management as a system

The 'Fruit fly management guide for vegetable growers' brings together basic information on use of protein baiting, MAT and other techniques. However, much of what is recommended within the guide is based largely on data from fruit crops, rather than specifically from vegetables.

The information on protein baiting height and substrate is an exception to this, having been only recently completed as part of project VG13041. Protein baiting is an important control method for managing fruit fly, yet understanding how, where and when to apply bait is clearly key to its success.

In recent times, significant outbreaks of cucumber fly have occurred in the Lockyer valley. Cucurbit fruit are often left in the field long after the crop has finished. It is not clear whether it is this practice ie lack of field hygiene, that has lead to such outbreaks. Indeed, little is known of this increasingly important pest. Even its distribution remains poorly understood. A food based lure recently been developed, but is still relatively untested.

In summary, there are many research gaps in what we know about fruit fly management in vegetable crops. In many ways, we are only just starting to understand some of the specific practices and techniques that are effective for vegetable farmers, and which may be quite different to the methods used in orchards. More information is needed to clearly understand what the main challenges are for vegetable growers, and how research, development, and extension can address these issues.

# Scientific Refereed Publications

One paper relating to the trials has been accepted for publication in a peer-reviewed journal. Three additional papers are currently at draft stage.


- Goldwater A., Ekman JH, Rogers G. 2016. The effects of floating row covers on yield and quality of field-grown capsicum (*Capsicum annuum* L.). In Press.
- Mendez V, Ekman JH, Taylor PW. 2017. Emitted light as a potential attractant for Queensland fruit fly – effect of wavelength, time of day, sex and age. J. Pest Sci. In Preparation.
- Mendez V, Ekman JH, Taylor PW. 2017. Emitted light as a potential attractant for monitoring and lure and kill management of Queensland fruit fly. J. Pest Sci. In Preparation.
- Ekman JH, Goldwater A. 2017. Netting and kaolin application for control of Queensland fruit fly in vegetable crops. J. Econ. Entomol. In Preparation.

# Intellectual Property/Commercialisation

The potential of the UV light attractant was discussed in terms of potential IP. However, the research team feels the results are not sufficiently strong, or the method sufficiently unique, to warrant protection of this IP. As a result it is proposed to publish the results, with a view to combining UV light with other fruit fly management strategies.

It is concluded that no commercial IP has been generated

# Acknowledgements

These trials would not have been possible without the generous assistance of a number of farmers;

- Eddie Galea, Werombi Farm Produce, Silverdale
- David dePaoli and John Coulombe, AustChilli, Bundaberg
- Robbie Barbera, Barbero Farms Bundaberg

Also the facilities and assistance provided by:

- Bundaberg Fruit and Vegetable Growers Association
- Queensland Department of Agriculture and Fisheries
- Macquarie University
- University of Sydney

# Appendices

Appendix 1 – Full report on field trials with netting and kaolin

Appendix 2 – Full report on UV light trials

Appendix 3 – Field test of prototype UV light trap

Appendix 4 – Fruit fly management for vegetable growers booklet

Appendix 5 – Article for Vegetables Australia magazine

## Appendix 1

# Field trial results, netting and repellents

# Contents

# 1. Net and repellent trials, NSW

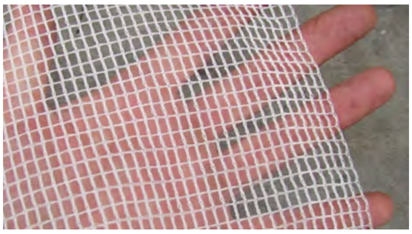
## 1.1. Aim

To test the efficacy of netting materials and kaolin clay at preventing fruit flies ovipositing in capsicum and chilli fruit.

## 1.2. Materials and Method

### 1.2.1. Netting materials

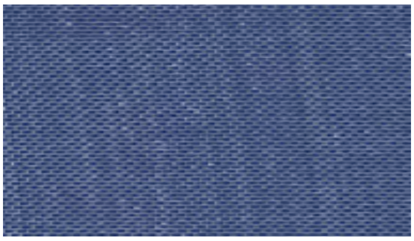
A number of different protective materials were tested;



**Vent Net** White, open strand knitted fabric used for screening the sides of greenhouses and other structures. Prevents entry of birds and large insects, reduces impact of wind or strong rain. Supplied by Redpath Australia. Mesh size approx. 6 x 4mm

**VegeNet** Knitted white high density polyethylene net designed to exclude larger pests and provide some protection from wind and rain. Mesh size approx. 1 x 3mm, shading 10%, weight 45g/$m^2$. Supplied by NetPro Pty Ltd.

**Aphid Net** Translucent woven material made from high density polyethylene. Designed to exclude most insects and last 8-10 years. Mesh size 0.6 x 0.6mm, shading 14%, weight 45g/$m^2$. Supplied by Crop Solutions UK.



**Insect Net** Translucent woven material made from high density polyethylene. Long lasting material used to construct insect-proof net houses. Mesh size approx. 0.5 x 0.9mm, shading 27%, weight 125g/$m^2$. Supplied by NetPro Pty Ltd.

**GroShield** Spunbonded polypropylene 'fleece' used primarily for frost protection but also insect exclusion and reduction of evaporation. Inexpensive but single use only as tears easily. Cohesive barrier (no holes), shading approximately 10-15%, range of thickness/weights from 18-50g/$m^2$. Supplied by NetPro Pty Ltd.

## 1.2.2. Trial 1 design (2014-2015)

A crop of capsicums was grown at a property near Silverdale in south-west Sydney. This property was chosen for the trial because the farmer normally grows leafy vegetables such as celery, kale, broccoli and beetroot. Effectively this meant that no other fruit fly host plants were being produced on the property, or on any properties within several km radius of the trial site. This meant that fruit flies could be released around the perimeter of the capsicum crop.

The aim of the trial was to test two exclusion strategies;

- A VegeNet floating row cover, secured with sandbags.
- A visual barrier, comprising a 2.3m high Vent Net screen. This was based on reports that flies tend to fly low across a crop, search for host plants using visual cues and are repelled by white.

The total area for the trial was 50m x 20m. Approximately 4,000 capsicum plants were planted in single rows spaced 1.3m apart. The nets and barriers were installed once the plants had reached approximately 30cm high and were starting to flower.

The VegeNet is a light material (45g.m$^2$) designed to exclude larger insects with a mesh hole size of approximately 1mm x 3mm. It is more durable than some of the other similar materials on the market, being designed for use over several cropping cycles. It was secured using sandbags so as to allow relatively easy access to the crop (Figure 1). Burying the edges with soil would have been suitable under normal circumstances.

**Figure 1 – VegeNet was draped directly onto the capsicum plants and secured with sandbags**

It was decided that the best way to create the fenced areas was to hire portable fencing panels. These are easily assembled using concrete bases, avoiding the need for a more permanent post mountings in the field. The Vent Net was then wrapped around the mesh fencing and secured with cable ties (Figure 2). One panel was left unsecured to act as a gate.

After erection the netting was coated with the synthetic pyrethroid insecticide Buldock 25 EC (active ingredient beta-cyfluthrin) mixed 1:2 with mineral oil. The insecticide was simply rolled on using a paint roller and extension pole. This combination was selected for long term persistence on the netting.

**Figure 2 – Temporary fencing was erected then wrapped in Vent Net to create a visual barrier**

The trial was planned around the dimensions of the temporary fencing panels and width of netting materials, with three replicated areas for each treatment. Approximately 1,000 capsicum plants were used per treatment (Figure 3).

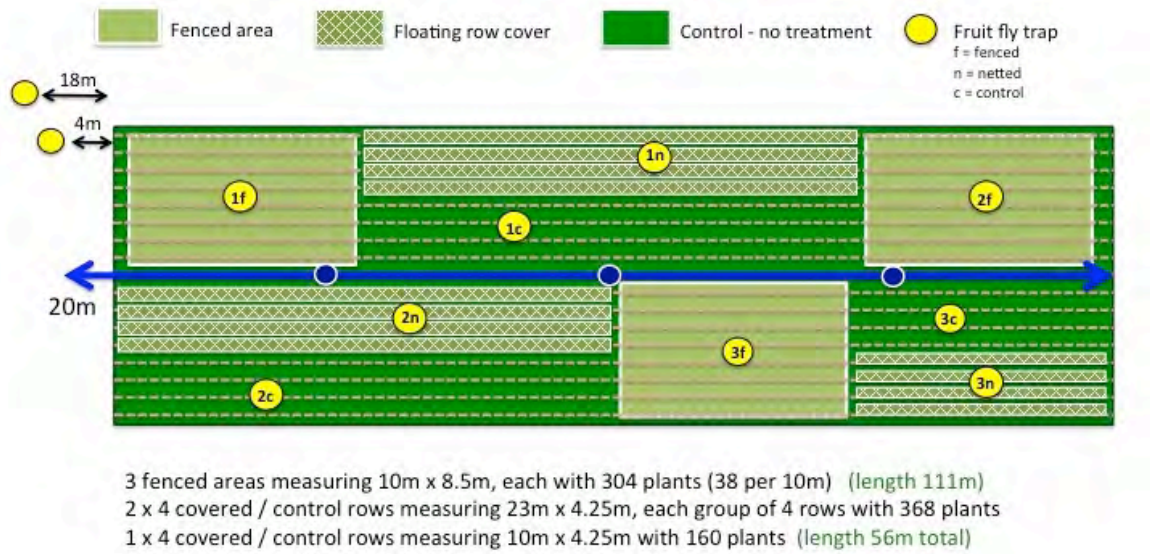



**Figure 3 - Layout of field trial with fenced areas, floating row covers and untreated controls**

A fruit fly trap (Biotrap) baited with FT Mallett CL wafer lure was installed in each treatment block. Additional fruit fly traps were hung from an adjacent fence (4m from crop) and in a nearby African olive tree (18m from crop) (Figure 4). Temperature and humidity recorders were also mounted inside the crop (location 1c) and a floating row cover (location 2n).

**Figure 4 - Installing a fruit fly trap inside a fenced area (L) and a data logger mounted underneath the floating row cover (R)**

### 1.2.3. Trial 2 design (2015 – 2016)

A mixed crop of birdseye and cayenne chillies was grown at the same commercial vegetable farm at Silverdale as used in Trial 1. Chillies were planted instead of capsicums due to the issues experienced the previous year in detecting larvae in the fruit; chillies are much easier to handle, and offer greater opportunity for replication.

A total of 8 rows of chillies were planted, measuring approximately 60m length. Although the chillies were planted into black plastic mulch, the plot was irrigated through overhead sprinklers, drip irrigation not being available. Weeds were controlled in the inter-rows through a combination of slashing and herbicide applications.

Treatments were applied approximately 6 weeks after planting. Treatments were:

1. Aphid Net
2. VegeNet
3. Vent Net
4. Surround® – kaolin clay sunburn protection, applied at 50g.$L^{-1}$
5. Untreated control

The Aphid Net and VegeNet were both considered to be exclusion netting – Qfly are too large to fit through the mesh in this material. Although the Aphid Net was finer weave than VegeNet, this material is composed of semi-transparent fibres, and has light transmission rates of approximately 90%, compared to around 80% for VegeNet.

The Vent Net was considered as a visual barrier only – although flies can crawl through the holes in this material without too much difficulty, it still acted as an effective visual barrier. Surround® also acts as a visual barrier against Qfly by coating the plants with white material. In addition, some researchers have hypothesised that the tiny, sharp particles of clay irritates flies, deterring them from ovipositing.

Three x 20m sections of crop were allocated to each treatment in a randomised complete block design (Figure 5). Edges of the netting were secured by shoveling soil every 1-2m along the length of the material.

Surround® was applied using a hand sprayer to thoroughly wet the foliage and fruit. The material was re-applied weekly once the plants started fruiting – this was necessary due to high rainfall during the trial, as well as the use of overhead irrigation. These washed much of the material from the plant leaves. NB Surround® is better suited to sites where little rain occurs during fruiting and overhead irrigation is not used.

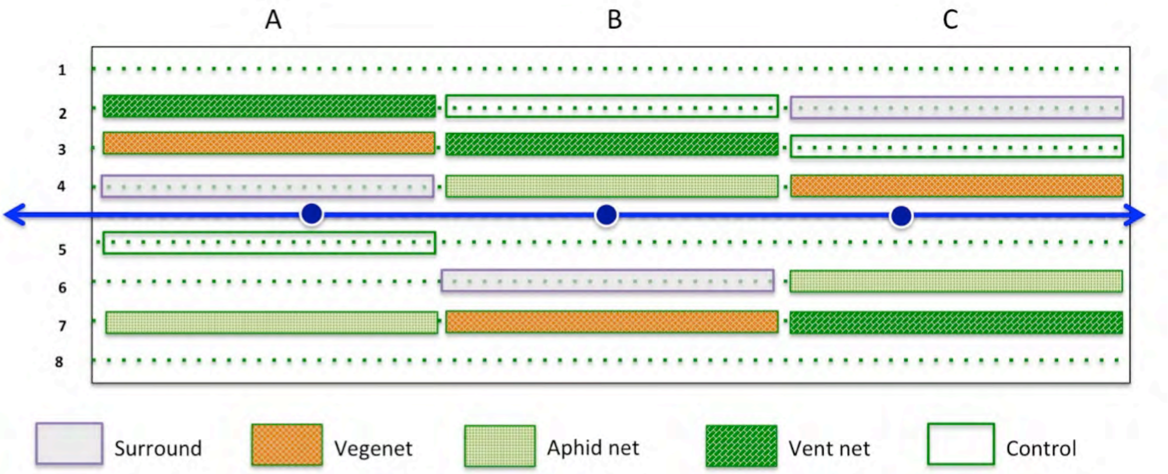



**Figure 5 - Layout of field trial, showing rows covered by VegeNet, Vent Net or Aphid Net, sprayed with Surround® or left uncovered.**

A Biotrap (fruit fly trap) baited with FT Mallett CL wafer was installed on a post under each section of netting as well as in control blocks. A data logger was also installed under each treatment type to monitor temperature and humidity.

**Figure 6. Biotraps hung in the chilli crop.**

**Figure 7 - Trial at Silverdale showing general layout, effect of Surround® application (top R), Aphid Net (L) and VegeNet (R).**

### 1.2.4. Fruit fly release

Although this area is considered endemic to Qfly, the lack of host plants at the farm as well as neighbouring properties mean that populations are generally extremely low. To test the effectiveness of the netting materials, it was therefore important to augmentatively release flies. Different techniques were used in each trial.

#### *Trial 1*

Two pupal releases were conducted. The first used pupae sourced from QDAF in Brisbane, the second were from the NSW DPI fruit fly factory at Camden.

Pupae (approx. 200) were placed in small dishes inside small foam containers with a generous hole drilled through each end. Water and sugar was provided for the emerging flies. A total of 16 pupal release boxes were placed around the perimeter of the crop on top of small stacks of bricks treated with barrier spray (Figure 8).

While examination of the pupal cases showed that many flies had emerged, large numbers of dead flies and detached wings were found inside the boxes. This made it seem likely that high daytime temperatures, as well as predation by ants and other insects, greatly impacted on the resulting population of adult flies.

**Figure 8 – Pupal release boxes were assembled with a petri dish full of pupae, water supply and sugar cube. These were placed around the perimeter of the crop**

### *Trial 2*

To avoid the high levels of mortality that had been observed the previous year, releases in 2016 consisted of mature adult Qflies. Fertile Qfly were obtained from Macquarie University. On each occasion two cages (BugDorm insect rearing cage, 475 x 475 x 475mm) were used for release, each containing several thousand male and female Qfly. Flies were released only once they were sexually mature (minimum 10 days after eclosion), as at this stage females are capable of laying eggs.

Releases and evaluations continued at the site for longer than initially planned due to the unseasonally warm weather that occurred in Sydney during April 2016. A total of nine cohorts of flies were released at the site at 1-2 week intervals between 27$^{th}$ January and 27$^{th}$ April 2016.

## 1.2.5. Trap catches and infestation

In both trials, the traps were monitored weekly for catches of fruit flies.

Assessment of infestation rates varied somewhat between Trial 1 and Trial 2.

***Trial 1*** Each week 20 capsicums were harvested from each treatment unit, examined for oviposition marks and then incubated to allow any fruit fly larvae inside to develop and pupate.

***Trial 2*** Rates of infestation were assessed weekly once the chillies fully ripened. Infestation was monitored by picking 50 fully ripe cayenne chillies from each treatment block and incubating at 20°C for 3-5 days. The fruit were then opened and visually inspected for Qfly larvae.

### 1.2.6. Yield and quality

In both trials, the effect of netting on yield and quality were assessed. In Trial 1, only a brief assessment was conducted; by the time of harvest weeds and diseases meant the plants were in poor condition, so it was felt yield may not be typical of the plants and treatments applied. However, following positive results in Sydney and Bundaberg, yield and quality were examined more closely in Trial 2.

***Trial 1*** Six randomly selected plants from each control unit and each unit covered with floating row cover (total = 36 plants) were strip picked of all fruit (19/3/2015).

***Trial 2*** Once the first fruit set reached commercial maturity, three birdseye chilli plants from each plot were cut at the base (total 9 plants per treatment x four treatments). All fruit were stripped from each plant and classified as green, mixed colour or red. Yield was recorded as total weight of fruit per plant.

A similar procedure was performed for the cayenne chillies, once fruit reached marketable stage. Three plants per plot were stripped of fruit. Fruit were classified by colour, as well as according to marketability. Yield was recorded as total weight of fruit per plant.

## 1.3. Results

### 1.3.1. Trial 1

The floating row cover netting completely blocked the ingress of fruit flies from the surrounding crop for four weeks. The fencing material was ineffective, with nearly as many flies caught inside as outside the enclosures.

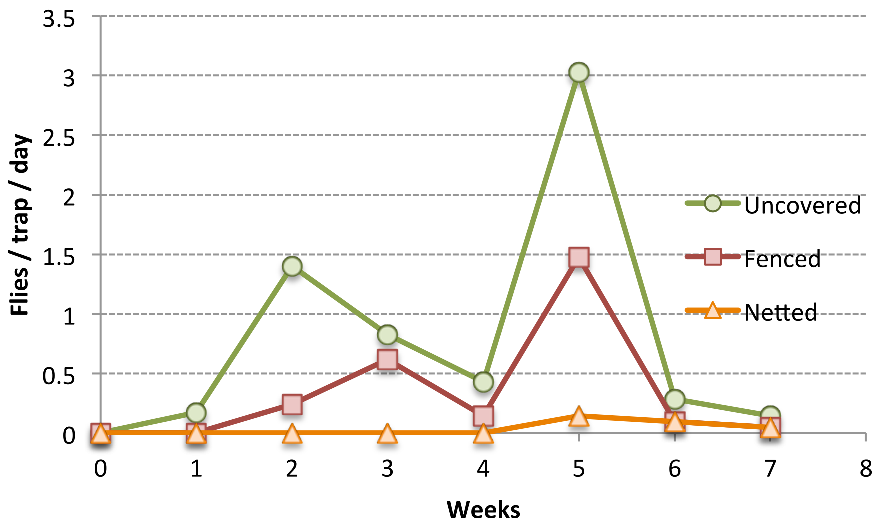



**Figure 9 - Average fruit fly trap catches per day from inside a fenced section of crop (Fenced), under a floating cover of VegeNet (Netted) or the untreated control plants (Uncovered) (n=3).**

Normal industry practice is to plant a double row of capsicum seedlings directly through plastic mulch irrigated with sub-surface drippers. One of the issues during this trial was that (as this grower does not normally produce capsicums) the capsicums were planted directly into the ground and watered with overhead irrigation. While no insecticides or fungicides were applied to the crop to avoid impacting the flies, there was also no weed control.

No fruit flies were found in traps under the netting until 5 weeks after the initial release. By this time weeds had become a major issue. The edges of the netting were pushed up by the weeds, so were no longer fully enclosing the plants inside. A neighbouring crop of spaghetti squash also caused issues with the barrier integrity.

Figure 10 - Weeds were a major problem during crop maturation as they pushed up the edges of the netting

Of all the capsicums sampled and examined during the trial (1,080 fruit), only two were positively identified as infested with fruit fly. This was a disappointing result given that flies were present in the crop and seen on the plants. However, there was also observed to be a large amount of rotten fruit. It seems possible that capsicums infested with Queensland fruit fly under these conditions rapidly develop rots and detach from the plant.

While the fencing materials had no effect, the netting appeared to have a positive effect on fruit quality. Total yield from strip-picked plants was the same in netted and non-netted plots (p=0.634). However, the percentage of marketable fruit was increased by netting. Marketable fruit averaged 808g/plant from the controls compared to 1,075g/plant from the netted fruit, a significant increase (p=0.033) of around 33% (Figure 11).

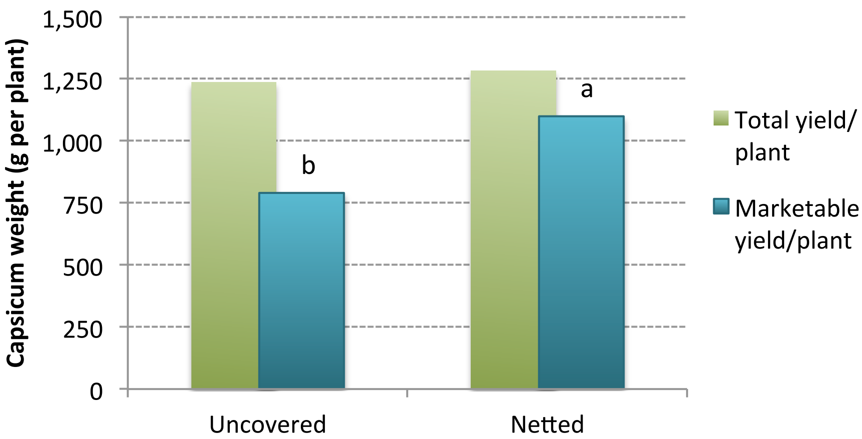



Figure 11. Total and marketable yield of capsicums grown with or without VegeNet floating covers. Letters indicate that there was a significant increase in marketable yield under the floating cover of VegeNet (p=0.033).

### 1.3.2. Trial 2

All three of the floating covers tested reduced the number of flies entering the crop. The VegeNet and the Aphid Net were the most effective, with a total of 32 and 12 flies caught respectively over the three month period of the trial.

The Vent Net was also surprisingly effective at keeping flies out of the crop. Even though the holes were large enough for flies to enter, the number of flies caught in the traps was reduced by over 70%.

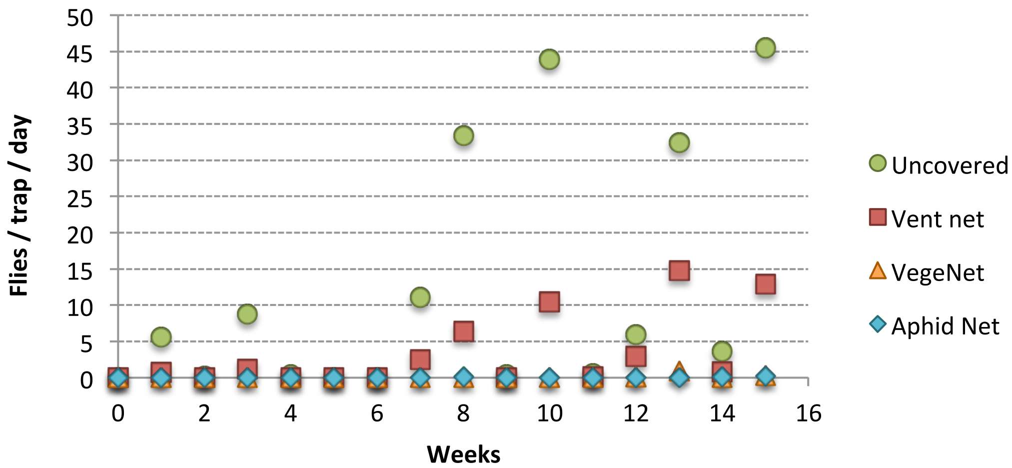



**Figure 12. Number of flies caught in Biotraps placed under netting or in uncovered control plants. Each point is an average from three replicate plots, expressed in flies caught per day.**

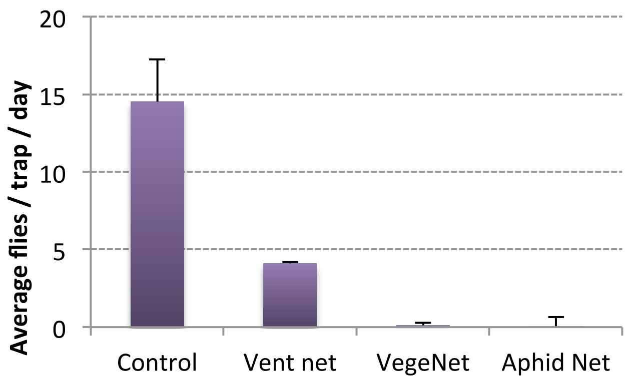



**Figure 13. Average number of flies caught in Biotraps placed under netting or in uncovered control plants during the trial period. Error bars indicate the standard deviation of each mean value (n=3).**

Assessment of infestation in fruit commenced 7 weeks after flies were first released, this being when the cayenne chillies matured. In total, 517 infested fruit were found in the control plots, compared to 24 from plants covered with Vent Net, 14 from plants protected by VegeNet, 4 from plants protected by Aphid Net and none from the plants sprayed with Surround®.

In total, 13 of the 14 infested fruit found under the VegeNet were found in week 9. However, the net had been significantly torn – farm workers weed trimming between the rows had slashed a large hole in one of the nets.

Similarly, all four of the infested fruit found under Aphid Net were discovered after one section of the netting was blown up by wind, allowing flies entry underneath.

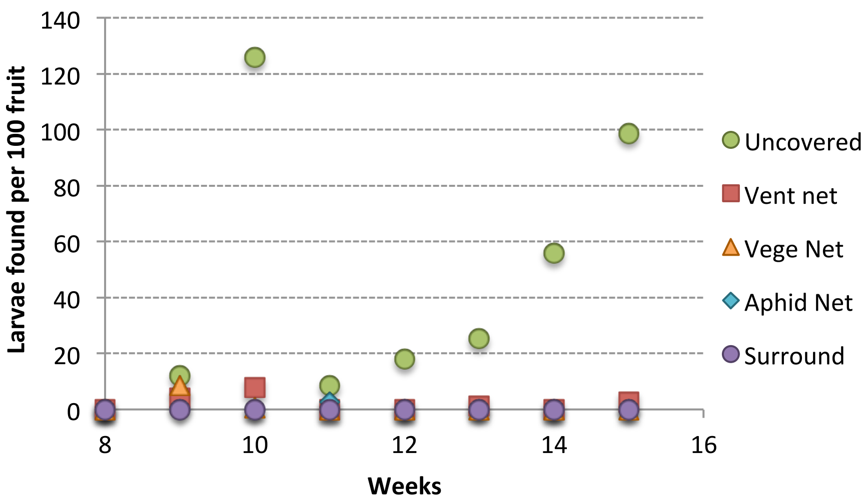



**Figure 14. Larvae found per 100 cayenne chillies examined. Chilli plants covered with netting, sprayed with Surround® or left uncovered. Each data point represents the average from three replicate plots.**

The full effectiveness of the Surround® application was somewhat surprising. The product was applied using a hand sprayer, so coverage of the plants was less than 100%. Coverage was further reduced by overhead irrigation and heavy rain during the trial. Despite this, none of the Surround® sprayed cayenne chillies that were examined were found to be infested.

**Figure 15. Kaolin spray on birdseye chilli plants.**

Unlike the results for capsicum plants, yield and/or quality were not significantly enhanced in either birdseye or cayenne netted chilli plants.

However, yield was measured at a single point in time. In reality, chilli plants are picked continually over weeks or even months. Any differences between the treatments would have been more clearly measured had red fruit been harvested weekly from selected plants.

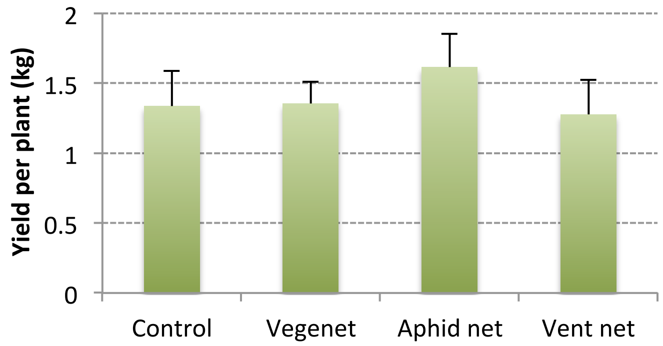



**Figure 16. Total yield from birdseye chilli plants grown under different types of netting or left uncovered. Plants were strip picked at the start of commercial maturity. Bars indicate the standard error of each mean value (n=9)**

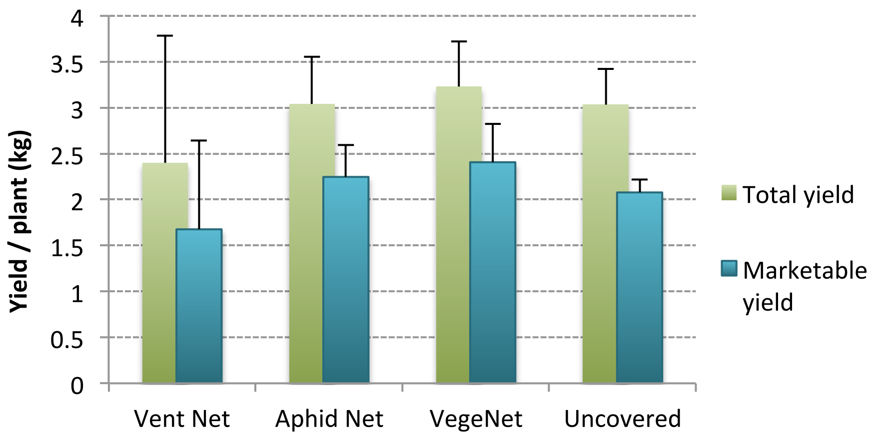



**Figure 17. Total and marketable yield from cayenne chilli plants grown under different types of netting or left uncovered. Plants were strip picked at the start of commercial maturity. Bars indicate the standard error of each mean value (n=9)**

Although yield from the plants covered with Aphid Net was similar to that of other treatments, as the trial progressed major differences occurred. No insecticides were applied during the trial, as the objective was to provide high pest pressure. In both 2014-2015 and 2015-2016 the crop was rich in beneficial insects, with pests generally kept under control.

