FINAL REPORT

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The Effects of Spectral Modified Filters on Invertebrate Pest Populations

October 2006

Commercial – In Confidence

Project title**:**	The Effects of Spectral Modified Filters on Invertebrate Pest Populations
Project number:	CP 19b
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Report:	Final report
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The results and conclusions in this report are based on a series of experiments and desk-based studies. The conditions under which the studies were carried out and the results have been reported with detail and accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with the interpretation of the results especially if they are used as the basis for commercial product recommendations.

Authentication

I declare that this work was done under my supervision according to the procedures described herein and that this report represents a true and accurate record of the results obtained.

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Grower summary

Headline

- Greater numbers of aphids and spider mites were produced on plants grown under UV transparent plastic and significantly less pest numbers under Solatrol and UV opaque plastic.
- While these pests were not completely controlled under Solatrol or UV opaque it is possible that future generations could be significantly reduced over time.

Background and expected deliverables

In 1999, the HDC commissioned a review project (PC 170) at Stockbridge House and Imperial College to gather information on the possible effects of photo-selective plastics on pest control. The review showed that past research had focused on the effects the plastics were having on the visual behaviour of the pests through emigration into the tunnels and the disruption of pollination by bees. The research had been focused in countries, such as Israel, where there are higher light levels than in the UK and large invasions of pests occur. Research on the actual growth of pest populations under the photo-selective plastics was not known.

Photo-selective plastics under examination at STC Research Foundation and Lancaster University have been shown to induce changes in plant quality as reported in HDC project CP 19. Population growth of insect pests is dependent on plant quality and so this project was designed to take an initial look at the potential different growth patterns of pest populations under the different plastics.

Insect pests can fall into one of several feeding groups dependent on the type of plant tissue they feed upon. Previous research has suggested that phloem feeding insects (e.g. the lettuce aphid) induce a different range of plant defences compared to cell-content feeders (e.g. spider mites). (J. Moore, Lancaster University, pers.com). The following project looked at the population growth of aphids (on lettuce and Fuchsia plants) and spider mites (on strawberry plants).

Summary of the project and main conclusions

- The project was designed to take an initial look at the potentially different growth patterns of pests on plants grown under different photo-selective plastics (spectral filters).

- A series of trials looked at the numbers of offspring produced by two pests on plants grown under five different photo-selective plastic films. The two pests were Peach-potato aphid (*Myzus persicae*) and two-spotted spider mite (*Tetranychus urticae*).

- Two spotted spider mites were released onto strawberry plants (cv' Elsanta), and peach-potato aphid were released onto Fuchsia (cv 'Tom Thumb') and Iceberg lettuce (cv 'Ardinas').

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- The results established a general pattern for both pest species in that the greatest numbers of offspring were produced on plants grown under UV transparent films. The fewest pests were recorded in Solatrol and UV opaque tunnels.

- The mechanisms involved in this effect are not readily apparent. Whether the difference in offspring production in the pests is due to the overall slightly higher temperatures that were recorded under the UV tunnel or any induced plant quality differences remains uncertain at this time.

- The results showed a high level of variation, which is reflected in the variation obtained in the plant themselves (see project HDC CP 19) and the variation that occurs with temperature.

- The effect of different photo-selective plastics on pest populations needs further work to verify patterns of population growth that also takes into account the variation inherent in the field trials and the growth of biological control agents on the pests.

<u>Aphids on Lettuce and Fuchsias</u>

Overall the numbers of aphids recorded on lettuce plants were greatest in UV transparent and Luminance plastic tunnels. The numbers of aphids recorded in UV opaque and Solatrol tunnels were significantly lower than the other tunnels.

On Fuchsias the greatest numbers of aphids were again produced under UV transparent tunnels, but this was only significant when compared to the lower numbers recorded in UV opaque and Solatrol.

The results show a general pattern of aphid growth being greatest in UV transparent tunnels and lowest in Solatrol and UV opaque. However when looking at the numbers of aphids recorded within the different tunnels, although statistically different, they are not largely different from each other. However the trial has looked at the production of single generations over relatively short periods of time. The actual values over several generations would be a multiplication of these small differences which would produce a greater difference in the numbers of aphids under each of the photo-selective plastics.

The results suggest that the differences in offspring produced may possibly be due to an interaction with temperature. Although the temperature differences are relatively small they are possibly enough to produce the changes in the numbers aphid offspring that were observed. The number of aphid offspring produced throughout the trial was very variable. Complications arose due to the repeated failure of aphids to establish on the lettuce and Fuchsia plants. There was also frequent invasion of other aphid species, predators and parasitoids. In addition aphids on lettuce plants fed from leaves, whereas on the Fuchsias, the aphids established only on the flower heads.

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This difference in the preferred areas for feeding is reflected in the different fecundities of the two aphids groups, with those on the Fuchsia plants producing more offspring, and could account for a slight difference in the response of the aphid to growth under the different tunnels on the two types of plant.

The long term effect (i.e. over several generations) of the various factors that can effect aphid population growth, plant quality, temperature and performance of biological control agents still needs to be ascertained.

