Project title:	Protected Crops: The potential of spectral filters for pest control
Report:	Final report, March 2001
Project number:	PC 170
Project leaders:	Ms Clare Sampson, HRI Stockbridge House Prof Jim Hardie, Imperial College
Project Co-ordinators:	Mr Stuart Coutts, Nightingale Cottage, Felhampton, Church Stretton, Shropshire SY6 6RJ Dr Nigel Dungey, Hazlewood VHB, Toddington Lane, Littlehampton, West Sussex. BN17 7PP. Mr Graham Ward, Snaith Salad Growers Ltd., West Bank, Carlton, Goole, N. Humberside DN14 9QA
Location:	HRI, Stockbridge House, Cawood, Selby, N. Yorkshire, YO8 3TZ Imperial College, Silwood Park, Ascot, Berkshire, SL5 7PY
Start Date:	1 October 1999
Duration:	15 months
Date completion due:	31 December 2000
Keywords :	Spectral filters, integrated pest management, pollination, biocontrol agents, UV light, insects, plastics

The results and conclusions in this report are based on a search of the scientific literature and collation of unpublished information from international scientists and extension workers who are working on spectral filters, and monitoring of crops in the U.K. The results have been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.

Signature…………………………………………………………………………….

C. Sampson
Project Leader
Horticulture Research International
Stockbridge House
Cawood, Selby
North Yorkshire, YO8 3TZ

Tel: 01757 268275
Fax: 01757 268996

Date …………….

Signature…………………………………………………………………………….

Professor Jim Hardie,
Imperial College,
Silwood Park,
Ascot,
Berkshire, SL5 7PY

Tel: 01344 294259
Fax: 01344 294339

Date …………….

Report authorised by ……………………………………………………………….
(signature)

Dr M Tatchell,
Head of Entomology Department,
HRI, Wellesbourne,
Warwickshire, CV35 9EF

Tel: 01789 470382
Fax: 01789 470552

Date……………..

CONTENTS

Page No.

PRACTICAL SECTION FOR GROWERS

Background and objectives 1

Summary of the findings from the review 1

Overall conclusions 4

Anticipated practical and financial benefits from the study 5

SCIENCE SECTION

1. Introduction 6
2. Objectives 6
3. The effects of different wavelengths on invertebrate biology and behaviour 7
4. The effect of spectral filters on pests, their natural enemies and pollination 11
5. Methods of using spectral filters 20
6. Crop monitoring in the UK 22
7. Specifications of the different plastics on the market 31
8. Recommendations 33
9. References 35

Appendix 1 41

PRACTICAL SECTION FOR GROWERS

Background and Objectives

Worldwide, cultivation of crops under plastic has increased dramatically during the past decade with approximately 400,000 Ha in the Mediterranean region alone (Castilla and Jarret, 1995). Plastic-covered greenhouses provide a protected environment, and facilitate improved control of temperature, humidity and light intensity.

In recent years a new generation of plastics have been designed to absorb or block light of certain wavelengths, changing the quality of light reaching the crop. This gives the plastics, known as spectral filters, particular properties such as the ability to modify plant growth as well as to moderate the temperature inside a greenhouse. It is not known how the different types of spectral filters may affect pest management under UK conditions.

The objective of this project was to collate information on the effect of spectral filters on the biology and behaviour of key pest species, their natural enemies and bumble bee pollination and to provide growers with guidance on how spectral filters might be used to improve pest control.

Summary of the Findings from the Review

Key biological details

1. There will be both direct and indirect effects of spectral filters on insect pests. Direct effects include the inhibition of movement of insect pests into the crop when specific UV-absorbing spectral filters are used as a mulch or crop cover as the reflected UV and blue light repels the insects. Inside a polythene clad tunnel (polytunnel), the altered spectral environment will change how the insects ‘see’ the plants and how they move. UV filters will probably influence the local spread of insects within polytunnels by reducing take off and dispersal. Increased red light is unlikely to have any effect.

2. It is unlikely that host location mechanisms will be altered by the blocking of UV or other light wavelengths within polytunnels.

3. Indirect effects of spectral filters derive from changes in plant metabolism and physiology influencing plant suitability to the insect. Such changes can affect the rate of growth and development as well as the fecundity of insects and so change the rate at which the populations build up.

4. Spectral filters can be used as polytunnels, mulches, to screen vents and doors, or even as traps and baits. Polytunnels are the most practical and common method of using the films and these are in widespread use in the Mediterranean region in particular. The effect of altered light conditions on pest numbers is dependent on the proportion of filtered: unfiltered light. Hence larger polytunnels will have a greater amount of filtered light than small tunnels and hence will have a greater effect on

insect invasion and behaviour. The effects will also be reduced if vents, sides and doorways are opened for ventilation. To maintain the best effect, fan and water-cooling systems may need to be considered as an alternative to venting.

5. It is most unlikely that spectral filters used as screens in glasshouses will have a positive effect in reducing pest invasion or in altering their behaviour inside the glasshouse as the proportion of unfiltered light will be too great. Therefore, the use of spectral filters as screens in glasshouses cannot be justified on their potential for pest control alone.

