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Project leader:	Dr W.D.J. Kirk
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Date project commenced:	01 October 2001
Date project completed:	30 September 2004
Key words:	western flower thrips, *Frankliniella occidentalis*, light intensity, visible light, ultra violet light, glasshouse, chrysanthemums

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Grower Summary

Headline

This project aims to suggest potential ways in which established control measures against the western flower thrips can be enhanced through simple and cost effective cultural techniques. It is proposed that small changes in lighting regime may affect western flower thrips behaviour, which in turn could be exploited. Increased insect activity, for example, could lead to higher pickup of insecticides or microbial biological control agents (*Beauveria*, nematodes etc.) thus enhancing control measures at low cost.

Background and objectives

This project is part of a three year PhD studentship at Keele University. The overall aim of the HDC Studentship Scheme is to fund PhD studentships in order to support the training of new research staff for the horticultural industry. The revised aims and objectives of this project are:

1. To record the daily patterns of oviposition by adult females under glasshouse conditions and under constant temperature
2. To record the daily patterns of flight (trap catches) by adult thrips under glasshouse conditions
3. To record the daily patterns of take-off under constant temperature
4. To quantify how lighting (brightness and wavelength) affects walking by adult females under constant temperature
5. To quantify how lighting (brightness and wavelength) affects feeding by adult females under constant temperature
6. To quantify how lighting (brightness and wavelength) affects take-off by adult females under constant temperature
7. To quantify how lighting (brightness and wavelength) affects oviposition by adult females under constant temperature

Frankliniella occidentalis (Pergande) (western flower thrips or WFT) has proved difficult to control on UK glasshouse salad crops and ornamentals since the species arrived in the UK in 1986. Its small size and preference for remaining hidden within small recesses of the plant reduces the chance of contact with chemical pesticides or natural predators, so that many escape control measures.

Much research has been undertaken to test the effectiveness of novel techniques, including biological control agents such as the entomopathogenic nematode *Steinerema feltiae* and the use of spectral films for pest control but little work has been carried out on the behaviour of the pest species itself.

It is likely that thrips would be more vulnerable to control measures such as high volume spray applications of entomopathogenic fungus or the presence of natural predators when actively walking about out on the plant surface. They would, therefore, be more likely to come into contact with the control agents. Higher mortality per application could then lead to a reduction in the number of applications required for adequate control, saving time and money.

The aims of this project are to investigate how the activity of western flower thrips is affected by changes in light intensity, daylength, and wavelengths of light. If, for example, flight or walking activity was increased by an increase of light intensity then the use of supplementary lighting at the time of a spray application could increase the efficiency of that application.

Summary of results and main conclusions

Measurement of light transmission

In order to investigate the effects of changes in light intensity (brightness), daylength and wavelength on the behaviour of western flower thrips in the laboratory, it was necessary to characterize the conditions found within commercial glasshouses. The daily range of light intensity of white light (400 – 700nm) and ultraviolet A (UVA) light (315 – 380nm) was recorded in two different commercial glasshouses in summer and winter. The maximum light intensity measured (>500 Wm^{-2}) was greater than the maximum total light intensity used in the laboratory (14 Wm^{-2}) but this was comparable to that measured on an overcast winter's day. The percentage

of UVA in the simulated daylight of the laboratory was close to the average found in commercial glasshouses. From these findings, it is reasonable to conclude that results from the controlled laboratory conditions may be compared with observations made on western flower thrips in commercial glasshouses.

The effect of light on take-off

Take-off was investigated because it is a component of flight. It was found that:

- There is a significant difference between the rates of take-off in the dark compared with the light. Fewer thrips take off in the dark.
- Thrips are stimulated to take-off under:
    - white light with UVA
    - white light without UVA
    - UVA light on its own.

White light is defined as light visible to human vision (400 – 750 nm). There was no significant difference between the rates of take-off under these three lighting conditions, therefore, from the results so far, the presence or absence of UVA makes no difference to the rate of take-off.

- There was no significant difference in the rate of take-off between a range of light intensities. Although light stimulates take-off, there is no firm evidence as yet, that a greater light intensity causes more thrips to take-off. The light threshold for take-off is low.

The daily pattern of flight and take-off

- No thrips were trapped during the night, in a population in an infested glasshouse. Both male and female thrips show a 24 h pattern of activity with most thrips in flight at the brightest time of day, on average. Although temperature affects flight in western flower thrips, the effect of light is more significant.

- Adult female thrips have a propensity to take-off during the day rather than the night since take-off was significantly quicker during the day than the night even under similar conditions of light.

Anticipated practical and financial benefits

The research could lead to simple and cost-effective ways to improve current pest management schemes in protected crops. Supplementary lighting could be used to increase the effectiveness of a control measure but how it was used would depend upon the nature of the control agent. For example, if an insecticide with a fumigant action were to be used in the evening, increasing the number of thrips in flight over the crop could increase its efficacy. This may be achieved with the use of extra lighting at the time of application, such as low cost UV-emitting fluorescents, which would stimulate the thrips to take-off without affecting the growth of the crop.

The experimental research is still in progress and although the primary aim of this project is to investigate the effect of light on thrips behaviour, secondary issues have become apparent such as the effect of population density on thrips activity. Work is underway to investigate this since it has significance in a commercial glasshouse in which control measures are likely to be implemented on very low thrips densities. However, further laboratory tests and glasshouses trials are necessary before firm recommendations can be made.

Action Points for Growers

None at this stage of the project.

Science Section

Introduction

2.1 Background to the project

Since its spread around the world in the 1980s, the western flower thrips (*Frankliniella occidentalis* (Pergande)) has become one of the most important insect pests of many edible and ornamental crops (Robb *et al.*, 1995; Bennison *et al.*, 1999b). It has caused substantial economic losses through direct physical damage to crops and by spreading plant viruses (Ullman *et al.*, 1997). The control of western flower thrips is not easy as it is resistant to chemical pesticides (Robb, 1989; Helyer & Brobyn, 1992) and its preference for remaining hidden within recesses in the plant host reduces the chance of contact with chemical pesticides. Integrated pest management has been used in glasshouse crops since the 1980s (Wardlow *et al.*, 1992) but the success of biological control of western flower thrips on ornamentals has been variable (Bennison *et al.*, 1999a). A better understanding of the behaviour of western flower thrips could be used to enhance the effectiveness of current management techniques. For example, if the manipulation of glasshouse conditions increased thrips activity, this would increase contact with chemical or biological control agents, which may improve their efficiency.

Very little is known about the patterns of behaviour in western flower thrips or the environmental factors that control their behaviour. Adult western flower thrips display a diel periodicity being generally more active during daylight hours than in the dark. This has been observed for several types of activity pattern including oviposition (de Kogel, 1997; Kirk *et al.*, 1999; Kiers *et al.*, 2000); walking (Cho *et al.*, 2000) and flight (Mateus *et al.*, 1996; Pearsall, 2002). Environmental factors that have been shown to affect these patterns of behaviour include photoperiod (Brødsgaard, 1994) and temperature (Shipp & Zhang, 1999). If other factors such as light intensity and wavelength have similar effects then small changes in the glasshouse environment such as changes in the lighting regime or the use of spectral filters may affect the efficacy of integrated pest management (IPM).

The western flower thrips, in common with other thrips, has the habit of crawling into narrow, enclosed spaces within the host plant structure and effectively hides from predators and chemical pesticides. Any environmental influence that increases walking and flight activity would increase contact with predators and chemicals and therefore increase mortality. Under glasshouse conditions, an increase of air temperature from 21-23° to 26-28° results in an increase in flight activity of western flower thrips and a corresponding increase in mortality from insecticide by 23-25% (Shipp & Zhang, 1999). By investigating the effects of light on activity patterns in western flower thrips, it may be possible to produce similar results by artificially increasing light intensity. Alternatively, it may be possible to reduce oviposition or predict an increase in oviposition with changes in the photoperiod. The results of this project are relevant to practical applications in the pest management of a serious pest of protected crops.

2.2 Project aims

The aim of the HDC Studentship Scheme is to support the training of new research staff for the horticultural industry. The aim of the project is to understand the factors that influence the behaviour of the western flower thrips with a view to exploiting this knowledge to develop means of enhancing control measures in glasshouses. The specific objectives of this project were agreed in advance with the Horticultural Development Council. At the start of the second year of the studentship, these objectives were adjusted in line with the restrictions of time within the PhD studentship and the potential overlap with a new DEFRA funded project. The amended aims and objectives are:

1. To record the daily patterns of oviposition by adult females under glasshouse conditions and under constant temperature
2. To record the daily patterns of flight (trap catches) by adult thrips under glasshouse conditions
3. To record the daily patterns of take-off under constant temperature
4. To quantify how lighting (brightness and wavelength) affects walking by adult females under constant temperature
5. To quantify how lighting (brightness and wavelength) affects feeding by adult females under constant temperature
6. To quantify now lighting (brightness and wavelength) affects take-off by adult females under constant temperature

7. To quantify how lighting (brightness and wavelength) affects oviposition by females under constant temperature.

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This year, results have been obtained from:

- Environmental monitoring both inside glasshouse and externally
- Take-off experiments including the effect of light on take-off and the diel pattern of take-off
- The measurement of flight activity in a commercial glasshouse

Trials have been started to monitor the diel pattern of oviposition and the effect of density on take-off but the results are not yet available.