Two spotted spider mites on strawberry plants

As found in the aphid trials, the largest numbers of offspring produced by the two spotted spider mite were on strawberry plants grown under the UV transparent plastic. It is possible that these results, as suggested for the aphid trials, could also be because of the small temperature differences recorded in the tunnels during these periods. However the relationship between temperature and spider mite offspring production is not as apparent as it possibly is for the aphids. It is possible that the habitat for the spider mites, which because of their smaller size is the leaf boundary layer, may not be as prone to the small changes in air temperature. Other factors, such as the differing plant quality established under the different tunnels, may be responsible for producing an effect on spider mites.

However the variability inherent in these field trials, as discussed above for the aphids, also created problems for the spider mite data. The data would benefit from further replication, not only to establish regular patterns in the response of the pests feeding on plants grown under different photo-selective tunnels, but also to gauge the longer term response of pest population growth under the tunnels and also the performance of biological control agents on the pest populations.

Financial benefit to growers

Photoselective plastics are one of the most important developing areas in protected horticulture. The changes occurring in the physiology of the plants that have been recorded (HDC project CP 19) could affect population growth of invertebrate pests. Reductions in pest population growth are of benefit to growers as it enables the introduction of effective integrated pest management with the reduction of pesticide applications.

Action points for growers

At this stage of the research it is too early to make recommendations however UV opaque plastic reduced the population growth of aphids and spider mites. However the performance of beneficials (predators) in these systems still needs to be examined.

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SCIENCE SECTION

GENERAL INTRODUCTION

Background:

In 1999, the HDC commissioned a project at Stockbridge House and Imperial College to gather information on the possible effects of spectral filters on pest control (PC 170). The review showed that research into spectral filters had focussed on the effects the filters were having on the visual behaviour of the pests, i.e. invasion, emigration and the disruption of pollination (Kring & Schuster, 1992, Antignus *et al*., 1996). The research had been focussed in countries, such as Israel, where there are higher light levels than the UK and larger invasive pressures from pests. Research on the growth of pest populations under the different spectral filters is not known.

Spectral filters under examination at STC and Lancaster University have been shown to induce physiological changes in the plants that lead to improvements in plant quality (HDC CP19). Since the population growth of insect pests is dependent on plant quality it is important to establish the effects these observed plant changes may be having on the insect populations.

Insect pests can fall into one of several feeding guilds dependent on the plant tissue they feed upon. Previous research has shown that phloem feeding insects (e.g. aphids) induce a different range of plant gene products compared to cell-content feeders (e.g. spider mites), using distinct and different signalling pathways. The signalling molecules associated with each of these pathways also control plant growth and development and are influenced by light (J. Moore, Lancaster University, pers.com).

Overall aim and specific objectives:

The project was designed to take a preliminary look at the potential growth of pest populations under five spectral filters in plastic tunnels.

Introduction

The manipulation of light spectra using manufactured plastic covers (spectral filters or photo-selective plastics) to optimise growing regimes for crops is an area of increasing research and commercial practice. The use of spectral filters has been mostly focused in countries around the Mediterranean including Israel. Recently, UK growers funded work at STC Research Foundation, in collaboration with Lancaster University (HDC project: CP 19), to examine the

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effects of five types of spectral filters on the growth of a wide range of crops under UK environmental conditions. However, the affects of spectral filters on crop pests in the UK is still poorly understood and further research is required.

The reported project looked at the interaction of plant and pest under different spectral filters. Differences in the level and type of light reaching crops under spectral filters have been shown to change plant growth and development (HDC project: CP 19). Such spectrally induced changes might impact on insect performance through changes in food quality and natural plant defence systems.

The project focused on two key pests, *Myzus persicae* (peach-potato aphid) and *Tetranychus urticae* (two-spotted spider mite). The species selected represent two different feeding guilds; a mesophyll feeder (spider mite) and a phloem feeder (aphid). The selection of the two species is important as changes in plant physiology can affect the two feeding guilds differently.

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A. The interaction of the pest and spectral filter

Materials and methods

<u>Spider mite and aphid cultures</u>

Spider mites (*T. urticae*) were reared on tomato plants in a glasshouse (16-24 ^{0}C).

Aphids (*M. persicae*) repeatedly failed to establish on round lettuce in culture (controlled environment room, 16L:8D, 21 ± 2^{o}C). It was agreed at a HDC review meeting (January 2006) to switch the lettuce to iceberg varieties rather than switch the aphid species. As observed for the round lettuce *M. persicae* did not readily establish on iceberg lettuce, but this system was eventually more successful.

Aphids (*M. persicae*) were established in culture on fuchsias (controlled environment room, 16L:8D, 21 ± 2^{o}C). As observed in the lettuce cultures, there were problems establishing these cultures. This is often the situation when pests in culture have spent many generations on plants different to that of the intended trial.

<u>Plants</u>

Strawberries (cv 'Elsanta) supplied as frozen root stock were potted on and placed under the different plastic tunnels. Lettuce (cv 'Ardinas') were germinated in propagation and at the first true leaf stage they were put into pots under the different spectral filters. Fuchsias (cv 'Tom Thumb) were supplied at the plug stage and were put into pots and placed under the different tunnels.