The plants under the Aphid Net were an exception. These nets excluded beneficial insects, with the result that once aphids penetrated the cover, the population exploded. The plants then rapidly deteriorated in condition; continual harvests would likely have demonstrated this decline in plant health.

**Figure 18. Heavy infestation of aphids underneath the Aphid Net. Aphids were not observed on other plants, suggesting that beneficial insects were keeping populations under control in other plots, but were unable to penetrate the fine mesh netting.**

## 1.4. Discussion

### 1.4.1. Fruit flies

The results indicate that floating row covers are an effective method to exclude fruit flies from vegetable crops.

The VegeNet was lighter than either the Insect Net or the Vent Net, and effectively excluded fruit flies from the plants. The trap catches were confirmed by observations of infestation rates in fruit. Fruits covered by the VegeNet only became infested when large holes were torn in the material, or the sides pushed up, breaking the integrity of the barrier.

The Vent Net was more effective than expected. The mesh size was large enough to allow male flies to enter when attracted by cuelure. However, it was still a visual barrier, which may explain the low level of infested fruit when plants were covered by this material.

The Aphid Net was highly effective at excluding fruit flies, but the increase in aphid populations is a clear concern. Had normal spray practices been followed and the nets kept fully sealed to the ground, this may have been less of an issue. The nets themselves were quite translucent, which could be a distinct advantage if light levels are low. However, it may also offer less “disguise” to fruit flies seeking host fruit.

The 2m high “fly fences” were not effective. It seems likely that overhead irrigation and sunlight fairly quickly de-activated the insecticide that had been applied to the Vent Net material. Flies landing on the barrier could then have simply climbed through the mesh, unharmed. It is also probable that the enclosures were too small and low to properly exclude flies. Although the idea of “fly fences” should work in theory, this was not a practical solution for vegetables farms.

The success of the Surround® kaolin clay powder is a standout result from these trials. Even though application of the material was sub–optimal, no infested fruit were found when cayenne chillies were coated with this material. It is possible that the presence of unsprayed crops in the adjacent row – offering the flies an easy alternative host fruit in which to oviposit – increased the effectiveness of the kaolin application.

Nevertheless, the results are extremely encouraging and warrant further investigation, especially if a method can be found to easily remove kaolin from treated fruit.

The results also appear to confirm that fruit flies primarily use their eyes to find host fruit. Even though neither Surround® nor Vent Net was a physical barrier to flies, both effectively disguised the host fruit and significantly reduced infestation. Applied over a larger area, with obvious hosts less readily available, these strategies may lose some of their effectiveness. However, visually disguising host fruit is clearly a valuable tool to add to systems approaches for fruit fly management.

### 1.4.2. Plant health

The increase in marketable yield of capsicums was an unexpected benefit of using the nets. The floating covers reduced sunburn, and excluded a range of larger pests. It seems possible that diffusion of light by the nets provides a better environment for plants to grow, almost similar to conditions inside a larger scale net house or greenhouse.

Improvements in quality and/or yield could help to offset the not–insignificant cost of netting, making this an economically viable option for vegetable farmers.

# 2. Net trials for capsicums, Bundaberg

## 2.1. Aim

To test the effectiveness of different types of netting for fruit fly management in capsicums in Bundaberg.

## 2.2. Materials and Methods

A series of four trials were conducted on four commercial capsicum crops (Barbero Farms Pty Ltd) grown around the Bundaberg area.

Capsicums were assessed as:

**green** **green-red** **neutral** **red-green** **red**

1. **Excellent** quality. Fresh, well formed, glossy, free of defects
2. **Good** quality. Fresh, minor defects (eg slight thrips injury, sunburn) but marketable
3. **OK** quality. Defects obvious but do not affect eating quality, just marketable
4. **Poor**. Not marketable due to rots, insect damage, significant sunburn etc.
5. **Very poor**. Extensive rots or other damage, completely inedible

### 2.2.1. Trial 1 – February to May 2015

Capsicum seedlings were planted at the beginning of February 2015. The nets were installed four weeks later, which allowed time for the plants to establish. At this stage plants were approximately 40cm high and starting to flower.

Two 30m long sections each of VegeNet and Insect Net were used in the trial. As the Insect Net was relatively heavy for a floating cover at 125g/m$^2$, it was suspended over the plants using cloche hoops. These are used for low tunnels, particularly for cut flower production. The hoops can be unclipped on one side to allow access to the crop. The cloche hoops were placed at 2m intervals, and clamped the net quite tightly.

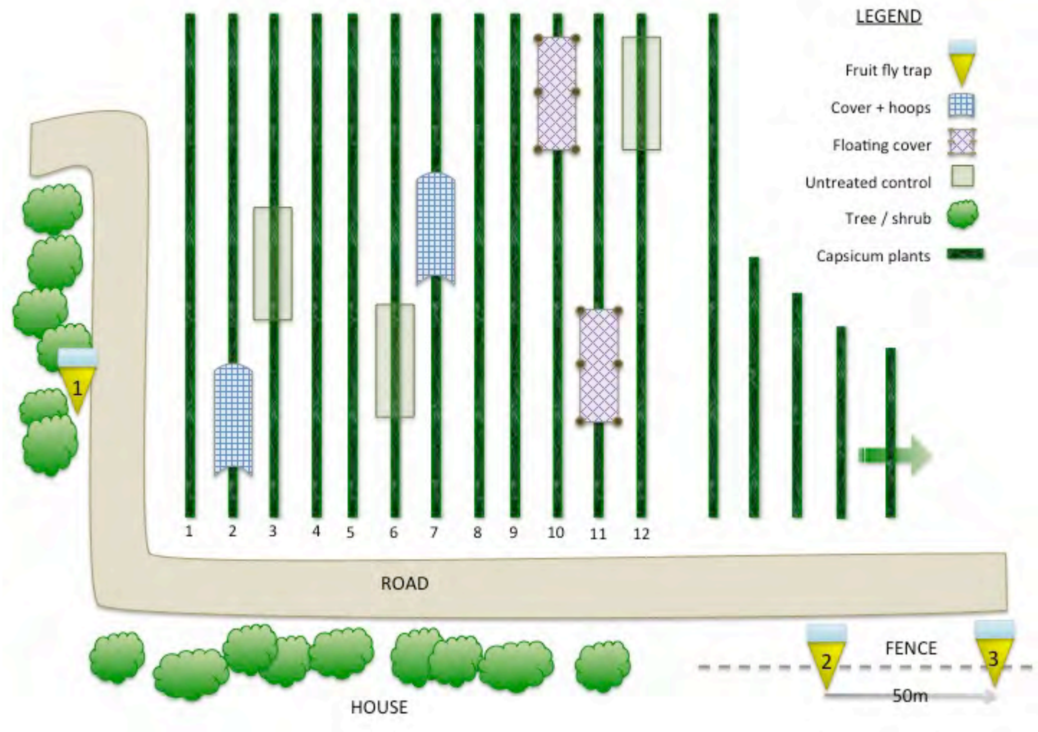



**Figure 19. Trial plan for capsicums in Bundaberg**

Yellow sticky traps were placed inside and outside each netting type to monitor insects. Temperature and humidity data loggers were installed within the uncovered crop and under each netting type.

**Figure 20. VegeNet (left) was draped directly on capsicum plants while the Insect Net (right) was secured using low cloche hoops**

Five days before the first commercial harvest the netting was removed and 2 x 5m long sections in the centre of each unit were vacuumed using an electric blower-vac. Insects were collected and kept for counting and identification (Figure 21).

**Figure 21. Temperature logger installed within the crop and collecting insects using an electric blower-vac**

Yield and quality was assessed using eight randomly selected plants from each treatment block (including the untreated controls). These plants were strip-picked of all fruit, including those below marketable size (n=16 / treatment). The harvested fruit were individually weighed and assessed in terms of insect damage, colour and quality. Total yield, total potential yield and marketable yield were calculated for each treatment.

### 2.2.2. Trial 2 – May to July 2015

This trial essentially repeated the procedure for trial 1, but only compared VegeNet to the uncovered plants. Three large (20m x 50m) sections of net were used, each covering three rows in different sections of the crop. The nets were applied to plants that were already flowering and just starting to set fruit.

Yield and quality were assessed by strip picking ten randomly selected plants from each plot (10 x 3 = 30 fruit/treatment). Capsicums were assessed for colour and marketability.

**Figure 22. Large sections of VegeNet were used to cover three rows of capsicums within a commercial crop. Crop shown at the start (left) and end of the trial.**

### 2.2.3. Trial 3 – July 2015 to November 2015

This trial was conducted during the coldest time of the year. In Bundaberg, harvesting of the autumn capsicum crop usually finishes by mid-July. While the spring crop is planted at about this time, there is a break in production between August and November. While capsicum production in Bowen covers much of this period, there is a period of several weeks when supply is short in the market. Increasing the temperature around capsicum plants could bring harvest forward. Earlier maturation, particularly if it increased the number of red fruit, could be a major benefit of using frost protection materials.

Frost protection materials are cheaper than nets, being designed for single use. This would avoid issues with cleaning and storing nets, while minimising the initial outlay for the materials needed.

Like small mesh nets, frost protection fleeces provide both a physical and a visual barrier to fruit flies entering the crop. Even if not fully secured around the edges, it was expected that they would effectively prevent infestation of the capsicums thus protected.

This trial therefore tested the application of different weights of fleece. Fleece material was applied in 20m sections to 1 week-old capsicum seedlings. Four separate rows of capsicum were used, with uncovered buffer rows in-between those used for the trial (Figure 23). As this was a winter crop, capsicums were planted in a single row, rather than a double row as is usual during warmer months. The edges of the fleece were secured with soil (Figure 24).

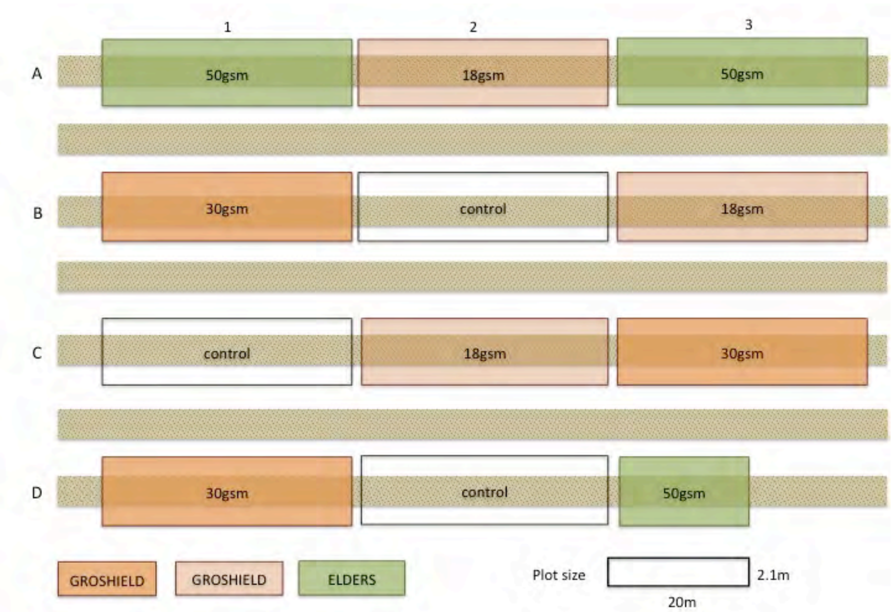



**Figure 23. Trial 3 plan in Bundaberg**

**Figure 24. Trial 3 initial setup**

Capsicums were harvested at commercial maturity. Six plants per treatment unit were strip picked, counted and weighed then assessed for colour and quality.

### 2.2.4. Trial 4 – November 2015 to January 2016

Previous trials found benefits from floating row covers including increased yield and quality of fruit, and a reduction in insect pests. However floating row covers can disrupt farm practices, such as spraying and weed control. Ideally, nets should be placed on the crop as late as possible, but early enough to still allow for the benefits that the row covers provide. This trial tested the application of VegeNet at three crop stages;

1. At flowering — 11th November 2015
2. Maturing fruit — 9th December 2015
3. Three weeks pre-harvest — 18th December 2015

Single rows of capsicums were covered using 10m long sections of VegeNet at the appropriate times. Fruit fly traps (Biotrap®) baited with FT Mallet CL wafers were placed in one plot per treatment and checked fortnightly for fruit flies. Air temperature and humidity were recorded as previously.

All fruit from six plants per plot were harvested on 13 January 2016. Fruit were weighed and assessed for colour (red, red-green, neutral, green-red or green), quality grade (perfect, good, ok, and non-saleable), and defects such as rots.

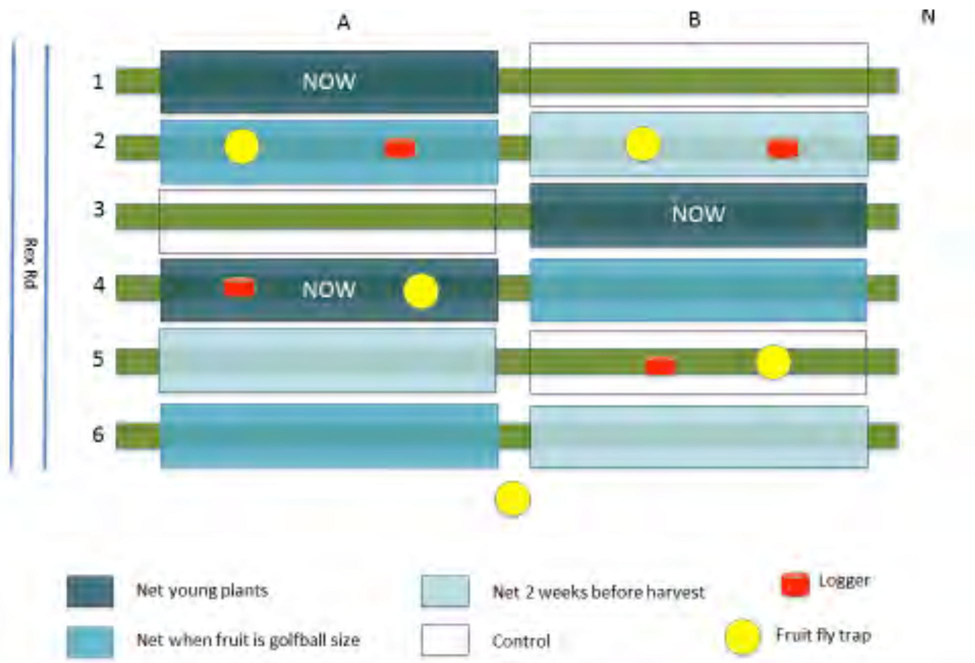



**Figure 25. Trial plan for testing the optimum time for application of VegeNet to a capsicum crop in Bundaberg**

**Figure 26. Size of plants when nets were first installed (left, top), second installation (right, top) and fruit three weeks prior to harvest when final installation was completed (below)**

## 2.3. Results

### 2.3.1. Trial 1

The number of insects found in the crop was very low, especially when compared with insect populations in the Sydney trial. While slightly fewer insects were caught under the VegeNet, numbers were too low to detect any differences between treatments. A large number of whiteflies (>50 per sheet) were caught on yellow sticky traps that were suspended under the frames. Fewer were caught in the uncovered crop, and fewer again in the perimeter vegetation. This indicated that even fine insect mesh was unable to exclude these pests from the crop, and that populations could even be increased in such a protected environment.

No fruit flies were detected in the crop.

**Table 1. Total insects captured by vacuuming 3 x 20m sections of crop**

| | Uncovered | Hoops | Netting |
|---|---|---|---|
| Thrips | 2 | 5 | 3 |
| Whitefly | 7 | 3 | 3 |
| Aphids | 2 | 0 | 0 |
| Jassid | 1 | 0 | 0 |
| Beetle | 0 | 0 | 1 |
| Heliothis | 0 | 4 | 0 |
| **TOTAL** | **12** | **12** | **7** |

Capsicum quality in this trial was very good, with nearly all fruit graded as marketable and a very high percentage scored as Grade 1. While total yield per plant was similar across the three treatments, 92% of capsicums from netted plants were classed as Grade 1, compared to 80% of capsicums from the uncovered plots. Plants covered by Insect Net with hoops were intermediate.

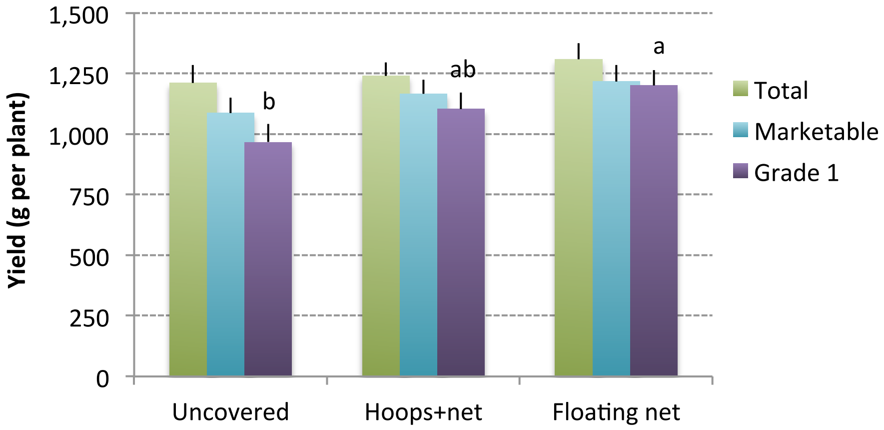



**Figure 27. Total yield, marketable yield, and the amount of fruit scored as Grade 1, recorded as g per plant in Trial 1. Bars indicate the standard error of each mean value. Total and marketable yield were not significantly different at p<0.05. Yield of grade 1 fruit was significantly increased under the floating VegeNet compared to the uncovered control (p=0.064).**

Around 23% of uncovered fruit were graded as red-green or green-red compared to 13% of the fruit grown under VegeNet.

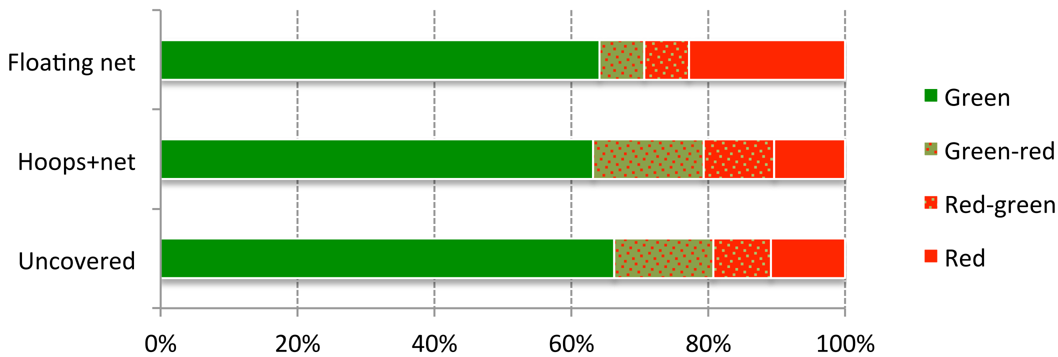



**Figure 28. Colour of harvested capsicums grown under floating VegeNet, hoops with Insect Net or left uncovered.**

### 2.3.2. Trial 2

Again, in this trial, the number of insects found in the crop remained extremely low. No differences were observed between the netted and control plots, or between the edges of the netted plots and the centres. No fruit flies were observed or trapped within the crop.

**Table 2. Average number of insects trapped by vacuuming 20m sections of the crop in plots covered, or not covered with VegeNet. Values are averages per section examined (n=4).**

| | Control | Netted - edge | Netted - centre |
|---|---|---|---|
| Bugs | 6.5 | 1.3 | 0.3 |
| Thrips | 3.8 | 5.0 | 4.3 |
| Aphids | 2.4 | 10.7 | 8.7 |
| Leaf hopper | 0.3 | 0.7 | 0.3 |
| Whitefly | 0.7 | 1 | 3 |
| Flea beetle | 1 | 0 | 0.3 |
| Beetle | 1.5 | 0 | 1.0 |
| Mites | 1 | 0.7 | 4.7 |
| Lacewing | 0.7 | 0 | 0 |
| Wasp | 3.2 | 3.7 | 3.3 |
| **TOTAL** | 21.1 | 23 | 26 |

a

The average number of fruit per plant was significantly affected by the floating VegeNet cover, increasing from 3.9 in the uncovered controls to 4.6.

Significant increases in total yield ($p<0.001$), marketable yield ($p<0.001$) and the yield of grade 1 fruit ($p=0.002$) were found in plants grown under the floating net. Total yield was increased by 27% in the netted crop. In this case a similar percentage (86–87%) of yield was classified as grade 1, but the higher yield under the netting resulted in an increase of 210g grade 1 fruit per plant.

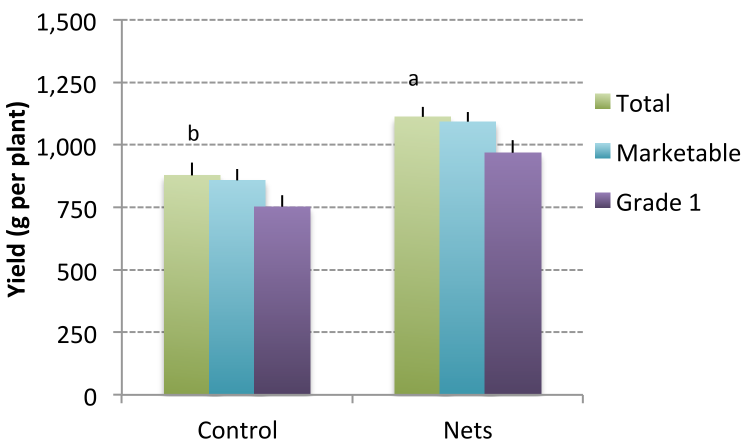



**Figure 29. Total yield, marketable yield, and the amount of fruit scored as Grade 1 from plants grown under floating covers of VegeNet (Nets) or uncovered controls (Control). Values recorded as g per plant. Bars indicate the standard error of each mean value. Letters indicate means of the same measurement that are significantly different ($p<0.05$)**

As previously observed, maturity was more compressed among capsicums grown under the netting. Although a similar percentage were red, the remainder was less likely to be mixed colour than found in the uncovered crop.

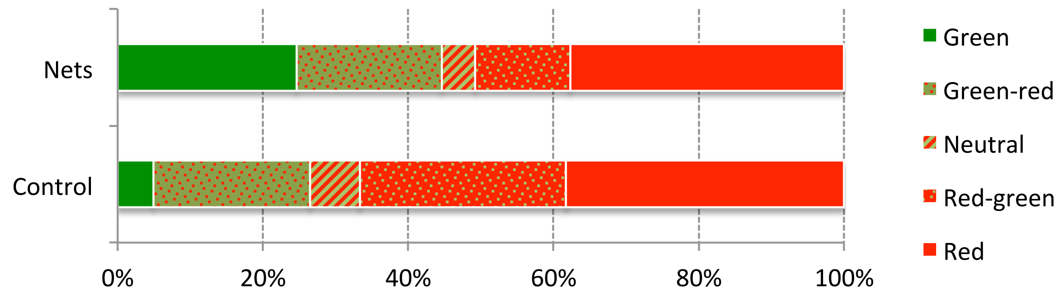



**Figure 30. Colour of harvested capsicums grown under floating VegeNet or left uncovered.**

### 2.3.3. Trial 3

Significant numbers of fruit flies were trapped during this trial, even though it was conducted during the cooler months. During October and November 2015, traps caught on average 16 flies per week. These were not all Qfly, with slightly more of the flies caught identified as *B. neohumeralis* or Lesser Queensland fruit fly. Traps also caught significant numbers of *B. bryoniae* – another fruit fly species believed to infest capsicum fruit – and *Dacus aequalis* – which is not considered to be an economic pest.

Despite this, no fruit flies were found in the crop itself, and no infested fruit were found during the trial.

As previously noted for netting, plants grown under the fleece appeared larger and healthier than those grown without this protection. To determine if this was the case, three plants per plot were cut at the base during growth. The fruit were stripped and total shoot weight of each plant recorded. Plants grown under fleece were approximately one-third larger, and significantly heavier than the uncovered plants ($p<0.001$).


Total yield was markedly increased under the 18gsm fleece (p=0.006), but not under the heavier material. The 18gsm fleece also significantly increased marketable yield (p=0.019) and the yield of grade 1 fruit (p<0.001) compared to the uncovered control plants. Effectively, the 18gsm fleece doubled the number of high quality fruit. While this result appears highly promising, it needs to be repeated to confirm these benefits.

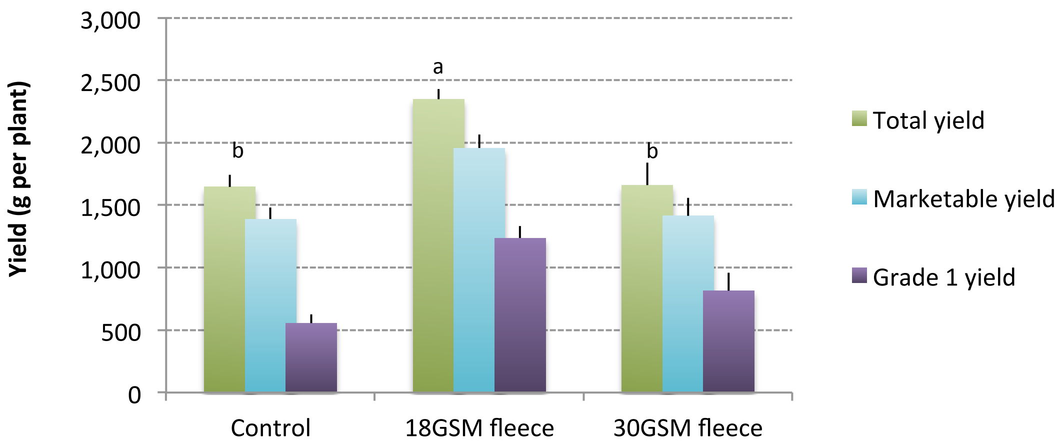



**Figure 31. Total yield, marketable yield, and the amount of fruit scored as Grade 1 from capsicum plants covered with floating covers of 18gsm or 30gsm frost protection fleece, or left uncovered (Control). Data recorded as g per plant. Bars indicate the standard error of each mean value, letters indicate means that are significantly different.**

Unlike previously observed with the netting, fleece had no effect on capsicum fruit maturity in terms of colour at harvest. There was evidence that capsicums grew faster under the fleece. Measurements while fruit were still maturing found significant yield increases (p=0.004) of up to 62% in plants covered with 18gsm fleece compared to the uncovered controls. By the time fruit was ready for commercial harvest, this difference had decreased to 43%.

This suggests that fleece allowed plants to grow faster while conditions were cool, but that the uncovered plants caught up to some extent when the weather warmed. Unfortunately this difference did not increase production of red capsicums early in the season, when supply is short and prices are high.

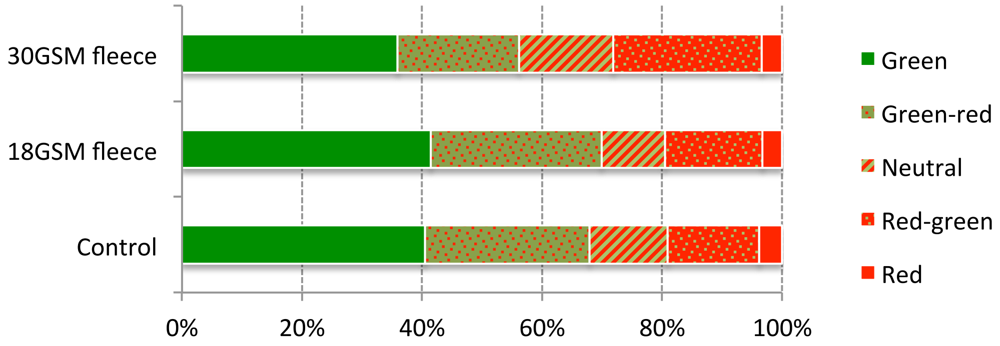



**Figure 32. Colour of harvested capsicums grown under floating covers of 18gsm or 30gsm fleece or left uncovered.**

A number of issues were encountered during the trial. Wind and storms damaged the fleece causing some large tears, especially the heavier grade material. As a result, no results were obtained from the 50gsm fleece plots. While losing the integrity of the seal did not necessarily affect the plants, they would have significantly reduced the potential of these materials to act as a barrier to fruit flies.

### 2.3.4. Trial 4

Fruit fly traps were placed within this crop approximately one month prior to harvest. Average catches during this period were;

| | Flies/trap/week |
|---|---|
| Netted at flowering | 1.3 |
| Netted maturing | 0 |
| Netted 3 weeks pre-harvest | 1.0 |
| Uncovered crop | 9.1 |
| Perimeter trees | 32.3 |

In this trial the VegeNet was not completely effective at keeping flies out of the crop. Most flies were found in the traps during the two weeks prior to harvest.

At this time weeds had grown up between the rows, which affected the integrity of the nets. The crop was also heavily rain damaged, and was subsequently abandoned as a commercial crop. Many fruit were rotting, while the warm, humid conditions created an environment ideal for flies. This may partially explain the high numbers of flies that were found, both inside and outside the crop.

Although yield / plant was reasonable, the number of marketable fruit was low and the number of grade 1 fruit less again. Most rejection was due to rots, an issue only rarely observed in previous crops. Plants were collapsing, and generally in very poor condition.

Despite this, total yield was increased for plants covered with VegeNet while fruit were maturing or 3 weeks before harvest (p=0.024) compared to the uncovered controls. Marketable yield was increased in plants that were netted at flowering or while fruit were maturing (p=0.06). Plants netted while fruit were maturing had half the number of rotten capsicums compared to that found for the uncovered controls.