2 Materials and methods

2.1 General methods

2.1.1 Introduction

Some of the techniques used in this project including;

- the culturing of a laboratory population of western flower thrips
- the measurement of environmental data using the Skye datalogger and sensors

are presented in the first annual report presented to the HDC on 30th September 2002. The same techniques were used during the past year. In addition, certain other methods were employed that were common to different experimental procedures. These are presented below.

2.1.2 Experimental lighting

In order to simulate daylight within the controlled conditions of the laboratory, an array of four fluorescent lights were used. These were 60 cm full spectrum Sylvania "Activa 172" 18 W fluorescent tubes powered with 240 V AC using a standard ballast with a flicker rate of 100 Hz. The tubes were diffused using a Rosco 450 white diffusion paper to provide an even, diffuse overhead source. Adjusting the distance between the light source and the experimental arena or altering the number of tubes used at a time adjusted light intensity. This array provided a light source with a spectral composition similar to that of natural daylight and with a UVA component comparable to that found within a glasshouse (fig 2.1). For the purposes of clarity, this spectral range was called white with UVA light.

The wavelengths of the full-spectrum light provided by this array, were adjusted with the use of spectral filters. For white light without UVA, a UVA absorbing plastic film, Sterilite HDF (XL Horticulture), was used.

UVA light was provided with a 60 cm Sylvania Blacklight Blue 18 W (λ_{max} = 350 nm) fluorescent tube powered as described above. This was diffused using the Rosco 450 diffusion paper and intensity was reduced as necessary using a neutral density filter (Lee ND1).

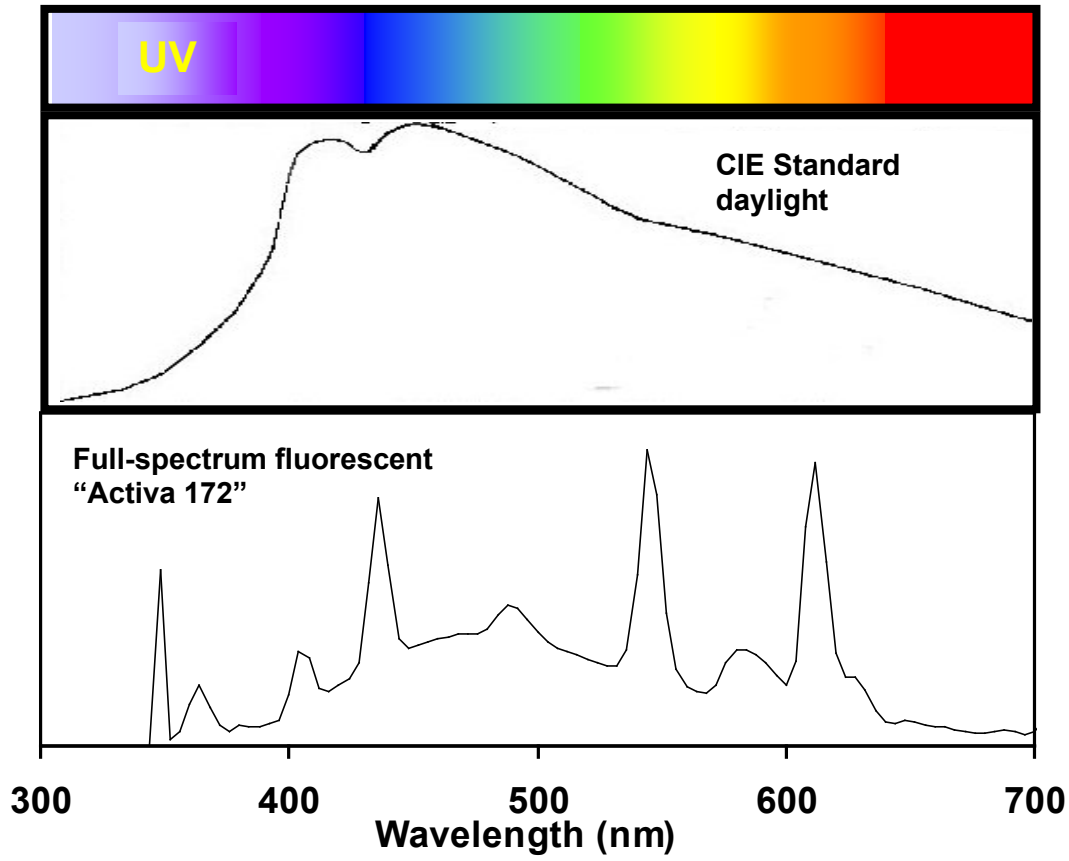

Fig 2.1 The spectral composition of the Sylvania "Activa 172" full spectrum fluorescent tubes compared with that of natural daylight as defined by the CIE.

Under dark conditions, a dim red light was used to facilitate handling of thrips (Schott fibre optic light source filtered with a Lee medium red filter no. 027, λ_{max} = 676 nm). The effect of this light on western flower thrips behaviour was tested to ensure that is was having no effect (sections 2.3.2 and 3.2.2).

In order to make observations in the dark, the experimental arena was illuminated using infra-red (IR) light-emitting diodes (LEDs) (1.5 V medium-beam angle IR emitters with a peak emission of 850 nm). This light was invisible to human and thrips vision (Menzel, 1979; Matteson *et al.*, 1992; Walbank, 1996) but was detected using a video camera fitted with an IR pass filter on a manual aperture lens. The insect behaviour was recorded and observed on a TV monitor. For consistency, the IR LED's were used during light as well as dark treatments. The IR pass filter on the video cameras allowed the transmission of IR light to the camera but little transmission of other

wavelengths, thus providing a consistent, sharp image on the monitor under all lighting conditions.

2.2 Light in commercial glasshouses

2.2.1 Introduction

Efficient crop production relies on the optimisation of the lighting regime within the glasshouse. There is currently much research into the use of spectral filters for pest control (Sampson & Hardie, 2001). The development and use of spectral filters and changes in supplementary lighting will affect the light within a glasshouse or polytunnel by altering intensity, photoperiod or the spectral composition. The subject of this investigation is specifically how changes in lighting, including UVA light may be used to affect western flower thrips behaviour in order to enhance control measures. In order to quantify lighting conditions within commercial glasshouses, measurements were collected using the Skye datalogger and sensors (HDC annual report CP 10, 2002). Since conditions will vary seasonally and from crop to crop, measurements were collected over 24 h from several sources. In addition, the spectral transmission properties of several different cladding materials were analysed using a spectroradiometer and the Skye light sensors.

2.2.2 Light measurements in commercial glasshouses

Environmental conditions inside glasshouses were monitored using the Skye datalogger, which allowed continuous measurements of white (400 – 700nm) light intensity; UVA light (315 – 380nm) intensity; temperature and relative humidity. The sampling rate was set at 5-minute intervals and these data were later averaged every half hour through a 24 h period. In all cases, the sensors were positioned clear of the crop and the mini temperature / relative humidity probe was protected from direct sunlight using a radiation shield. The measurements taken up to now have been taken in full light and clear of the crop whereas thrips tend to spend much time hidden away within the recesses of the crop. Trapping experiments, however, have shown that thrips fly actively during the day so they will also be subjected to direct light.

The sources of the data collected so far are summarised in table 2.1.

Location	Dates collected	Crop	Production details
West Sussex, SE England	20 - 21 Nov 2002 & 30 –31 Jul 2003	Cut-flower chrysanthemum	Long-day light regime (night break lighting)
Humberside, NE England	17 - 18 Sept 2003	Cucumber	Mature harvestable crop

Table 2.1 Sources of commercial glasshouse environmental data.

2.2.3 Light transmission through glasshouse cladding materials

When white light passes through a transparent material such as glass or plastic, certain wavelengths may be absorbed by the material more than others. The light transmitted through various cladding materials was defined in terms of:

1. the percentage of the incident light which is transmitted, measured as integrated light intensity across two spectral bands, visible (400 – 750 nm) and UVA (315 – 380 nm) (Wm^{-2})

2. spectral composition of the transmitted light between 300 nm and 750 nm. This is the spectral radiance ($W/sr/m^2/nm$) for each light sample measured across one hundred wavelengths each of a bandwidth of 8 nm, to produce a spectral curve for each light source.