Evidence of the effects of spectral filters on pest control in other countries

6. Of the range of spectral films available, the effect on pest management has only been studied for UV-absorbing films which have been shown to reduce the incidence of flying pests within polythene structures in a number of countries with warmer climates. UV-absorbing films had the greatest impact on aphid numbers (100 x reduction) as well as a significant effect on whiteflies, thrips and leaf miners (10 x reduction). It is possible that the numbers of some species of mite (e.g. spider mites and broad mites) were also reduced but further work is required to confirm this.

The films also reduced the incidence of insect-transmitted virus diseases, such as Tomato Yellow Leaf Curl, partly as a result of there being fewer insect vectors, but also because the flight frequency of the insects was reduced under UV-absorbing films, so slowing the spread of viruses.

7. Limited information is available on the effects of UV-absorbing films on the performance of beneficial insects. Experiments in progress in Israel indicate that the performance of natural enemies such as *Aphidius colemani*, *Eretmocerus mundus, Orius majusculus* and *Phytoseiulus persimilis* were not adversely affected under the films. In Israel, UV-absorbing films are now used commercially for the production of tomato, cucumber and spice crops. As a result, growers have reduced insecticide use by 25-50% and biological pest control is more feasible.

8. There are reports that bumblebee pollination efficiency is reduced under UV absorbing films and this is most likely due to a change in the visual appearance of the plants. Insects ‘see’ UV but bees use UV reflectance from petals to locate pollen. Indeed growers in Israel have noticed that pollination of salad crops using bumblebees is adversely affected under UV absorbing films and 1 ½ to 2 times more hives are required to achieve the same level of pollination as under normal plastic films.

Preliminary observations on the likely effects of spectral filters on pest control under UK conditions

9. The numbers of pests were monitored under unreplicated single span (4.5 m x 20 m) French tunnels growing cut flower crops at HRI Kirton during the summer of 2000 (see HDC project PC 168). At HRI Kirton there were 200 x fewer aphids under UV-absorbing films (XL Sterilite and Visqueen Anti-Botrytis film) and reflective films (Luminance THB and experimental Lee Filter Steel Blue). There were also 2 x fewer leaf miners and caterpillars under UV-absorbing films. There were fewer thrips under Luminance THB and experimental Lee Filter Steel Blue plastic films compared to the standard film.

   Under the same series of French tunnels, the levels of downy mildew (*Peronospora destructor*) on stocks were reduced significantly on plants growing under Experimental Lee Filter Steel Blue and Visqueen Solatrol as compared to standard polythene films. Three other spectral films (Balanced PAR, XL Super Green and XL Super Clear) reduced the level of downy mildew on the stocks although not significantly. Only very low levels of *Botrytis cinerea* and other pathogens were noted during each assessment and no obvious differences were recorded.

10. At HRI Stockbridge House under replicated cloches (1.75 m x 1.4 m), a UV-absorbing film (Visqueen AB) was compared to a standard film. The first aphids were observed under the UV-absorbing cloches 14 days later than under the standard cloches. Once inside the cloches, aphids numbers increased at similar rates and there was no significant difference between numbers under the different cloche types.

11. These results from trials at HRI Kirton and Stockbridge House indicate some potential for the reduction in pest invasion in polythene tunnels that are clad with UV-absorbing plastic films. The principal target should be aphids. This area of work requires further investigation so as to improve pest management and reduce pesticide use in crops grown under polythene tunnels.

12. The use of UV-absorbing films may not be appropriate for all crops. Possible adverse effects include delayed ripening in strawberry and aubergine, colour changes in some flowers, such as roses and lisianthus, as well as etiolation in some seedlings, such as lettuce. The effect of UV-absorbing films on specific crops under UK conditions will have to be tested before they can be recommended for use.

Potential for use of spectral filters for pest control in UK grown crops

Protected salad crops

13. The greatest potential uses for UV-absorbing filters are to protect crops that are attacked by invasions of pests. One potential use of UV-absorbing films is to reduce aphid numbers (various species) in lettuce. However, these films are known to cause etiolation in lettuce seedlings and will change the colour of red varieties. High value crops, such as organic herbs, may also benefit from these films to reduce numbers of aphids (various species) and leaf hoppers.

    These films may also reduce numbers of Liriomyza spp. on tomatoes and numbers of *Aphis gossypii* on cucumbers. In Israel, no adverse affects of the UV-absorbing films have been observed on tomatoes or cucumbers. Red-blocking filters are unlikely to be used for salad crops as the change in spectral properties that produces compact plants may also have a yield penalty. In any case, only a small area of tomato, cucumber and pepper crops are grown under plastic in the UK at present, so the potential contribution of spectral filters to pest control in the production of these crops overall is minimal.