**Figure 33. Condition of capsicum plants in trial 4 at assessment time. Crop was severely damaged by heavy rain combined with hot summer weather.**

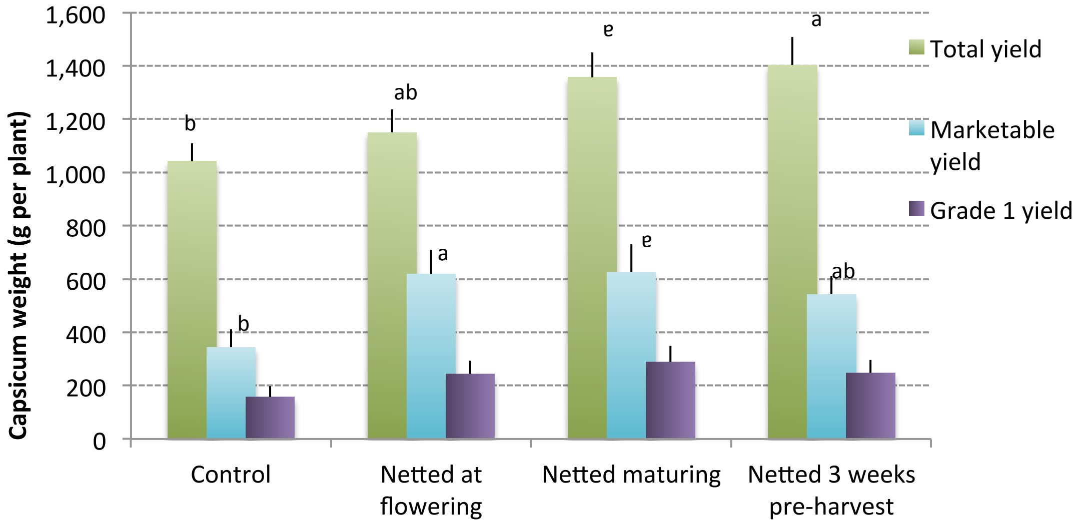



**Figure 34. Total yield, marketable yield, and the amount of fruit scored as Grade 1, recorded as g per plant in Trial 4. Bars indicate the standard error of each mean value. Letters indicate means that are significantly different.**

Although there was a trend to narrower maturity in the crops netted early in the trial, the results are unreliable due to the extensive crop damage.

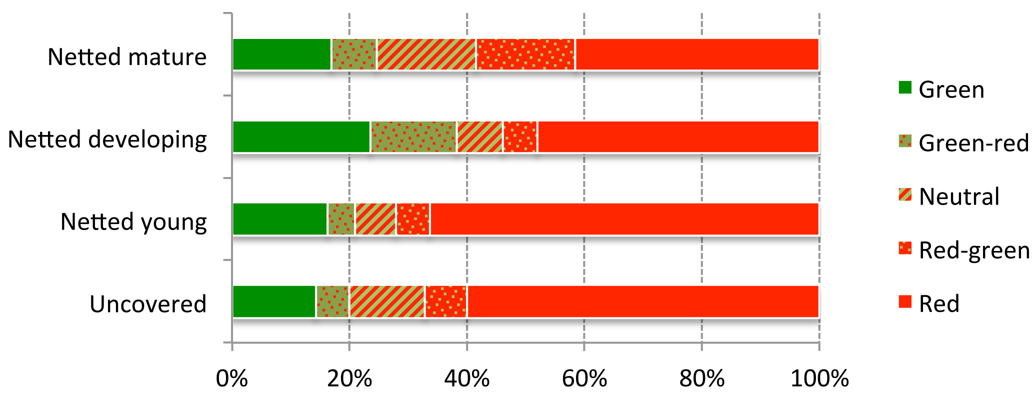



**Figure 35. Colour of harvested capsicums covered with floating covers of VegeNet while young, as fruit were developing, or close to harvest maturity. Controls were left uncovered.**

## 2.4. Discussion

Although fruit flies are endemic in Bundaberg, and can be trapped in high numbers in vegetated areas, they are rarely found in capsicum crops. HIA project VG06028 (Subramaniam, 2011) also found that capsicums were rarely infested in the field, even though fruit fly was consistently trapped in the surrounding vegetation. Field cover sprays for other insect pests were considered to be largely responsible for this effect.

Given the chemical controls in place on commercial vegetable farms, it seemed unlikely that any effect of netting on infestation of fruit would be recorded during these trials. The only exception to this could have been the final trial, where significant numbers of fruit flies were recorded in the crop.

Trials in NSW demonstrated that fruit fly can be effectively excluded from vegetable crops using netting. The trials in Bundaberg reported here therefore focused on the effects of netting on capsicum productivity and yield.

The trials have confirmed that fruit quality and yield is increased under netting. In some trials the effect was slight, but in others there was a significant benefit. The increase in total yield ranged from 10 to 42%, while the increase in marketable yield ranged from 12 to 82%. The largest effect was observed in the crop grown during winter – grade 1 fruit per plant increased from 556g/plant in the uncovered crop to 1.24kg/plant in the plots covered with 18gsm fleece.

Plants growing under floating covers grew larger, and appeared generally healthier. This was likely due to diffusion of light, as well as protection from the strong winds that occur in Bundaberg at many times of year. Perhaps as a result, the best results were gained when netting was applied early in the cropping cycle, or while fruit was still developing.

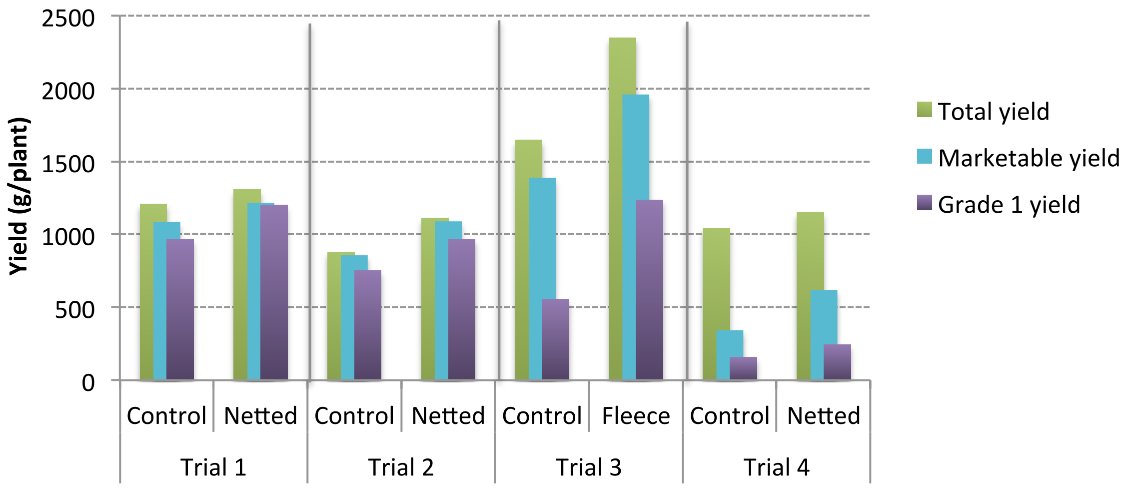



**Figure 36. Summary of total yield, marketable yield, and the amount of capsicums scored as Grade 1 when plants were grown under VegeNet / 18GSM fleece compared to uncovered control plants. Yield recorded as g per plant from four trials in Bundaberg.**

Although there was a trend to a smaller spread of fruit maturity under the netting materials, the effects was not consistent for all trials. It had been hoped that netting and/or fleece would advance capsicum maturity, but the results were inconsistent between trials, so do not substantiate this hypothesis.

# 3. Net trials for chillies, Bundaberg

While it was clearly not possible to augmentatively release fruit flies on commercial vegetable farms in Bundaberg, agreement was reached with Austchilli Pty. Ltd. to leave a section of a cayenne chilli crop unsprayed. This would allow us to determine background levels of infestation. The grower also suggested monitoring a crop of habanero chillies; although this crop was subject to normal commercial practice, habaneros are particularly prone to fruit fly infestation.

Chillies were very suitable for this trial because they are an extremely attractive host for fruit flies. It is also easier to find fruit fly larvae in chillies than in capsicums, and their small size allows a higher degree of replication than is practically achievable with capsicums.

## 3.1. Aim

To examine the effect of netting on infestation of chillies in Bundaberg.

## 3.2. Materials and Method

Three trials were conducted on chilli crops grown by Austchilli Pty Ltd on properties close to Bundaberg.

Unfortunately trial 3 was destroyed by an extreme rain event, so only the results of the first two trials are reported.

### 3.2.1. Cayenne chillies

Two or three-week old cayenne chilli plants in a commercial planting in Bundaberg were covered with 10m lengths of either VegeNet or 18g/m$^2$ fleece on 10 December 2015. In each of the two and three week-old plants there were two replications of each treatment. Temperature and RH were monitored as previously.


**Figure 37. Trial setup on cayenne chillies. A block of chili plants 12 rows wide x 20m long was left unsprayed during the trial. Fruit fly traps were installed under the nets and inside the crop.**

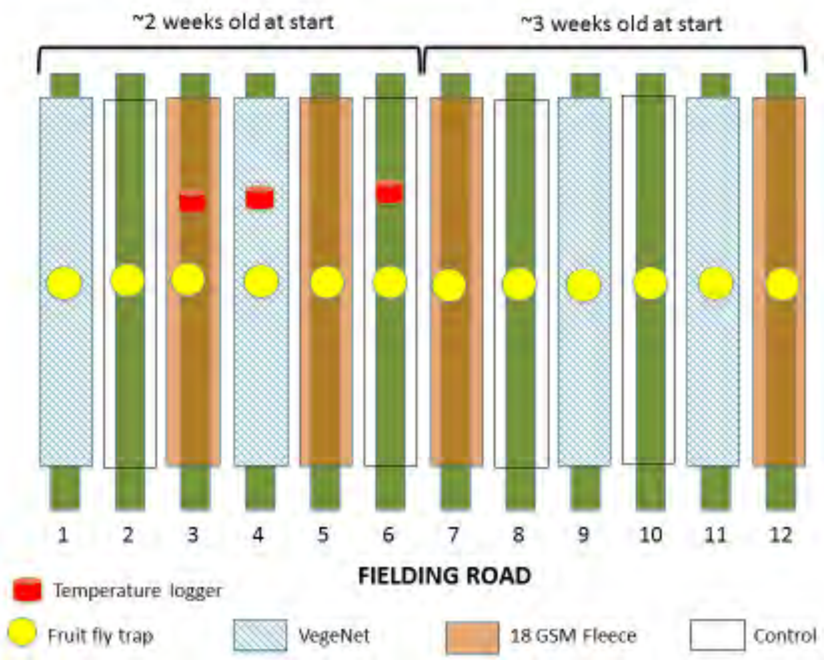



**Figure 38. Trial setup on Cayenne chilli plants in Bundaberg**

The chillies were not sprayed with any fruit fly insecticides, but all other commercial practices remained the same. Fruit fly traps (Biotraps) baited with FT Mallet CL wafers were located within the crop and under netting. These were checked fortnightly during the trial.

**Figure 39. Mature cayenne chilli plants. Plants grown under the nets (right plant in picture at left) grew larger than uncovered plants (left). Chilli plants generally grew much larger than capsicums, with the result the nets could not be properly sealed (right).**

Once fruit were mature, 50 fully-red fruit were randomly harvested from each plot fortnightly. Fruit were incubated at approximately 25°C for up to five days then checked for signs of fruit fly larvae.

Yield and quality were assessed on 10 February 2016. Six plants from each treatment plot were cut at soil level, with whole shoot weight, fruit weight, fruit colour and other quality attributes recorded.

### 3.2.2. Habanero chillies

Three 10 m sections of VegeNet were placed on an established commercial crop of Habanero chillies in Bundaberg in December 2015. Controlling fruit fly is particularly challenging on this variety, which appears to be highly attractive to Qfly. The crop was being managed under an IPM program, meaning that some – although minimal – insecticides were being used during production.

Three uncovered sections were marked out as uncovered controls. Fruit fly traps were placed in both control and netted plots and checked fortnightly during the trial (Figure 40).

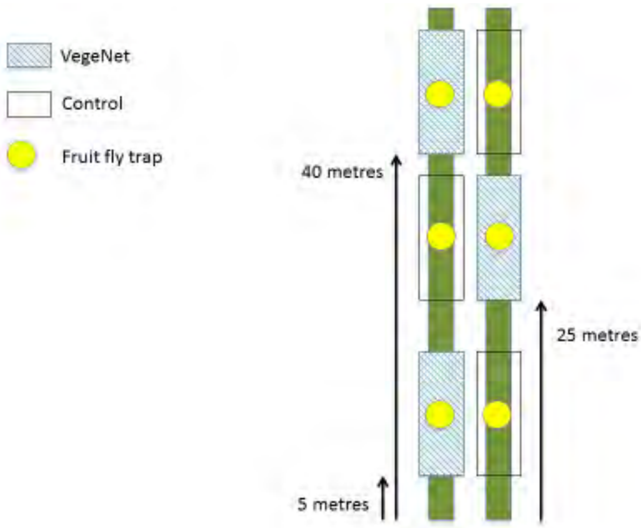



**Figure 40. Trial setup on Habanero chillies in Bundaberg.**

Once nets had been in place for 3 weeks, randomly selected samples of 50 mature (red) fruit were harvested from all six treatment plots. Fruit were incubated at approximately 25ºC for 4 days to allow for any larvae to develop. All fruit were then cut open and examined for signs of fruit fly infestation. This process was repeated fortnightly.

**Figure 41 - Trial using nets on habanero chillies at New Farm Rd, Bundaberg. Plants were already large at the start of the trial.**

One problem encountered during this trial was that the habanero plants grew very large. This made it impossible to properly secure the nets at the base, as they were too narrow to properly cover such large plants. The nets were replaced, however the trial was abandoned shortly afterwards due to heavy rain which destroyed the crop.

## 3.3. Results

### 3.3.1. Cayenne chillies

The cayenne chilli plants grew too large for the width of the nets, and so proved challenging to secure the nets, especially under windy conditions. The fleece material was also too narrow and could not be effectively secured to the ground, so was removed soon after trial commencement. Nine weeks after the trial was set up, fruit fly began to get under the netting where it had become unsealed (Figure 42).

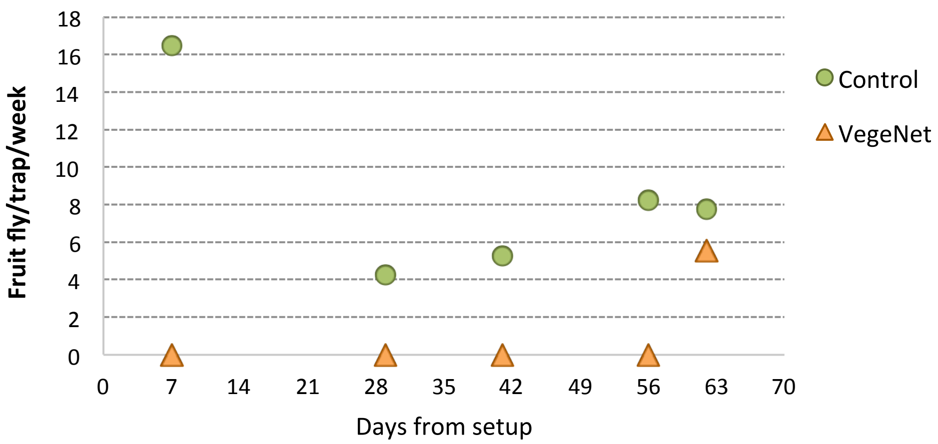


**Figure 42. Fruitflies trapped per week in unsprayed cayenne chilli plants covered with VegeNet or left as uncovered controls.**

Fruit fly larvae were found in both the uncovered and netted crops. However, only one larvae was found during each examination of 200 fruit from netted plants, compared to up to 16 larvae per 50 fruit sample from the uncovered plants.

**Table 3. Average number of fruit fly larvae found per 100 cayenne chillies examined (n=4).**

| | Larvae per 100 fruit | |
|---|---|---|
| | Day 56 | Day 62 |
| **VegeNet** | 0.5 | 0.5 |
| **Control** | 7 | 19 |

Unlike the results observed for capsicums, netting did not improve yield or quality of chillies. Total yield was the same or significantly reduced in chilli plants netted two or three weeks after planting respectively. The number of fruit per plant, average fruit weight and the percentage of rotten fruit were not significantly affected by netting. The proportion of red fruit tended to be slightly reduced, rather than increased under the netting (Figure 43).

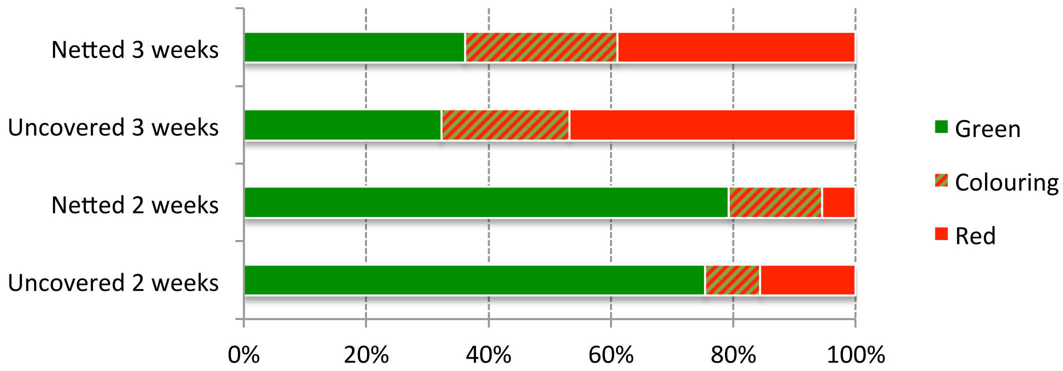



**Figure 43. Colour of harvested capsicums covered with floating covers of VegeNet either two or three weeks after transplanting compared to uncovered control plants of the same age.**

### 3.3.2. Habanero chillies

After only two weeks, the VegeNets became ineffective at protecting the crops from fruit flies. This was because the plants grew too large for the nets to be properly secured to the ground. Four weeks after the trial started the nets had been lifted from the ground, exposing the bases of the plants. As a result, flies entered the crop.

Trap catches were much lower in the Habanero chillies than the unsprayed cayenne chillies. Four weeks after the trial started, just as many fruit flies were caught under the net as were caught in the uncovered crop.

**Figure 44. The habanero chilli plants grew so large the net could no longer be secured to the ground**

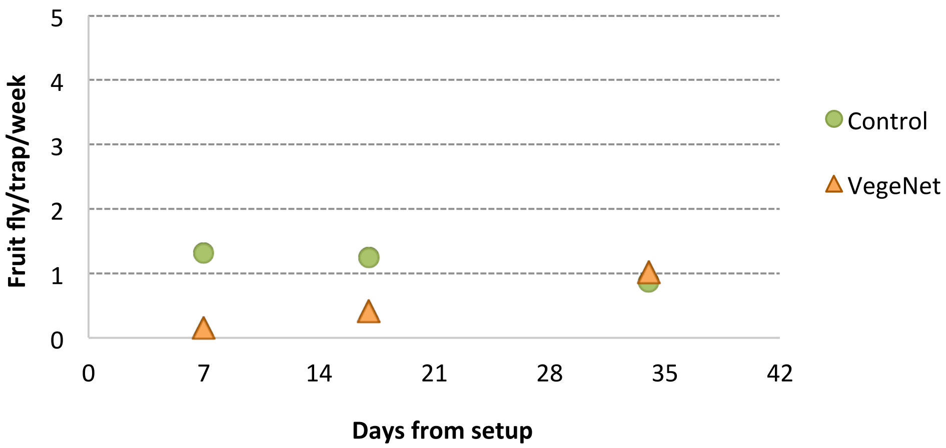



**Figure 45. Fruit flies trapped per week in IPM grown Habanero chilli plants covered with VegeNet or left as uncovered controls.**

Once fruit flies started to be trapped in the crop, larvae were found infesting the fruit.

**Table 4. Average number of fruit fly larvae found per 100 habanero chillies examined (n=4).**

| | Larvae per 100 fruit | | |
|---|---|---|---|
| | Day 7 | Day 17 | Day 34 |
| **VegeNet** | 0 | 0 | 1.3 |
| **Control** | 8 | 2.7 | 1.3 |

## 3.4. Discussion

There are key differences in the responses of chilli plants to netting compared to those of capsicum plants.

Chilli plants are considerably larger and more densely foliaged than capsicums. This made it difficult to secure floating row covers. The trial plots testing fleece were abandoned, as the material was too narrow to properly cover the plants. Fleece was also easily torn – while tearing had been an issue on capsicums, the problem was increased in chilli plants due to their taller structure. It became clear fleece was not going to be an option for chilli plants only a few weeks into the trial.

Similar issues were encountered with netting, the cayenne chilli plants growing extremely large. It is interesting that no such issues were encountered in Sydney – possibly due to the cooler environment, or simply to the variety of cayenne chilli that was planted.

The netting only excluded fruit fly for as long as it was properly secured. This is consistent with results from the Sydney trials, which also found that nets that had been torn by workers, or partly blown off the plants, allowed fruit fly into the crop. Although a significant part of the success of netting is due to it acting as a visual, not just physical, barrier, if holes appear it soon loses effectiveness.

# Appendix 2

# UV light tests, Macquarie University

# Emitted light as a potential attractant for monitoring and lure and kill management of Queensland fruit fly

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Final report for Macquarie University subcontract on
Horticulture Innovation Australia Project VG13042:
New in-field treatment solutions to control fruit fly (2)

## SUMMARY

Fruit flies, including Queensland fruit fly (‘Q-fly’), are known to be attracted to certain colours and this information is used routinely in the development of effective traps. We here considered the possibility that Q-fly might be attracted not only to sunlight reflected off coloured surfaces as reported in the literature but also to emitted light, which might then serve as a foundation for development of novel light-based attractants for monitoring or lure-and-kill management tools.

In laboratory trials, Q-fly exhibited very distinctive responses to three types of light; fluorescent UV, green LED and fluorescent white. Both males and females were attracted to UV light when tested at both 5 and 10 days of age. Attraction to UV light was especially pronounced at and for several hours after dusk, the usual period of mating for Q-fly, suggesting that attraction to UV light is associated with mating activity. Q-fly were also attracted to green LED light, but timing of attraction was very different to what was observed for UV light. Rather than being attracted to green light at and after dusk, flies were attracted to green light during the laboratory ‘day’ phase and showed no significant response to green light after dusk. Contrasting the attraction to UV and green light, both male and female Q-fly tended to avoid areas illuminated by white light in laboratory trials or, alternatively stated, tended to associate with areas of shade.

Attraction to UV light was also evident in trials carried out in a glasshouse where significantly more male and female Q-fly came into contact with a toxicant-treated citrus plant that was illuminated with UV light than was the case for a similar plant that was not illuminated. Very similar results were obtained in large field cages containing potted citrus trees, a larger scale again and with increased relevance to field settings. The two field cages in which trials were run differed in shading and this led to additional findings on how shade influences response to UV lights. The UV lights were far more effective at attracting flies to toxicant-treated trees when located in a shaded field cage than when located in an unshaded field cage, and this has implications for recommended placement of UV light emitting traps that might be developed for field application.

This study presents the first evidence that fruit flies, Q-fly specifically, can be attracted to light emitted by fluorescent UV globes similar to those found in commercial ‘bugzappers’ and can also be attracted to green LED globes. While substantial engineering and design work would be required to develop a light-emitting fruit fly trap, findings of this study encourage the development and exploitation of emitted light as a new mechanism for luring of fruit fly pests.

## INTRODUCTION

*Bactrocera tryoni* (Froggatt) (Diptera: Tephritidae), the Queensland fruit fly (or 'Q-fly'), is the most economically damaging fruit fly pest in Australia (Dominiak et al 2003, Dominiak and Daniels 2012). Q-fly is a highly polyphagous species, infesting more than 100 native and introduced hosts and causing significant economic impact from direct yield losses, management costs and loss of opportunities in domestic and international markets (Sutherst et al. 2000 Clark et al 2011). With increased regulatory restrictions on the use of cover sprays, there is an urgent need to develop alternative technologies for control of Q-fly and its relatives. Lure-and-kill devices are a prominent option, co-locating a toxicant with a lure. By this approach, toxicants can be isolated in a way that avoids potential contamination of produce or the environment. However lure-and-kill approaches rely on effective lures, and the development of new lures is a very active area of current research activity. Lure-and-kill devices for fruit flies vary in efficacy and they usually only target one of the sexes or a particular age class - protein-based baits can contribute to control of females and to some extent males, while cuelure attracts sexually mature male Q-fly (Weldon et al. 2008). A means of attracting those sex and age classes that do not respond to other attractants would be particularly valuable.

Tephritid fruit flies rely in part on visual cues to find food, mating sites and hosts for oviposition and these cues have been used in the design of trapping systems (Epsky and Heath 1998). Visual traps have been found to attract Q-fly (Hill and Hooper 1984, Schutze et al. 2016), and these offer some promise for wider use. Although not yet tested with tephritid fruit flies, there has been interest in the use of emitted light for manipulation of insect behaviour and particularly as an attractant for monitoring and lure-and-kill solutions (Shimoda and Honda 2013, Johansen et al. 2012). In particular, Ultra Violet (UV) light traps have been used to monitor populations of some insects and also for lure-and-kill, most often by using an electrical discharge system or 'Bugzapper' (Shimoda and Honda 2013). However, there are no reports in the literature of fruit fly attraction to emitted light sources and, given the urgent need for new fruit fly management tools, this is an option that should be considered. Drew et al. (2003) found adult Q-fly to be more attracted to bluish fruit-mimicking spheres that had an enhanced level of UV reluctance than to spheres that lacked UV reflectance. This response is thought to reflect responses of Q-fly adults to colours that resemble their ancestral rain forest host fruit such as *Gmelina* spp (Drew et al. 2003). *Gmelina* fruits reflect UV light due to a waxy bloom on the fruit's surface (Willson and Whelan 1989), and so it is quite possible that UV-reflectance has a role in Q-fly host location.

Knowing that emitted UV light attracts other species of flying insects and that it has been used to attract and kill other pests (Shimoda and Honda 2013, Johansen et al. 2012), the objective of this study was to investigate the potential effectiveness of light as an attractant for monitoring or lure-and-kill of immature and mature Q-fly females and males. Because UV light is well known as an insect-attracting wavelength, and because Q-fly appear to be attracted to UV-reflecting surfaces that may resemble certain fruit (Drew et al. 2003), particular attention was paid to the potential of emitted UV light as a Q-fly attractant. However, Q-fly also responds to other wavelengths of reflected light (Drew et al. 2003) and so responses to emitted green and white light were also considered. Experiments were conducted in several contexts ranging from highly controlled laboratory settings through to glasshouse and then large field cage enclosures.

## METHODS

*Phase 1: Light as an attractant in laboratory settings*

Source and maintenance of flies

Q-flies were obtained as pupae from the New South Wales Department of Primary Industries Fruit Fly Production Facility at Elizabeth Mcarthur Agricultural Institute, Menangle, New South Wales, Australia. Pupae were housed in mesh cages of 47.5 x 47.5 x 47.5 cm (Megaview Bugdorm 44545) and the adults emerged inside, with approximately 2,000 adults per cage. Cages were supplied with a sponge soaked in water and a Petri dish containing a 3:1 mixture of granular sucrose and dry hydrolysed yeast enzymatic (MP Biomedicals, Australia) for food. All cages were maintained in a laboratory under controlled temperature (25 ± 0.5°C) and humidity (65 ± 5%) on an 11:1:11:1 h light:dusk:dark:dawn cycle. During the light phase the laboratory was illuminated with a 50:50 mix of metal halide and halogen lights. At the commencement of the dusk phase, the metal halide lights turned off and the halogen lights lowered in intensity until switching off after 1h. At the commencement of the dawn phase, the halogen lights switched on at 5% output and then increased in intensity until at 100% output after 1h, at which time the metal halide lights turned on.

UV, White and Green light as attractants

Trials were conducted in an Oz Trail Gazebo Screen House Inner Kit, 280 x 280 x 280 cm, that was erected inside a controlled environment room. The screen house was divided in two by a 2m wide 1.80m high freestanding divider that was covered with black plastic. On top of the divider there were two covered plastic containers full of water. A slit was made in the middle of each lid and a sponge was inserted through the slit to keep the sponge in contact with the water in the container, and the water-soaked sponge accessible to the flies. A pole was fixed transversally to the divider and two plastic containers with food were suspended from the pole on each side of the divider.

Two light bulbs were suspended from the pole, one on each side of the divider. A sheet of black cardboard, bent for form a half-cylinder 'lampshade', was used to cover each light bulb so that the light was directed in front and below. Two sheets of clear transparency film (8.5 x 21 cm), covered with tanglefoot were suspended with hooks to the inside of the cardboard lampshade, in front of the light, to catch flies coming near the light. An artificial tree (Ikea Fejka, 170 cm high) was placed on each side of the divider (Figure 3).

Approximately 2000 flies were released in the screen house and were left for a day to acclimate before trials commenced (dawn at 2 am and dusk at 2 pm). The trial ran for 40 h starting at 6 pm. Two sheets of transparency film covered with tanglefoot were suspended in front of each light bulb (UV light Nelson 20W, White light Phillips 20W, cool daylight, Green light Liquid LEDs 2.5W) on both sides of the divider. The light on one side of the divider was left on while the light on the other side remained off. The sheets of transparency film were replaced every 2 hours between 10:00 am and 6:00 pm. After 6:00 pm the sheets of transparency film were left overnight and removed the next day at 10:00 am. Flies trapped in the tangle foot on the transparency film were stored in the refrigerator and later counted. Eight replicates were run for each of the three light types (24 trials in total), with half of the replicates using 5-day-old flies and half using 10-day-old flies.