Together with mean daily light intensity range recorded monthly at Keele University, these data provide a reference for the lighting conditions that could be expected within glasshouses or polytunnels clad either with glass or plastic.

The integrated light intensity measurements were taken using the Skye datalogger and sensors. The sensors were placed in a black box with the test material covering one side and the full-spectrum light source at a given distance to ensure comparable results between test materials (fig.2.2).

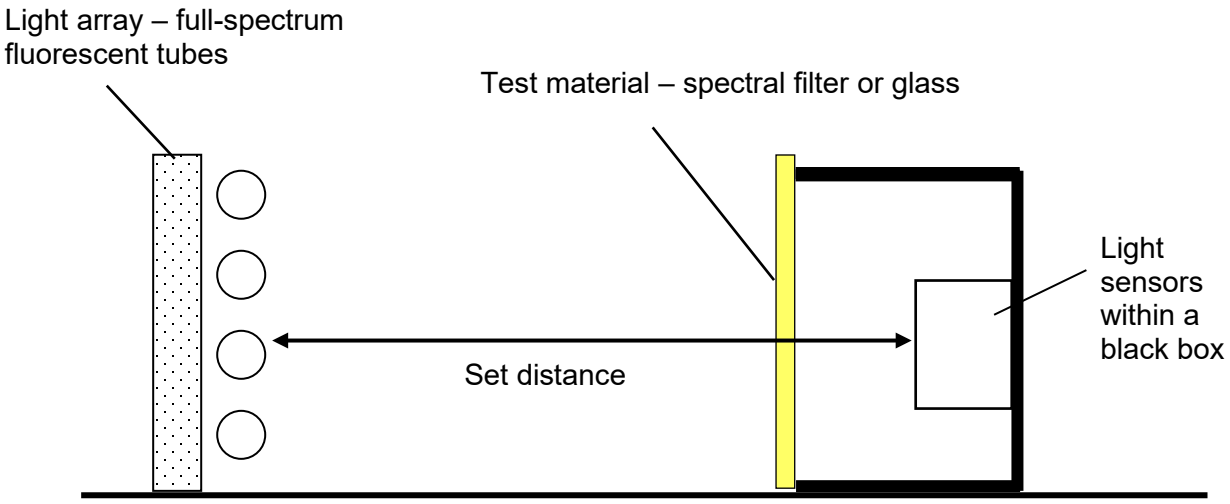

Fig 2.2 Apparatus used to measure the overall light intensity of white light (400 – 700 nm) and UVA light (315 – 380 nm) which is transmitted through various test materials such as horticultural glass.

The spectral composition of the same test materials was measured using a PR – 650 Spectra Scan spectroradiometer and a reflectance standard. The arrangement of the Spectra Scan and test materials is shown in fig 2.3.

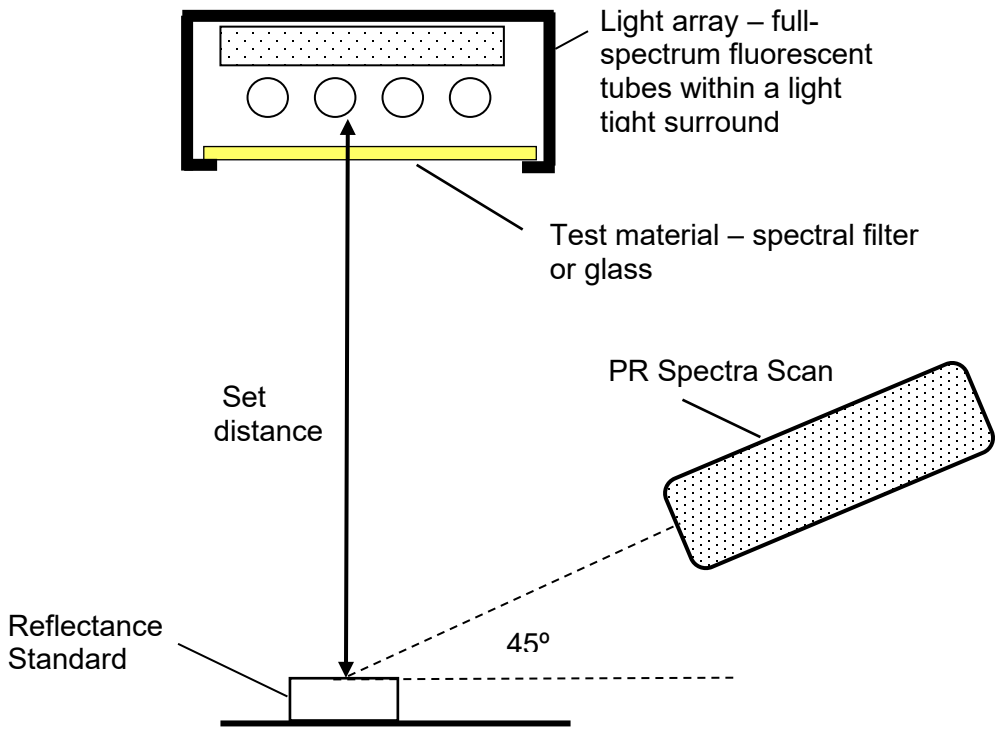

Fig. 2.3 Apparatus for the measurement of the spectral composition of transmitted light using a PR – Spectra Scan spectroradiometer.

2.3 The effect of light on take-off

2.3.1 Introduction

There are many factors that affect insect take-off, including temperature (Lewis, 1963), relative humidity (Haufe, 1963), light and physiological state (Haufe, 1962). Under natural conditions, several factors may act together to affect take-off (Johnson, 1969) and it is necessary to take these into consideration when testing the effects of a single factor such as light. Experiments on the effect of light on take-off were carried out here under constant temperature and relative humidity.

The effect of light intensity and wavelength on take-off in the western flower thrips has not been investigated although there has been some work on other thrips species (Lewis, 1963). In common with most insect species, the western flower thrips is highly sensitive to UVA light (350 –380 nm) (Matteson *et al.*, 1992) and work by Antignus et al. (2000, 1996, 1998) and Costa et al. (1999, 2002) has demonstrated that the numbers of western flower thrips trapped inside polytunnels can be affected by the use of UVA absorbing spectral films. Thrips behaviour is affected by the spectral composition of the light inside the glasshouse but the mechanism is not yet understood. The trials presented here aim to investigate how light affects take-off as a component of flight.

2.3.2 The effect of light intensity on take-off

Previous trials have shown that the western flower thrips takes off more readily in the light compared to the dark. Significantly more thrips take off in the light and they take off significantly more quickly (tables 3.2. and 3.3 and figs 3.10 and 3.11). The purpose of this experiment is to find the lowest light intensity that will stimulate take-off and to test whether increasing light intensity will increase the rate of take-off.

Mixed-age females were collected from the culture on chrysanthemums and placed individually in stoppered glass tubes (diam. 10 mm; height 37 mm) using an aspirator. These were kept under culture conditions of light and temperature until used. Trials were conducted in a constant temperature room maintained at 25±1ºC with an ambient relative humidity of 41 - 43 %. The areas below and surrounding the experimental arenas were lined with matt black card and black plastic to prevent unwanted light reflection. Take-off was measured from an arena consisting of a circular glass coverslip (diam. 19 mm) floating on distilled water to discourage escapes by walking (Fig. 2.4).

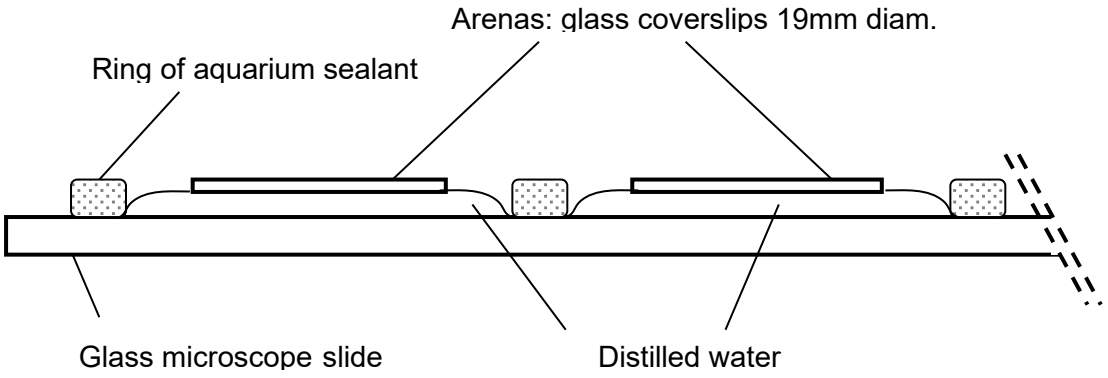

Fig 2.4 Diagram of the arenas used in take-off experiments

The glass tubes previously loaded with one thrips were taken, two at a time, and chilled for 3 minutes in ice to immobilise the thrips inside. Each thrips was then placed carefully onto an arena and the time until take off was recorded up to a maximum of 300 s. Dead, missing or escaped thrips were discounted. Both arenas were discounted if one thrips walked onto the neighbouring arena. The process was recorded on video and illuminated using infra-red LEDs as described in section 2.1.2. on experimental lighting (fig 2.5).