Protected ornamental crops

14. UV-absorbing and reflective films may be used to reduce pest numbers in protected ornamental crops. Red-blocking films are likely to be used for ornamental plants but these are unlikely to affect pest numbers. The efficacy of natural enemies should not be affected under red-blocking films unless temperatures are reduced below optimum (e.g. 20°C for *Encarsia*).

    The effect on thrips numbers will depend on the crop type and cropping system. There may be less benefit in crops such as AYR chrysanthemums where the thrips population is present in the greenhouses throughout the year.

    Examples of crops where the UV-absorbing films might be of use include:

    - aphids on nursery stock and cut flowers
    - leafhoppers on primroses
    - leaf miners on a range of crops

Outdoor crops

15. There are a number of possible uses either as crop covers or cloches. UV-absorbing or reflective crop covers may be used to protect crops from a range of pests, for example, carrots from carrot fly, brassica crops from aphids and daffodils from large narcissus fly. Mulches could also be used to reduce incidence of aphids, leaf miners and other pests on outdoor cucurbits. ***However, none of these options are likely to be cost effective under the current economic climate.***

Overall Conclusions

There is insufficient evidence to recommend spectral filters as a cost-effective method of reducing pest numbers under UK conditions. However, work in Israel and some preliminary studies in the UK, show that UV-absorbing films may be of benefit in delaying pest invasion and reducing pest numbers (especially of aphids).

If any benefits of pest control through the use of spectral filters are to be realised, then crops grown in polythene tunnels are the best targets. It is most unlikely that spectral filters used as screens in glasshouses will have a positive effect in reducing pest invasion or in altering their behaviour inside the glasshouse as the proportion of unfiltered light will be too great. Therefore, the use of spectral filters as screens in glasshouses cannot be justified on their potential for pest control alone.

It is recommended that monitoring of pest populations and of natural enemies be carried out on crops grown under UV-absorbing films under semi-commercial or commercial conditions. Good target crops include nursery stock, lettuce, bedding plants and cut flowers grown in polythene tunnels.

Anticipated Practical and Financial Benefits from the Study

Growers from all protected crop sectors have identified spectral filters as one of the most exciting new developments in protected horticulture. Spectral filters are likely to have an impact on ornamental, fruit and salad crops. It is likely that a range of different spectral filters will be used for different purposes within the industry. These will be used primarily to improve plant production or quality. If spectral filters were also shown to reduce pest invasion or development, it would be a good starting point for integrated pest management. Benefits would include reduced pesticide use, improved plant quality and marketing support where there is an increasing demand for produce without pesticides. For some pest species, such as western flower thrips, a lower pest pressure may make biological control a viable option for pest control.

SCIENCE SECTION

1. INTRODUCTION

Worldwide, cultivation of crops under plastic has increased dramatically during the past decade with approximately 400,000 Ha in the Mediterranean region alone (Castilla and Jarret, 1995). Plastic-covered greenhouses provide a protected environment, and facilitate improved control of temperature, humidity and light intensity.

In recent years a new generation of plastics have been designed to absorb or block light of certain wavelengths, changing the quality of light reaching the crop environment. This gives the plastics particular properties that result in a modification to plant growth or moderate the temperature inside a greenhouse. For example, ultra-violet (UV) absorbing films reduce the scorching effect of the sun; red blocking filters make plants tall; far-red blocking films make compact plants and light scattering filters improve plant growth habit (see HDC projects PC 150 & PC 168). Recent studies in Israel have shown that the use of UV-blocking filters can reduce the numbers of insect pests and virus diseases (Antignus *et al*., 1996a). However, there is no information on whether UV-blocking films affect pest numbers under UK conditions where light levels are half those of Israel and where there are fewer invasive pests. There is no information on how the other types of spectral filters may affect pest management, although it is likely that any properties that change plant growth or alter the spectrum of light may also affect pest biology and behaviour.

Commercial Objective

The overall objectives of this project were to collate information on the effect of spectral filters on the development and behaviour of key pest species, their natural enemies and bumble bee pollination and to provide growers with recommendations on how spectral filters might be used to reduce pest incidence.

2. OBJECTIVES

The specific objectives of the project were:

1. To collate available information on the effect of different light wavelengths on insect/mite biology or behaviour.
2. To collate available information on the effect of existing spectral filters on pests, their natural enemies and pollination.
3. To identify appropriate methods of applying spectral filters for pest control.
4. To determine whether UV-blocking films affect pest control under UK conditions.
5. To confirm which wavelengths are blocked by the different plastics on the UK market.
6. To produce recommendations for the use of existing spectral filters on the market for pest control in different cropping systems.
7. To identify gaps in the knowledge of the effects of spectral filter types on pest control and pollination and make recommendations for further research work required for the new range of spectral filters in development.

3. THE EFFECT OF DIFFERENT LIGHT WAVELENGTHS ON INVERTEBRATE BIOLOGY AND BEHAVIOUR

3.1 Introduction

There will be both *direct* effects on invertebrate biology and behaviour from the changed spectral environment following transmission of natural light through the filters and from reflected light outside the filter, as well as *indirect* effects resulting from changes in plant growth characteristics.