**Figure 1.** Light settings for the UV light attraction experiments in controlled environment rooms.

<u>Light as a mating inhibitor</u>

An Oz Trail Gazebo Screen House Inner Kit, 280 x 280 x 280 cm, was erected inside each of two controlled environment rooms (dusk at 2pm and dawn at 2 am). An artificial tree (Ikea Fejka, 170 cm high) was placed inside each screen house and a UV or white light was suspended from the middle of the roof. In one room the suspended light was on and in the other room the light was off.

Flies were sorted by sex at 3 days after emergence and kept in two separate 5L plastic cages, 150 flies per cage. Once the flies were 12 days old, 100 females and 100 males were released in each room at 9 am (5 hours before dusk) and the number of mating pairs was counted every hour from until 6 pm. Three replicates were carried out using UV light and three replicates were carried out using white light.

Light as an oviposition inhibitor

Trials were ran in an Oz Trail Gazebo Screen House Inner Kit, 280 x 280 x 280 cm, erected inside a controlled environment room (dusk at 6pm and dawn at 6 am). The setting inside the screen house was similar to that described above. The light on one side of the divider was left on, while the light on the other side remained off. Perforated plastic bottles (250 ml) were used as oviposition devices. An orange segment was rubbed against the walls of the bottle and a piece of orange skin was suspended inside the bottle to stimulate oviposition. An oviposition device was suspended from each artificial tree (Ikea Fejka, 170 cm high), 1m away from the light bulb (Figure 4).

One cage of approximately 2000 7-day-old flies were released inside the screen house in the controlled environment room, 3 days before the beginning of the trial. At 10 days after emergence, when most flies have reached maturity and mated, oviposition devices were suspended from the artificial trees at noon for 48 hours. After removing the oviposition devices, we counted the number of eggs (by volume) in each device. Three replicates were completed using UV light bulbs and three were completed using white light bulbs.

**Figure 2.** Light settings for experiments on the effect of light on oviposition in a controlled environmental room.

*Phase 2: UV light as an attractant in a glasshouse setting*

Glasshouse trials were carried out in a 9 x 6 x 2.4 m glasshouse at the Plant Growth Facilities of the Department of Biological Sciences, Macquarie University, Sydney, New South Wales. A black plastic sheet was suspended from the ceiling so that it separated the glasshouse into halves up to a height of two metres. As a source of UV light on one side of the dividing sheet, a Bugzapper was suspended 1.80 m above the ground. No UV light was used on the other side of the plastic sheet. Between five and six thousand sexually mature flies, 12 to 28 days old, were released in the middle of the glasshouse. The plastic sheet did not completely isolate the two treatments such that flies could move freely between treatments (Figure 1).

Two lemon trees, each planted in a black plastic bag, were placed 1 m away from each side of the dividing plastic sheet. Three oranges and one capsicum were inserted in sticks next to the lemon trees. All four trees and were sprayed with Bulldock 25 EC insecticide at a concentration of 2 ml/L.  To collect dead flies, a 3 x 3 m sheet of white fabric was placed underneath each lemon tree. To ensure that dead flies were not lost in the potting soil, a sheet of tulle covered the soil around the base of each tree (Figure 1). Each day at noon, all flies found on the white fabric were collected and later counted until the day when no flies were found. Before each replicate the trees were re-sprayed with insecticide. Replicates lasted between three and six days. A total of three replicates were completed.

**Figure 3.** Experimental setting for glasshouse UV light attraction experiments.

*Phase 3: UV light as an attractant in a field cage setting*

A field cage of 24 m length x 4 m wide x 5 m high was divided into two 12 x 4 x 5 m enclosures using black 70% shade cloth positioned at the mid-point so that the two sides of the cage were completely separated. One field cage enclosure was shaded at one end by overhanging foliage, and so was somewhat darker and more sheltered than other other. At each end of the cage there was an entrance and at 2 m from each entrance two UV light bulbs (Nelson 20W, 200-240V, 50Hz) were suspended from a metal frame that provided both support for the lights and attachment for a sheet of white plastic that protected the lights from rain. The lights were 1.70 m above the ground so that the light shone onto a potted lemon tree placed 1.5 m away from the light. These potted trees were sprayed with Bullock 25 EC insecticide. Approximately five thousand recently emerged flies were released on each side of the cage. To collect the dead flies falling from the sprayed lemon trees, a 3 x 3 m sheet of tulle was placed underneath the foliage of the tree, supported by six 50 cm long poles inserted into the ground. Dead flies were collected around noon on each day for 11 days. The light bulbs were on 24 h / day at one end of the field cage (UV light treatment), and were off at the other end (No UV light treatment). Thirteen 100-200 cm tall, unsprayed, potted lemon trees were placed evenly through each enclosure (Figure 2). As food for released flies, yeast hydrolysate and sugar were provided in Petri dishes that were suspended on eight different trees in each enclosure. Water was also provided in water-filled plastic containers that had a slit in their lids where a sponge was inserted so that it was soaked with water. Eight water stations were set up for each treatment, with each station on a different tree. Insecticide was reapplied every four days. Potted citrus trees were irrigated twice each week. Six replicates were completed, with the lighting treatment (UV light/ No UV light) switching back and forth between the two enclosures.

**Figure 4.** Experimental setting for UV light attraction experiments in field cage enclosures.

## RESULTS

*Phase 1: Light as an attractant in laboratory settings*

UV Light as an attractant

The total number of flies captured over 24 hours on acetate sheets differed between the Light treatments (presence vs. absence of UV light) and Sexes (male vs. female), and with age (5 vs. 10 days old), as well as exhibiting a significant Sex x Light treatment interaction (Table 1, Figure 5). This significant interaction arises because in the absence of UV light there is no difference between the sexes in total number of flies captured (Least square mean ± standard error: Males 102.79±1.02, Females 84.73±1.02, Test Slice $F_{1,20.69} = 1.384$, $P = 0.253$) whereas in the presence of UV light significantly more males than females were caught (Least square mean ± standard error: Males 261.57±1.02, Females 159.24±1.02, Test Slice $F_{1,20.69} = 20.052$, $P < 0.001$). Significantly more flies were captured in the presence of UV light both for males (Test Slice $F_{1,20.69} = 57.810$, $P < 0.001$) and for females (Test Slice $F_{1,20.69} = 18.505$, $P < 0.001$). That is, although both sexes were more likely to be caught on the side of the cage where the UV light was positioned, this effect was stronger for males than it was for females. Generally, more flies were caught when tested at 10 days of age than when tested at 5 days of age (Least square mean ± standard error: 5 days 100.42±0.92, 10 days 197.30±1.01), which may reflect a general increase in activity as flies mature.

**Table 1.** Three-way Analysis of Variance comparing the total number of flies captured over 24 hours (square root transformed, replicate included as a random effect) on tanglefoot-coated clear acetate sheets with and without an adjacent UV light ($R^2$=0.87).

| | *DF* | *F* | *P* |
|---|---|---|---|
| Light treatment | 1, 20.69 | 70.866 | **<0.001** |
| Sex | 1, 21.65 | 15.986 | **<0.001** |
| Age | 1, 23.1 | 33.149 | **<0.001** |
| Sex x Light treatment | 1, 20.69 | 5.450 | **0.030** |
| Age x Light treatment | 1, 20.69 | 0.084 | 0.775 |
| Sex x Age | 1, 20.69 | 3.872 | 0.063 |
| Light treatment x Sex x Age | 1, 20.69 | 2.921 | 0.102 |

Considering the timing of attraction through the day, significant effects of all predictors were found in three significant 3-way interactions (Table 2, Figure 5). Of the four predictors (Light treatment, Time of day, Age, and Sex), Sex was the only predictor that was common to all 3-way interactions. This suite of complex interactions is most readily understood as sex differences in Time x Light treatment, Time x Age, and Light treatment x Age. To further explore these interactions, separate ANOVAs were run for males and females (Tables 3 & 4).

**Table 2.** Four-way Analysis of Variance comparing the number of male flies captured at different time points through the day (square root transformed, replicate included as a random effect) on tanglefoot-coated clear acetate sheets with and without an adjacent UV light ($R^2$=0.88).

| | *DF* | *F* | *P* |
|---|---|---|---|
| Light treatment | 1, 116.9 | 127.393 | **<0.001** |
| Time | 4, 116.9 | 55.205 | **<0.001** |
| Age | 1, 116.9 | 16.794 | **<0.001** |
| Sex | 1, 116.9 | 54.686 | **<0.001** |
| Time x Light treatment | 4, 116.9 | 49.440 | **<0.001** |
| Time x Sex | 4, 116.9 | 14.828 | **<0.001** |
| Time x Age | 4, 116.9 | 8.033 | **<0.001** |
| Light treatment x Sex | 1, 116.9 | 8.828 | **0.003** |
| Light treatment x Age | 1, 116.9 | 1.568 | 0.208 |
| Sex x Age | 1, 116.9 | 7.592 | **0.006** |
| Time x Light treatment x Sex | 4, 116.9 | 9.877 | **<0.001** |
| Time x Light treatment x Age | 4, 116.9 | 1.212 | 0.310 |
| Time x Sex x Age | 4, 116.9 | 4.670 | **0.001** |
| Light treatment x Sex x Age | 1, 116.9 | 4.864 | **0.028** |
| Time x Light treatment x Sex x Age | 4, 116.9 | 1.450 | 0.222 |

For males, a significant Time x Light treatment interaction was detected (Table 3). Slice analyses detected no significant differences between light treatments in number of flies captured at 10 - 12 am ($F_{1,60.75}$ = 0.003, $P$ = 0.955), significantly more flies captured on the side without UV light 12 - 2 pm ($F_{1,60.75}$ = 7.554, $P$ = 0.008), and significantly more flies captured on the side with UV light 2 - 4 pm ($F_{1,60.75}$ = 155.741, $P$ < 0.001), 4 - 6 pm ($F_{1,60.75}$ = 56.058, $P$ < 0.001), and 6 pm - 10 am ($F_{1,60.75}$ = 4.642, $P$ = 0.035) (Figure 5). Additionally, a significant Age x Light treatment interaction was detected (Table 3). Both in the presence and absence of UV light more flies were captured when tested at 10 days than when tested at 5 days (Least square mean ± standard error: No UV 5 days 9.67±0.58, No UV 10 days 22.88±0.62, Test Slice $F_{1,63.68}$ = 11.698, $P$ = 0.001; UV 5 days 26.23±0.58, UV 10 days 65.31±0.62, Test Slice $F_{1,63.68}$ = 36.635, $P$ < 0.001), although the absolute difference was greater on the side with UV light than on the side without. Significantly more flies were captured on the side with the UV light at both 5 days (Test Slice $F_{1,60.75}$ = 21.408, $P$ < 0.001) and 10 days (Test Slice $F_{1,60.75}$ = 57.602, $P$ < 0.001), although the absolute difference was greater at 10 days than at 5 days.

**Table 3.** Three-way Analysis of Variance comparing the number of male flies captured over at different time points through the day (square root transformed, replicate included as a random effect) on tanglefoot-coated clear acetate sheets with and without an adjacent UV light ($R^2$=0.87).

| | *DF* | *F* | *P* |
|---|---|---|---|
| Light treatment | 1, 60.75 | 74.621 | **<0.001** |
| Time | 4, 60.75 | 28.757 | **<0.001** |
| Age | 1, 60.75 | 37.065 | **<0.001** |
| Time x Light treatment | 4, 60.75 | 37.344 | **<0.001** |
| Time x Age | 4, 60.75 | 1.636 | 0.177 |
| Age x Light treatment | 1, 60.75 | 4.389 | **0.040** |

For females, as for males, a significant Time x Light treatment interaction was detected (Table 4). Slice analyses detected no significant differences between light treatments in number of flies captured at 10 - 12 am ($F_{1,60.61}$ = 2.215, $P$ = 0.142) or 12 - 2 pm ($F_{1,60.61}$ = 3.362, $P$ = 0.072), and significantly more flies captured on the side with UV light 2 - 4 pm ($F_{1,60.61}$ = 61.621, $P$ < 0.001), 4 - 6 pm ($F_{1,60.61}$ = 27.239, $P$ < 0.001), and 6 pm - 10 am ($F_{1,60.61}$ = 15.734, $P$ < 0.001) (Figure 5). Additionally, a significant Time x Age interaction was detected (Table 4). Slice analyses detected no significant differences between testing ages (5 vs. 10 days) in number of flies captured at 12 - 2 pm ($F_{1,62.83}$ = 3.374, $P$ = 0.071), 2 - 4 pm ($F_{1,62.83}$ = 3.036, $P$ = 0.086), or 4 - 6 pm ($F_{1,62.83}$ = 3.166, $P$ = 0.080), but that significantly more 10-day-old than 5-day-old flies were captured during the periods 10 - 12 am ($F_{1,62.83}$ = 53.027, $P$ < 0.001) and 6 pm - 10 am ($F_{1,62.83}$ = 17.277, $P$ < 0.001) (Figure 5).

**Table 4.** Three-way Analysis of Variance comparing the number of female flies captured over at different time points through the day (square root transformed, replicate included as a random effect) on tanglefoot-coated clear acetate sheets with and without an adjacent UV light ($R^2$=0.87).

| | *DF* | *F* | *P* |
|---|---|---|---|
| Light treatment | 1, 60.75 | 55.714 | **<0.001** |
| Time | 4, 60.75 | 49.729 | **<0.001** |
| Age | 1, 60.75 | 13.644 | **<0.001** |
| Time x Light treatment | 4, 60.75 | 13.614 | **<0.001** |
| Time x Age | 4, 60.75 | 16.878 | **<0.001** |
| Age x Light treatment | 1, 60.75 | 0.732 | 0.396 |

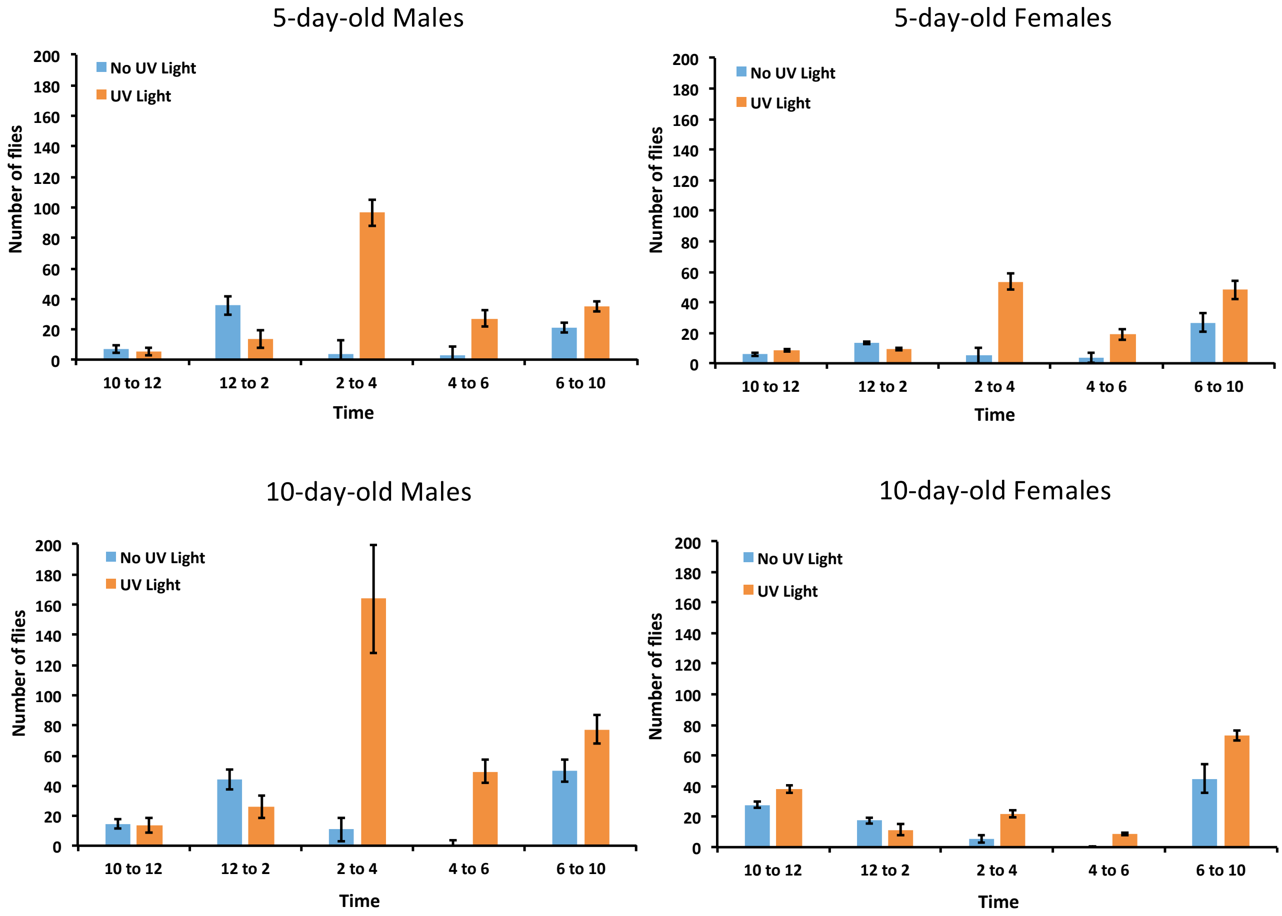


**Figure 5.** Mean (± standard error) number of flies captured on tanglefoot-coated clear acetate sheets with and without an adjacent UV light at different times of day (10 am - 12 pm, 12 - 2 pm, 2 - 4 pm, 4 - 6 pm, and 6pm - 10 am). Values are averages of eight replicates, four at 5 days of age and four at 10 days of age.

Green Light as an attractant

The total number of flies captured over 24 hours on acetate sheets was greater on the side with the Green light than on the side without (Least square mean ± standard error: Green Light 290.98±1.24, No Green light 109.60±1.24), but did not vary significantly with Sex (male vs. female) or Age (5 vs. 10 days old) (Table 5).

**Table 5.** Three-way Analysis of Variance comparing the total number of flies captured over 24 hours (square root transformed, replicate included as a random effect) on tanglefoot-coated clear acetate sheets with and without an adjacent Green light ($R^2$=0.82).

| | *DF* | *F* | *P* |
|---|---|---|---|
| Light treatment | 1, 21 | 65.126 | **<0.001** |
| Sex | 1, 21 | 2.522 | 0.127 |
| Age | 1, 21 | 4.028 | 0.058 |
| Sex x Light treatment | 1, 21 | 1.552 | 0.227 |
| Age x Light treatment | 1, 21 | 0.358 | 0.556 |
| Sex x Age | 1, 21 | 0.057 | 0.814 |
| Light treatment x Sex x Age | 1, 21 | 0.488 | 0.492 |

Considering the patterns of attraction to Green light through the day (Figure 6), significant effects of Light treatment, Time, Sex and Age were detected, including Light treatment x Time interaction and Time x Sex interaction (Table 6).

The Light treatment x Time interaction arises because more flies were captured on the side with the Green light than the side without light only during the hours that wholly or partly included the photoperiod light phase (Slice analyses: 10 am - 12 pm $F_{1,117}$ = 46.028, $P$ < 0.001, 12 - 2 pm $F_{1,117}$ = 49.908, $P$ < 0.001, 6 pm - 10 am $F_{1,117}$ = 73.293, $P$ < 0.001) while showing no effect during the hours that were wholly in the photoperiod dark phase (Slice analyses: 2 pm - 4 pm $F_{1,117}$ = 0.371, $P$ = 0.544, 4 - 6 pm $F_{1,117}$ = 0.437, $P$ = 0.510). That is, Green light is only an effective attractant during the day.

The Time x Sex interaction arises because males are more attracted to Green light than are females over the period 12 pm - 2 pm (Slice analyses: 12 pm - 2 pm $F_{1,117}$ = 16.022, $P$ < 0.001) but show attraction similar to that of females at other times (Slice analyses: 10 am - 12 pm $F_{1,117}$ = 0.101, $P$ = 0.751, 2 pm - 4 pm $F_{1,117}$ = 1.353, $P$ = 0.247, 4 pm - 6 pm $F_{1,117}$ = 0.063, $P$ = 0.802, 6 pm - 10 am $F_{1,117}$ = 0.200, $P$ = 0.656). That is, males are more attracted to Green light than are females in the period that immediately precedes dusk, the typical timing of mating activity that takes place on leaves on tree canopy.

**Table 6.** Four-way Analysis of Variance comparing the number of male flies captured at different time points through the day (square root transformed, replicate included as a random effect) on tanglefoot-coated clear acetate sheets with and without an adjacent Green light ($R^2$=0.87).

| | *DF* | *F* | *P* |
|---|---|---|---|
| Light treatment | 1, 117 | 99.979 | **<0.001** |
| Time | 4, 117 | 133.709 | **<0.001** |
| Sex | 1, 117 | 10.1167 | **0.026** |
| Age | 1, 117 | 5.0880 | **0.002** |
| Time x Light treatment | 4, 117 | 17.5146 | **<0.001** |
| Time x Sex | 4, 117 | 3.1628 | **0.017** |
| Time x Age | 4, 117 | 1.2636 | 0.288 |
| Light treatment x Sex | 1, 117 | 3.5028 | 0.064 |
| Light treatment x Age | 1, 117 | 1.2455 | 0.267 |
| Sex x Age | 1, 117 | 0.0244 | 0.876 |
| Time x Light treatment x Sex | 4, 117 | 1.0798 | 0.370 |
| Time x Light treatment x Age | 4, 117 | 0.1199 | 0.975 |
| Time x Sex x Age | 4, 117 | 0.5837 | 0.675 |
| Light treatment x Sex x Age | 1, 117 | 0.5936 | 0.443 |
| Time x Light treatment x Sex x Age | 4, 117 | 0.2962 | 0.880 |

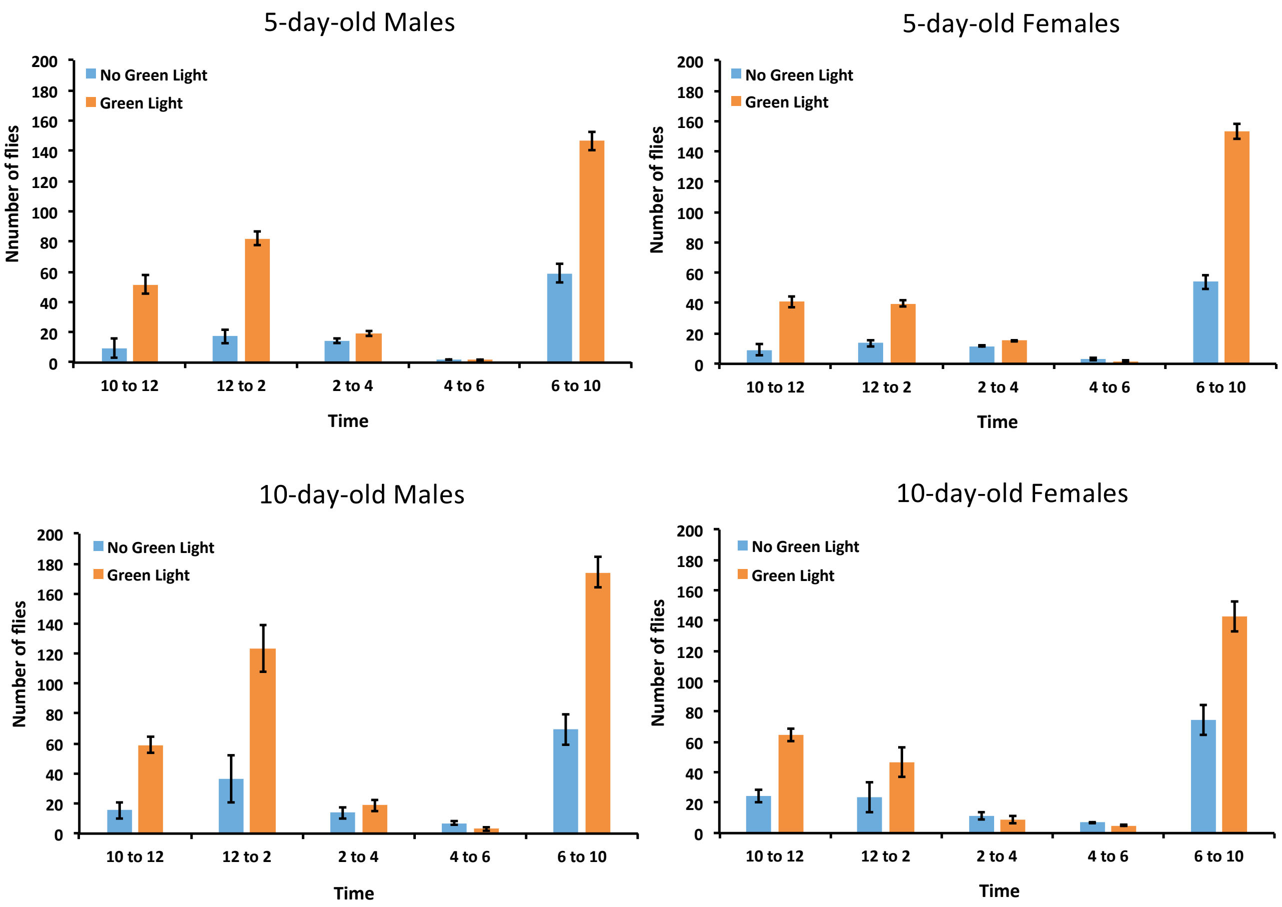


**Figure 6.** Mean (± standard error) number of flies captured on tanglefoot-coated clear acetate sheets with and without an adjacent Green light at different times of day (10 am - 12 pm, 12 - 2 pm, 2 - 4 pm, 4 - 6 pm, and 6pm - 10 am). Values are averages of eight replicates, four at 5 days of age and four at 10 days of age.

White Light as an attractant (repellent)

The total number of flies captured over 24 hours on acetate sheets was significantly *less* on the side with the White light than on the side without and the numbers of flies captures increased significantly with Age (5 vs. 10 days old) (Least square mean ± standard error: 5-day-old White Light 31.65±0.82, 10-day-old White Light 93.52±0.82, 5-day-old No White Light 77.59±0.82, 10-day-old No White Light 126.53±0.82), but did not vary significantly with Sex (male vs. female) (Table 7, Figure 7). That is, White light repelled both male and female flies. While captures increased at 10 days of age, perhaps because of generally increased activity levels once flies are mature, the repellence of white light was evident at both ages tested.

**Table 7.** Three-way Analysis of Variance comparing the total number of flies captured over 24 hours (square root transformed, replicate included as a random effect) on tanglefoot-coated clear acetate sheets with and without an adjacent White light ($R^2$=0.89).

| | *DF* | *F* | *P* |
|---|---|---|---|
| Light treatment | 1, 21 | 55.457 | **<0.001** |
| Sex | 1, 21 | 3.120 | 0.092 |
| Age | 1, 21 | 82.098 | **<0.001** |
| Sex x Light treatment | 1, 21 | 0.119 | 0.734 |
| Age x Light treatment | 1, 21 | 2.227 | 0.151 |
| Sex x Age | 1, 21 | 2.287 | 0.145 |
| Sex x Age x Light treatment | 1, 21 | 1.393 | 0.251 |

Considering the patterns of response to White light through the day (Figure 7, Table 8), significant effects of Light treatment, Time, Sex and Age were detected, including Time x Light treatment x Age interaction (Table 6). That is, there was significant difference between 5-day-old flies and 10-day-old flies in the daily pattern of responses to White light. To further explore these patterns, separate ANOVAs were run for 5-day-old flies (Table 9) and 10-day-old flies (Table 10).

**Table 8.** Four-way Analysis of Variance comparing the number of male flies captured at different time points through the day (square root transformed, replicate included as a random effect) on tanglefoot-coated clear acetate sheets with and without an adjacent White light ($R^2$=0.84).

| | *DF* | *F* | *P* |
|---|---|---|---|
| Light treatment | 1, 117 | 68.165 | **<0.001** |
| Time | 4, 117 | 76.555 | **<0.001** |
| Sex | 1, 117 | 3.003 | 0.086 |
| Age | 1, 117 | 86.616 | **<0.001** |
| Time x Light treatment | 4, 117 | 9.809 | **<0.001** |
| Time x Sex | 4, 117 | 2.777 | **0.030** |
| Time x Age | 4, 117 | 7.657 | **<0.001** |
| Light treatment x Sex | 1, 117 | 0.123 | 0.726 |
| Light treatment x Age | 1, 117 | 0.999 | 0.320 |
| Sex x Age | 1, 117 | 3.036 | 0.084 |
| Time x Light treatment x Sex | 4, 117 | 2.101 | 0.085 |
| Time x Light treatment x Age | 4, 117 | 5.252 | **<0.001** |
| Time x Sex x Age | 4, 117 | 2.373 | 0.056 |
| Light treatment x Sex x Age | 1, 117 | 1.552 | 0.215 |
| Time x Light treatment x Sex x Age | 4, 117 | 0.662 | 0.620 |

For flies tested when 5 days old, significantly fewer flies were captured on the acetate sheet with the light present (Least square mean ± standard error: White Light 4.77±0.34, No White Light 12.88±0.34) and there was significant variation in number of flies captured at the different time periods. Tukeys HSD tests found significantly more flies captured in the 6 pm - 10 am period compared with all of the two-hour periods, as might be expected owing to the much longer duration. Of the four two-hour periods between 10 am and 6 pm, fewer flies were captured in the 4 - 6 pm period (i.e., the period of greatest time after dusk) than in the 2 - 4 pm period, but all other comparisons were non-significant.

**Table 9.** Three-way Analysis of Variance comparing the number of flies tested at 5 days of age that were captured at different time points through the day (square root transformed, replicate included as a random effect) on tanglefoot-coated clear acetate sheets with and without an adjacent White light ($R^2$=0.76).

| | *DF* | *F* | *P* |
|---|---|---|---|
| Light treatment | 1, 61 | 41.104 | **<0.001** |
| Time | 4, 61 | 31.614 | **<0.001** |
| Sex | 1, 61 | < 0.001 | 0.993 |
| Time x Light treatment | 4, 61 | 1.203 | 0.319 |
| Time x Sex | 4, 61 | 0.384 | 0.819 |
| Sex x Light treatment | 1, 61 | 0.625 | 0.432 |

For flies tested when 10 days old, there was significant variation across the day in the response of flies to White light and in the relative tendency of males and females to be captured (Table 10).