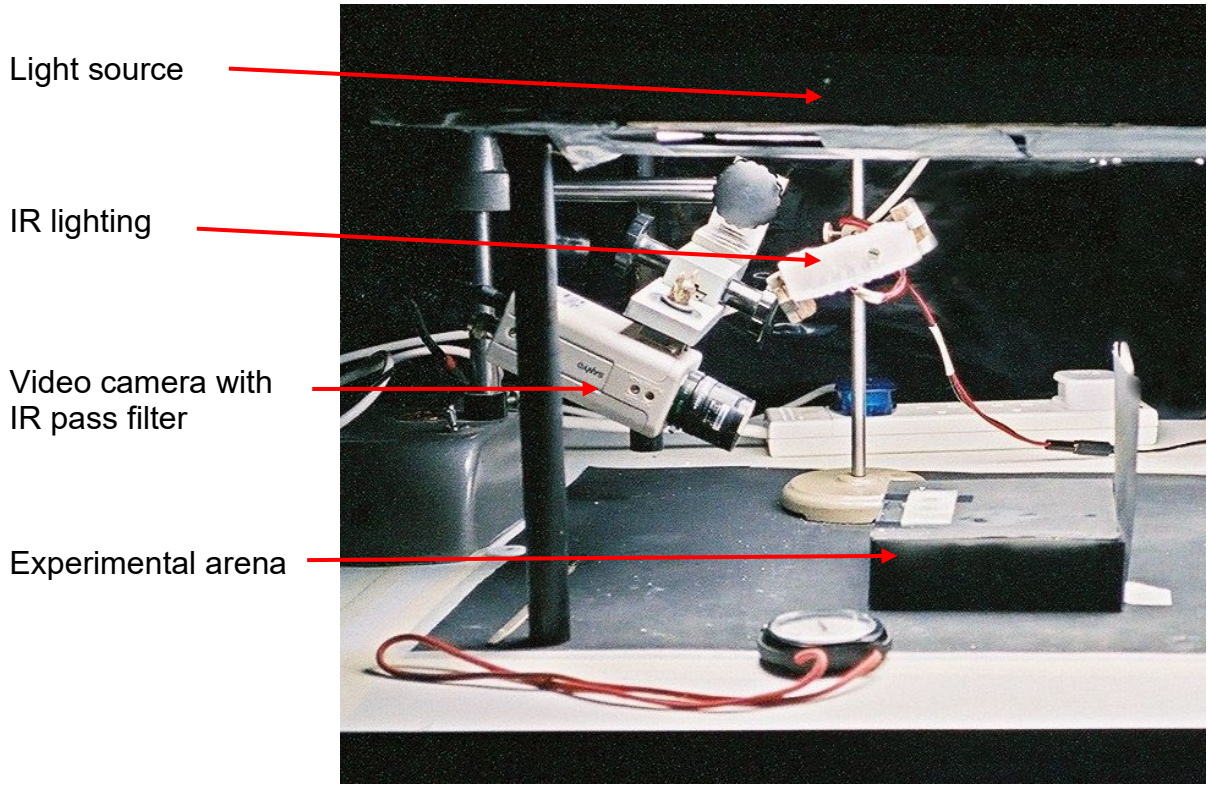

Fig. 2.5 Apparatus used in take-off experiments

The treatments were changed after every 6 to 8 thrips. The sequence of treatments was assigned randomly. The trial was conducted between 1120 h and 1530 h GMT. The experiment was not replicated due to a change in the general take-off behaviour of the thrips population.

The light intensity was decreased by increasing the light source to experimental arena distance and by reducing the number of tubes. The light treatments are described in table 2.2.

Treatment	White light intensity (Wm^{-2})	UVA intensity (Wm^{-2})
Dark	0	0
Low	< 3.26 *	< 0.121 *
Medium	7.89	0.225
Bright	13.72	0.346

* Light intensity below the sensitivity of the light sensors

Table 2.2.The light intensities of the four light treatments in light intensity trials (all light treatments classed as +white+UVA and the dark treatment as –white-UVA)

2.3.3 The effect of wavelength on take-off

The western flower thrips is highly sensitive to UVA light (350 – 380 nm) (Matteson *et al*., 1992) and is sensitive to wavelengths from 350 nm to 650 nm with peak sensitivity at 365 nm (near ultra-violet or UVA) and 540 nm (yellow) (Matteson *et al*., 1992; Walbank, 1996). During these experiments, a similar procedure was used as described in section 2.3.2. Instead of varying the light intensity however, the wavelengths of the light source was varied to determine which wavelengths are necessary for take-off and whether certain wavelengths stimulate take-off more than others. There has been much horticultural research to explore the effect of UVA-blocking plastic films on insect pest populations. Plots covered with plastic film that reduces or removes the UVA element from the incident solar radiation have a lower population of western flower thrips than comparable plots covered with a standard polytunnel film (Antignus *et al*., 1996, 1998; Antignus, 2000; Costa *et al*., 2002). If thrips are stimulated to take-off at a greater rate under the standard film with white light plus UVA, the resulting increased flight activity could explain the

how more thrips are caught under this plastic film. White light in this context is defined as the light visible to human vision (400 – 750 nm).

While carrying out experiments on the effect of light on take-off, measurements are also taken in the dark and a red light is used to facilitate placing the thrips onto the arena. The effect of this light on take-off was tested to ensure that western flower thrips are not sensitive to it and that its use does not affect the results.

2.3.3.1 The effect of red light on take-off

The filtered light from a Schott fibre optic source (section 2.1) was used to determine the effect of red light on take-off (table 2.4). The spectral composition of this filter was confirmed using the PR-Spectra Scan as detailed in section 3.1.2 (fig 3.6). Between 20 and 23 thrips were subjected to each treatment over a period of two days between 0800 h and 1400 h GMT during the photophase of the insect culture.

2.3.3.2 The effect of white light, with and without UVA, on take-off

Four light treatments were used to compare take-off in the presence and absence of UVA and white light. The commercial UV-absorbing film, Sterilite HDF from XL Horticulture was used to remove UVA light (+white-UVA) and UVA was provided in the absence of most white light with the use of a “Blacklight blue” (-white+UVA) as detailed in section 2.1. (table 2.3). Ten thrips were subjected to a given light treatment before changing the conditions. The sequence of treatments was assigned randomly. The experiment was replicated four times over four days and all trials were conducted between 0700 h and 1800 h GMT during the light phase of the thrips culture.

Treatment	White light intensity (Wm^{-2})	UVA intensity (Wm^{-2})
+white+UVA	10.6 – 13.3	0.3
+white-UVA	12.3	0
-white+UVA	0	0.4
-white-UVA	0	0

Table 2.3. The light intensities of the light treatments used to test the effect of UVA light

Treatment	White light intensity (Wm^{-2})	UVA intensity (Wm^{-2})
-white-UVA	0	0
>600nm – red	0*	0
+white+UVA	13.72	0.346

*White light intensity below the sensitivity of the light sensor but dimly visible to the naked eye.

. Table 2.4. The light intensities of the three light treatments used to test the effect of red light on take-off.

2.3.4 Data analysis

Take-off times were compared using a Kruskal-Wallis test and multiple Mann-Whitney U-tests with *P*-values adjusted for multiple comparisons by Holm's procedure (Holm, 1979). The proportion of thrips that took off was compared between treatments with a chi-square test.

2.4 The effect of photoperiod on flight and take-off

2.4.1 Introduction

The western flower thrips is more active during the day and flight activity has been shown to peak either in the early afternoon (Pearsall, 2002) or in the morning and late afternoon (Mateus *et al*., 1996). These observations were made with the use of coloured sticky traps in Canadian orchards and Portuguese polytunnels, respectively. The flight behaviour of western flower thrips in glasshouses in the UK may be different. Also, the use of coloured sticky traps introduces bias to the experiment since thrips are attracted to the trap. Flight activity was measured inside an infested commercial cucumber glasshouse using a suction trap which catches passing thrips in flight without the element of attraction. For comparison, blue sticky traps were also used. Take-off was investigated under constant conditions within the laboratory. Measurements within the glasshouse provide information on the natural behaviour of a wild population and the laboratory experiment was carried out to investigate the observed behaviour. When investigating the effect of light on take-off behaviour, it is important to consider the time of day that the experiment is being carried out if thrips are shown to be more active at certain times.