The impact on insect pests will derive from influences on:

i) Plant finding

Insect behaviours associated with host-plant finding can involve vision, olfaction, gustation and touch but the relative importance of each changes through a sequence of predefined behaviours.

ii) Plant utilisation

Changes in plant metabolism/physiology may alter the quality of plants as food for pests. Thus, damage could be affected by alterations in the feeding rate of individual insects arriving on the crop and by altering growth rate and fecundity. Thus the build-up of pest populations will be altered.

In addition, there will be implications for beneficial insects, predators and parasitoids used for biological control as well as pollinators.

3.2 How will pest insects behave outside spectral filters?

Any physical barrier will affect access to a crop but the light reflecting properties of a cover will also influence insect immigration. Since the 1960s there have been studies on the effect of different mulches placed under crop plants (see section 5.2). These can be living, in the form of an undersown crop (e.g. Finch and Collier, 2000), but more relevant to spectral filters is the use of aluminium foil and plastics (e.g. Kring, 1964; Kring and Schuster, 1992; Costello, 1994). The reflection of the UV and blue wavelengths of natural light (see Appendix 1) by silver surfaces deters insects from landing on the crop despite the plants being visible. Landings of thrips and aphids in yellow traps placed above these mulches are also much reduced when UV-reflecting surfaces are utilised (Kring and Schuster, 1992). It is thought that flying insects distinguish sky and plant by the relative proportions of long- (c. 500 – 650 nm) and short-wavelength light (c. 350 – 500 nm) perceived with landing being inhibited by the shorter wavelengths that predominate in natural light.

Where spectral filters reflect these shorter wavelengths, and where the crop is hidden from outside view by non-transparent plastics, the films will deter insect approach and is, therefore, a major mechanism preventing insect entry into the crop environment. However, none of the plastics are likely to disguise plant volatiles which may be an important mechanism for host-plant finding by insects. Insects are extremely sensitive to olfactory cues and as the smell of host plants drifts downwind, flight upwind will take an insect closer to a plant.

3.3 How will pest insects behave on crops beneath spectral filters?

Many of the reports on the effect of spectral filters on pest infestations and their impact on plant health have included speculations on the precise mechanism of pest/vector reduction (see Section 4). There have been few reported attempts to identify precise mechanisms and, while the major focus in developing spectral filters is to control plant growth, the secondary implications for how insect pests might be affected are crucial and a detailed understanding of mechanisms is required.

The literature indicates that for plant-eating insects, take-off and maintained flight depend upon UV and the shorter wavelengths of light (c. 350 - 500 nm). At this time, the visual responses to longer wavelengths are inhibited and this flight can be termed migratory (Hardie, 1993). A change in behaviour, or relative strengthening of a positive response to longer (c. 500 – 650 nm) wavelengths, and a repulsion to shorter wavelengths, will then lead to insects returning earthwards and landing on a plant surface (foraging flights; Moericke, 1952, 1955; Kennedy *et al*., 1961). The landing response is, of course, crucially important to pest infestation.

The sensitivity of the insect eye to different wavelengths of light has been investigated in thrips, *Frankliniella occidentalis*, (Matteson *et al*., 1992) and whitefly, *Trialeurodes vaporarium*, (Mellor *et al*., 1997). These studies recorded electrical responses of the eye to stimulation by light and found maximum sensitivity in the UV and the green (c. 520-550 nm) regions of the spectrum. Behavioural responses to light of single wavelengths (monochromatic light) have been investigated in aphids (Zdarek and Pospisil, 1962; Rautapaa, 1980; Hardie, 1989) and whitefly (MacDowall, 1972; Vaishampayan et al., 1975; Coombe, 1981). Physiological responses were recorded to UV and green (c. 550 nm) although it is likely that these represent different behaviours. Early work with honey bees showed that movement towards a light source peaked in the UV region while responses to moving objects, as occurs when insects fly past a plant, were maximal in longer wavelengths, c. 530 nm (see Goldsmith, 1994).

Under more natural conditions flying insects respond to a combination of light from skylight and reflections from coloured surfaces.

Direct responses to changes in spectral quality

Take-off can be inhibited by environmental factors such as temperature, light intensity, wind, humidity and all may be altered inside a structure covered by a plastic film. Thus flight muscle must reach a minimal temperature before flight can occur and this will differ between species (e.g. Wiktelius, 1981). Spectral filters designed to increase temperatures inside a poly-tunnel will enhance take-off and flight. All insect have a minimum or maximum light intensity before which flight will occur, while high winds and rain-fall/humidity can inhibit flight in aphids (Rautaupaa, 1980). In reduced UV environments created under spectral films, take-off and movement will be restricted.