<u>Spectral Filters</u>

The trial looked at five tunnels (700m^2), each with a different photo-selective plastic (Figure 1). See HDC CP19, for further details of the plastics.

The plastics used were:
St = standard
UVt = UV transparent.
Sol = Solatrol.
UVo = UV opaque.
Lum. = Luminance

Figure 1: Single four bay tunnel with photo selective plastic (standard)

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In initial trials comparisons of insect data from the above tunnels were made with plots situated outside of the tunnels. However these results showed that the development of both species of pest was too dissimilar (slow) in the outside plots for any valid comparison to be made.

Aphids

Numbers of offspring (Fecundity)

Initial methods monitored the second generation of aphids establishing on the fuchsia (cv 'Tom Thumb) and lettuce (cv 'Ardinas') plants under the different spectral filters. However high rates of parasitisation (*Aphidius* spp. and *Praon* spp.) and predation (a range of general predators) in the aphid trials in each of the tunnels resulted in the repeated failing of pest populations to establish.

A second method was devised. This used perforated Teflon sleeves placed around parts of the plants (see Figure 2). The attachment point of the cages avoided actual contact with plants to prevent alterations in plant defence systems and thereby potentially effecting results. The purpose of the sleeves was to provide a partial barrier against attack by parasitoids and predators of the aphids. However, condensation gathered around the flower heads and the sleeves (the sight

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of aphid establishment) causing problems with the flowers development and resulted in poor aphid establishment.

Figure 2: perforated sleeve loosely attached around part of plant (fuchsia)

The third and the most successful method used 3rd instar aphids to establish the aphid population and monitored their subsequent offspring. Using 3rd instars allowed the development of the aphids, and the subsequent production of their offspring, to be subject to the same plant food quality consumed by the parent aphids. Additionally this helped in establishing a second generation by reducing the period the aphids were left on the plants to be attacked by predators and parasitoids. On each plant the offspring were recorded from 10 adult aphids over five days.

Development

Ten adult female 4th instars were put onto excised leaves in Petri dishes. These leaves were then placed on a tagged part of the plant and the aphids allowed to transfer themselves to the experimental plants and to develop into adults. After 24 hours the adults were killed. The period of time for their offspring to go on and produce the second generation of offspring was recorded. Aphids were introduced to four plants in each plastic tunnel and the trial was repeated three times for fuchsias and lettuce.

Spider mites

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Numbers of offspring (Fecundity)

2005

Four adult female spider mites were released onto a tagged leaf on a strawberry plant (cv 'Elsanta). After 48 hours the adults were killed. The offspring were allowed to develop to adults and the offspring of the second generation recorded over seven days. (July –August)

2006

As with the method used in 2005, four adult spider mites were released onto a tagged leaf on a strawberry plant (cv 'Elsanta). However the method established in the previous year's trials developed problems through the invasion of non-introduced spider mites and their associated predators. To reduce these problems two adjustments were made to the method used in 2006. These were the attachment of a perforated Teflon sleeve around the tagged strawberry leaf. (Figure 3). This created a partial barrier to invasion. In addition offspring numbers were recorded over just four days to reduce the overall time of each trial and thus reduce the period for predators to locate infested leaves.

Figure 3: Perforated Teflon sleeve loosely attached around strawberry leaf.

Development

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Four female adult spider mites were released onto a tagged leaf on a strawberry plant (cv ‘Elsanta) as in the previous method. After 24 hours the adults were killed. The development of the offspring on these leaves was monitored and the period of time for the production of eggs was recorded. There were 10 replicate plants per tunnel.

Analysis of data

Analysis was done using Anova on square root transformed data and means from each of the spectral filters was compared using least significant difference (LSD) tests.

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Results and Discussion

Aphids

Aphids on Lettuce

The results show that overall throughout the trial, aphid reproduction was greatest in UV transparent and Luminance plastics (Table 1 and Figure 4).

Figure 4: The mean number of aphid offspring per adult recorded over five days on lettuce plants grown under different photo-selective plastics (spectral filter).