Variation in response to white light across the day arises because flies were significantly repelled by the light only during the periods that wholly or partly included the photoperiod light phase (Slice analyses: 10 am - 12 pm $F_{1,61} = 15.636$, $P < 0.001$; 12 pm - 2 pm $F_{1,61} = 33.961$, $P < 0.001$; 2 pm - 4 pm $F_{1,61} = 2.525$, $P = 0.117$; 4 pm - 6 pm $F_{1,61} = 0.204$, $P = 0.653$; 6 pm - 10 am $F_{1,61} = 38.806$, $P < 0.001$). Alternatively stated, during those times of the day when the room lights were on the flies tended to associate more with an area of shade than with White light.

Variation across the day in relative tendency of males and females to be captured arise because males were significantly more likely to be captured during the periods that preceded and included the dusk phase (Slice analyses: 10 am - 12 pm $F_{1,61} = 6.267$, $P = 0.015$; 12 pm - 2 pm $F_{1,61} = 5.226$, $P = 0.026$; 2 pm - 4 pm $F_{1,61} = 8.531$, $P = 0.005$; 4 pm - 6 pm $F_{1,61} = 2.314$, $P = 0.133$; 6 pm - 10 am $F_{1,61} = 1.043$, $P = 0.311$). That significant sex differences were not found in the 6 pm - 10 am period suggests that the increased captures of males in the periods preceding and including dusk was related to greater activity related to the mating activity, which takes place in the evening, rather than being related simply to the presence of light.

**Table 10.** Three-way Analysis of Variance comparing the number of flies tested at 10 days of age that were captured at different time points through the day (square root transformed, replicate included as a random effect) on tanglefoot-coated clear acetate sheets with and without an adjacent White light ($R^2$=0.86).

| | *DF* | *F* | *P* |
|---|---|---|---|
| Light treatment | 1, 61 | 39.036 | **<0.001** |
| Time | 4, 61 | 58.291 | **<0.001** |
| Sex | 1, 61 | 5.504 | **0.022** |
| Time x Light treatment | 4, 61 | 13.024 | **<0.001** |
| Time x Sex | 4, 61 | 4.469 | **0.003** |
| Sex x Light treatment | 1, 61 | 1.162 | 0.285 |

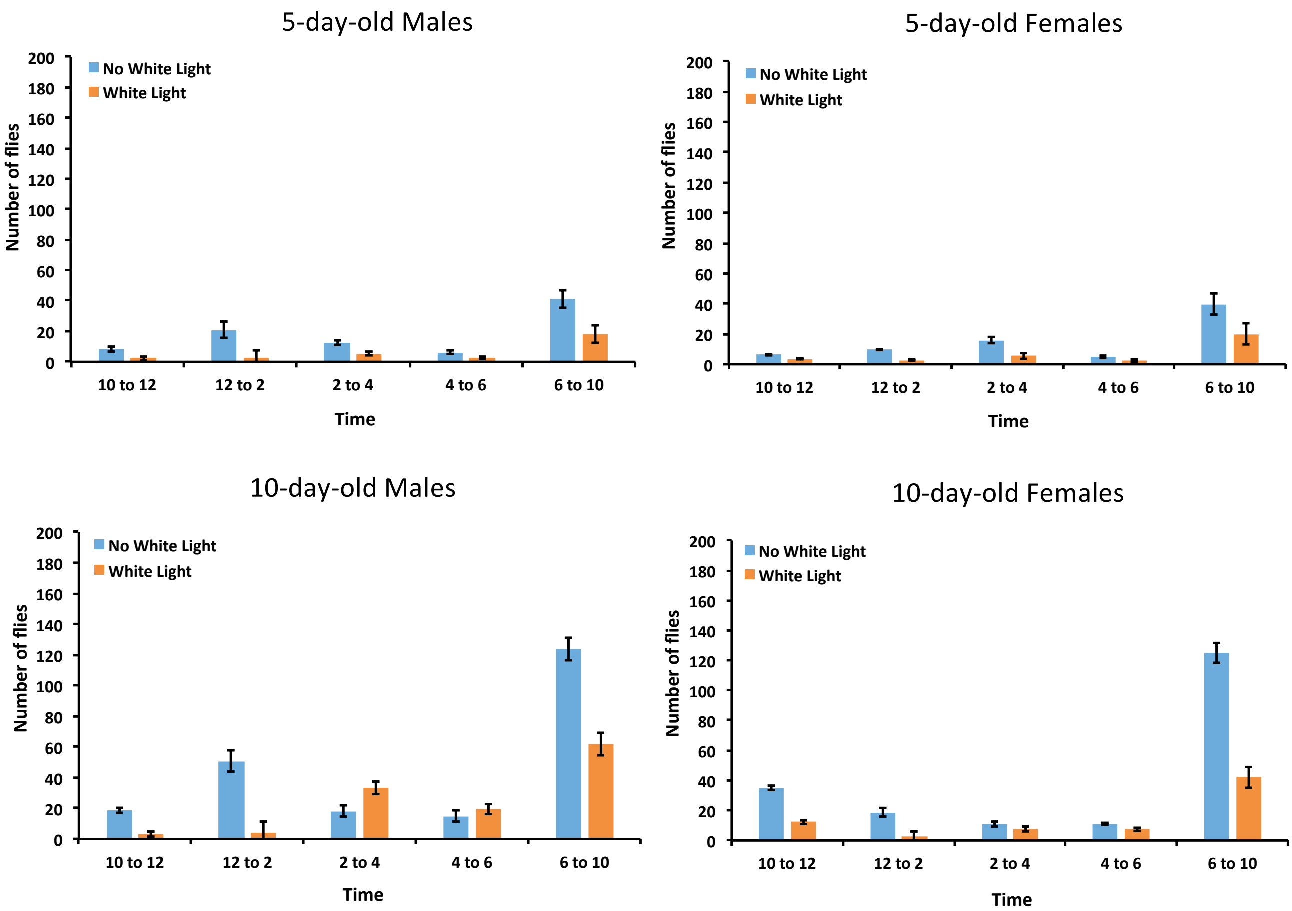


**Figure 7.** Mean (± standard error) number of flies captured on tanglefoot-coated clear acetate sheets with and without an adjacent White light at different times of day (10 am - 12 pm, 12 - 2 pm, 2 - 4 pm, 4 - 6 pm, and 6pm - 10 am). Values are averages of eight replicates, four at 5 days of age and four at 10 days of age.

UV and White light as mating inhibitors

Neither the UV nor the white light affected the number of pairs mating between 1 and 10 pm. However, as was expected, time did have an effect on the number of flies found mating since mating in Q-fly occurs at dusk (Number of matings, UV light 178, No UV light 155, White light 200, No White light 168) (Treatment $F_{3,115}$ = 0.408, $P$ = 0.747, Time $F_{1,115}$ = 10.461, $P$ = 0.002, $N$ = 120).

UV and White light as oviposition inhibitors

The UV and the white light had no significant effect on the number of eggs laid by females (Number of eggs, UV light 26,600, No UV light 28,000, White light 21,000, No White light 30,800, $H$ = 1.288, $P$ = 0.732).

*Phase 2: UV light as an attractant in a glasshouse setting*

The number of dead flies collected from the side of the glasshouse with the UV light was significantly higher than from the side with no light and there was no evidence of difference between males and females in number of flies attracted and killed (Table 11, Figure 8). Over the three replicates completed, a total of 3057 flies were collected from beneath the tree with the UV light (1520 females, 1537 males) and 2402 flies were collected from beneath the tree without the UV light (1220 females, 1182 males).

**Table 11.** Two-way Analysis of Variance comparing the total number of flies killed and collected from the ground beneath insecticide-treated citrus trees with and without an adjacent UV light ('bugzapper') ($R^2$=0.44). Significantly more flies were killed and collected over the test period from the tree that had an adjacent UV light.

| | *DF* | *F* | *P* |
|---|---|---|---|
| Light treatment | 1 | 6.228 | **0.037** |
| Sex | 1 | 0.707 | 0.425 |
| Light treatment x Sex | 1 | 0.864 | 0.380 |

Considering the number of flies killed and collected each day (Table 12), more flies were collected each day from beneath the tree that had an adjacent UV light, although this number declined each day of testing as flies were depleted from the enclosure (Least Squares Means ± standard error: day 1 = 232.11±0.61, day 2 = 141.46±0.61, day 3 = 50.38±0.61, day 4= 27.06±0.67, day 5 = 1.79±0.82, day 6 = 3.03±0.82) (Figure 9). As was the case for analysis of total numbers of flies killed and collected, there was no evidence of differences between males and females in the number of flies killed and collected each day.

**Table 12.** Three-way Analysis of Variance comparing the daily number of flies killed and collected from the ground beneath insecticide-treated citrus trees (square root transformed) with and without an adjacent UV light ('bugzapper') ($R^2$=0.96).

| | *DF* | *F* | *P* |
|---|---|---|---|
| Light treatment | 5 | 8.182 | **0.008** |
| Day | 1 | 103.792 | **<0.001** |
| Sex | 1 | 0.259 | 0.615 |
| Light treatment x Day | 5 | 0.648 | 0.665 |
| Light treatment x Sex | 1 | 0.006 | 0.938 |
| Day x Sex | 5 | 0.145 | 0.980 |
| Light treatment x Day x Sex | 5 | 0.304 | 0.906 |

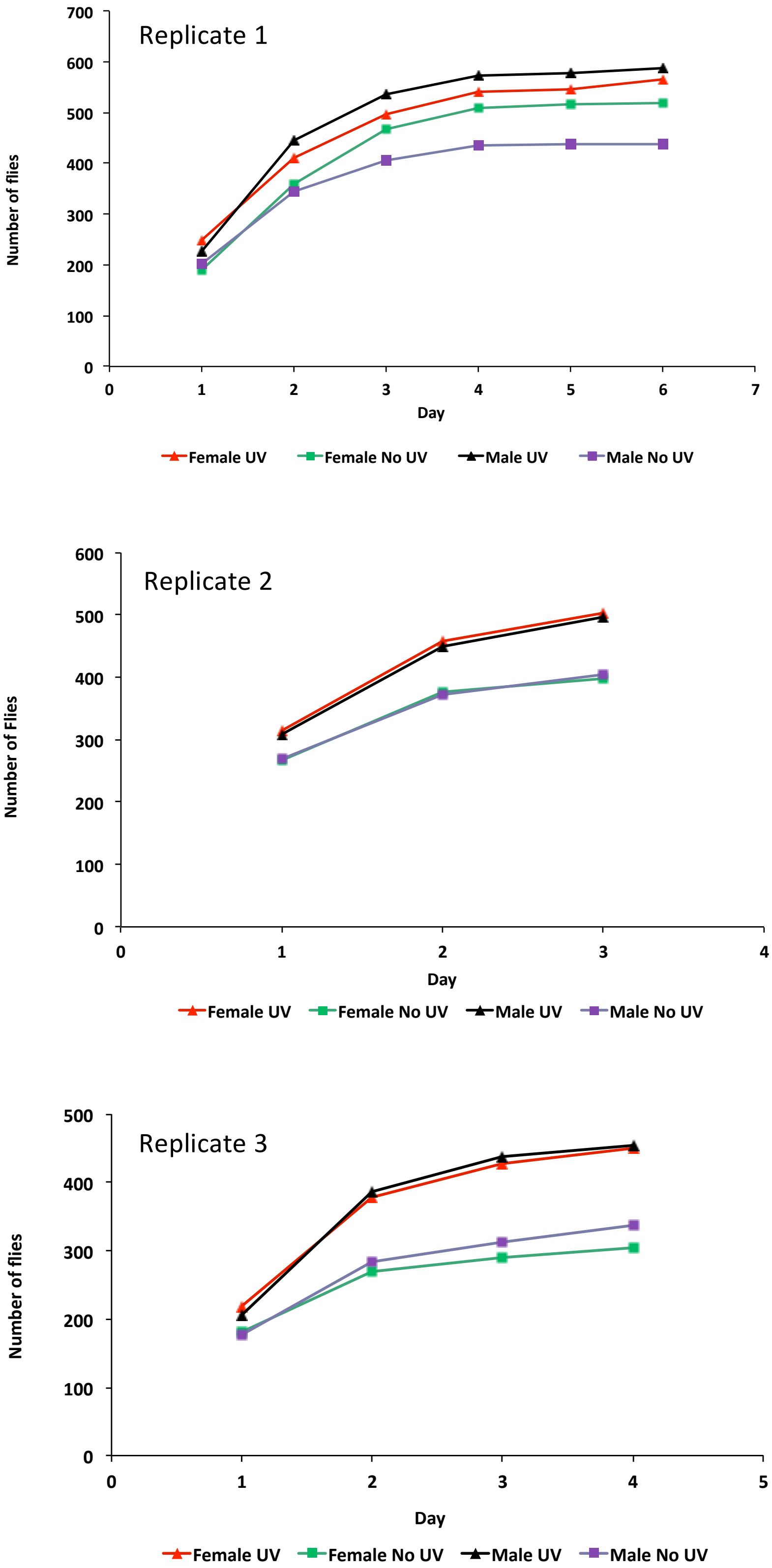


**Figure 8.** Cumulative number of male and female Q-flies killed after landing on toxicant-treated citrus plants that were or were not illuminated by a UV light in a glasshouse setting.  Total numbers of captured flies analysed in Table 9 are those reported on the final day of collection in this figure.

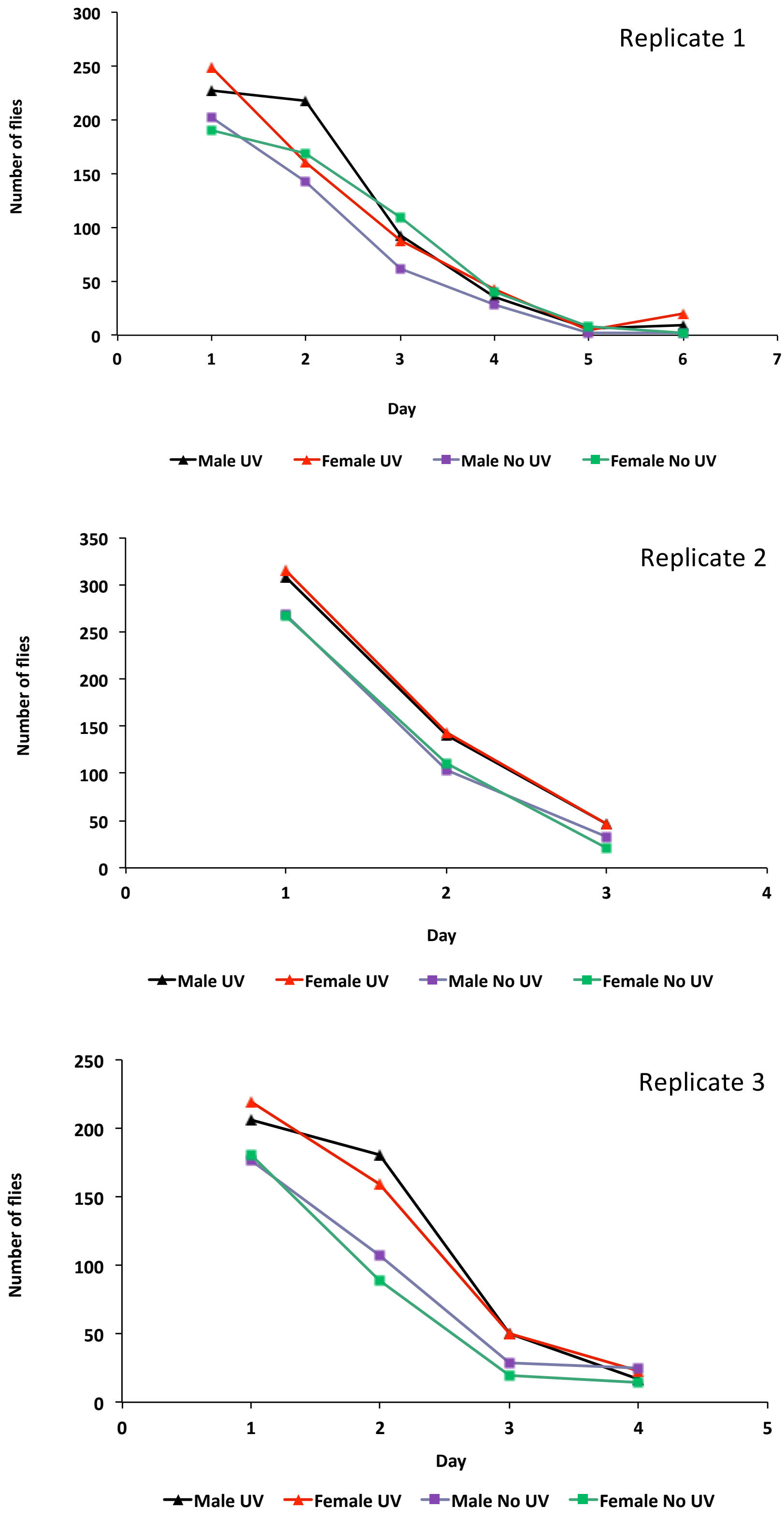


**Figure 9.** Number of male and female Q-flies killed each day after landing on toxicant-treated citrus plants that were or were not illuminated by a UV light in a glasshouse setting. Daily numbers of captured flies analysed in Table 10 are those reported on each day of collection in this figure.

*Phase 3: UV light as an attractant in a field cage setting*

Trials carried out in field enclosures yielded results that closely resembled those of the glasshouse trials - the total number of flies collected in the enclosure with UV light treatment was significantly higher than in the enclosure with no light and males and females were attracted equally (Number of flies killed: (a) UV light: 5353 flies total; 2344 females, 3009 males; (b) No UV light: 2901 flies total; 1349 females, 1552 males) (Figure 10).

One field cage was darker than the other owing to overhanging foliage and location of the UV light (shaded vs. un-shaded cage) had a very strong effect on the results (Figure 10) (Least Squares Means ± standard error: UV light in shaded cage = 706.87±2.07, No UV light in shaded cage = 99.99±2.07, UV light in unshaded cage = 153.12±2.07, No UV light in unshaded cage = 371.87±2.07). In the shaded cage significantly more flies were attracted when the UV light was present (Slice analysis $F_{1,12} = 212.555$, $P < 0.001$) but in the unshaded cage significantly fewer flies were attracted when the UV light was present (Slice analysis $F_{1,12} = 36.883$, $P < 0.001$).

**Table 13.** Two-way Analysis of Variance comparing the total number of flies killed and collected from beneath insecticide-treated citrus trees (square root transformed, replicate included as a random effect) with and without an adjacent UV light ($R^2$=0.95).

| | *DF* | *F* | *P* |
|---|---|---|---|
| Sex | 1 | 2.604 | 0.131 |
| Light treatment | 1 | 31.693 | **<0.001** |
| Light location | 1 | 0.765 | 0.431 |
| Sex x Location | 1 | 0.283 | 0.604 |
| Sex x Light treatment | 1 | 0.475 | 0.503 |
| Light treatment x Location | 1 | 186.831 | **<0.001** |

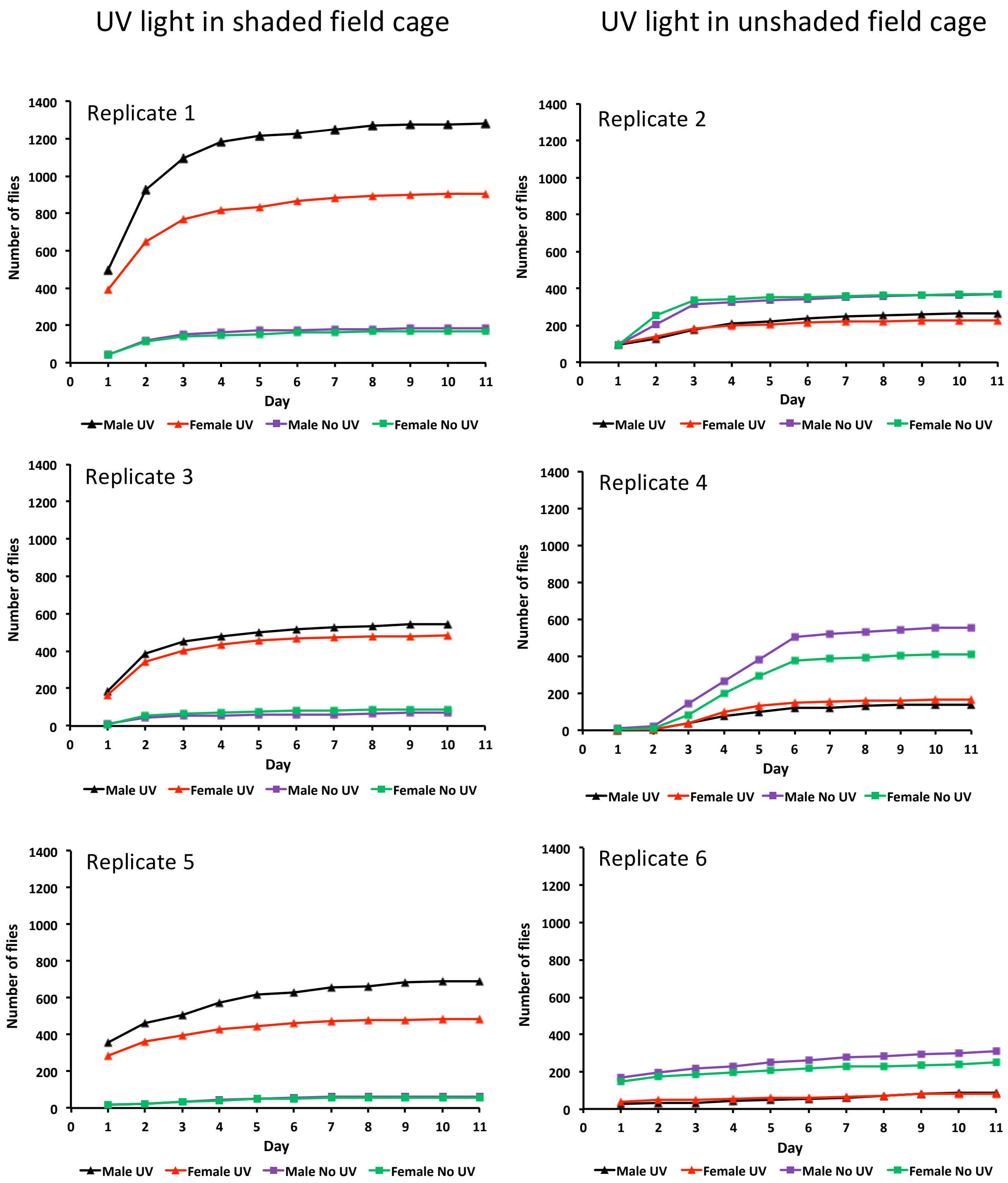


**Figure 10.** Cumulative number of male and female Q-flies killed after landing on toxicant-treated citrus plants that were or were not illuminated by a UV light in a field cage setting. Total numbers of captured flies analysed in Table 11 are those reported on the final day of collection in this figure.

Considering the daily capture rates over the eleven days of each replicate, a significant three-way interaction of Day x Location x Light treatment was evident (Table 14, Figure 11). That is, the effect of light treatment (i.e., presence or absence of UV light) on attraction of flies to the toxicant-treated tree varied over the days of testing in a way that varied depending on whether the UV light was located in the shaded or unshaded field cage. To further explore this interaction, the Four-way ANOVA of Table 14 was re-run separately for field cages with and without UV light present (Tables 15 and 16).

**Table 14.** Four-way Analysis of Variance comparing the number of flies killed and collected from beneath insecticide-treated citrus trees on each of the 11 days of each replicate (square root transformed, replicate included as a random effect) for field cages with and without a UV light adjacent to the treated tree ($R^2$=0.77).

| | *DF* | *F* | *P* |
|---|---|---|---|
| Day | 10,199.1 | 35.869 | **<0.001** |
| Sex | 1,199 | 0.322 | 0.571 |
| Location | 1,31.06 | 17.041 | **<0.001** |
| Light treatment | 1,199 | 35.786 | **<0.001** |
| Day x Sex | 10,199 | 0.036 | 0.999 |
| Day x Location | 10,199 | 5.683 | **<0.001** |
| Day x Light treatment | 10,199.1 | 3.604 | **<0.001** |
| Sex x Location | 1,199 | 0.040 | 0.842 |
| Sex x Light treatment | 1,199 | 0.474 | 0.492 |
| Location x Light treatment | 1,199 | 83.020 | **<0.001** |
| Day x Location x Light treatment | 10,199 | 6.853 | **<0.001** |

Considering separate three-way ANOVAs investigating variation in daily rates of flies killed by the insecticide-treated tree in each field cage enclosure for field cages with a UV light (Table 15) and without a UV light (Table 16) reveals changes across the eleven days and with location (shaded vs. unshaded field cage) both in the presence and absence of a UV light, but that there was a significant Day x Location interaction only when the UV light was present. That is, in the absence of UV light more flies were captured in the unshaded field cage (Least squares means: Shaded 20.87±0.99, Unshaded 66.83±0.99) and the rate of decline in capture rates was similar across the eleven days. In contrast, in the presence of UV light more flies were captured in the shaded field cage (Least squares means: Shaded 302.17±0.92, Unshaded 30.45±0.92) and the rate of decline in capture rates differed across the eleven days in the shaded and unshaded field cages.

**Table 15.** Three-way Analysis of Variance comparing the number of flies killed and collected from beneath insecticide-treated citrus trees on each of the 11 days of each replicate (square root transformed, replicate included as a random effect) for field cages *with* a UV light adjacent to the treated tree ($R^2$=0.88).

| | *DF* | *F* | *P* |
|---|---|---|---|
| Day | 10,92.05 | 37.760 | **<0.001** |
| Sex | 1,91.99 | 0.396 | 0.531 |
| Location | 1,23.09 | 83.622 | **<0.001** |
| Day x Sex | 10,91.99 | 0.065 | 0.999 |
| Day x Location | 10,92.05 | 15.118 | **<0.001** |
| Sex x Location | 1,91.99 | 1.741 | 0.190 |

**Table 16.** Three-way Analysis of Variance comparing the number of flies killed and collected from beneath insecticide-treated citrus trees on each of the 11 days of each replicate (square root transformed, replicate included as a random effect) for field cages *without* a UV light adjacent to the treated tree ($R^2$=0.57).

| | *DF* | *F* | *P* |
|---|---|---|---|
| Day | 10,92.27 | 8.010 | **<0.001** |
| Sex | 1,92.09 | 0.048 | 0.827 |
| Location | 1,75.34 | 6.671 | **0.012** |
| Day x Sex | 10,92.09 | 0.054 | 0.999 |
| Day x Location | 10,92.27 | 0.668 | 0.751 |
| Sex x Location | 1,92.09 | 0.611 | 0.437 |

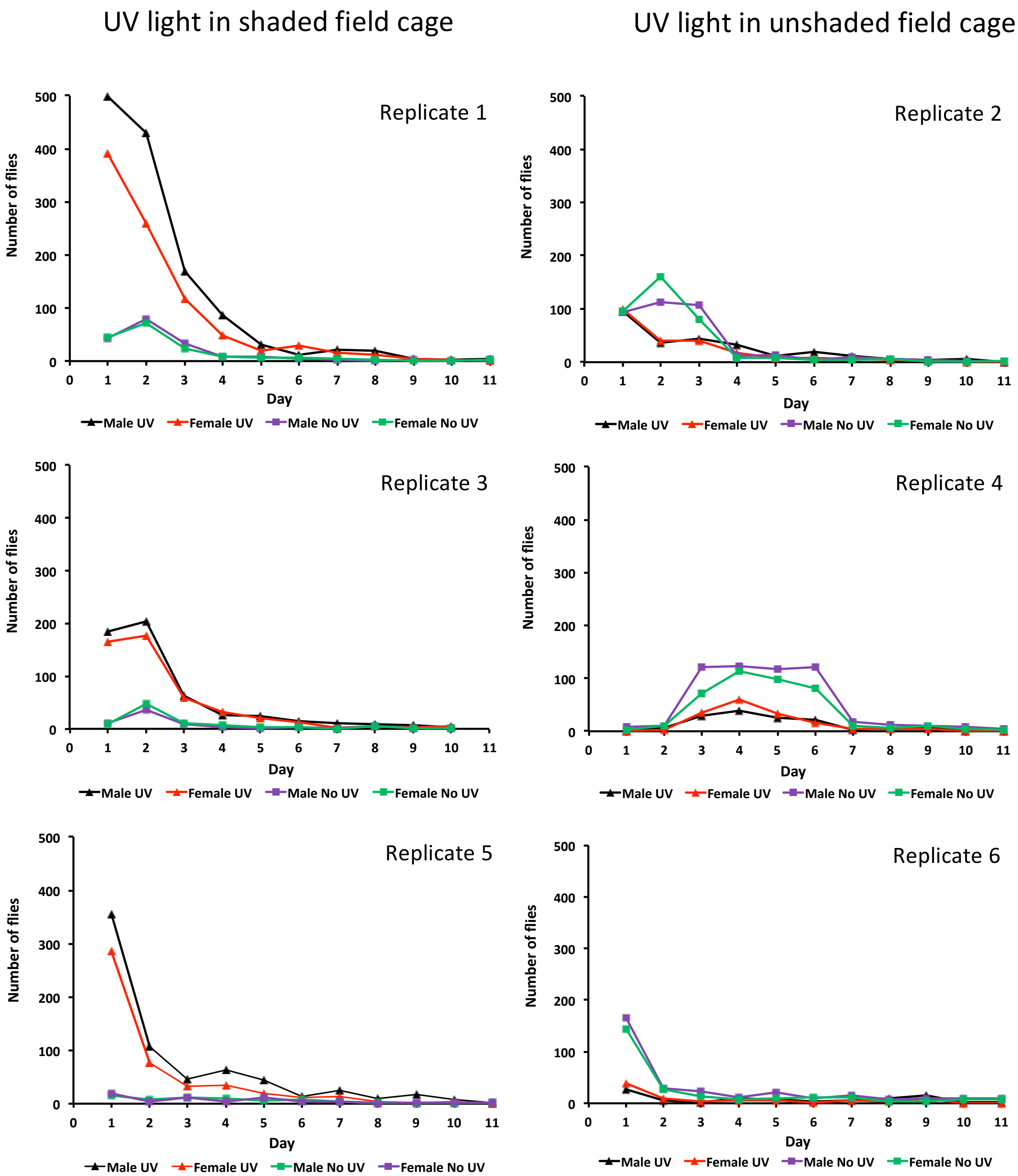


**Figure 11.** Number of male and female Q-flies killed each day after landing on toxicant-treated citrus plants that were or were not illuminated by a UV light in a field cage setting.  Daily numbers of captured flies analysed in Tables 12, 13 and 14 are those reported on each day of collection in this figure.