Sticky coloured surfaces have been used for many years to trap and monitor pest insects in glasshouses and in the field. The majority of plant pests are particularly attracted to what humans see as yellow (e.g. Kring, 1972; Vaishampayan *et al*., 1975; Affeldt *et al*., 1983; De Barro, 1991). Despite the fact that yellow appears to humans to be very different to plant-green, yellow surfaces reflect a high proportion of the 'green' wavelengths (wavelengths 500-560 nm) which are maximally reflected from plant leaves (Prokopy and Owens, 1983; Hardie, 1989). Also crucial to the attractiveness of yellow surfaces is the absorbance of wavelengths below 500 nm. White surfaces do not attract flying insects despite the fact that they reflect a large proportion of green wavelengths (in a similar way to yellow) but they also reflect the shorter, 400-500 nm light. It has been shown that altering UV reflectance can affect the attractiveness of a yellow surface. For example, the plum aphid, *Hyalopterus pruni*, is maximally attracted to yellow surfaces with some UV reflectance, but for the black bean aphid, *Aphis fabae*, no UV reflectance is optimal (Moericke, 1969). The implications of these types of experiment are two fold:

1. The visual impact of growing plants to insects will be altered by filtering light through a spectral film

2. The efficiency of coloured traps used for monitoring may be affected.

Not only might flight be affected, but also the probing/feeding responses are affected by the quality of light. In aphids, Moericke (1950) showed that wingless aphids maximally probed surfaces illuminated with green/yellow wavelengths (500-600 nm). These findings were supported by similar studies using coloured surfaces (Pelletier, 1990). It has also been shown that aphids feeding on artificial diets reproduce and survive better when illuminated by yellow or green light (e.g. Cartier and Auclair, 1964). Thus changes in the spectral environment can directly affect feeding irrespective of any effects on plant quality (see below). Insects under spectral filters could be adversely affected by delayed initiation of feeding or more direct wavelength effects. Such affects are likely to be minimal under the spectral filters currently available.

Indirect responses to plant quality

The effects of spectral filters on plant quality with respect to pest insect utilisation is also an unknown factor. It is known that exposure to UV-B (280-320 nm, beyond the 'visible' spectrum for most insects) affects plant chemistry and insect preference/performance (Hatcher and Paul, 1994; Lavola *et al*., 1998). The overall amount of light may also be important, e.g., tobacco hornworm caterpillars grow faster on tomato plants grown in shade (Jansen and Stamp, 1997). No corresponding studies have been completed with plants reared under spectral filters.

Possibly of minor importance to rearing plants under spectral filters is the finding that plant/leaf shape can affect insect behaviour. For example, female carrot flies, *Psila rosae*, prefer to lay their eggs on artificial leaves having a similar shape to the host plant (Degen and Städler 1997). This may not, however, always be the case as cabbage root fly, *Delia radicum*, and onion fly, *Delia antiqua*, do not show such a preference (Degen and Städler, 1996).

3.4 How can spectral filters affect the impact of beneficial insects on crops?

Insect predators, parasitoids and pollinators use similar behavioural mechanisms to the plant-seekers in their search for resources. The spectral environment will also affect them both directly and indirectly via influences on plant growth. Predators and parasitoids often use plant-derived stimuli to detect the habitats suitable for prey/host insects as well as changes in plant volatiles induced by pest insects feeding which offer specific direction to these beneficials (e.g. Turlings, 1995). Parasitoids use colour as a cue for oviposition sites but chemicals detected on host contact are also important (Michaud and Mackauer, 1994; Battaglia *et al*., 2000).

Flower recognition by pollinators involves visual and olfactory cues. In particular, bumblebees utilise patterns of UV reflectance/absorbance from petals and where ultraviolet wavelengths are excluded, visual recognition may be affected (Lunau, 1992). Flower volatiles are also used and changes in plant metabolism could affect odour.

4. THE EFFECT OF EXISTING SPECTRAL FILMS ON IPM SYSTEMS

4.1 UV absorbing films

UV-absorbing films are thought to reduce the numbers of pests invading greenhouses and to affect flight behaviour once inside greenhouses (see part 3). The effect of UV-absorbing films on specific pest and natural enemy species and on bumblebee pollination is summarised below.

The effects of UV-absorbing films on pest control in warmer climates

Whiteflies (*Bemisia tabaci).*

A series of experiments in Israel demonstrated an up to 10 fold reduction in the numbers of *B. tabaci* under UV-absorbing films and UV-absorbing mesh structures (at or above 50-mesh size), in tomatoes and herbs (Table 1). Control was not improved under larger mesh sizes of 30-mesh and 16-mesh. The size of the mesh affects its ability to eliminate UV from the light spectra. The 50-mesh bionet eliminates ~ 50% of the UV transmitted by the conventional 50-mesh net, while the 30-mesh and 16-mesh bionets eliminated only 18% and 15% respectively of the UV light and these levels were not sufficient to affect the visual behaviour of insects. In the tomato crops, fewer plants were infected by Tomato Yellow Leaf Curl Virus (TYLCV) under UV-absorbing films. This was primarily associated with the reduction in numbers of vector *B. tabaci*. Virus infection was either reduced or delayed under the UV-absorbing films and in all cases the plants grew more vigorously and had a higher yield. Experiments and observations suggest that the reduction in virus infestation was greater under the larger tunnels where the proportion of filtered light is greater. Once inside UV-absorbing greenhouses whiteflies were able to fly (Costa & Robb, 1999) but spread more slowly through the crop (Antignus, pers. comm.), which may slow the spread of virus diseases.