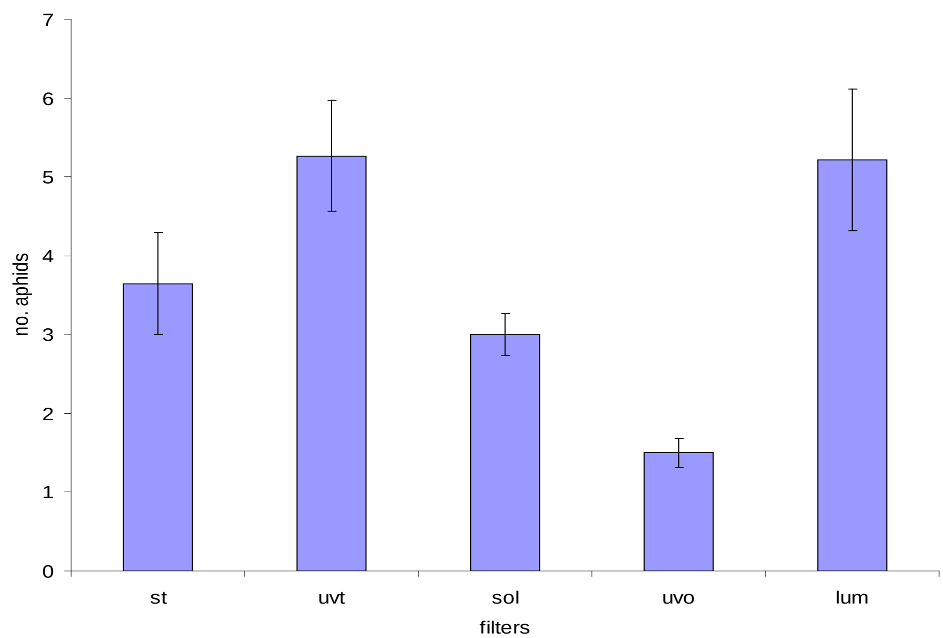

Table 1: The mean number (square root transformed value) of *M. persicae* on each lettuce plant.

Filter	No. of replicates	Mean
St	17	3.65 (1.80)
UVt	15	5.27 (2.04)
Sol	8	3.00 (1.72)
UVo	16	1.50 (1.20)
Lum	14	5.21 (2.17)
SED		
Min. rep		(0.347)
Max-min.		(0.298)
Max rep.		(0.239)

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The numbers of aphids recorded in UV opaque and Solatrol. tunnels were significantly lower than that recorded in other tunnels.

When looking at the numbers of aphids recorded within the different tunnels, although statistically different, they are not largely different from each other (Table 1). However the trial looked at the production of a single generation over a relatively short period of time. The actual values over several generations could produce a greater difference in the numbers of aphids under each of the spectral filters.

The numbers of aphid offspring produced throughout the trial was very variable (Table 2). Complications arose due to the repeated failure of aphids to establish on the lettuce plants. Within the trials, plants that had high rates of parasitisation or observed predators were discarded. In addition invasions onto trial plants by large numbers of other aphid species, primarily *Macrosiphum euphorbiae*, resulted in plants being discarded from the trial.

Table 2: The mean numbers (±sd) of *M. persicae* per lettuce plant per replicate over time

Date	St	UVt	Sol	UVo	Lum
20/7/06	3.20	4.20	3.00	1.60	6.60
	(1.64)	(3.77)	(0.82)	(0.89)	(3.91)
27/7/06	3.20	4.20	3.00	1.60	5.80
	(1.64)	(3.77)	(0.82)	(0.89)	(3.27)
1/09/06	4.00	16.00	*	1.33	3.50
	(3.00)	(1.45)		(0.58)	(2.12)
8/9/06	4.50	1.67	*	1.33	2.00
	(4.72)	(1.15)		(0.58)	(1.41)

* Invasion of large numbers of *Macrosiphum euphorbiae*

Section B (Figure 8a) shows a possible interaction of temperature on the fecundity of the aphids. The temperatures are the mean values obtained during the period the fecundity trial was run. These results suggest that the differences in fecundity may be due to temperature and/or plant quality. Although the temperature differences are relatively small they are possibly enough to produce the corresponding differences in the aphid fecundity. However the temperature relationship between the different photo-selective plastics is not always consistent (see Section B).

A result of the inherent variation within the field trials was the production of extremely variable data. Data from replicates over time (Table 2) was too variable to be analysed. This was also observed in the trials on spider mites. Therefore the analysis for all three sets of trials (spidermites and aphids on fuchsias and lettuce) was done on the overall values obtained during the period July to September.

The development period for aphids in the five tunnels was found to be the same (ranging between 17-18 days in each tunnel). This would suggest that there is no effect in the

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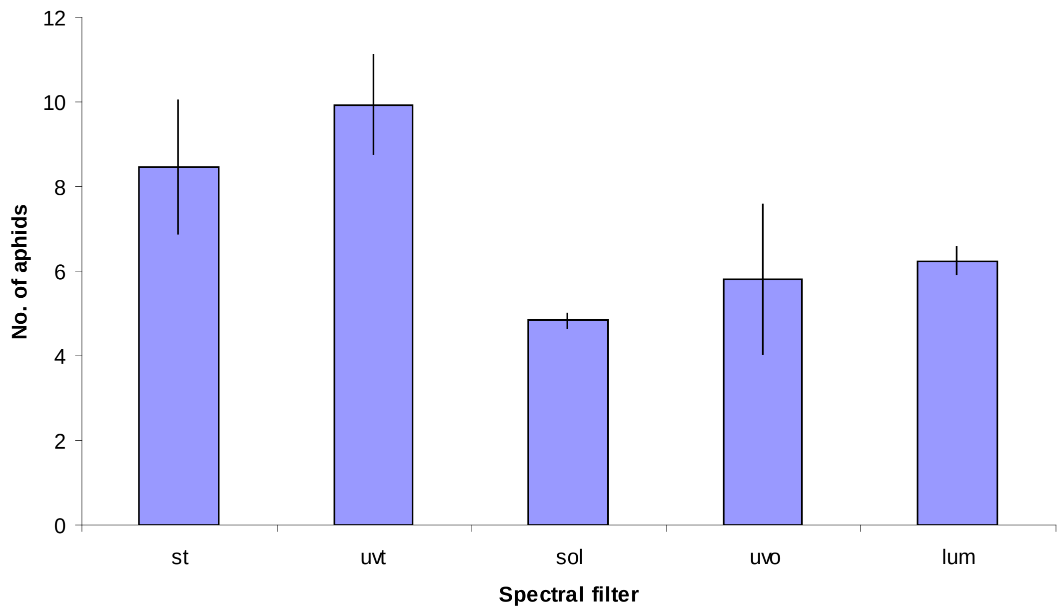
development time of aphids on lettuce plants grown under the different photo-selective plastics. The development studies were undertaken during a period when there was very little difference in internal temperature between the different tunnels (Table 3). However Section B shows a possible influence of temperature on the fecundity of the pests, therefore it could be expected that if temperatures within the various tunnels were consistently different then a development affect may also be observed that could influence population levels.