## DISCUSSION

Cuelure is currently by far the most effective olfactory lure for Q-fly, but only targets sexually mature males (Weldon et al. 2008). Protein-based olfactory lures do attract females and to some extent immature males but are effective over that have only short-range (Dominiak 2006). Coloured spheres that rely on reflected sunlight, especially those that reflect UV, attract female Q-fly and to a lesser extent also males (Drew et al. 2003). Colour is central to claimed effectiveness of the blue 'Fruition' trap from Agnova Technologies that has been recently announced but is not yet available. Q-fly are also attracted to reflected yellow and yellow-green (Hill & Hooper 1984). In a recent study, Schutze et al. (2016) tested 'Ladd traps' for the effectiveness with Q-fly and found encouraging results. Ladd traps comprise sticky red hemispheres attached to the centre of a sticky yellow panel. More females were captured on the red hemispheres and more males were captured on the yellow panels, suggesting sex differences in response to colour or shape. Schutze et al. (2016) suggest that the red spheres mimic fruit whereas the yellow panels mimic leaves, and that sex differences in preference for fruit and leaves underlies the sex differences in where on the Ladd traps the flies are captured. Many olfactory trap designs are coloured, especially yellow, because incorporation of such visual cues has been found to be effective at increasing trap captures for many fruit fly species (Epsky & Heath 1998).

Reflected daylight has been widely exploited in the development of fruit fly traps both in colour-only traps and as a means of enhancing the effectiveness of olfactory lure based traps. However reflected light has quite limited scope and range. Reflected light only has incident sunlight to draw on for the generation of attractive stimuli. This means that they are only effective during the day and their intensity of stimulus is constrained by how much light reaches them during the day. To date there has been no investigation of whether these constraints of existing colour-based traps might be overcome by the use of emitted light rather than reflected light. That is, rather than passively relying on reflected sunlight to attract flies, it might be possible to actively generate an attractive colour stimulus through the emission of light from coloured globes.

We demonstrated that Q-fly males and females are attracted to areas illuminated by green light during daylight periods, but not at night. This attractance likely has a sensory basis that is similar to that underlying response of flies to yellow and yellow-green reflected light that is of similar wavelength (Hill & Hooper 1984). Given that reflected yellow and yellow-green colours are effective during daylight hours, and the competing prevalence of natural daylight and other green stimuli, such as leaves, it seems that emitted green light is unlikely to form the basis of a practical Q-fly trap.

Of greater potential value for the development of a practical trap, we demonstrated that Q-flies are attracted to UV light after dusk. The two hours immediately after dusk showed the greatest effect, although significant attraction persisted in the following two-hour period as well. For males the level of attraction increased as they aged from 5 to 10 days, and for females level of attraction diminished. These patterns suggest that the effect of UV light is to mimic the local conditions on tree canopy where mating activity takes place in these flies. As they mature males become more sexually active and this would explain greater attraction of older males to stimuli associated with the mating arena. Similarly, young virgin female might be attracted to light cues associated with the mating arena whereas older mated females would be less attracted, and this may explain the reduced attraction of older females.

While other colour-based attractants are only effective during the day, the extension of potential colour-based luring into the evening and night hours by use of emitted UV light offers new opportunities for the development of fruit fly management tools, especially for those species that mate in the evening.

Emitted light can stimulate mating and oviposition in some insects (Zhang et al. 20010). A device that attracts flies but also elevates mating and oviposition would potentially be compromised in its overall effect on pest populations, especially if the effect on local mating and ovipositing was stronger than the effect of attraction and kill. We found no evidence that mating or oviposition of Q-fly are increased by exposure to continuous UV or white light. Potentially, population control and local pest management efficacy of a lure-and kill light device might be augmented if such devices also inhibit mating and / or oviposition but our results indicate little or no scope for such effects.

We have here confirmed that attraction of Q-fly to emitted light is very much dependent on the type of light; flies are reliably attracted to areas illuminated by UV light and Green light, although at different times of day, but were repelled from areas illuminated by White light. Further studies of specific narrow bands of light band, narrowing the wavelengths of the UV light and tuning it to the phototactic preferences of Q-fly might increase trap capture (Duehl et al 2011), as has been done with mosquitoes (Burkett et al. 1998, Burkett and Butler 2005) and phlebotomine sand flies (Mellor and Hamilton 2003). Light-Emitting Diode (LED) technology can be used to emit a narrow bandwidth and this might improve capture efficiency of a light trap for Q-fly, LEDs are efficient as a source of light, converting energy to light with a low generation of heat (Cohnstaedt et al. 2008). The use of such an efficient light source might enable the subsequent development of rechargeable or stand-alone solar powered systems.

In the field cage enclosure experiments, there was heterogeneity in light environment between the two enclosures used, with one enclosure being fully exposed and the other being shaded by overhanging trees. In this experiment, we consistently found much stronger effects of the UV light treatment in those replicates in which the UV light in the shaded field cage enclosure was active. That is, locating the UV light in a dark location increased the number of flies attracted and killed.  This effect may be because of higher contrast between the UV light and the illuminated foliage through the dusk period.  Trap placement will need to be considered as an important element of design of UV light-based traps.

Attraction of Q-fly to UV light occurs immediately after dusk, and this contrasts sharply with the time of day when male Q-fly is attracted to cuelure (and its analogues) and when Q-fly of both sexes forage for protein. Cuelure response is strongest early in the morning with little effect after midday (Weldon et al. 2008) and foraging is only observed during daylight hours.  Mating activity and attraction to emitted UV light is at dusk and the flies are then are quiescent overnight. Combining use of a UV light attractant and a cuelure or protein attractant would potentially enable two periods of the day in which attract-and-kill might operate. Further, additional benefits might accrue from collocating a UV and an odor-based device.  Flies attracted by the emitted UV light but not killed in the evening would presumably remain overnight in the general vicinity of the device. They would then be close to the odor-based attractant the following morning when these lure-and-kill devices are active. Similarly, flies attracted to odor-based attractants but not killed in the morning hours or through the day would tend to be in the vicinity of a UV light-based device in the evening when such devices are active. While both UV light devices and odor-based devices might be effective alone, through their effects on the distribution of flies not killed on a particular day each would likely elevate the overall efficacy of the other.

Our results together with additional information available the literature on attraction of fruit flies to reflective surfaces and use of UV light to attract other insect taxa, provides foundations for the design of a potential UV light trap or lure-and-kill device for Q-fly. The development of such a device will need to consider both design features of the device itself, and also optimal deployment. We have focused on the potential of emitted UV light for attract-and-kill devices that might target Q-fly. However, given similarities in general biology and biorhythms, it is very likely that such devices would be similarly effective with other species both in Australia and elsewhere, and especially other *Bactrocera* species.

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# Appendix 3

# Field trial of UV light trap

The trials at Macquarie University demonstrated that Qfly is attracted to UV light. Attraction was mainly at dusk, with both male and female flies equally attracted. In contrast, protein baits and para-pheromone lures are most attractive during the morning. This suggested that a UV trap could be combined with either a protein bait or para-pheromone lure as part of an attract and kill strategy.

However, the first step was to find out whether the UV light had any effect in an open field situation.

## Aim

To test whether UV light could attract fruit flies in an open vegetable crop

## Method

A prototype light trap was developed (Figure 1). Strips of UV-C lights were stuck onto a black corflute background protected from rain by a small shelter. The lights were run from a 12V battery, itself attached to a solar panel mounted on the roof of the unit. A programmable switch was included, so that the lights could be turned on for three hours at dusk.

The trap was placed at the edge of the chilli crop used for the netting and kaolin trial in Sydney (Trial 2). The unit was faced outwards, so that the light shone to the sides and out of the crop, minimising any disruption to the existing experiment.

Attraction to the unit was monitored using yellow sticky traps hung either side of the light. Additional yellow sticky traps were deployed at the same height in the general crop area, well away from the light and at approximately equal distances from it. Yellow sticky traps were installed after field releases of fruit flies; initially they were put out before release, however it was observed that large numbers of flies immediately stuck to the traps.

The sticky traps were replaced twice weekly. Flies were counted and their sex recorded.

**Figure 1. UV light and yellow sticky-trap setup. Light is pointed towards the non-netted rows.**

## Results and Discussion

Significantly more flies were caught on sticky traps located near the UV light than in the general field area. In total, 828 females and 134 male flies were caught on the traps next to the UV light, compared to 343 females and 82 males on the traps in the general field area. This represents an approximate doubling of catches on sticky traps due to the effect of the UV light.

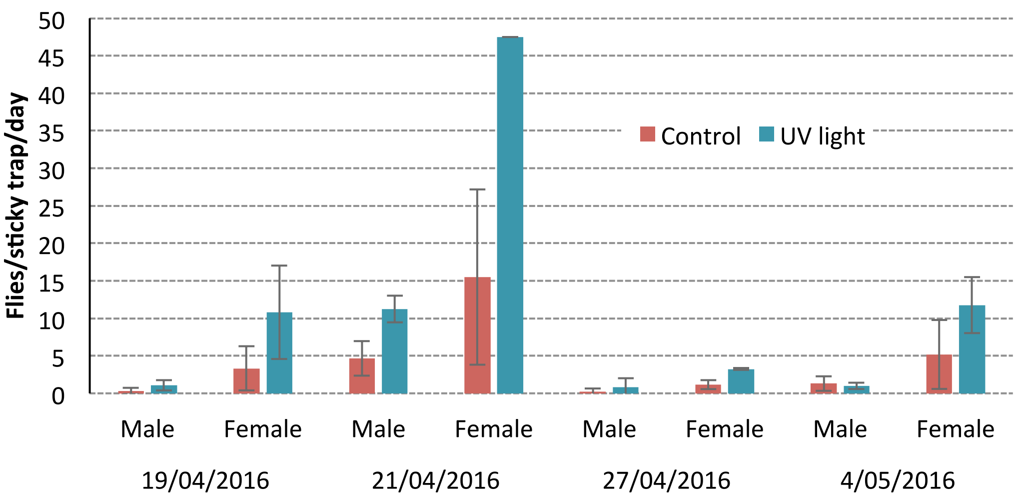


**Figure 2. Daily numbers of Qfly caught on sticky traps next to a UV light, or 30 metres from the UV light (control).**

Significantly more female flies were caught than males, regardless of the presence or absence of UV light. This suggests that there was a stronger general attraction of females to the yellow sticky traps. The ratio of females to males was approximately 4:1 in most of the trials, regardless of the presence or absence of UV light.

The results confirmed that UV light can attract fruit flies. While this attraction is not very strong, it could be possible to combine UV light with other lure to enhance their effectiveness. Flies attracted to the area near a UV light at dusk are likely to rest there overnight. If a protein or para-pheromone lure is nearby in the morning, when flies are foraging, then this could increase the effectiveness of these treatments.

More field-testing is required to optimise any trap or lure based on UV light. However, the results suggest that a combination of UV light and a visual or odour-based lure could provide an alternative method for monitoring fruit fly populations. For example, the combination of a Ladd trap – which acts as a visual stimulus – and UV light could be greater than either of these methods used alone.

If farms are using male annihilation technology (MAT) as part of their fruit fly management strategy, then results from standard monitoring traps can be unreliable. In this circumstance, an alternative monitoring system – such as Ladd trap plus UV light – could be a useful tool.

**Figure 3. Ladd trap**

# Fruit Fly Management for Vegetable Growers

Horticulture Innovation Australia

# contents



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*All photographs and diagrams by AHR unless otherwise indicated*



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01.

FRUIT FLIES CAN INFEST MANY FRUITING VEGETABLE CROPS. WHILE COVER SPRAY OPTIONS ARE DECREASING, THERE ARE MANY OTHER TOOLS GROWERS CAN USE. THIS PUBLICATION DESCRIBES THE OPTIONS AVAILABLE AND SUGGESTS BEST PRACTICE BASED ON CURRENT KNOWLEDGE.

# Introduction

*Fruit flies are a major pest of fruiting vegetable crops, not only because they damage production, but also because of their impact on market access.*

Fruit fly management and control have two quite separate objectives

- Producing a marketable crop and
- Accessing fruit fly sensitive markets.

A pest free crop can be produced using a range of control measures to keep damage below an economic threshold. These can include exploitation of fruit fly biology and behaviour, chemical controls, food and para-pheromone lures, physical barriers and postharvest treatments. Systems approaches combine two or more of these strategies, and could be considered integrated pest management for fruit flies.

In contrast, market access requires a much higher level of certainty that no pests are present. Either probit 9 (99.9968% mortality) or probit 8.7 (99.99% mortality) are likely to be used as a standard, with no consideration given to actual infestation levels in a given consignment, the probability of establishment, or other factors likely to limit risk to the importer. Market access usually requires a postharvest kill step, or at least an inspection, to ensure the product is pest free.

This publication is focussed on the first objective – producing a marketable crop. Without this, there is little purpose to progressing towards objective two.

## WHAT DO WE KNOW

Nearly all of the research on control measures for fruit flies has focused on tree fruits; a quick assessment suggests that at least 15 papers on tree fruits are published for every paper on vegetables. While research in orchards can provide some useful guidance, it is unclear how readily such strategies can be applied to vegetable crops.

For example, there has been considerable work on how Qfly (Queensland fruit fly, *Bactrocera tryoni*) and Medfly (Mediterranean fruit fly, *Ceratitis capitata)* move about within orchards, including flight distances and searching for hosts. However there is little or no information about how these pests behave in a vegetable crop such as capsicum or squash.

Cucumber fly (*Bactrocera cucumis*) is an important pest of cucurbits but has been barely studied, with little known about behaviour and biology. Other species including Jarvis fly (*Bactrocera jarvisi*), mango fly (*Bactrocera frauenfeldi*), Island fly (*Dirioxa pornia*) and lesser Queensland fruit fly (*Bactrocera neohumeralis*) can also infest fruiting vegetables, but almost nothing is known about them.

## THIS PUBLICATION

This publication aims to combine published literature, experimental data, and commercial practices to provide a "Best Bets" manual for fruit fly management on vegetable farms.

The guide is split into sections on:

- Species
- Lifecycle
- Monitoring
- Protein baits
- Male annihilation
- Female biased traps
- Physical protection
- Field hygiene

A number of cover sprays are currently allowed for fruit fly management. Regulations vary between states, and even between regions, with many products covered under temporary permits.

Due to the complexity of issues relating to chemical use, this aspect is not covered in the guide. Growers are advised to seek local professional advice on the use of cover sprays for control of fruit fly.

02.

THERE ARE MANY DIFFERENT FRUIT FLY SPECIES IN AUSTRALIA. IDENTIFYING WHICH ONES CREATE A PROBLEM IN THE CROP IS AN IMPORTANT STEP IN MANAGING THESE PESTS.

# Fruit fly species

*More than 78 species of fruit fly occur in Australia. While only a few are known to attack vegetable crops, many are of increasing quarantine concern with trading partners. Little is known of most species, including the effectiveness of current control strategies.*

## QUEENSLAND FRUIT FLY *(Bactrocera tryoni)*

Queensland fruit fly or Qfly is the species most people think about when discussing fruit fly control. Qfly can infest nearly all fruit and fruiting vegetables, including Solanaceae (capsicums, chillies) and cucurbits (zucchini, cucumber).

Qfly is found through the Northern Territory and eastern Australia, stretching from Cape York to East Gippsland in Victoria.

The Fruit Fly Exclusion Zone (FFEZ) was developed to eliminate Qfly from the NSW Riverland and Sunraysia, including east to Shepparton and west to Waikerie. Government officers checked traps and took action if outbreaks occurred. Over the last few years outbreaks have increased, with flies continuing to be trapped even in late autumn. The zone is no longer in place, and flies are now found regularly in regions previously free of this pest.

Qfly adults are about 5–8mm long with reddish eyes. They are generally brown with yellow “shoulder pads” and other markings, including a yellow triangle at the base of the thorax (midsection).

Male cucumber fly (Photo by M Tattersall)

Female Qfly

Female Medfly (Photo by USDA)

Qfly (left) and lesser Qfly (right). Lesser Qfly lacks one set of yellow 'shoulder pads'. (Photo by UNSW Fruit Fly Lab)

## LESSER QUEENSLAND FRUIT FLY *(Bactrocera neohumeralis)*

Lesser Qfly infests a similar range of crops as Qfly. It is thought to occur in large numbers, especially in northern areas, where populations may be similar to those of Qfly.

It is difficult even for practiced entomologists to distinguish Lesser Qfly from Qfly, as they look very similar. Lesser Qfly is slightly darker than Qfly, and lacks one set of yellow "shoulder pads". However the main difference between the two is that Lesser Qfly mates during the day, whereas Qfly mates at dusk.

Lesser Qfly has been raised as a quarantine pest by a number of trading partners.

## MEDITERRANEAN FRUIT FLY *(Ceratitis capitata)*

Medfly is a native of Africa, but has spread widely throughout Europe, Central and South America and the Middle East. It is found in south-west WA, and north along the coast as far as Carnarvon. Although also introduced to eastern Australia, it has not been found in NSW since 1941. This is thought to be due to competition from Qfly.

Like Qfly, Medfly can infest a very wide range of fruit and fruiting vegetables. Medfly is somewhat smaller than Qfly, with adults around 3-5mm long. It is quite colourful, with black and silver patches on its thorax (middle) and a striped brown abdomen.

## CUCUMBER FLY *(Bactrocera cucumis)*

Until recently, cucumber fly was not considered of great economic importance. However, outbreaks are becoming more frequent in areas producing pumpkins, melons, squash, zucchini and other cucurbit crops. It can also occasionally infest capsicums and other Solanaceae. Cucumber fly is likely to present increasing problems in the future.

Cucumber fly does not respond to the lures used for other fly species. As a result its distribution is poorly understood, although it is known to occur in south-west Queensland and northern NSW.

Cucumber fly is lighter brown and more slender than Qfly. It also has a distinctive yellow keel in the centre of its back, so the two species are relatively easy to distinguish.

Female B. jarvisi. (Photo by G Cocks)

## JARVIS FLY *(Bactrocera jarvisi)*

Like cucumber fly, Jarvis fly is increasingly being recognized as a major pest, able to attack a wide range of fruiting vegetables. It is very common in north-west Queensland, where populations may be greater than Qfly. It is found from Broome through the Northern Territory, and down the east coast possibly even extending to Sydney. Jarvis fly has recently been discovered to respond to the lure zingerone, which should allow more information on distribution to be collected.

Jarvis fly looks similar to Qfly, which is perhaps one of the reasons it has only been recently recognized as an important pest. It can be distinguished by the even colour on its thorax and more intense striping on its abdomen. The abdomen has a distinct, wide cream band with dark stripe either side and a dark keel down to the tip of its tail. Female flies also have a longer ovipositor than Qfly.

# 03.

UNDERSTANDING THE LIFECYCLE AND BEHAVIOUR OF FRUIT FLIES PROVIDES MANY CLUES AS TO THE BEST WAY TO PREVENT THEM INFESTING VEGETABLE CROPS.

# The life of fruit flies

*From a freshly laid egg to an adult fly laying several hundred eggs, a fruit fly generation can be completed in less than a month. Understanding this lifecycle can help identify management practices that can control these pests. The information in this section is based primarily on Qfly. Other species are similar, but specific details will vary.*

Female Qfly laying eggs

Sting (oviposition) marks on an apple

## LAYING EGGS

A female Qfly can potentially lay more than 500 eggs during her lifetime, while a Medfly can lay over 700. All female fruit flies are equipped with a sharp ovipositor, which they use to deposit eggs just under the skin of the host fruit. Both Qfly and Medfly ovipositors are not very strong, so they often use a natural opening, like a split, wound or the fruit lenticels (breathing holes) to lay into.

Female Qfly find it difficult to lay eggs directly into smooth, firm fruit with no natural openings – such as a cherry tomato. Their ovipositor simply slides off the surface, unable to pierce the skin.

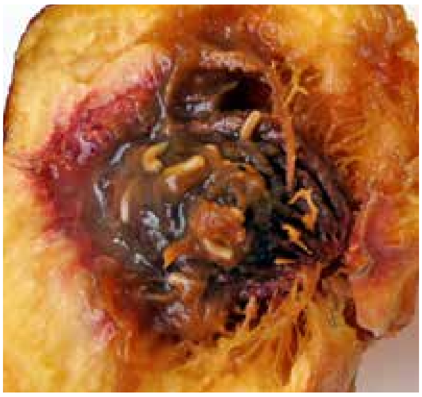
## EGGS

It takes a female fruit fly only 2–5 minutes to lay a batch of at least six, and up to 20, eggs into the host fruit. Fruit fly eggs are white, slender and around 1mm long, so barely visible with the naked eye. They hatch after around 1-2 days at 26°C.

"Sting" marks, where flies have laid eggs, are easy to see on light coloured fruit such as apples and loquats. However, they are more difficult to detect on vegetable crops.

Eggs laid into a red capsicum





When larvae hatch they use bacteria to dissolve the fruit flesh so they can digest it (left). They can eat out a capsicum, leaving only the fruit skin (centre). In other fruit, they head to the centre and eat out the core (right)

## LARVAE

Qfly larvae are les than 2mm long when they hatch, but grow quickly. They mature after only 6 days at 26°C, reaching 5-9mm long. Medfly larvae are a little slower, taking around two weeks to mature in summer, but up to 45 days in winter. When mature, their black feeding hook can be easily seen. Both Qfly and Medfly larvae are a creamy colour, with guts coloured by the food they are eating.

Fruit fly larvae are associated with a number of bacteria. The bacteria help break down the fruit flesh into a semi liquid, making it easy for the larvae to scoop up and digest. This is why they cause so much damage.

Larvae feed underneath the fruit skin, so damage may not be easily seen from the outside. Sunken or discoloured areas can indicate where the underlying flesh has been broken down, leaving the skin intact.

Breaking the fruit open reveals soft, cavity riddled flesh but without obvious fungal infection. In orchard fruit such as stonefruit and apples, the maggots burrow their way into the centre of the fruit, which can become quite brown and slimy.

Pupal cases. Note that some pupae are intact, but in others the cap has come off and the fly emerged, leaving behind just the empty shell.

Infested capsicum from the outside (left)

## PUPAE

Once larvae mature they hop from the fruit and bury themselves in the soil. Here they form a pupae. Pupae look like large grains of brown rice.

It takes around 10 days for the larvae to re-assemble itself inside its pupal case, becoming a fly. When it is ready to emerge the young fly breaks the top off the pupal case (operculum) and scrambles to the soil surface. In the picture above, some of the flies have emerged, leaving behind the empty pupal cases.

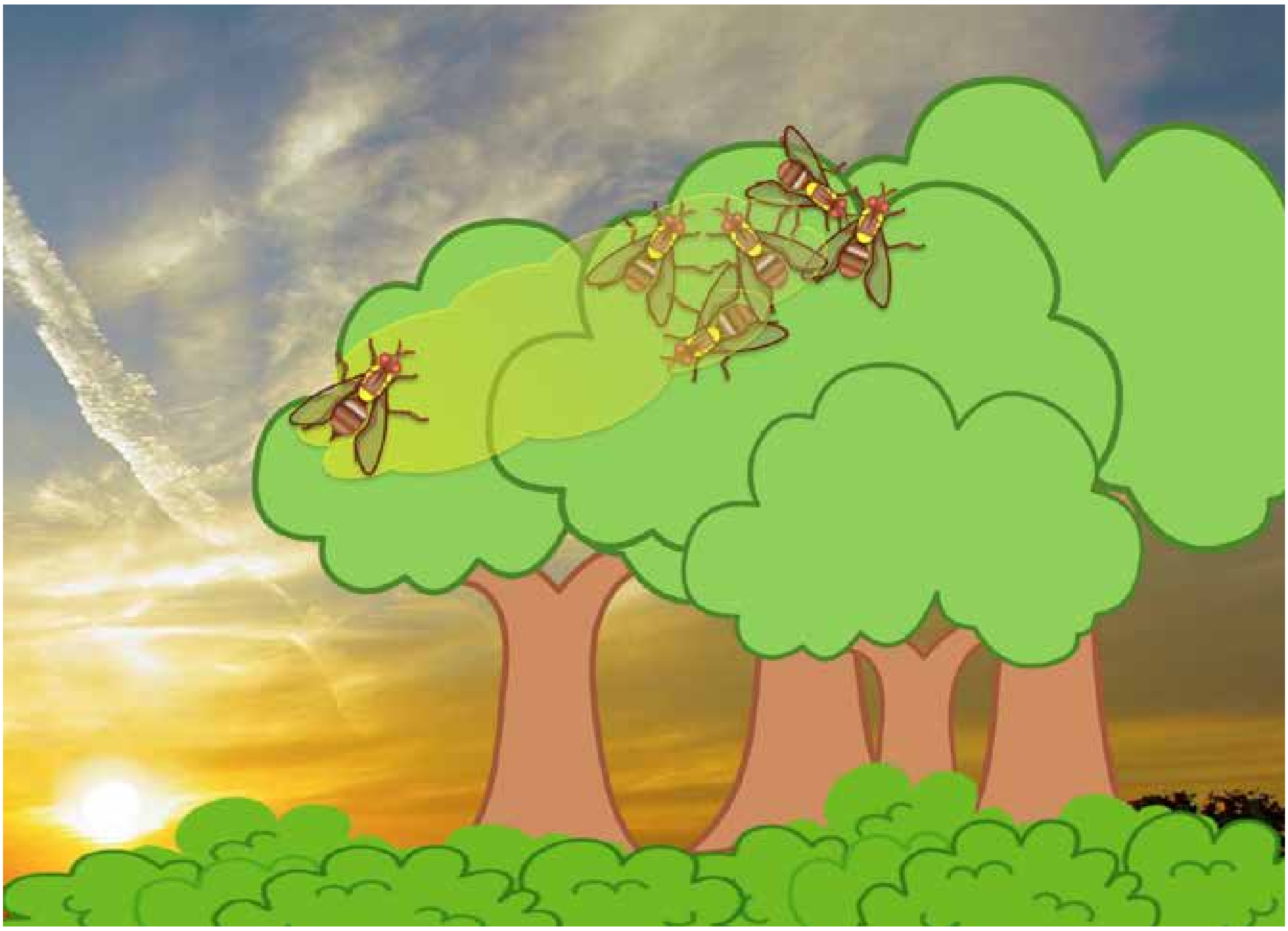
Fly feeding on sugar syrup on a leaf (left) and males gathered together in a citrus tree at dusk (right)

## ADULT FLIES

Once the adult fly emerges and expands its new wings, the first thing it needs is a drink of water. In warm conditions, flies will die after less than 48 hours without water.

As flies can't feed on solids, they need either liquid food or food they can dissolve in regurgitated gut liquid. It is unclear what fruit flies feed on in nature, but it is believed food sources include nectar, juice from damaged fruit and exudates on leaves.

Both male and female flies need to feed on protein to become sexually mature. This is especially important for the female in order to produce viable eggs. The more protein the female can find, the more eggs she



At dusk, male Qflies gather together at "lekking points" in trees and emit a pheromone to attract female flies


Female (left) and male (right) Qflies

is able to lay. Natural sources of protein include bird droppings and bacteria on leaves.

Fruit flies can breed when daily maximum temperatures are at least 20ºC. Under these conditions, and with adequate water and protein, flies become sexually mature 10–14 days after emergence. They then search for a mate.

Qflies only mate for around 30 minutes at dusk. At this time, male flies gather in groups in trees (lekking points) and emit a cloud of pheromone to attract female flies. Males are more likely to mate if they have fed on the para-pheromone cue-lure, as well as if they are able to “sing” (produce a buzzing noise).

Females may mate once or many times. They are more likely to re-mate if they sense their first mate lacked fitness. Female flies can store sperm from a single mating for weeks, using it to fertilise eggs throughout their life.

It is easy to tell male and female flies apart. Female flies have an ovipositor, which protrudes behind them, whereas males simply have a rounded abdomen.

Once the female fly has mated, she searches for a suitable host to lay her eggs. It is believed she mainly uses visual cues, but smell is also important. Her preferred hosts are soft fruit such as peaches, loquats and feijoas. However, potential hosts also include lemons, grapes, passionfruit and even avocados if they have started to soften. Fruit usually has to be ripe, but flies will lay eggs in unripe fruit if no other hosts are available.

Female fruit flies only lay into attached fruit; fruit that is rotting or on the ground is not attractive. However, infested fruit that has started to decay sometimes detaches from the plant. Orchards with a lot of fallen fruit can prove to be a breeding ground for fruit flies.

Female Qfly on a backyard loquat tree, looking for a good place to lay eggs.

It is not clear how long flies can live in the wild. Adult Qfly survival is poor if average yearly minimum temperatures are below 2.6ºC. However, it is widely believed that flies overwinter as adults, not as pupae or larvae. This suggests flies can live for at least three months, possibly longer.