2.4.2 The diel pattern of flight in a commercial glasshouse

2.4.2.1 Johnson and Taylor Insect Suction Trap

A Johnson and Taylor insect suction trap (Burkard Manufacturing Co. Ltd., Herts, England) (Taylor, 1951, 1955; Johnson & Taylor, 1955) was used to collect western flower thrips at one hour intervals through two 24 h periods (17th and 18th September 2003). The trap was placed in an area that was noted to be well infested with western flower thrips between two rows of cucumber plants with the fan 30 – 40cm below the level of the top of the crop canopy, which was about 220 cm high (figs 2.6 and 2.7).

Fig 2.6. Johnson and Taylor suction trap in position in the cucumber crop

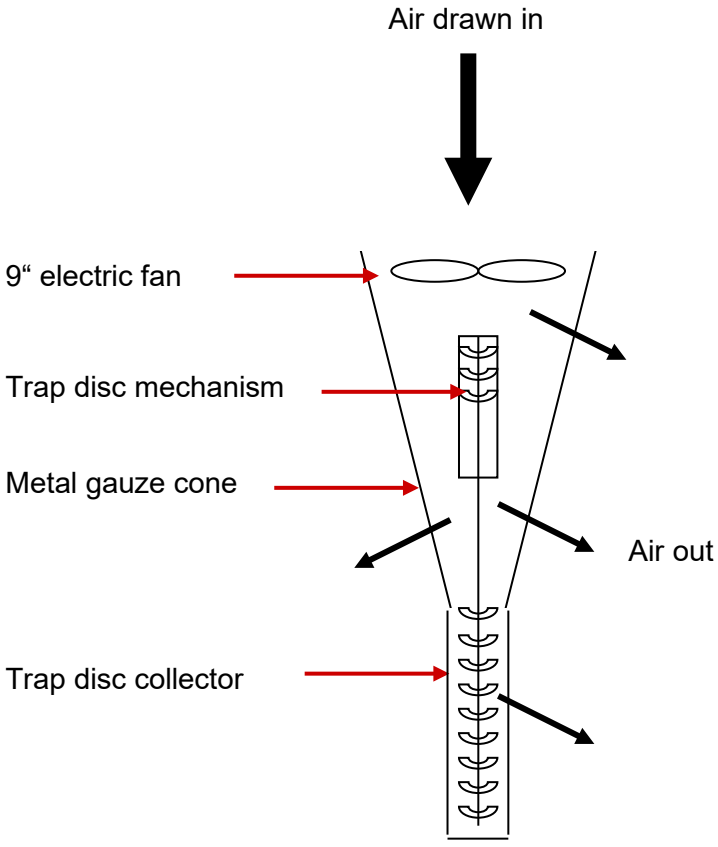

Fig.2.7. Simplified diagram of the suction trap showing the main component parts

The trap discs were prepared in advance by coating each one with a concentrated solution of Decis (deltamethrin). This was allowed to dry for several hours and then just prior to use, the discs were coated with a layer of mineral oil (N. Holmes, pers. comm. 2003). The mechanism of the trap allowed the segregation of the catch into one-hour batches with the first trap disc starting at 0000 h GMT. A new set of 25 discs was inserted after 0000 h GMT on the second day. The discs were examined under a dissecting microscope in the laboratory to count thrips present and then the thrips were individually collected and examined under a light microscope to confirm identification.

2.4.2.2 Sticky trap catches

Blue sticky traps were placed in four positions around the suction trap. They were positioned in a line with the first two 2.7 m either side of the suction trap to avoid any interference. These were hung from the crop wires at a similar height to the top of the suction trap (fig 2.8). The first sticky traps were placed at 0000 h GMT on the first day and were replaced every two hours over the next 24h. The numbers of male and female western flower thrips caught were counted with the use of a dissecting microscope.

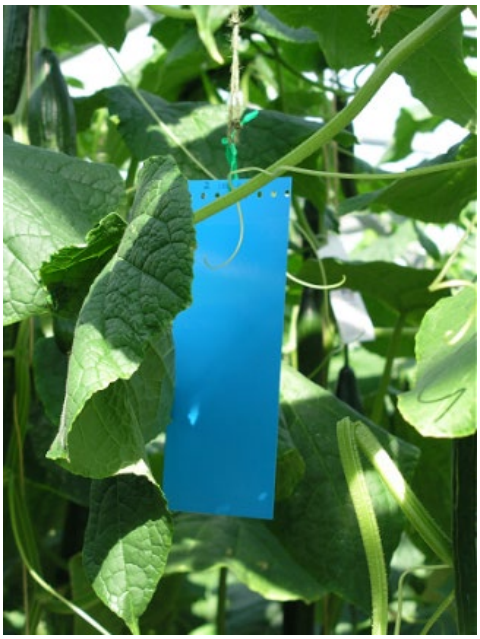

Fig.2.8. A blue sticky trap in position within the cucumber glasshouse.

2.4.3 The diel pattern of take-off under constant conditions

Workers in the field have observed a daily pattern of flight in western flower thrips with no flight taking place in the dark. Light stimulates take-off in western flower thrips with little take-off in the dark (section 3.1.3). In this investigation, thrips are taken from the normal rearing conditions immediately prior to the test and the rate of take-off is measured under bright light throughout one 24 h cycle. In this was, the propensity to take-off at different times of day when under optimal conditions for take-off (with lights on), is measured.

The method used to investigate the diel pattern of take-off involved a technique that has since been improved. This experiment is therefore to be repeated to ensure that results are consistent with those achieved in other take-off trials. The technique was similar to that used to investigate the effect of light on take-off (section 2.3). Instead of glass coverslips as arenas, small gelatin capsules were used. These were supported in roughened petroleum jelly to prevent escapes, with one thrips placed in each of four capsules on a microscope slide (fig. 2.9). No glass tubes were used but instead the thrips were placed directly into the capsule and chilled immediately prior to the bioassay. Although the technique worked well, it was considered that the edge of the gelatin capsule itself provided a stimulus to take-off, which could bias the results.

In this trial, four capsules at a time, each with one adult female thrips, were chilled and then placed onto the experimental arena under standard fluorescent lighting (visible light intensity, 5 Wm^{-2} and UVA light intensity, 0 Wm-2). The capsule lids were removed and the time until take-off was recorded up to a maximum of 300 s. Up to twenty thrips were tested in each batch and batches were removed from the culture and tested every three hours over a 24h period starting at 0000 h GMT.

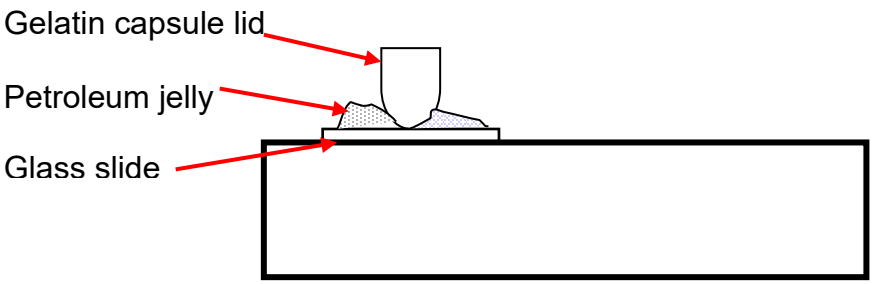

Fig.2.9. Diagram showing the arrangement of gelatin capsules used in take-off trials

2.5 The effect of photoperiod on oviposition

Experiments are underway to investigate the diel pattern of oviposition in adult female western flower thrips using the techniques described in "Annual Report 2002 – CP10" and using multiple humidity tanks (fig 2.10) that can accommodate up to 50 oviposition tubes each. With this technique, oviposition tubes can be set up under different lighting conditions and run simultaneously to determine the effect of light on oviposition. The experiments have not yet been completed.