Table 3: Mean temperatures under different spectral filters.

	St.	UVt	Sol	UVo	Lum
mean	18.78326	18.62021	18.36531	18.37656	18.68778
sd	1.976486	1.828286	1.800855	1.819145	1.750486

Aphids on fuchsia

Figure 5: The mean number of aphid offspring per adult recorded over five days on Fuchsia plants grown under different photo-selective plastics (spectral filter).



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The analysis of the overall numbers aphid offspring produced (Table 4 and Figure 5) show that the greatest numbers of aphids are produced in UV transparent tunnels. This was significantly greater than the low numbers recorded in UV opaque and Solatrol.

Table 4. The overall mean number of *M. persicae* (square root transformed value) per plant (fuchsia).

Filter	Mean
St	8.46 (2.69)
UVt	9.94 (3.09)
Sol	4.83 (2.14)
UVo	5.82 (2.37)
Lum	6.25 (2.43)
LSD (cf with Sol)	(0.814)
LSD (cf except Sol)	(0.754)

Table 5: The mean (± standard deviation) numbers of aphids on fuchsias (number of replicates = 4) over four periods

	3/7/06	14/7/06	1/9/06	15/9/06
St	8.33 (3.21)	12.50 (0.71)	8.28 (5.12)	4.75 (2.88)
UVt	12.00 (4.83)	9.67 (3.79)	6.75 (6.40)	11.33 (14.43)
Sol	5.00 (2.00)	5.00 (1.41)	*	4.50 (2.65)
UVo	7.33 (5.86)	5.67 (3.21)	1.00 (0.00)	9.25 (4.57)
Lum	7.00 (4.36)	5.00 (0.71)	6.00 (3.37)	6.50 (3.32)

When comparing the results for numbers of aphids on lettuce and fuchsia plants, there is a similarity in that the greater numbers are recorded on plants grown under the UV transparent tunnel. Although this effect is greater on aphids feeding on lettuce plants, the overall numbers of offspring are higher on the fuchsia plants. It is important to point out that these differences in numbers of offspring could be accounted for by the different feeding sites selected by the aphids on these two plants. Aphids on the lettuce plants were feeding on leaf tissue, whereas aphids on the fuchsia plants moved to feed on flower heads only.

As stated above, when considering the growth of the pest population it is also important to consider the growth and behaviour of the beneficials under the different spectral filters (see section B).

As observed on the lettuce plants, there was no effect of photo-selective plastics on the period of development for the aphids.

Overall the result from the above trials suggests that the fecundity of the aphid populations is affected by the photo-selective plastics. Although the numbers produced in the UV transparent

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tunnels were not dramatically different, it is possible that over several generations small differences would be multiplied and the differences between the plastics would be accentuated over time. Section B shows that the affect on the fecundity of the aphids may be due to the temperature differences between the tunnels (Figure 8b), as suggested for aphids on lettuce.

In addition, consideration would need to be given to the influence a photo-selective plastic would have on other factors such as the role of invasion and population growth of the natural predators.

Spider mites

The results below are given for the trials done in 2005 and 2006.

2005

The results in Table 6 show that the greatest numbers of offspring were produced on strawberry plants grown under the UV transparent tunnel. This number however was only significantly greater than that recorded on strawberry plants grown under UV opaque and luminance tunnels.

Table 6: The mean numbers (square root transformed values) of offspring per adult spider mites (*T. urticae*) over seven days on strawberry plants under different spectral filters.

Filter	Mean
St	32.40 (5.59)
UVt	43.01 (6.48)
Sol	34.71 (5.73)
UVo	17.18 (3.97)
Lum	22.69 (4.70)
Max. LSD	(1.456)

It is possible that that these differences could also be because of the small temperature differences recorded in the tunnels during these periods. (Figure 8 shows the mean temperatures and the offspring produced and is discussed further in Section B).

As discussed in the materials and methods, the field trial conducted in 2005 was complicated by the invasion of non-introduced spidermites and their predators and subsequently many replicates were discarded. Therefore in 2006 the trial was repeated using sleeves made from transparent perforated Teflon.