# Queensland fruit fly

*Bactrocera tryoni*

mating and oviposition

14 days

Adult

fly emergence

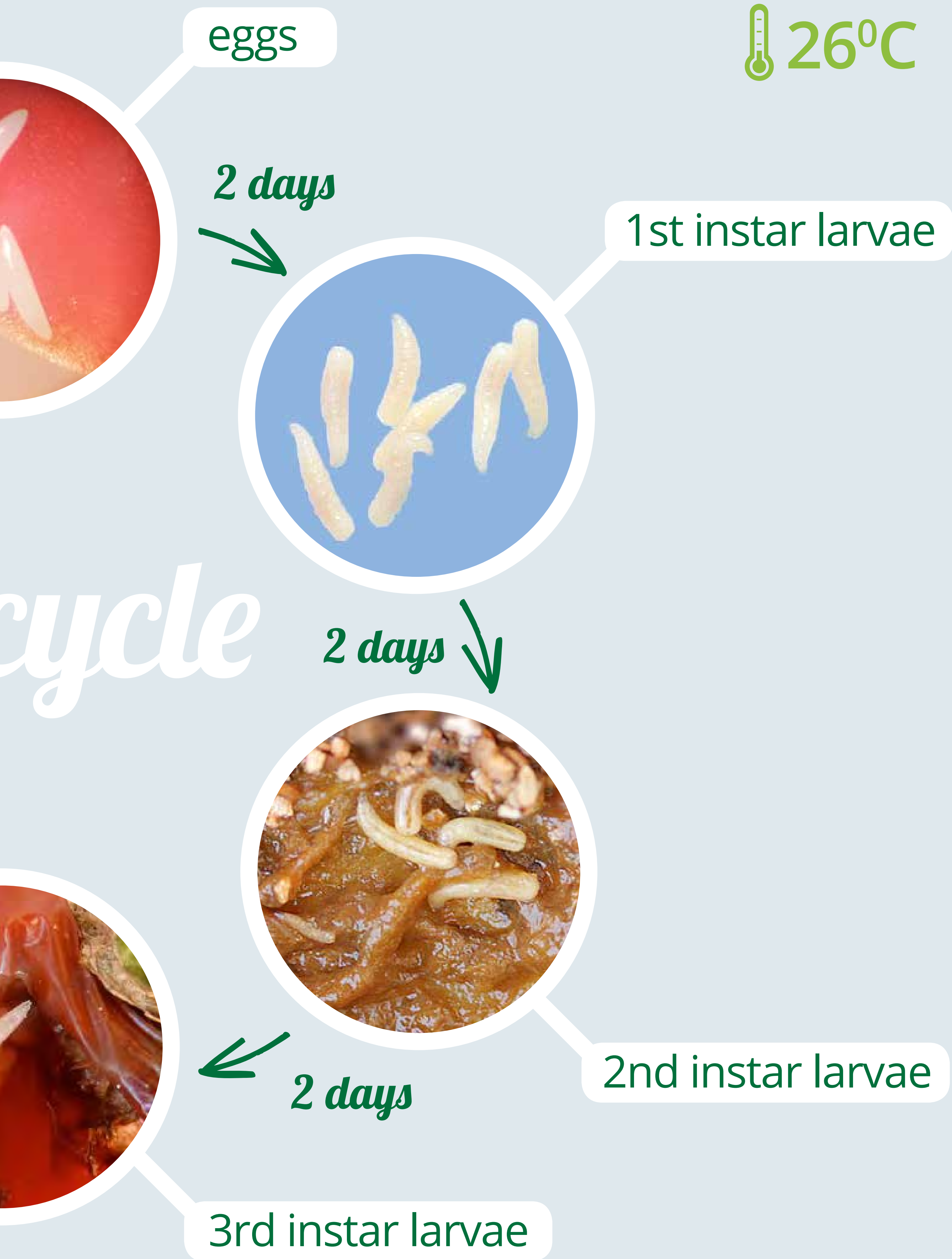
10 days

life

Pupae

2 days

larvae hop from fruit


eggs
26°C
2 days
1st instar larvae
cycle
2 days
2nd instar larvae
2 days
3rd instar larvae

## FRUIT FLIES VS VINEGAR FLIES

In general, if larvae are found in fruit already rotting on the ground, it is likely it has been infested by *Drosophila melanogaster* – vinegar fly. It is important to be able to tell the difference between these larvae and those of fruit flies; fruit fly damages intact fruit and can affect market access, whereas vinegar fly only attacks previously damaged fruit and is not a market access issue.

Vinegar fly larvae are generally smaller and thinner than Qfly larvae.

Other key differences are shown below:

| | **Qfly** | **Vinegar fly** |
|---|---|---|
| | **Generally intact fruit** | **Rotting fruit or vegetable** |
| **Larvae number** | Usually 2 – 10 per fruit, but can be 20 or more. | Usually >30 per fruit, rarely <10 per fruit. |
| **Larvae appearance** | White to cream, black feeding hook visible in mature larvae, smooth bodied, 2–9mm long. | White with black feeding hook, slightly notched along body, 1–5mm long. |
| **Larvae shape** | Wedge shaped, plumper at tail than head. | Slender throughout. |
| **Larvae breathing holes (spiracles)** | Very slight bumps for breathing holes in tail end.<br> | Distinct, long breathing tubes coming out of tail end.<br> |
| **Host material** | Soft, spongy, starting to rot. May be fully eaten out with only skin left.<br> | Liquified and rotting.<br> |
| **Pupae appearance** | Like a large grain of brown rice, variable colour.<br> | Like a small, rather slender grain of brown rice, with two small prongs at one end.<br> |

## FRUIT FLY BEHAVIOUR

### Natural habitat

The natural habitat of fruit flies is the forest, particularly the forest edges. They mate in trees, search for host fruit in trees, and generally feed and rest there as well.

Trees are sources of food and moisture. Bacteria on leaves and bird droppings on branches are also important foods for fruit flies. Food is therefore likely to be much easier to find in the forest than in vegetable crops, which represent a relatively barren environment for fruit flies.

This means that although flies will enter a crop to search for host fruit, they usually travel only a relatively short distance into it. Fruit near the crop edges is the most likely to become infested, especially if trees or other shelter is nearby. As the main reason for being in a vegetable crop is to lay eggs, it seems possible that more female flies enter crops than males.

### Flight distance

Fruit flies are not strong fliers. They spend far more time walking around the tree canopy than flying. When they do fly, it tends to be relatively short distances (5–50cm) from branch to branch, or close to (~2m) the ground in between trees. However, flight is an essential skill. Without it, fruit flies are unable to find a mate or fruit in which to lay eggs.

Flight-ability is affected by factors such as temperature, humidity and nutrition. For example, Qfly is unable to fly at temperatures below 16°C, while Medfly is inactive below 12°C. Flight is also restricted by high winds or low humidity. Conversely, adult flies are able to fly better if they were well-fed as larvae.

As long as food and host fruit are available, 90% of Qflies will range only 600m from where they emerged. Medflies are similar, with 90% of flies travelling less than 700m. Both species rarely travel more than 1km during their lifetime.

One of the reasons flies rarely disperse widely is because it makes it difficult for them to find mates. In the case of Qfly, flies mate for only around 30 minutes at dusk. During this short period groups of males gather together, producing a plume of scented pheromone to attract female flies. It seems likely that the relatively small amount of pheromone produced by a single male makes it difficult to attract distant females. This may be why dispersal more than 1km from their origin results in 'non-viable density' of the population.

On the rare occasions flies do disperse long distances, it is probable this is by accidental "hitch-hiking" on vehicles, equipment or plant material. Reports of Qflies travelling tens of kilometers are likely to be human assisted journeys rather than ones taken by wing power alone!  Most outbreaks of fruit flies in remote areas have been linked to infested fruit carried into the region, rather than incursions by travelling flies.

### Likes and dislikes

There are conflicting reports about what colours attract or repel fruit flies. There is general agreement that yellow is attractive, which is why many monitoring traps are this colour. However the attractiveness of red, blue and other colours is unclear. This may be because flies see in shorter wavelengths than humans, so items that reflect a lot of ultraviolet (UV) might look quite different to flies than they do to us. It has been shown that reflected UV light can attract fruit flies, especially at dusk.

It is also clear that fruit flies prefer to gather in dark spaces rather than brightly lit ones, probably due to their origin in forests. Conversely, flies appear to be repelled by white. White plastic may be one of the reasons fruit flies almost never enter greenhouse environments.

Fruit flies can be attracted by certain fruit volatiles, as well as by ammonia. There is increasing interest in combining fruit aromas with fruit mimics – generally spheres – to attract female fruit flies.

As previously noted, fruit flies are also attracted to "tree shaped" objects. Tree-lined areas around creeks and dams are good habitats for flies, and it has been suggested that creek-lines are the main route they use to move through the landscape; fruit flies rarely fly directly across open grassland or grain crops.

04.

MONITORING CAN HELP IDENTIFY WHERE FRUIT FLIES ARE COMING FROM, WHETHER POPULATIONS ARE INCREASING OR DECREASING, AND WHAT ACTIONS ARE NEEDED. TRAPS NEED TO BE PLACED IN HIGH-RISK AREAS AS WELL AS AROUND CROP PERIMETERS AND CHECKED REGULARLY.

# Monitoring

*The purpose of monitoring is to find out whether flies are present, and whether numbers are increasing or decreasing.*

- *Monitoring DOES NOT indicate how many flies are in the crop, whether females are present, or fruit are infested. Depending on the crop, even significant numbers of flies in traps does not mean the product is infested.*
- *Monitoring DOES indicate whether control strategies are proving effective. It can also help focus extra control measures on fly hot spots, inside or outside the crop.*

## GOVERNMENT MONITORING GRIDS

While there are clear differences between Government grids and monitoring on vegetable farms, these protocols do provide guidance as to trap spacing and actions to be taken.

Monitoring grids are maintained by Government authorities in certain growing regions. These are primarily areas where fruit fly is absent, or pest numbers are low enough to make claims in relation to market access. Monitoring grids may be targeted at detecting any fruit fly (in the case of a fruit fly free production zone) or for detecting incursions of species not present in that area (such as Qfly into WA).

Trapping grids are therefore maintained in areas around ports, in the north of Australia, and regions such as the Sunraysia Pest Free Area in Victoria / NSW. For example, the Tasmanian Government maintains a monitoring grid of over 900 traps for both Qfly and Medfly.

Urban monitoring grids have traps spaced at 400m intervals and are checked weekly, at least during summer. Grids in orchard areas more commonly use 1km spacing. Exotic fly incursions may be detected using grids spaced even more widely, on a 5km grid.

## PARAPHEROMONE LURES

Monitoring usually invo lves traps baited with male attractants – 'parapheromones'. These are manufactured chemicals that have pheromone–like activity. Parapheromones improve mating performance in male flies that have been exposed to them. They do not usually attract female flies.

Attractiveness varies by lure and species;

- Cuelure attracts Qfly and lesser Qfly
- Trimedlure attracts Medfly.
- Methyl eugenol attracts wild tobacco fruit fly *(B. cacuminata)* and exotic species such as Oriental fruit fly *(B. dorsalis).*

**Standard actions relating to detections on a 1km grid are:**

| Fly detection | Time interval | Action |
|---|---|---|
| **One male** | 2 weeks | Do nothing |
| **2-4 males** | 2 weeks | Supplementary trapping |
| **5 males** | 2 weeks | Control program for >12 weeks within 1.5 km of trap |
| **Gravid female** | any | Control program |
| **Larvae in fruit** | any | Control program |



Wafer type lure (left), Ladd trap (centre) and wick lure (right)

- Zingerone attracts Jarvis fly.

Approximately 40% of fruit fly species do not respond to any of the known para-pheromones. For example, Cucumber fly is an increasingly important pest of cucurbits. Unfortunately it does not respond to any of the existing parapheromones, so cannot be readily monitored. (note: a new lure using cucumber volatiles may provide a monitoring tool in the future).

In addition, monitoring traps have a limited zone of attractiveness. For example, the zone of attraction of cuelure to Qfly is unclear, but may be in the order of 10–20m. The attraction of Medfly to trimedlure is stronger, with flies drawn from 32–50m distance. However, even within this zone, only a percentage of the total population is likely to be captured by the lure. No lure will attract 100% of male flies.

## OTHER TYPES OF LURE

If a parapheromone is being used as part of an attract and kill strategy (eg MAT) then monitoring using the same attractant becomes unreliable.

Although lures based on food or volatiles have a smaller zone of attraction than parapheromone lures, they can provide some information about fruit fly populations. Lures containing protein and/or volatiles can attract female as well as male flies. However liquid lures need to be topped up regularly and can become smelly and messy, especially when trying to count flies. They also attract by-catch, such as blowflies and other non-pest insects.

New gel lures are becoming available, but are relatively untested for monitoring purposes.

Fruit mimics can also be used to attract fruit flies. For example, the Ladd trap consists of a sticky yellow sheet and red ball in the centre. The sticky sheet has to be replaced regularly, with flies identified and counted.

## TRAP TYPES

There are many different types and styles of traps sold for monitoring Qfly and Medfly. With the exception of visual / aroma based traps such as the Ladd trap, all contain a dispenser for the parapheromone. This is usually a fabric wick or a waxy 'wafer'. The new FT Mallett-CL wafer provides more controlled release of cuelure than fabric wicks, and is very attractive to Qfly.

Traps also contain a contact insecticide, which may be added by the operator or already included in the wick / wafer. Malathion (maldison) and DDVP (dichlorvos) are two insecticides commonly used.

The McPhail trap is the original fruit fly trap widely used in Government trapping grids. It has a yellow base and clear lid. The lure can be suspended from the lid, or a liquid lure added to the base. Flies enter through a hole in the base. Originally constructed of hard plastic, newer models are more lightweight and less expensive.

The Biotrap also has a clear lid with yellow base. Either a para-pheromone lure or a liquid can be added. When baited with a wax wafer impregnated with cuelure + maldison, the Biotrap has been demonstrated to be a very effective tool for monitoring Qfly.

The Probodelt Conetrap comes flat packed, and is easily clipped together. As the inside of the lid is pre-coated with an insecticide, it can be safely assembled even without gloves. The cuelure is contained inside a tyvec sachet, which is placed inside. Flies enter through inverted side holes but then move towards the light, and are killed on contact with the lid.

Other traps include the Lynfield trap, and similar, modified versions sold by companies such as Organic Crop Protectants (OCP) and Bugs for Bugs. The Lynfield trap is usually baited with dental wicks that have been soaked in cuelure, or other parapheromone, plus maldison. The OCP trap avoids handling risks by using a fabric wick already impregnated with cuelure plus maldison. The wick is secured inside a plastic protector, which is then safely installed under the lid.


Traps (clockwise from top left) – McPhail trap, Biotrap, Conetrap, Lynfield trap and modified Lynfield trap (Organic Crop Protectants, Bugs for Bugs)

## TRAP PLACEMENT

The natural habitat of fruit flies is the forest. Flies tend to feed and rest in trees, preferring those near moist areas such as creek lines or dam edges. Trees are also where they go to mate. Fields of vegetables are not the natural habitat of fruit flies, although females will enter them to lay eggs.

The best place for traps is therefore in tree lines around the edges of the crop.

Extra traps can be placed around areas where infestation may come from, such as neighbouring orchards, town areas with backyard fruit trees, or creek lines. Areas with abandoned or unmanaged fruit crops are a particular risk, so well worth monitoring.

Under cold conditions, flies are likely to be attracted to warm spots, such the northern side of trees. However, if conditions are hot and dry, then the flies are more likely to be found on the eastern or southern side of trees.

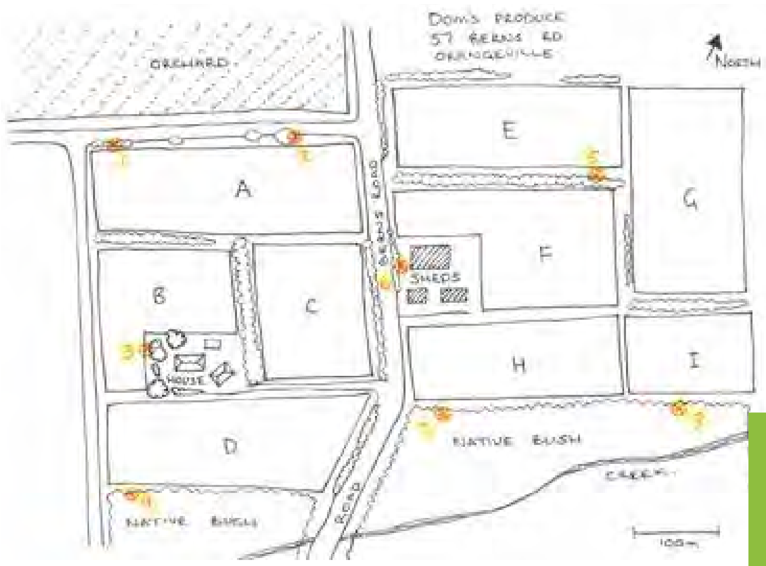
In large cropping areas, or where there are no alternatives, it may be necessary to place traps within the crop itself. However traps attract male flies, whereas it is the female flies that are searching for host fruit. Trap catches of male flies within a crop may therefore provide only limited information on the local population.

## CHECKING TRAPS

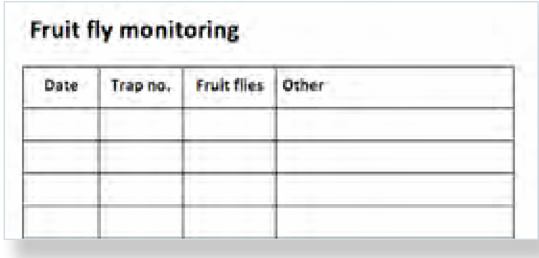
Traps should be numbered and listed on a farm map, so that anyone can check them. They need to be checked weekly when populations are expected to be increasing or high. For Qfly, this is when daily maximums exceed 22°C. Traps may be checked every 2–4 weeks at other times. The operator needs to record the number of flies found using a record sheet. The trap should then be emptied and reset.

If possible, the operator should also record whether any female flies are found inside the trap – finding a female fly inside a para-pheromone baited can indicate that populations are high, and action needs to be taken.

Checking and maintaining traps takes time. However, the more traps there are, the better the warning of incursions into the crop. Standard trap spacing is 400m, but it can be useful to include more traps in high-risk areas.




Farm map showing placement of fruit fly traps



**Fruit fly monitoring**

| Date | Trap no. | Fruit flies | Other |
|---|---|---|---|
| | | | |
| | | | |
| | | | |
| | | | |

Example of fruit fly record sheet

The purpose of monitoring is to detect incursions of fruit flies into the area, and determine whether populations are increasing or decreasing. How this information is used will depend on risk of crop infestation. The actions taken for Government trapping grids shown in Table on page 14 may be useful for areas with low pest populations. However, for areas where fruit flies are present throughout the year, higher action thresholds may be appropriate.

Abandoned citrus orchards are a major potential source of fruit flies, so well worth monitoring with an extra trap.

## BEST PRACTICE

- ✔ Monitoring usually involves a para-pheromone lure. Lures need to be appropriate to the target species.
    - The FT Mallett-CL wafer is very effective for Qfly and lesser Qfly.
    - Trimedlure is used for Medfly.
    - There are currently no commercial lures for Cucumber fly or Jarvis fly.
- ✔ Suitable traps include the Biotrap, Conetrap and versions of the Lynfield trap.
- ✔ Monitoring traps should be located at least every 400m around the cropping area.
- ✔ It is recommended to install additional traps in high-risk areas, such as adjacent to orchards, near urban areas and along treed watercourses.
- ✔ During cool periods, traps are best located in warm spots, such as the northern side of trees. In hot conditions traps are best in cooler, sheltered areas.
- ✔ Traps need to be numbered and recorded on a farm map.
- ✔ Check traps weekly when populations are increasing or high and every 2–4 weeks at other times. Record the number of flies, noting if any are female, and re-set the trap.
- ✔ For Government run fruit fly monitoring programs, catching 5 male flies or 1 female fly in a single trap within a fortnight triggers a control program. Higher or lower thresholds may be appropriate for vegetable farms depending on the crop and farm circumstances.

05.

PROTEIN BAITS ARE AN IMPORTANT PART OF ANY FRUIT FLY MANAGEMENT PLAN AS THEY TARGET IMMATURE FEMALE FLIES. THEY SHOULD BE APPLIED WEEKLY ONCE FLIES START TO EMERGE.

# Protein Baits

*Protein baits can attract both male and female flies. They are especially attractive to newly emerged female flies, which need to feed on protein to mature and develop their eggs. The ingredients used, and how and when baits are applied, greatly influences their effectiveness in the field.*

## Sprayable baits can contain:

Protein

+

Insecticide

+


Carbohydrate

+


Thickeners

## PROTEIN

Protein needs to be partially broken down (hydrolysed) to make it attractive to the flies. Yeast autolysate is the usual protein source used. Commercial products include;

| Protein product | Formulation | Protein content | Bait consistency |
|---|---|---|---|
| **Fruit Fly Lure™** | Thick liquid | 420 g/L | Suspension |
| **Natflav 500™** | Thick liquid | 420 g/L | Suspension |
| **CERABAIT™** | Liquid | 360 g/L | Suspension |
| **Flavex® FL622** | Liquid | 140 g/L | Liquid |
| **HYM-LURE™** | Liquid | 425 g/L | Liquid |
| **ANAMED™ SPLAT (protein)** | Paste | | Paste |
| **Flavex SPA400** | Powder | 420 g/L | Liquid |
| **DacGEL™** | Powder | | Gel |

While all of these products provide protein, they have different attractiveness to flies.

Trials conducted by QDAF suggest that Hym-Lure is highly attractive to both Qfly and Jarvis Fly. The bait was applied at 0.84% concentration (2L per 100L water), slightly more concentrated than the suggested label rate of 1.5L per 100L water. Qfly is also strongly attracted to Flavex SPA400, followed closely by Flavex FL622.

Cucumber fly was also strongly attracted to Flavex SPA400, as well as to Fruit Fly Lure.

Note that some growers have found that mixing bait the night before application helps to avoid any potential lumps in solution, especially if a powdered protein source is used.


## INSECTICIDE

Insecticide needs to be mixed with the protein source.

The main two insecticides currently used in protein bait sprays are Maldison and Spinosad. Trichlorfon (Dipterex™ 500) is also registered but considered to be less effective.

Fipronil (Regent® 200SC) and Abamectin (CroPro STEALTH©) have both been shown in trials to be effective against Qfly, while Fipronil and Spinetoram (Success™ Neo) were highly effective against cucumber fly. Unlike Maldison, these insecticides do not have a repellent effect on fruit fly feeding. However, none of these insecticides are currently registered for use in fruit fly baits.

### Maldison

Maldison is a highly effective, contact insecticide. This means the fly is killed simply by landing on the bait. It is relatively stable, so remains active for weeks or even months after application. Registered commercial products include HyMal®, Maldison 500™, Amgrow Malathon® and Fyfanon 440 EW®.

Maldison is an anti-cholinesterase compound; it works as a nerve poison. As a result, it is hazardous to humans and other mammals, highly toxic to insects including bees and deadly to fish. Protective equipment must be worn when mixing or applying maldison based baits. Extreme care is needed if applying maldison baits in areas near water-courses or residential areas.

Applying maldison baits in the early morning while conditions are cool will help limit any effect on bees as well as maximise its effectiveness.

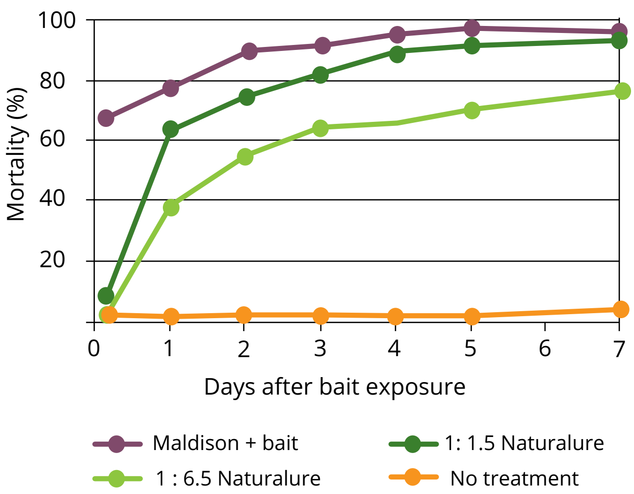
### Spinosad

Spinosad kills by ingestion, making it safer for bees and other beneficial insects. It is applied as part of the pre-mixed bait Naturalure™; other formulations of spinosad (eg Success Naturalyte™) are not registered for use in fruit fly baits. Spinosad is derived from a naturally occurring soil bacterium. It is classified as organic (under some schemes) and has very low toxicity to humans. It can therefore be used in sensitive areas and poses minimal risk to worker health and safety.

Spinosad is degraded by UV light. Depending on weather conditions, it remains toxic for 3 to 7 days after application. Baits need to be applied at approximately weekly intervals anyway, and this is particularly important if using Naturalure.

Another factor to consider is that the fly has to eat enough Spinosad to get a toxic dose – if it only eats a little it will not be killed. Sub-lethal doses can increase development of resistance. If flies have already fed on protein they will be less attracted, and eat less of the bait if they do respond. Naturalure is therefore less effective against female flies that have already fed on protein.

The Naturalure label specifies two dilution rates; 1:1.5 and 1:6.5. Different volumes are applied for each rate, so as to deliver the same total amount of Naturalure per hectare. The more concentrated solution is a thick liquid, so difficult to apply through normal spray equipment. However, trials have found that the 1:1.5 dilution rate is more effective at controlling flies. It is also longer lasting in the environment, still killing flies for up to 7 days whereas the 1:6.5 solution loses effectiveness more quickly.




Mortality of Qfly exposed to two different label rates of Naturalure over a seven day period. Results are compared to a standard Maldison + protein bait and no treatment.


Windbreak plants such as sorghum are very suitable for applying baits. Baits for Qfly and Medfly should be applied 1.5-2m above the ground, whereas baits for cucumber fly are best at 1m above the ground, as that is where the flies are likely to be foraging.

## OTHER INGREDIENTS

Carbohydrate sources – sugars – can be added to baits to increase attractiveness. However, this may also attract non-target insects such as ants and even bees.

Thickeners can increase the time the bait remains effective. Thickened bait is more resistant to washing off during rain or irrigation. Thickeners can also help stop the bait from drying out, which is likely to extend the time it stays attractive.

## WHERE TO PUT BAITS

In orchards, baits are usually sprayed on the bases of trees along every second row. However in vegetable crops it is not possible to spray within the crop itself.

Bait must therefore be applied to the perimeter vegetation. This is appropriate, as perimeter vegetation is where flies are most likely to feed, rest and search for mates. Baits have only a very small zone of attractiveness, so they need to be applied where flies are most likely to be.

Baits perform better when sprayed onto vegetation than inert surfaces (such as posts, boards etc.). This is thought to be because baits stimulate bacteria already on the plant leaves, and it is volatiles from the bacteria that help attract hungry fruit flies.

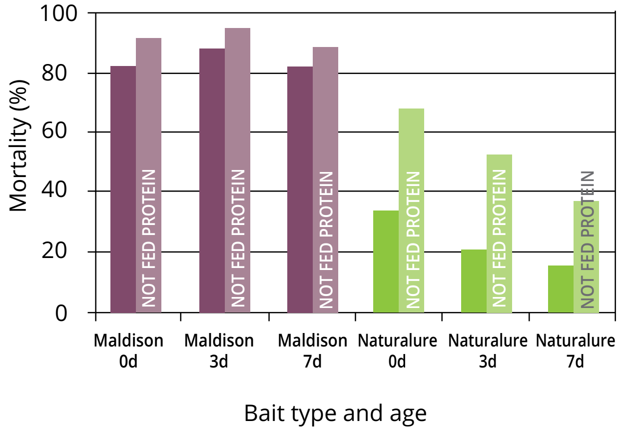
The type of plants growing around the perimeter also affects baiting effectiveness. Sorghum, cassava and sweet corn appear to be more suitable for baiting than vegetable crops or permanent hedging plants such as orange jessamine and lilly pilly. This may be due to the density of leaves, which provides sites for roosting and a larger surface for the bait itself.

One of the other criteria for plant suitability is height. Qfly tends to roost high in trees, so baits should be applied 1.5m to 2m above the ground. Cucumber fly, in contrast, tends to stay closer to the ground. In this case baits should be applied at approximately 1m height.

## WHEN TO APPLY

After emerging from the pupae, it takes female flies around two weeks reach full maturity. This is when they most actively search for protein to mature their eggs; once they have fed on protein they are less interested in finding more, although they will feed if it is there in front of them.

Baits need to be where flies will find them, right when they most need a protein meal.




**Effect of insecticide type and bait age on protein fed (dark bars) and protein deprived (light bars) female Qflies. The trial was conducted in small cages; even accidental contact with the Maldison bait killed flies. Naturalure kills by ingestion so mortality depends on how much the flies eat. Flies fed protein before the trial did not eat the bait, especially if it was a few days old. Flies that had <u>NOT</u> fed on protein before the trial were more likely to eat the bait but still ate less if the bait was old.**

Like bread from the bakery, baits are most attractive when they are fresh. Even though Maldison-based baits can remain active for several weeks, once they have dried out and aged they are not nearly so attractive to flies.

Bait applications therefore need to start when young, female flies are starting to emerge. They should be applied weekly for best effect, or at least every 10 days. Some growers apply every five days, just in case they are forced to miss a date.

Bait applications should use a coarse spray, resulting in droplets of 2mm across. If more than 5mm rain occurs it may be necessary to re-apply the bait.

Fruit flies most actively forage for food in the morning. Spraying early in the day not only reduces risk to bees, it ensures fresh bait is there when flies want it.

As with any other chemical, bait applications need to be recorded.

## BEST PRACTICE

- ✔ Baits need to combine an attractive protein source with an effective insecticide.
  - Protein sources Hym-Lure and Flavex are both very attractive to Qfly and Jarvis fly Natflav 500 is also appropriate.
  - Flavex and Fruit Fly Lure are very attractive to Cucumber fly.
  - Maldison is an effective and long lasting insecticide.
  - Adding a thickener helps to preserve bait in the environment
- ✔ Naturalure is a less toxic alternative to maldison-based baits, so may be used in sensitive areas. Apply heavy droplets at the 1:1.5 dilution rate for best results.
- ✔ Newly emerged female flies are most strongly attracted to protein baits. Bait applications should start when flies are just starting to appear, before fruit matures.
- ✔ Baits should be applied in the early morning, when flies are actively searching for food.
- ✔ Apply baits weekly when fly populations are high. If >5mm rain falls bait may need to be re-applied.
- ✔ Spray baits on windbreak plants around the crop perimeter.
  - Dense foliaged plants such as sorghum, cassava or sweet corn are very suitable.
  - Permanent hedging and vegetable crop plants are less attractive.
  - Baits should be applied at least 1.5m from the ground to target Qfly and Medfly, but 1m from the ground for Cucumber fly.
- ✔ Like any other chemical, bait applications must be recorded.