Thrips (*Frankliniella occidentalis, F. intonsa, Thrips palmi, Ssirtothrips dorsalis*)

A 10 fold reduction in the numbers of thrips was observed under UV-absorbing films on cucumbers, herbs and tomatoes (Table 2). UV-blocking meshes of different sizes (50-mesh, 30-mesh and 16-mesh) failed to reduce *F. occidentalis* (Western Flower Thrips, WFT) numbers. The holes in the netting were thought to be large enough to allow the thrips to see UV light through the net and to allow entry into the greenhouses. In some assessments there were more WFT under UV-absorbing nets. This was thought to be because there was less competition from the other pests in these houses (Antignus *et al.*, 1998). As above, the reduced numbers were thought to be due mainly to reduced invasion into the crops. Kuwai (1986) reported that dispersal of *T. palmi* was slower under UV-absorbing films. Three days after releasing 500 *T. palmi* in UV-absorbing greenhouses containing cucumbers, 91% remained on the release plant or on the two adjacent plants. In contrast only 37% were on the equivalent plants in the control greenhouse.

Aphids (*Aphis gossypii, Myzus persicae*)

UV-absorbing films may have a greater affect on aphid numbers than on other pest species. Delayed infestation and up to 100 fold reduction in numbers under UV-absorbing films and 50-mesh nets were observed on cucumber, tomato and sweet pepper (Table 3). UV-absorbing 30-mesh and 16-mesh netting did not reduce aphid numbers. Different aphid species may differ in their response to UV-blocking filters. For example, *M. persicae* may be affected more by UV-absorbing plastics than *A. gossypii*. However, this needs to be investigated further.

Leaf miners (*Liriomyza bryoniae, L. trifolii*)

Up to 10 fold reductions in leaf miner numbers were observed on tomato and mint grown under UV-absorbing films and 50-mesh nets (Table 3). Reduced invasion was cited as the main reason for these differences. Laboratory experiments indicated that the life cycle of *L. trifolii* was not affected by UV-absorbing plastics (Benyakir, per. comm.).

Mites (*Polyphagotarsonemus latus, Tetranychus telarius, Vasates lycopersici*)

Reports on the affects of UV-absorbing films on mites vary (Table 4). Spider mite (*T. telarius*) numbers may be reduced but not russett mites (*V. lycopersici*). Reports vary on the effects against broad mites (*P. latus*), but numbers of this species may have been influenced by whitefly numbers, which are known to spread broad mites.

Moths (*Laphigma* sp.)

Antignus *et al.* (1996) reported a reduction in the numbers of *Laphigma* sp. in walk in tunnels made of UV-absorbing plastic. It is likely that the number of day flying moths are reduced by UV-absorbing plastics but not night flying moths.

Other insect groups, such as leaf hoppers, may also be reduced by UV-absorbing filters. This applies particularly to invasive pests.

Table 1. The effect of UV-absorbing greenhouses on whiteflies (*Bemisia tabaci*)

Products *	Crop	x reduction in Nos. of whitefly under ‘UV’	% plants infected with TYLCV		plant height		Structures	Reference - Country
			‘UV’	Control	‘UV’	Control		
IR sunselector antivirus –Ginegar IR 504 - Polyon IR 604 - Polyon IR sunselector -Ginegar	Tomato	4-10 x No difference between products	< 50%	100%	>70% over 120 cm	<20% over 120 cm	24 walk–in tunnels, 6m x 6m x 2.7m,	Antignus *et al*, 1996 - Israel
IR sunselector antivirus (Ginegar) IR sunselector (control)	Tomato	2-3 x	1%	87%	-	-	2 walk-in tunnels, 6m x 18m x 2.7m	Antignus *et al*, 1996 - Israel
Bionet (Meteor) Control net Both at 50 mesh	Tomato	2-3 x	Delayed infection by 5 days under ‘UV’ but no difference in % infected.		More vigorous plants	-	2 walk-in tunnels, 6m x 18m x 2.7m	Antignus *et al*, 1996 - Israel
Bionet (Meteor) Control net Each at three sizes, 50 mesh, 30 mesh & 16 mesh	Tomato	50 mesh - 4 x 30 mesh – 0 x 16 mesh. – 0 x	50 mesh – 25%	50 mesh – 80%	50 mesh – 10% stunted	50 mesh – 60% stunted	36 walk-in tunnels 6m x 6m x 2.7m	Antignus *et al*, 1998 - Israel
Polyon 504 Polyon 303	Sage	10 x reduction in white fly numbers over a 10-week period. Insecticide applications were reduced from 3 in the control to 1 under ‘UV’. (TYLCV not applicable)					2 tunnels 10.5m x 55m	Antignus *et al*, 1997 - Israel

‘UV’ = UV-absorbing plastic

* Underlined products are UV-absorbing films, others are control films

Table 2. The effect of UV-absorbing greenhouses on Thrips species (*F. occidentalis, F. intonsa ,T. palmi, S. dorsalis*).