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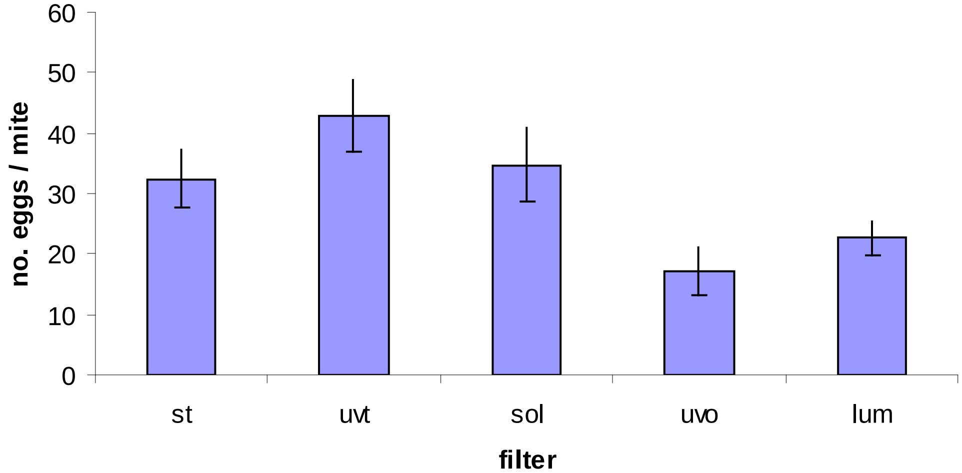
Figure 6: The mean numbers of eggs per adult female spider mite (*T. urticae*) under different photo-selective plastics (2005)



2006

The results in Table7 show that spidermites under UV transparent tunnels produced significantly more offspring than any of the other tunnels. Numbers of offspring produced under Solatrol, UV opaque and luminance plastics were very similar and lower than the result for UV transparent plastic.

In comparison to the results from year 2005, the 2006 results show that UV transparent plastic is the treatment where most offspring are consistently produced and therefore where potentially the greatest pest population could be seen.

Table 7: The mean numbers (square root transformed values) of offspring per adult spider mites (*T. urticae*) over four days on strawberry plants under different spectral filters.

Filter	Mean
St	18.89 (4.25)
UVt	26.59 (5.05)
Sol	13.94 (3.52)
UVo	14.49 (3.64)
Lum	14.54 (3.60)
Max. LSD	(0.204)

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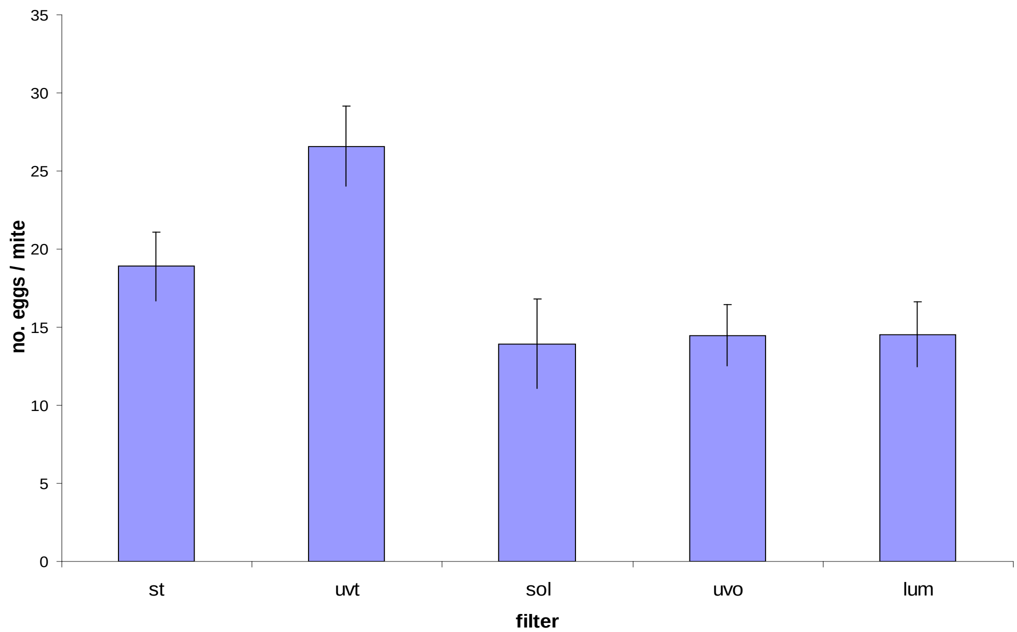
Figure 7: The mean number of eggs per adult female spider mite (*T. urticae*) under different photo-selective plastics (2006)



As suggested above there is considerable variation in the data. This can be due to the variability in the temperatures that are recorded under the different tunnels (see Section B) which affects the pests directly or indirectly through the plants. However the temperature influence on spider mite fecundity is not as apparent as it is for the aphid trials. It is possible that air temperature is not influencing the environment of the minute spider mites as much as that of the relatively larger aphids.