### Protein bait application record

| Date | Start time | Finish time | Location treated | Product | Rate | Equipment | Wind | Operator signature |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |
| | | | | | | | | |

**Sample form for recording sprays of protein bait.**

06.

**MAT USES A PARA-PHEROMONE LURE PLUS INSECTICIDE TO LURE AND KILL A PERCENTAGE OF MALE FLIES IN THE POPULATION. AS MALES CAN MATE MANY TIMES, MAT NEEDS TO BE COMBINED WITH OTHER CONTROL STRATEGIES TO BE EFFECTIVE.**

# Male annihilation

*The Male Annihilation Technique (MAT) involves the same lures and insecticides that are used for monitoring, just without the trap to retain dead flies.*

MAT block made from caneite soaked in a mixture of cuelure and maldison (left), the OCP MAT cup (centre) and Amulet MAT containing cuelure plus fipronil insecticide (right, Photo by Daleys Nursery)

## TYPES OF MAT

MAT combines a parapheromone such as cuelure with an insecticide, such as Maldison.

This mixture can be soaked into an absorbent material such as caneite blocks or compressed cardboard and simply hung out in the field. The wick lure used in the OCP / Bugs for Bugs trap can also be used separately as an MAT device. This unit has the advantage that the plastic cap protects the wick from rain and UV, extending its useful life.

Similarly, the Magnet MED trap contains trimedlure inside a protective, laminated shell. The outside of the device is coated with insecticide, and remains able to kill Medfly for approximately 6 months.

Flies which are not attracted to a known parapheromone, such as Cucumber fly, cannot be managed with MAT.

As no trap is involved, MAT blocks are cheap. They can remain both attractive and insecticidal for 3– 6 months depending on weather conditions.

## HOW TO USE MAT

Just as with traps, not every male will be attracted to a lure. Parapheromones are attractive to male flies because feeding on them increases their mating success. Just as with protein in baits, they will be less responsive once they have been exposed to cuelure or a similar natural product. MAT is therefore most likely to be effective with newly matured male flies.

As previously noted, para-pheromones have a limited zone of attraction. For example, cuelure can attract Qfly from 10–20m distance. However even within this distance not all flies will respond.

Magnet MED trap for Medfly

For best results, MAT units need to be spaced regularly around the crop edges and other areas where flies are likely to gather, such as trees near watercourses. Spacing every 20m, or more frequently, will maximise the effects.

The other issue with MAT is that males can mate many times. Even eliminating a large number of males from the population will not prevent female flies from mating and laying eggs.

Finally, if the same lure and kill system is being used for MAT and in traps, this can affect the outcomes of the monitoring program. Reducing the number of male flies caught in traps can suggest that the population is low, when the number of female flies in the crop may actually be increasing in the crop.

MAT needs to be used in combination with other strategies, particularly protein baiting. MAT will be ineffective if used alone.

## BEST PRACTICE

- ✔ MAT devices should be installed no more than 20m apart around the crop perimeter and other places that flies may gather.
- ✔ Units need to be replaced every 3–6 months to ensure the insecticide remains effective.
- ✔ As MAT uses the same lures and insecticides that are used in monitoring traps, trap data should be interpreted cautiously if MAT is in place.
- ✔ MAT is ineffective used alone, but can be combined with other control strategies, particularly protein baiting.

07.

**THERE ARE A NUMBER OF COMMERCIAL DEVICES AVAILABLE THAT LURE AND KILL FEMALE FRUIT FLIES. IT IS NOT CLEAR WHAT PERCENTAGE OF THE POPULATION IS REMOVED, AND SO FAR NONE HAVE BEEN DEMONSTRATED AS EFFECTIVE FOR VEGETABLE CROPS.**

# Female biased traps

*Female biased traps aim to lure and kill a large percentage of the fly population. They can be based on food, fruit volatiles or fruit mimics. Despite many years of searching, there are no pheromone based lures for female fruit flies.*


Cera Trap (left) and dead flies inside a trap (right)

## CERA TRAP

The Cera Trap is food based, containing a liquid protein mixture with a mild ammonia smell. No insecticide is needed as flies simply drown. The liquid needs to be kept well topped up, so units need to be serviced regularly in hot weather.

Also, the trap can attract significant by-catch – blowflies, ants, etc – especially once captured insects start to rot. If large numbers are caught, the trap contents need to be strained to remove dead insects then replaced into the trap. This is a rather unpleasant and time consuming task.

Cera Traps attract both male and female fruit flies, with a bias to females. While Cera Traps can certainly kill Qfly, Jarvis fly and other fly species, it is unclear what percentage of the local population is trapped by this device.

Liquid protein does not have a strong smell, so the zone of attraction of the Cera Trap appears to be quite limited. Even placing traps at 15m intervals around the perimeter of a cropping area may only kill a relatively small percentage of the population. While it is satisfying to see dead flies in traps, this has not been demonstrated to significantly reduce the number of infested fruit in Australian vegetable crops.

Fruition trap (Photo by Griffith University)

Biotrap with gel attractant and DDVP cube

## FRUITION TRAP

This new device (launched November 2016) combines a slow release sachet of fruit volatile aromas with a large, sticky, cobalt blue sphere. Flies attracted by visual and olfactory cues become stuck on the sphere. The developers claim that their synthetic ripe fruit aroma remains highly attractive to Qfly for up to eight weeks, as well as potentially other species. As this is a new device, its effectiveness for vegetable crops has not been tested.

## BIOTRAP WITH GEL ATTRACTANT

The Biotrap Fruit Fly Attractant Gel is an ammonia and fruit volatile based gel which is stated to last up to three months. It is combined with a DDVP cube which kills flies entering the trap.

Suggested spacing is 15m intervals around the perimeter of the crop. As this is a new system, its effectiveness for vegetable crops has not been tested.

## BEST PRACTICE

- ✔ Female biased traps can kill a percentage of the fly population.
- ✔ They need to be installed at intervals of 15m or less around the crop perimeter then checked and re-set regularly.
- ✔ There is no published evidence that they are effective in vegetable crops. However, they may be useful in combination with other control strategies.

08.

GREENHOUSE WALLS, NETTING AND EVEN PLANT COATINGS CAN PREVENT OR REDUCE FLIES ENTERING THE CROP AND INFESTING FRUIT. AS WELL AS BEING PHYSICAL BARRIERS, THESE DEFENSES CAN PREVENT FLIES FROM SEEING AND/OR SMELLING POTENTIAL HOSTS.

# Physical protection

*Physical protection can be expensive and is not suitable for all crops and field situations. However, it is a highly effective way to protect vegetables from fruit fly. It can also provide additional benefits in terms of productivity, quality, reduced irrigation requirements and control of other pests.*

Greenhouses offer a major barrier to fruit flies, whether glass (left) or plastic (right). Even though the house shown at right has a retractable roof, flies rarely – if ever – enter this environment.

## GREENHOUSES

Fruit flies rarely, if ever, enter greenhouses.

Greenhouse walls are clearly a physical barrier to fruit flies. They usually present a flat, white exterior, the crop inside being obscured.

In contrast, fruit flies are known to orient towards dark, tree shaped objects. They tend to avoid white or reflective areas. This suggests that greenhouses in general are likely to be relatively unattractive.

Although fruit flies could still enter through un-meshed roof vents or opened doors, they generally do not do so. This may be due to their habit of flying low to the ground or darting from tree to tree. Fruit flies rarely fly high across open spaces. They are only likely to enter roof vents if strongly attracted by fruit aroma or pheromone, or if they are blown there accidentally.

## NET HOUSES

Net houses can be used to protect crops from weather, sunburn and pests ranging from wallabies to thrips.

The traditional view of netting against fruit fly was that the crop had to be fully enclosed in insect proof netting, with “air-locks” for entry of people and equipment.

However, most of the benefits of netting can be obtained with much lower levels of security.


Net houses, such as this one in Carnarvon WA, can greatly reduce the number of flies entering a crop. Even though flies can physically fit through or go under the mesh, the combination of a visual and a physical barrier greatly reduces incursions.

Hail netting is not fruit fly proof, as holes are large enough for flies to crawl through. Despite this, experience with orchard fruit has shown that installing hail netting on both top and sidewalls greatly reduces entry of flies into the orchard. If the hail netting is white, it is likely to offer even better security, as white is repellent to fruit flies.

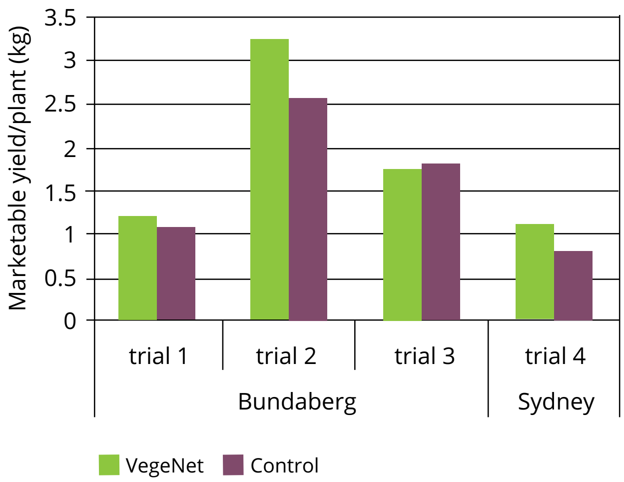
Flies use both visual and scent cues to find host fruit. Hail netting and windbreak materials hide the crop from flies, and may even reduce drifting of fruit aromas. If flies cannot see or smell the fruit, there is no reason for them to try to go inside.

## FLOATING ROW COVERS

Unlike the permanent structures required to construct net houses, floating row covers involve simply draping netting over plants and securing the edges with shovelfuls of soil.

Various grades of netting can be used, ranging from coarse windbreak materials to extra fine nets designed to exclude all pests. The weight of materials can be an issue if they are not supported, but upright plants such as capsicums and eggplant can easily support lighter grade nets as they grow.

As with net houses, floating covers can give plants protection from wind, heavy rain and sunburn. They also reduce water requirements and exclude various pests. Light is diffused and evaporation is reduced, resulting in larger and healthier plants. For example, floating covers have been shown to increase marketable yield of capsicums, mainly through improved fruit set and reduced damage from wind and sun.



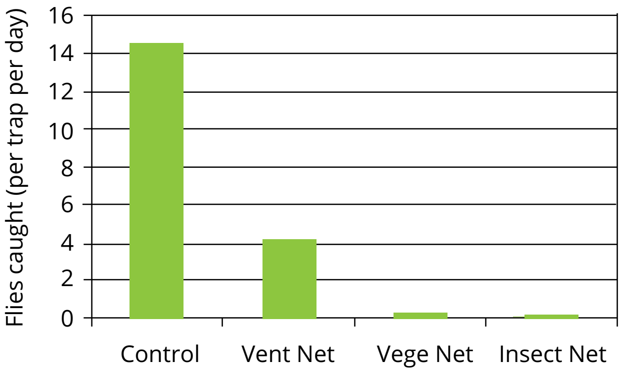

Marketable yield of capsicums (kg/plant) assessed at initial commercial maturity from four separate trials conducted in Bundaberg and southwest Sydney. Capsicums were grown under VegeNet or left uncovered (controls).

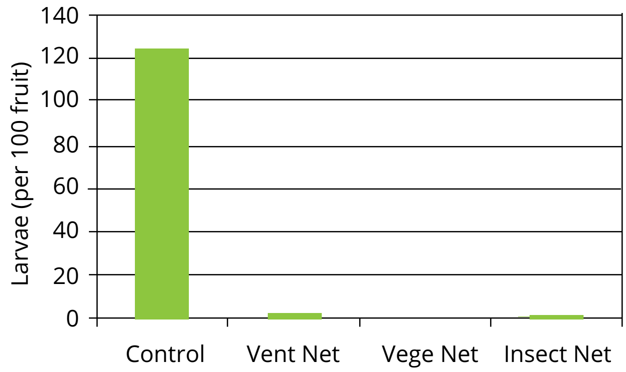
Like net houses, floating covers also provide a visual barrier to fruit flies. Even if a few flies do penetrate the netting, the number of infested fruit can be reduced to almost zero.

Lightweight materials such as VegeNet (NetPro) are very suitable for excluding fruit flies from vegetable crops. This material weighs 45g/m² and has mesh size approximately 1 x 3mm.

Trials in Bundaberg and Sydney testing various netting types found that;

- VegeNet was an effective visual barrier and did not exclude natural predators from the crop. No infested fruit were found under this material while it remained intact.




Number of flies caught (left) and number of larvae found per 100 fruit sampled (right) in a cayenne chilli crop where plants were left uncovered (control) or covered with VentNet (windbreak material), VegeNet (lightweight net) or Insect Net (fine net).

- Insect Net with mesh size 0.8mm was relatively transparent. No insecticides were used in the trial and the net excluded beneficial insects, with the result aphids infested the covered plants.
- Although flies could get into crops covered with Vent-Net screening material, oviposition was almost zero. It seems likely male flies were strongly attracted by cuelure in traps under the material, motivating them to find their way through the mesh, whereas female flies were less intent.

Placing netting over the crop while the plants are still small, even before fruit set, gave the best improvements in plant health.

Netting adds cost, both in materials and labour. Accessing the crop is more difficult, which is especially an issue if there are multiple harvests. While netting can be used for several years, cleaning the material between uses (to ensure disease is not spread) also creates challenges.

Single use frost protection fleece materials such as Daltex Groshield or Agryl can make effective insect barriers. While these materials are inexpensive, they tear easily if wind gets beneath the covers. These materials are therefore not suitable for application to upright plants such as capsicums and eggplant, but may be used for low growing crops such as pumpkin.

Male Qfly on the outside of VegeNet, unable to reach the cuelure baited trap inside.

In Europe, mechanical systems are used for installing and recovering floating covers. Such systems could potentially reduce costs and enable use of netting on large scale vegetable farms.



VegeNet (left) and Insect Net (centre) on capsicum plants. VegeNet is 1 x 3mm mesh size and $45 g/m^2$ whereas Insect Net is 0.8mm mesh and $70 g/m^2$. Vent-Net (right) on capsicum plants, with plague soldier beetle on the outside.

Kaolin on chilli plants (left), showing the effect after two kaolin applications followed by several rain events. Although some of the material has been washed from the plants, they still appear white from a distance. Kaolin on a potted chili plant (right).

## KAOLIN CLAY

**Kaolin** – aluminium silicate – comes from kaolinite, a natural mineral. It is allowed under organic systems, and has a wide range of both industrial and agricultural uses.

Commercial sprayable kaolin products (eg Surround WP) are most commonly applied to tree crops such as apples and pears to prevent sunburn. The suspension is sprayed on using an agitated tank, coating the plants with fine, white powder. The crystalline structure of the clay reflects red light wavelengths and diffuses sunlight, so photosynthesis is actually increased. Kaolin lowers temperatures on the leaf surface and reduces water loss.

Plants sprayed with kaolin look white – which is repellent to fruit flies. The material also disguises the fruit, which are hard to distinguish from the foliage. Additionally, the fine clay particles are believed to irritate flies that land on the material, discouraging them from settling.

Trials using kaolin clay have found that it can reduce the number of larvae in fruit by 90 to 100% compared to untreated controls.

Kaolin is not without drawbacks. The material is relatively expensive, and has to be applied several times to get a good coating. Kaolin will likely need re-application if it rains or overhead irrigation is used. After harvest fruit needs to be thoroughly washed to remove the material, which usually requires water jets and brushes. It is likely to be difficult to remove all kaolin residues from irregularly shaped products such as capsicums.

## BEST PRACTICE

- ✔ Physical barriers are highly effective against fruit fly.
- ✔ Fruit flies rarely enter greenhouses, even if the roof is open.
- ✔ Floating covers are an effective way to reduce the number of flies entering a crop and can also improve plant health.
    - Net with 1 x 3mm diameter mesh is very suitable for excluding fruit flies.
    - Nets that are not insect-proof can still be effective if they provide a visual barrier.
    - Secure nets well around the edges using shovelfuls of soil.
    - Clean nets between uses to avoid transferring disease to new crops.
    - Disposable fleece materials could potentially be used to exclude fruit flies from low growing plants.
- ✔ Coating plants with kaolin may be a useful management tool, but cost and issues with removal must be considered.

09.

REMOVING POTENTIAL SOURCES OF INFESTATION CAN STOP FRUIT FLY POPULATIONS BUILDING UP ON FARMS AND HELP PREVENT INCURSIONS FROM NEIGHBOURING AREAS.

# Hygiene

*On-farm hygiene and biosecurity are good practice in terms of managing ALL pests and diseases, not just fruit flies. Fruit flies can move, which creates additional challenges. However, limiting incursions into a crop can both reduce infestation of fruit and increase the effectiveness of other control measures.*

## ISOLATING THE CROP

As previously described, fruit flies are tree dwellers, at home in vegetation. They are not strong flyers, generally travelling less than 1km, and usually less than 600m, during their lifetime.

Grassy fields and vacant paddocks offer no food, shelter or potential hosts. Traps located in cereal crops or pastures consistently fail to trap any flies. Fruit flies just don't go there.

Crops that are located well away from orchards, town areas, and natural bushland are likely to be less susceptible to incursions by flies. While flies do move, a 200–400m wide "no-mans-land" around cropping areas still presents a significant barrier to infestation from the surrounding countryside.

Of course, it is not always possible to maintain such a large distance between a fruiting vegetable crop and potential hosts and roosting sites. However, it is worthwhile considering how and where flies can move into the crop from other areas.

Once harvesting has finished, potential fruit fly host crops need to be destroyed as soon as possible.

This hydroponic tomato farm is located in an area endemic to fruit fly. However the farm is isolated, with more than 1km dry grassland in all directions. Combined with low pest pressure and the high walls of the greenhouse itself, fruit flies are effectively prevented from entering the crop.

Cucurbit fruit such as melons or pumpkins can persist for a long time in the field, even after the plants have died (left). This can allow large populations of Cucumber fly to build up (right), then potentially transfer to neighbouring crops.

## REDUCING INCURSIONS

Removing feral fruit trees is key to managing fruit flies; a single feijoa tree can produce up to 30,000 flies in a season if left unmanaged.

Backyard trees and urban areas in general are common breeding grounds for fruit flies. Tree owners may be unwilling or unable to control fruit flies themselves.

In addition, urban areas provide overwintering refuges. This is particularly important in regions with cold climates, which are only marginal for fruit fly survival. Microclimates around houses and shops are often significantly warmer than the surrounding countryside, and allow adult flies to survive temperatures that would normally kill them. The flies then disperse to neighbouring crops when the weather is warm enough to fly (>16°C for Qfly, >12°C for Medfly).

Physical barriers, or bare zones, can help prevent incursions from such areas.

Fruit fly outbreaks have also been associated with holidaymakers and workers, who unknowingly bring infested fruit into production areas. Ensuring that staff and contractors do not bring suspect fruit on-site can also reduce the chance of an outbreak.

## FARM HYGIENE

Standard recommendations for fruit fly management in orchards state that all fruit needs to be removed to prevent further infestation.

For vegetables this is not feasible, as picking and removing every single chilli, capsicum or squash is uneconomic. Moreover, flies do not usually lay eggs in fruit already on the ground and rotting. Unmarketable fruit noticed during harvest should therefore be pulled from the plant, dropped into the inter-row and crushed. Stomping with a boot or driving through with the tractor are effective methods. This will ensure the fruit decays quickly and cannot become a host to fruit flies.

In addition, host crops should be destroyed as soon as possible once harvesting is complete. This could just involve turning off the irrigation to kill the plants. Preferably, plants should be mulched into the ground.

If infested fruit is found, it is essential it should be destroyed to make sure the larvae do not survive. To do this either:

- Freeze the infested product overnight.
- Place inside black plastic garbage bags and leave in the sun (solarise).
- Bury at least 50cm deep.

## BEST PRACTICE

- ✔ Remove unmanaged fruit trees within 600m of the crop.
- ✔ Fruit trees within 600m of the crop that can't be removed need to be treated with insecticide during fruiting, or fruit picked before maturity.
- ✔ Ensure workers and contractors do not bring infested fruit onsite.
- ✔ Instruct harvesting staff to pull unmarketable fruit from the plant and crush them to speed decay.
- ✔ Destroy fruit fly host crops as soon as possible once harvesting is complete.
- ✔ If infested fruit is found, it must be destroyed by freezing, solarisation or burial.

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# Net benefits for fruit flies

Fruit flies can breed rapidly, disperse widely and successfully infest many fruiting vegetables. They not only destroy fruit, but are a market access barrier in domestic and international markets.

Fruit flies used to be effectively controlled with pre-harvest cover sprays. However, de-registration of dimethoate and fenthion (Lebaycid) means vegetable growers have had to find other ways to manage these pests.

One option is to replace the chemical barriers with physical barriers. According to Applied Horticultural Research (AHR) scientist Dr Jenny Ekman, "Flies rarely, if ever, enter greenhouses. Theoretically, they could get in through open roof vents or doors, but they rarely do. If they can't see or smell the plants inside, they have no reason to try. Also, fruit flies are forest dwellers who tend to fly close to the ground, or dart from tree to tree, rather than venturing into the open sky looking for a roof vent".

Net houses are another solution. They can protect crops from rain, hail, wind and sunburn, as well as keep out many pests. White hail netting that includes sidewalls is surprisingly good at keeping flies out of orchards. However, net houses are expensive to erect and can be inconvenient; unlike apple trees, vegetables are not necessarily grown in the same place all the time.

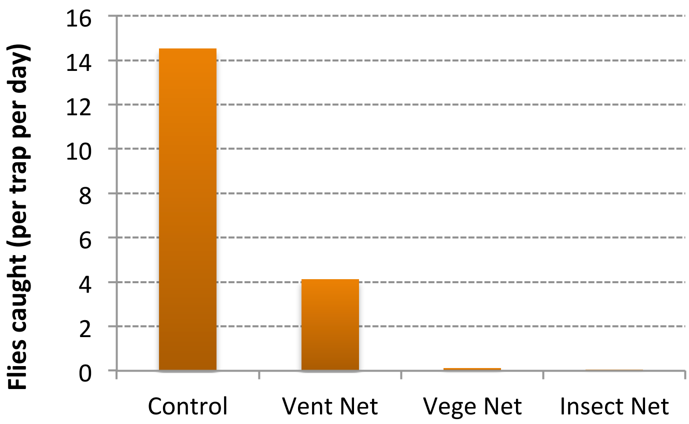
However, many of the benefits of net houses are achieved using simple "floating row covers". Netting or frost protection fleece is simply draped over plants and secured at the base with soil.

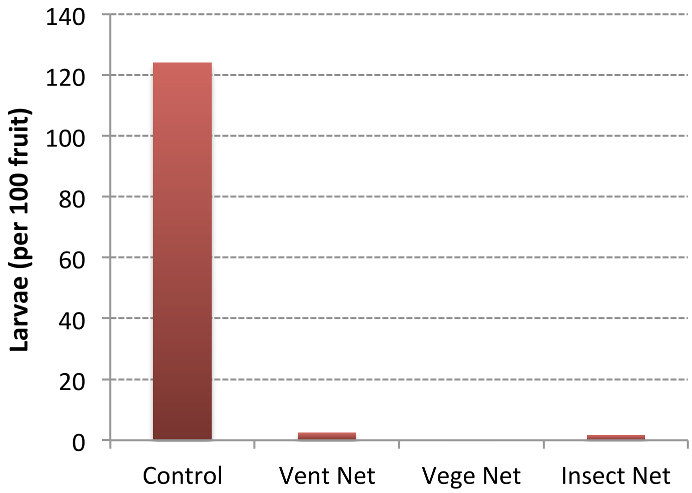
A recent AHR project has been testing how well floating row covers work. According to Jenny, "We used to think that keeping fruit flies out required fine mesh with no holes or gaps. However, even fairly coarse netting has achieved great results, despite there being holes that the flies could wriggle through if they really wanted."

"Flies use a lot of visual cues to find host fruit. Netting obscures the crop surprisingly well. It also offers many of the advantages of net houses – it reduces irrigation requirements and gives plants some protection from extreme weather and other pests."

In the Sydney based trials, large numbers of mature fruit flies were deliberately released into sacrificial crops of capsicums and chillies. Monitoring traps were placed under different types of netting, to see how readily the flies could get under the covers. In addition, samples of fruit were harvested weekly to check for larvae.

"We tested VentNet (5 x 4mm mesh) – which is really a windbreak material – as well as VegeNet (1 x 3mm mesh) and a fine Insect Net (0.8 x 0.8mm mesh) as floating covers. The VegeNet weighed only 45g/m$^2$, and proved very effective at keeping fruit flies away from the plants. Even though some flies got through the Vent Net, these were mainly males attracted by cue lure in the traps, with infestation in the fruit remaining extremely low. "

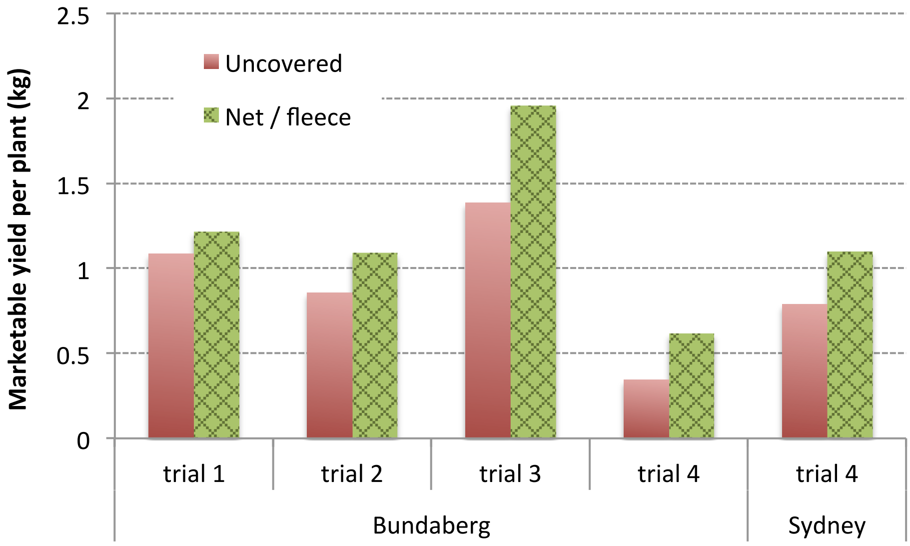



**Flies caught per day in monitoring traps (Biotrap baited with FT Mallett CL wafer) and larvae found per 100 fruit sampled, in a chilli crop with sections covered by Vent Net, VegeNet or fine Insect Net. Queensland fruit flies were released into the crop prior to assessments.**

Controlling fruit fly is one thing, but what happened to the crop?

Bundaberg trials focused on the effect of netting on capsicum plants. "It's hard to quantify, but the plants under the netting just looked healthier" says Jenny. "There was less wind damage, and sunburn was avoided in fruit under netting. The result was a moderate, but potentially important, improvement in yield and quality that was consistent across all the trials we did".




**Effect of floating covers on marketable yield of capsicum plants. Yield was assessed at the start of commercial harvest of each trial by stripping all fruit from 10 plants in 3 replicate areas per treatment. NB Trial 4 was strongly rain-affected.**

The best results were achieved when netting was applied to young plants. However, even applying nets only 2 weeks before harvest still provided significant benefits for fruit quality.

The research also found that fruit grown under nets tended to have more consistent colour. That is, there was a smaller range of fruit colour on each plant.

Although nets can be used many times, re-use creates potential issues with weed and disease management. Cleaning large nets is no simple matter.

“We thought one solution would be to use disposable frost protection fleece” explains Jenny. “This material is cheap, presents an excellent barrier to fruit flies and could potentially help plants grow faster during cooler months. However, it is easily damaged by wind. In the end, we decided it just isn’t suited to use on upright plants such as capsicums.”

“Nets aren’t going to suit every producer of fruiting vegetables, but they are definitely good for managing fruit fly, and can have other benefits as well”.

**PULLOUT BOX**

As part of project VG13042 on in-field management of fruit fly, AHR have produced “Fruit fly management for vegetable growers”. This 32pp booklet summarises the options available to producers of fruiting vegetables, and some of the pros and cons of each strategy.

The key practices described in the guide are further demonstrated in a series of five short YouTube videos on controlling fruit fly in vegetables. These can be viewed through the AHR website (www.ahr.com.au) or directly:

1. Targeted control https://youtu.be/HQgvrbTULTw
2. Monitoring https://youtu.be/YvKVmXaWvSc
3. Food based baits https://youtu.be/u-DGF_QpUrg
4. Male annihilation and female biased traps https://youtu.be/kC4oFEVt3cI
5. Netting, repellents and field hygiene https://youtu.be/hzZYhH5CC0Y

The book and videos will be available at Hort Connections 2017 in Adelaide, as well as at Field Days and other events.

Alternatively, contact AHR directly: E: sandra.marques@ahr.com.au

AHR researcher Adam Goldwater examines Bundaberg capsicum crops covered by VegeNet. Note the fruit fly trap visible under the netting.

Netting on capsicum crops, Bundaberg, showing the healthy plants underneath.

VegeNet on capsicums, Bundaberg.

Netting trial at Silverdale, SW Sydney

Biotrap with ‘wafer’ type lure, installed among the uncovered chillies.

Queensland fruit fly, trying to lay eggs into a capsicum.

Male flies, attracted by the cuelure wafer, unsuccessfully trying to get through the VegeNet.

Female Queensland fruit fly, laying eggs into a capsicum.


Fruit fly management booklet – free for vegetable growers