Product *	**Crop / pest**	**Results**	**Structures**	**Country**	**Reference**
Polythene ±'UV' P.V.C. ±'UV' Entrances covered in 50-mesh screen, ± 'UV'	Cucumber *F. occidentalis*	After 60 days: 'UV' PVC + 'UV' nets - 0.7 WFT/ flower 'UV' PVC + non-'UV' nets - 0.8 WFT/flower 'UV' polythene – 10 WFT/ flower non-'UV' polythene – 66 WFT/ flower	24 walk–in tunnels, 6m x 6m x 2.7m,	Israel	Antignus *et al*, 1996b
<u>Polyon 504</u> Polyon 303 Entrances covered with Aluminet 60%	Chives & Chervil *F. occidentalis*	During a 5 week crop, there were 10-90 WFT / trap / week in the control, and 0-10 WFT / trap / week under 'UV'. The numbers of insecticide applications reduced from 3 to 0 under 'UV'.	2 walk-in tunnels, 6m x 18m x 2.7m	Israel	Antignus *et al*, 1997
<u>Bionet</u> with or without 'UV' absorbing at sizes: 50, 30 & 16 mesh	Cucumber *F. occidentalis*	No significant reduction in WFT numbers in any of the treatments	36 walk-in tunnels 6m x 6m x 2.7m	Israel	Antignus *et al*, 1998
P.V.C. ± 'UV'	Cucumber *T. palmi*	Equal numbers of *T. palmi* were released in both greenhouses but there were 1.5 x more thrips in the control greenhouse after 33 days. Increased immigration was suggested as a possible cause.	2 walk-in tunnels 5.4m x 25m	Japan	Kuwai, 1986
'UV' down to 390 nm, Control film	Sweet pepper *F. intonsa*	There were 2 to 3 x fewer thrips under the 'UV'	2 greenhouses 19.8 m²	Japan	Nakagaki *et al.*, 1982
'UV' down to 390 nm, Control film	Tomato *F. intonsa* & *S. dorsalis*	There were 4 x fewer thrips under 'UV' and 6 x less damage.	4 greenhouses 19.8 m²	Japan	Nakagaki *et al.*, 1984

'UV' = UV-absorbing plastic   * Underlined products are UV-absorbing films, others are control films

Table 3. The effect of UV-absorbing greenhouses on aphids (*M. persicae, A. gossypii*) and leaf miners (*L. bryoniae, L. trifolii*)

Product *	**Crop / pest**	**Results**	**Structures**	**Reference - country**
Polythene ±’UV’ P.V.C. ±‘UV’	Cucumber *A. gossypii*	After 90 days there were 100 x more aphids on yellow sticky traps under non-‘UV’	24 walk–in tunnels 6m x 6m x 2.7m,	Antignus *et al*, 1996 - Israel
Bionet with or without ‘UV’ at 50, 30 & 16 mesh	Cucumber *A. gossypii*	At 50 mesh there were <10 aphids / leaf under the ‘UV’ and >150 per leaf under the control. There was no reduction in aphid numbers under 30-mesh ‘UV’ or 16-mesh ‘UV’ treatments.	36 walk-in tunnels 6m x 6m x 2.7m	Antignus *et al*, 1998 - Israel
‘UV’ blocked to 390 nm Non-UV control	*M.persicae* on sweet peppers *A. gossypii* on cucumbers	*M. persicae* was not observed under ‘UV’ for the 2 month trial but infested 1-10% of leaves in the control. *A. gossypii* invaded ‘UV’ 10 days later than the control and there were 100 times more aphids in the control.	4 greenhouses 19.8 m²	Nakagaki *et al.*, 1982 - Japan
Polyon 504 Polyon 303	Mint *L. trifolii*	Non-‘UV’ - 75-220 adults / trap / week. -3 insecticide treatments applied, crop unmarketable ‘UV’ - 10-45 adults / trap / week - No insecticides required	2 tunnels 10.5m x 55m	Antignus *et al*, 1997 - Israel
50 mesh netting ±‘UV’	Tomato *L. trifolii*	8 x less leaf miners under ‘UV’. >30% leaves infested under non-‘UV’ & 4% leaves infested under ‘UV’.	36 walk-in tunnels 6m x 6m x 2.7m	Antignus *et al*, 1998 - Israel
PVC +PSAC, Polysak PVC 300, Rav Hozeck	Tomato *L. trifolii*	After 50 days; ‘UV’ - 52% plants infested non ‘UV’ – 98% plants infested	12 walk–in tunnels 6m x 6m x 2.7m	Antignus *et al*, 1996 - Israel

‘UV’ = UV-absorbing plastic * Underlined products are UV-absorbing films, others are control films

Table 4. The effect of UV-absorbing greenhouses on mites (*P. latus*, *T. telarius*, *V. lycopersici*)