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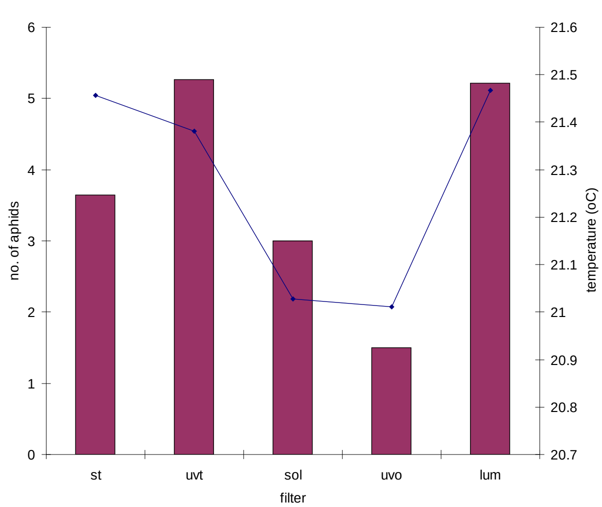
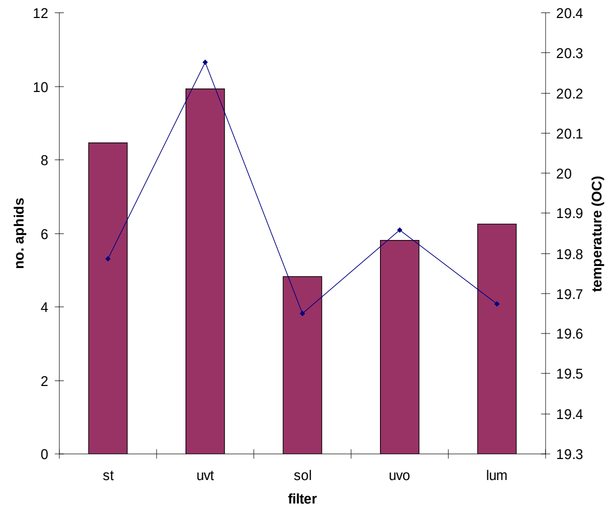
B. The interaction of temperature and offspring production

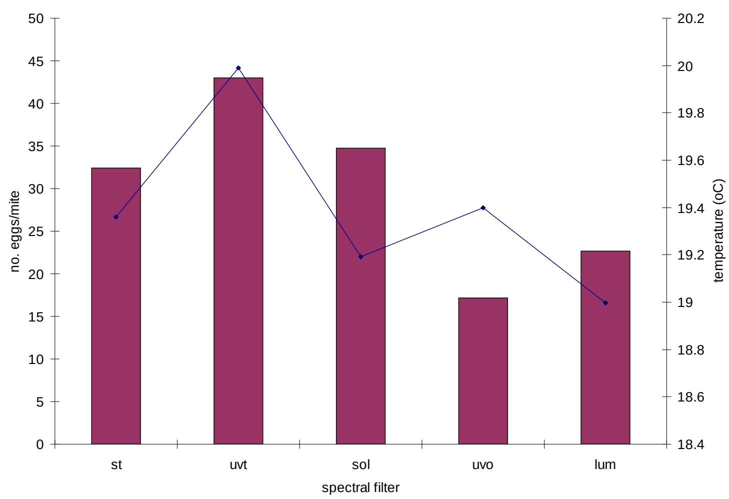
Figure 8 (a, b, c, d): Comparison of temperature and offspring production under different photo-selective plastics.



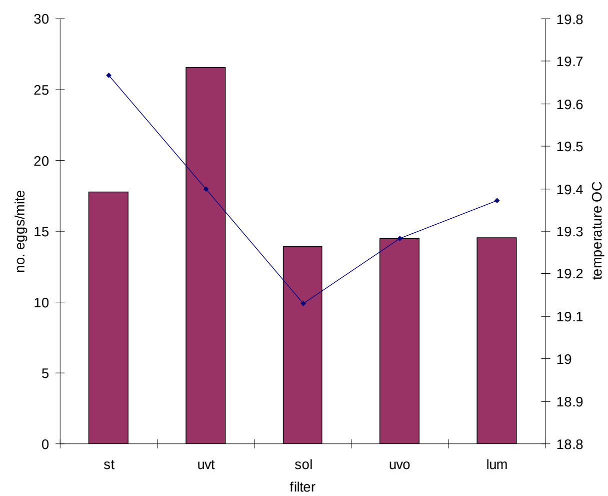
a. Aphids on lettuce plants



b. Aphids on fuchsia plants



c. Spider mites on strawberry plants (2005)



d. Spider mites on strawberry plants (2006)