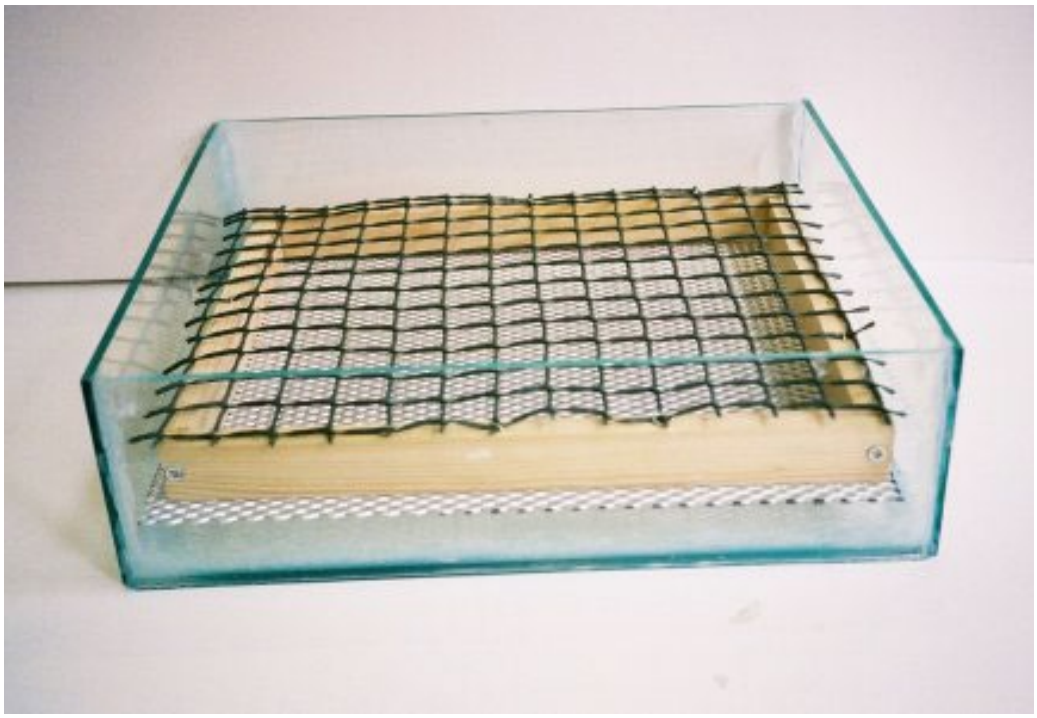

Fig.2.10. A humidity tank without lid showing oviposition tube rack

3 Results and discussion

3.1 Light in commercial glasshouses

3.1.1 Light measurements in commercial glasshouses

Figure 3.1 shows the range in light intensity over 24 h inside a chrysanthemum glasshouse in winter. This result is an example of how the growing season is extended with the use of supplementary lighting, which increases daylength as well as the total light receipt. Supplementary lighting, however, provides only a small proportion of the light reaching the crop as compared to sunlight, even in winter. The variability in light intensity on a seasonal basis is great (figs 3.2 and 3.3) with a tenfold variation in the maximum white light intensity between summer and winter as shown here.

The maximum light intensity inside even a winter glasshouse is greater than the light intensity that can be produced in simulated daylight within the laboratory. The highest light intensity achieved within the laboratory (14 Wm^{-2}) is realistic although it is only comparable to the light intensity that could be expected during a winter's morning within a glasshouse (fig 3.1). The mean UVA component of the light environment within the glasshouses tested was between 2.7 and 3.9% of the total light intensity (fig 3.2 and 3.3) and ranged from <1% to 5% through the day. The UVA component of the daylight simulated in the laboratory is 2.5% and is within the range found within a glasshouse and close to the mean figure. It is thus reasonable to compare the results of laboratory trials on UV-A with observations from glasshouse conditions.

3.1.2 Light transmission through glasshouse cladding materials

The percentage transmission of human –white light (400 – 700 nm) and UVA (315 – 380 nm) through the various filters and glasshouse cladding materials used in laboratory trials are shown in table 3.1. The main observation is that the proportion of UVA light lost on transmission varies between materials tested and this changes the spectral composition of the transmitted light. This needs to be taken into consideration when attempting to alter the quality of the light source for experimental purposes. For example, if the Lee neutral density filter were used in order to reduce light intensity this would half the UVA component of the transmitted light. Any differences observed in the results could be due to this reduction in the UVA component rather than the reduction in overall light intensity.

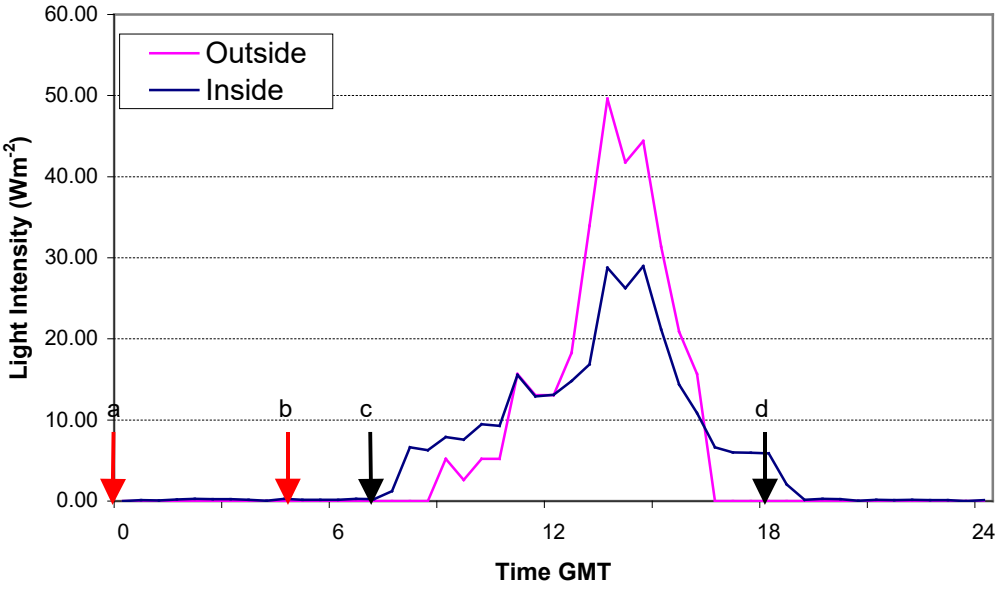

Fig. 3.1 Daily range in visible light intensity (PAR) at SGP glasshouse (November 2002). Inside measurements using Skye sensors and datalogger averaged at 30 minute intervals and outside measurements converted from Kipps solarimeter readings of total radiation. a = night break lighting ON; b = night break lighting OFF (0.5Wm-2). c = supplementary lighting ON and d = supplementary lighting OFF (9.6 Wm-2)

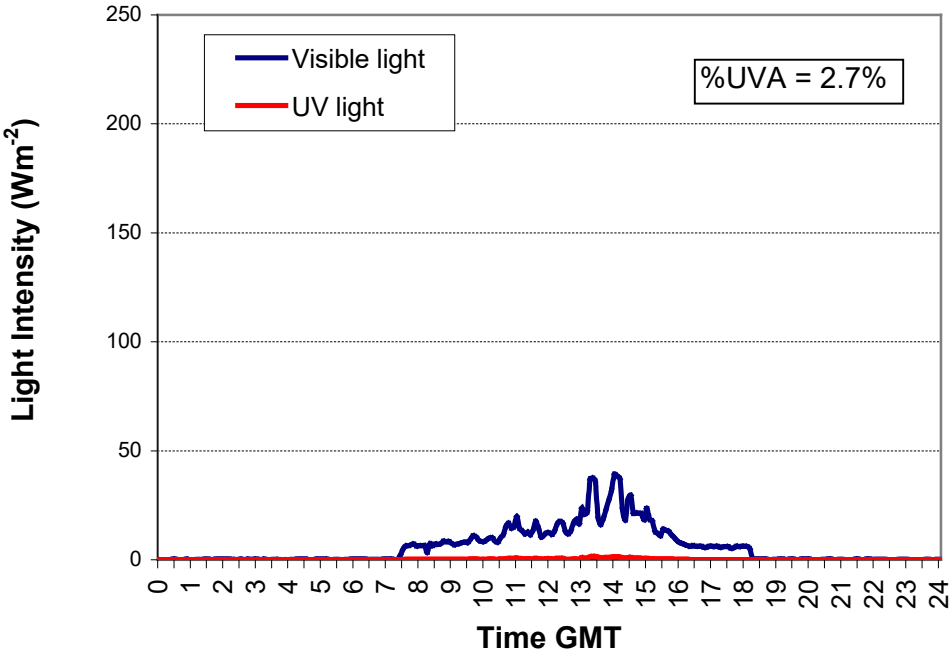

Fig 3.2 Daily range of visible and UVA light in a south coast chrysanthemeum glasshouse in early winter. As a comparison, mean percentage of UVA of daylight measured outside at Keele in the same month = 6.3%

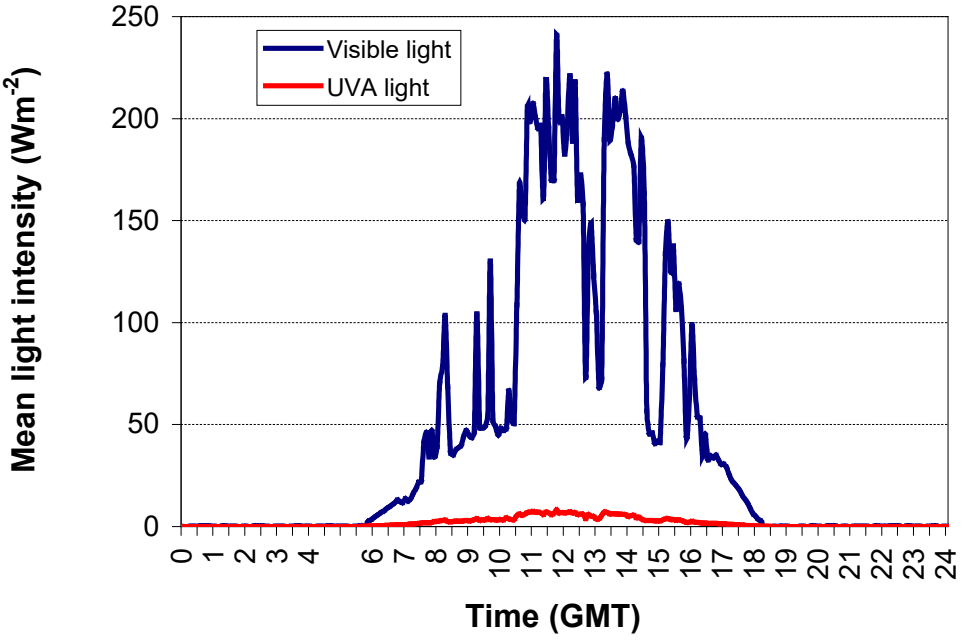

Fig 3.3 Daily range of visible and UVA light in a north east cucumber glasshouse in late summer. Mean percentage of UVA of daylight measured outside at Keele in the same month = 5.5%

Material tested	A Percentage transmission		B % UVA	
	White	UVA	Transmitted	Direct
Horticultural glass	91.0%	83.0%	3.1%	3.5%
Polytunnel plastic films - XL Horticulture				
Sterilite HDF	82.1%	0.0%	0.0%	3.0%
Super Blue	58.3%	0.0%	0.0%	3.0%
Super Clear 400	90.8%	77.3%	2.3%	3.0%
Super Green	64.0%	20.2%	0.6%	3.0%
Super Strength 600	84.9%	31.0%	0.9%	3.0%
Filters and materials used during trials				
Clingfilm®	91.5%	70.7%	2.1%	3.0%
Neutral density - Lee	69.9%	47.6%	1.4%	3.0%

Table 3.1 Percentage transmission of light through materials using four full spectrum "Activa 172" as a light source. Column A shows percentage of light source which is transmitted through material. Column B shows percentage UVA in transmitted light and in the light source expressed as a percentage of the total of white and UVA light.

In addition, these results confirm that UVA transmission through several horticultural films is low or completely inhibited.

These measurements will continue as new materials are brought into use.

The Skye datalogger and sensors are only able to provide an integrated measure of light intensity over a wide spectral range. The PR-Spectra Scan spectroradiometer (or Spectra Colorimeter) provided data on the spectral composition of filtered and direct light between 380 – 780 nm. A comparison of the spectral composition of the full spectrum light array (fig.3.4) with that of standard household fluorescents (fig 3.5) as used in earlier trials, shows the former to have a more even spread of wavelengths with less output at the red end of the spectrum and more UVA light.

An analysis of the light from the red filter used with the Schott fibre optic light source demonstrates most of the light output to be above 600 nm although the demarcation is not very sharp and the band width is approaching 200 nm (fig 3.6). This light source is used when handling the thrips in the dark. Thrips are sensitive to light wavelengths between 350 and 650 nm (Matteson *et al.*, 1992) so it is possible that they would respond to this light source. Behavioural trials, however, support the assumption that this light is not visible to the western flower thrips (section 3.2.2).

The manipulation of light to provide “white” and “UVA” only sources involved the use of a UVA blocking filter (Sterilite HDF) and a Blacklight Blue fluorescent tube respectively. Filtering the Activa 172 fluorescents with Sterilite film results in a light which is identical in relative spectral composition as far down as about 420 nm (fig 3.8). Below this wavelength the spectral output rapidly diminishes to zero at 380 nm. Although the Spectra Scan is unable to measure below this wavelength, no UVA light is detected by the Skye sensors. The Blacklight Blue fluorescent tube, as well as emitting light in the UVA spectral range, also emits a small amount of violet light between 380 - 410 nm (fig 3.7).

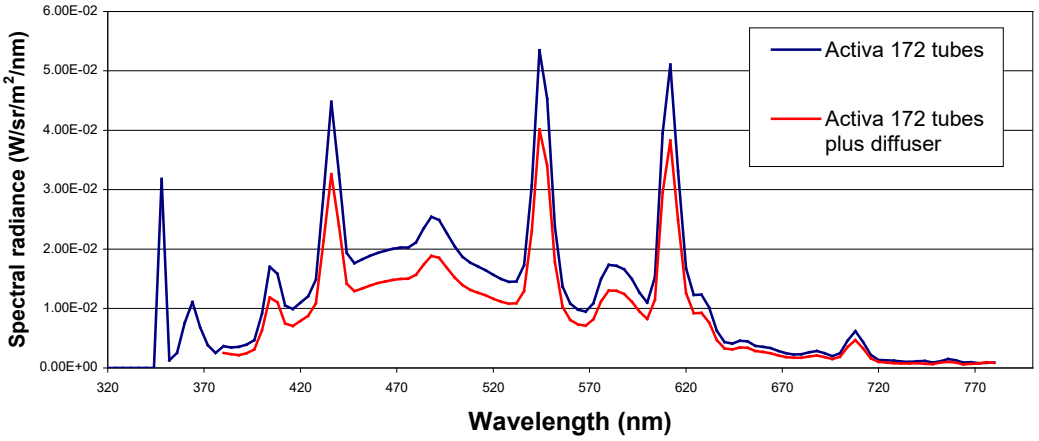

Fig 3.4 Spectral composition of full spectrum light source from "Activa 172" fluorescent tubes with and without diffuser. * Measurements below 380 nm extrapolated from manufacturers specifications

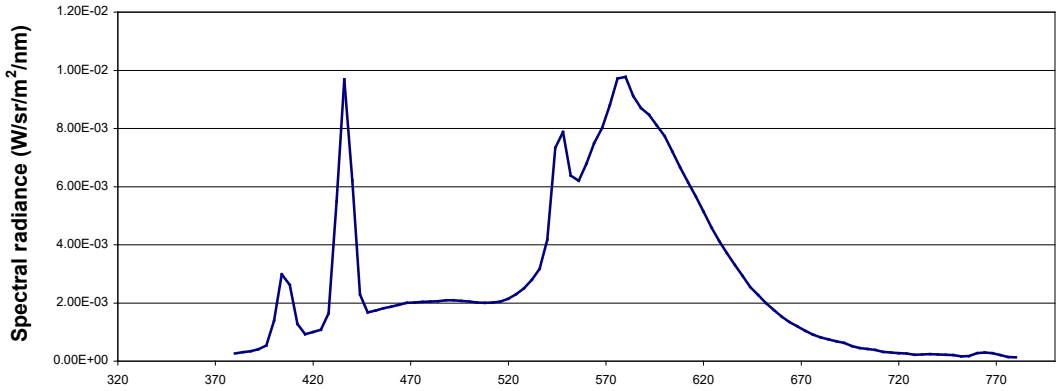

Fig 3.5 Spectral composition of four standard 5' fluorescent tubes - F35 W/35 - used in earlier take-off and oviposition trials.

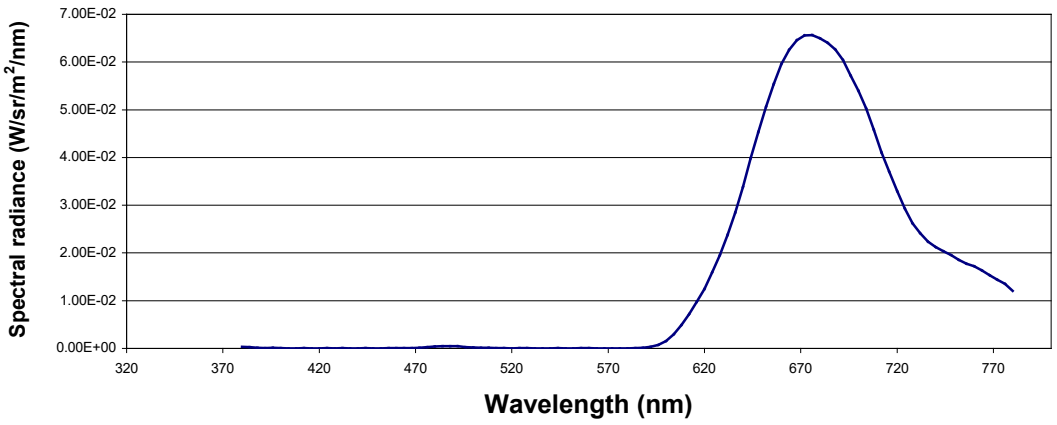

Fig 3.6 Spectral composition of a Schott fibre optic source filtered using Lee filter - medium red - intensity E and colour temperature 3300 K. - used in dark conditions

3.2 The effect of light on take-off

3.2.1 The effect of light intensity on take-off

Preliminary results on the effect of light intensity show no significant difference between treatments at the light intensities used in this trial (fig. 3.1) (Kruskal-Wallis, $H_{(2)}$=1.04, P=0.59 ns). Unfortunately, sample size is very small and this trial needs to be replicated to increase the sample size. The overall percentage take-off rate in this trial was low compared to other trials (table 3.2 to table 3.4). Replicate trials were attempted but the take-off rate remained low. It is possible that this may be due to a low population density in the culture. Thrips density has a marked effect on oviposition activity with fewer eggs laid at higher densities (HDC annual report CP10, 2002). Observations show that at a high population density, western flower thrips are more active and this disturbance may inhibit oviposition. It is possible that at low densities, they are less active with a lower propensity to take-off. A bioassay to determine the effect of thrips density on take-off rate is planned.