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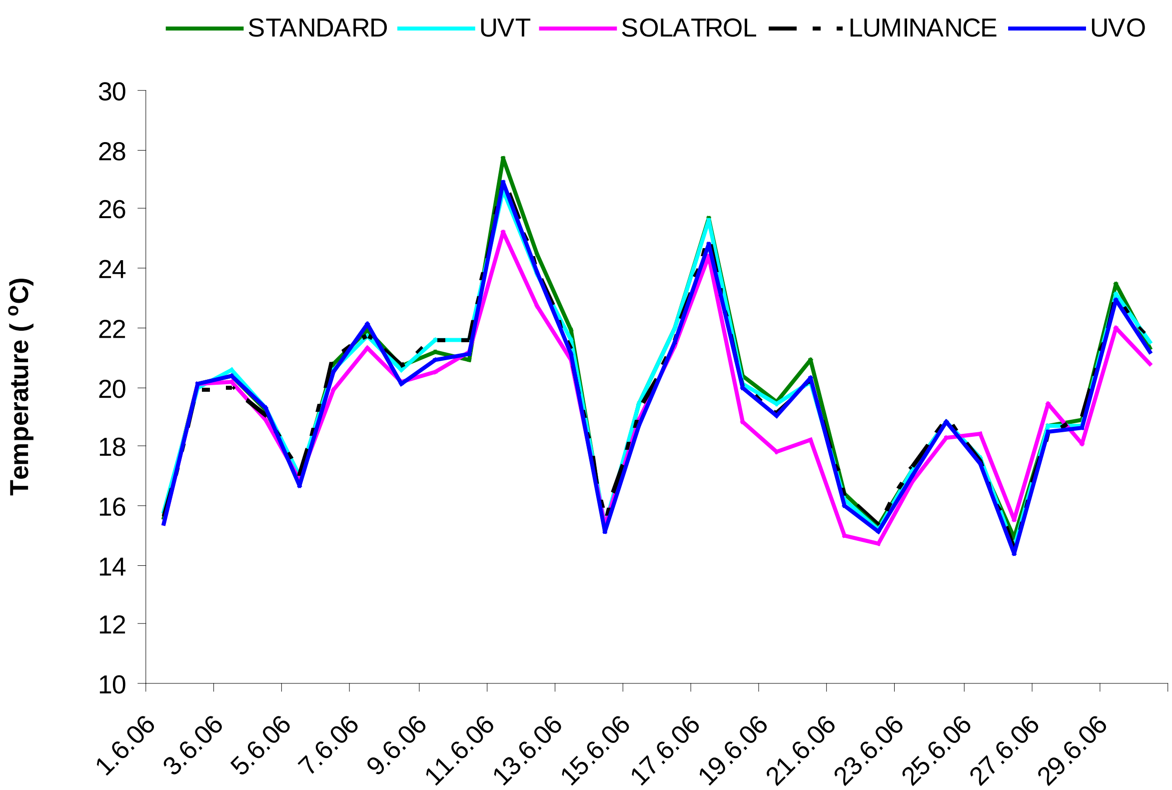
Figures 8a, b, c and d plot the mean temperatures and the corresponding offspring production during the same period for each photo-selective plastic and the two species of pest.

These simple visual comparisons suggest an interaction of temperature on the overall fecundity of the pests. Although from Figure 8, it can be seen that best fit of temperature to fecundity is that for aphids on lettuce and fuchsias. Spider mites are a much smaller animal than aphids and live in the lower leaf boundary layer, where perhaps small changes in air temperature have less influence.

Figure 9: Mean daily air temperature under different photo-selective plastics



Although the actual differences in the mean temperature recorded during the trial periods did not differ by more than one degree, it is possible that a one degree difference could produce a variation in fecundity. In addition the pattern of temperature within the different tunnels was also irregular. (Figure 9), therefore the variable pest data may also reflect this variation. There were also a number of factors which influenced variation including the invasion of other pests and

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predators and irregular establishment of the introduced aphids. Further work is required to establish the influence of temperature within photo-selective plastics on the growth of pest populations.

Conclusions

For both feeding systems, cell feeders (spider mites) and phloem feeders (aphids), the overall largest numbers of offspring were recorded under UV transparent tunnels.

The actual numbers of aphids produced under the UV transparent tunnels was statistically different to that recorded in the other tunnels. Since the trial recorded offspring from one generation further population growth would obviously be the result of multiplication of these numbers over several generations. It is possible therefore that greater numbers of aphids would result under UV transparent plastic over time.

In general there is a tendency for the lowest pest growth (aphids and spider mites) under UV opaque and Solatrol tunnels, but this pattern was not consistent.

The pattern in pest numbers between photo-selective plastics is possibly the result of air temperature differences in the different plastic covered tunnels. Overall slightly higher temperatures were recorded in the UV transparent tunnel and lower temperatures in the Solatrol and UV opaque tunnels.

Aphids established on the lettuce leaves, whereas on the fuchsias, the aphids established only on the flower heads. This difference in the preferred areas for feeding is reflected in the different fecundities of the two aphids groups, with those on the fuchsias plants producing more offspring despite lower temperatures.

The largest numbers of two spotted spider mite offspring were on strawberry plants grown under the UV transparent plastic. As for the aphid trials this could be because of the small temperature differences between tunnels. However the relationship between temperature and production of spider mite offspring is not as clear as it is for aphids with the strong possibility that spider mite leaf habitat may not be as prone to the small changes in air temperature as that occupied by the aphids. There may be other factors therefore affecting mite numbers.

It was not possible to separate temperature from plant quality differences under the different photo-selective plastics as both of these factors could be acting on the pest population growth and contributing to the variability in the data obtained.

The results show there is a considerable variation in the field trials and our understanding would benefit from repeating the work. The growth of several generations of pests over time under the

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different photo-selective tunnels, subjected to the range of variations (temperature and plant quality), needs to be ascertained.

In addition biological control agents would be influenced by a similar range of variations to that experienced by the pest, which in turn would impact on the pest populations. This is an area that also needs to be investigated.

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