When this trial is to be repeated, lower light intensities are to be used in an attempt to define the lower light threshold for thrips take-off. Since the western flower thrips was found to take-off readily under a light intensity that is already below that measurable by the radiometric light sensor currently available, measurement of the low light threshold may pose a problem.

These results provide no evidence for a correlation between light intensity and the rate of take-off above a low light threshold. Such a correlation, however, has been described for black flies (Wolfe & Peterson, 1960) and the diel pattern of flight activity of western flower thrips (fig 3.14) suggests a possible correlation with a greater range in light intensity. Further experiments should clarify this situation.

3.2.2 The effect of wavelength on take-off

The results of trials on the effect of red and UVA light are shown in figs 3.10 and 3.11 and tables 3.2 and 3.3 respectively.

3.2.2.1 The effect of red light

There was a significant difference in the proportion of thrips that took-off within 300 s between the treatments ($\chi^2_{(2)}$=27.76, *P*<0.001) (Table 3.3) with a much lower proportion taking off in the dark and under red light. There was no significant difference in the median time to take-off in the dark (using the red light to position the thrips onto the arena) and in constant red light (Mann-Whitney, W=489.0, *P*=0.69). In both cases, there was a significant difference between red light (Mann-Whitney, W=574.5, *P*<0.001) and dark (Mann-Whitney, W=693.0, *P*<0.001) compared to bright, full spectrum light. It is thus reasonable to assume that the western flower thrips is not sensitive to red light under these conditions and that it is safe to use the red light in dark conditions to allow for handling.

3.2.2.2 The effect of white light, with and without UVA, on take-of

There is a significant difference in the proportion of thrips that took off within 300 s between the light treatments ($\chi^2_{(3)}$=39.14, *P*<0.001) (Table 3.4) with a much lower proportion taking off in the dark. The median time to take-off was significantly different between the light treatments (Kruskal-Wallis, $H_{(3)}$=29.2, *P*<0.001) (fig. 3.11) and thrips took longer to take off in the dark. The median time to take-off was slightly longer with +White-UVA compared to –White+UVA (Mann-Whitney, W=897.0, *P*=0.72) or +White+UVA (Mann-Whitney, W=963.5, *P*=0.62) and there was a slight reduction in the proportion of thrips that took off. These differences, however, were not statistically significant.

There was no significant difference between the median rates of take-off of thrips under +White+UVA compared to –White+UVA (Mann Whitney, W=1050.5, *P* = 0.773). The western flower thrips was, therefore, taking-off as readily under UVA light alone as under white with UVA.

Take-off is greatly reduced or absent in the dark even though the thrips are naturally active during the daytime when the experiments were carried out. The western flower thrips, therefore, is stimulated to take off by light. A low intensity of UVA elicits a take-off response similar to that from a higher intensity of full-spectrum light, since thrips took-off readily when illuminated by UVA alone. This occurred even though the intensity of this wavelength was very low, only 0.4 Wm^{-2}, similar to the UVA intensity that would naturally be encountered in low daylight conditions in a glasshouse. This compares with a total white plus UVA light intensity of 13.6 Wm^{-2} under the

full spectrum lighting. Not only was UVA light a stimulant but also the white spectrum (400-700 nm) was not necessary for take-off to occur.

There was, however, no significant difference in the rate of take-off under white light without UVA compared with the take-off rate under either white with UVA or UVA alone). Although UVA will stimulate take-off, it is not essential for take-off to take place. Trials carried out to test the effect of UVA absorbing spectral films found that more thrips were caught under standard films than under the UVA absorbing spectral films (Costa & Robb, 1999; Costa *et al.*, 2002). Standard plastic will allow white with UVA light onto to the crop. If the thrips were taking off more readily under white light with UVA than under white without UVA, this would help to explain how more western flower thrips were trapped under the standard, UVA transmitting plastic film but this has not been demonstrated here. The difference in flight behaviour, which could explain the preference by western flower thrips for UVA transmitting plastics and therefore white with UVA light, may involve the duration and direction of flight activity after take-off. The results presented here show that there is no significant difference in the rate of take-off in the absence or presence of UVA light in combination with white light.

Many factors affect insect take-off and under natural conditions these factors will interact to have an effect. In *Aedes aegypti* (L.) (Diptera, Culicidae) the previous environmental conditions affect its readiness to take-off (Haufe, 1961, 1962). It is possible that a change in conditions is as important as the imposed experimental conditions themselves. The western flower thrips used in these trials were cultured at a higher relative humidity than in the bioassay and in the absence of UVA light. It will be necessary to repeat these trials with western flower thrips raised under full-spectrum lighting to test whether they respond in the same way as thrips raised without UVA.

3.3 The effect of photoperiod on flight and take-off

3.3.1 The diel pattern of flight in a commercial glasshouse

No western flower thrips were caught during the hours of darkness either on the blue sticky traps or in the suction trap (figs. 3.12 – 3.13). These results support the findings of the take-off trials (section 3.3) in which it was found that take-off was stimulated by light and was reduced or absent in the dark.

Adult thrips started to fly mostly after 0730 h GMT as light intensity began to increase. Flight activity reached a peak between 1100 and 1130 h GMT and then declined through the afternoon until between 1730 h and 1900 h when flight activity stopped. This relates to the change in light intensity through the day (figs. 3.14 to 3.15and 3.18 to 3.19). The effect of light and temperature in the glasshouse are not independent. A multiple regression analysis of the number of thrips caught against light intensity and temperature shows a significant correlation with light (P=0.034*) but not with temperature when combined with light. The regression analysis shows 57.8% of the variation in the number of thrips caught is explained by the light intensity with only 3% explained by temperature. The remaining 40% of the variation is unexplained. Mean light intensity ranged from 0 – 130 Wm^{-2}.

More thrips were caught in the middle of the day on day 2 (18/9/2003) than on day 1(17/9/2003). The mean temperature inside the glasshouse on these days rose above 30ºC on day 1 but not on day 2 (figs 3.14 – 3.15).

3.3.2 The diel pattern of take-off under constant conditions

Adult female western flower thrips take-off significantly more quickly during the day (photophase) than during the night (scotophase) (fig.3.17) (Mann-Whitney, W=8192.0, P=0.004). The proportion of thrips to take-off within 300s increased from 0330 h GMT to a peak at 1830 h GMT with a small decline at 1430 GMT (fig 3.16). These results were obtained under constant conditions of bright light in both photophase and scotophase. This shows a greater tendency for take-off during the day than the night.

4 Conclusions

At the end of the second year of the three-year studentship, experimental work is in progress and a summary of the results obtained this year are presented below.

The light intensities used within the controlled conditions of the laboratory, although low, are similar to those found on a winter's day within a glasshouse. Results from laboratory conditions can therefore be reasonably compared to those from glasshouse conditions.

Take-off in adult, female western flower thrips is strongly affected by light. White light, UVA light or both together can stimulate take-off and take-off is greatly reduced or absent in the dark. There is, however, no significant difference in the rate of take-off under white light with or without UVA. In a choice experiment, thrips show a preference for areas of white light with UVA compared with one without UVA as found under UVA-transmitting plastics (Costa & Robb, 1999). There is no significant difference between take-off under white with UVA as compared to white without UVA. The difference in numbers caught under different spectral filters is not due to a difference in the tendency to take-off.

There was no significant difference found in the rate of take-off between a range of light intensities although this investigation requires further replication.

Western flower thrips show a diel pattern of take-off activity with take off being faster during the day than the night, even when subject to the same light intensity. They therefore show a higher propensity for increased take-off activity during the day.

As results are obtained and observations made, the need for further investigations have arisen. In particular, it has been noted that take-off behaviour is very variable in mixed age adult females from the culture. It appears that the proportion of thrips that takes off within 300 s is reduced when the thrips culture is at a lower density. This hypothesis is currently being tested under controlled conditions. If behaviour is markedly different at high and low densities, experiments need to take this into account.

5 Glossary

Term used	Definition
White light	Light visible to the human eye between 400 – 750 nm.
UVA light	Ultra-violet A light of wavelengths 315 – 380 nm.

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