Product *	**Crop / pest**	**Results**	**Structures**	**Reference, Country**
50 mesh netting with or without ʻUVʼ	Tomato *Tetranychus telarius* *Vasates lycopersici*	10 x more *T. telarius* in conventional tunnels No significant difference in numbers of *V. lycopersici*	36 walk-in tunnels 6m x 6m x 2.7m	Antignus *et al*, 1998 - Israel
<u>PVC + PSAC, Polysak</u> PVC 300, Rav Hozeck	Tomato *Polytarsonemus latus*	A difference observed but not quantified	12 walk–in tunnels, 6m x 6m x 2.7m	Antignus, pers. comm., 2000 -Israel
<u>‘UV’ blocked to 390nm</u> Non-UV control	Sweet pepper *Polytarsonemus latus*	Mite numbers were monitored for a two month period and there was no significant difference in numbers.	2 greenhouses 19.8 m²	Nakagaki *et al.*, 1982 - Japan

ʻUVʼ = UV-absorbing plastic * Underlined products are UV-absorbing films, others are control films

The effects of UV-absorbing films on biological pest control

There is little published work on the effect of UV absorbing films on natural enemies. Kajita (1986) found that UV-absorbing films did not affect the performance of *Encarsia formosa* against glasshouse whitefly (*T. vaporariorum*) on tomatoes. Different densities of whitefly-infested tomato plants were placed in a UV-absorbing greenhouse and a standard vinyl greenhouse (each 4.5m x 5m). Three weeks after *E. formosa* were released in the centre of each greenhouse, there was no significant difference between the percentage parasitism or distribution of parasitoids between treatments. In both greenhouses, *E. formosa* parasitism was greater on plants with more whiteflies.

Although there is little published work, a number of experiments are in progress at the Began Experimental Station in Israel (Mr Yoel Messika, pers. comm.). These were visited in April 2000. The interim results can be summarised as follows:

- *Aphidius colemani* – The experiment was in UV-blocking and non UV-blocking tunnels (250 m^2), each containing 500 pepper plants replicated four times. Single pepper plants that had been infested with *Myzus persicae* were placed in the centre of each greenhouse. Fifty *A.colemani* were then released at each corner of the greenhouses and the time taken for the parasitoids to find the aphids and the percentage parasitism was recorded. *Aphidius colemani* was observed on the infested pepper plants in both treatments within 24 hours of release and there was approximately 60% parasitism after three weeks with no significant difference between treatments. It is possible that *Aphidius* spp. perform equally well in UV deficient and UV environments because they are more dependent on aphid olefactory cues than visual cues for host finding. Olefactory cues include honeydew (Budenberg & Powell, 1988) and plant volatiles (Duebal, 1998).

- *Eretmocerus mundus* - In the same greenhouses (above) cucumbers that had been infested with *B. tabaci* were placed in each of the four corners around the outsides of the pepper crops. *Eretmocerus mundus* were released in the centre of each greenhouse and initial observations indicated that host searching and parasitism was not affected by UV-absorbing plastics. This may be because odours emitted from whitefly-infested foliage are a key factor in host finding for *E. mundus* (Heinz & Parrella, 1998).

- *Orius majusculus* and *Phytoseiulus persimilis* – The establishment and population development of these predators, their ability to control pests were being monitored weekly in a UV-absorbing and a control greenhouse (10 m x 55 m). After three weeks no differences between the treatments were observed.

Three commercial growers were visited in Israel who had UV-absorbing greenhouses and were using biological pest control. No adverse effects were observed on the use of *Aphidius, Orius* or *Aphidoletes.* A commercial biological control producer (Bio-bee) was also rearing parasitoids in UV-blocking greenhouses. This suggests that commercial biological control, where natural enemies are released inside greenhouses, is not adversely affected by the use of UV-blocking films. There is insufficient evidence to conclude that none of the natural enemies are affected and each natural enemy needs to be tested separately.

The effects of UV-absorbing films on pollination by bumblebees

UV wavelengths (320 nm -380 nm) are known to be vital for the orientation and foraging of bumblebees. Thus the absence of UV might negatively effect pollination and fruit set in crops. This was studied in a collaborative study in Israel (Steinberg *et al.*, 1997). The performance of the bumblebees was tested in a replicated greenhouse experiment (12 greenhouses of 75m²). It was found that the hive activity (number of bees flying in and out of the hives) was reduced in approximately 40% of the hives for four to nine days under UV absorbing films. Pollination declined and some of the bumblebee larvae in affected hives died of starvation as a result. After the first few days, hive activity and pollination was back to normal, but it was possible to loose pollination on a truss of tomatoes, which was not commercially acceptable. When hives were positioned so they were exposed to more sunlight (e.g. on a south facing greenhouse wall), the performance of the bumblebees improved. However, in Israeli conditions, where temperatures might reach 45°C during the day, this can kill the bumblebees.

As the above experiment was done in small greenhouses where there was a large proportion of non-diffused light, further studies were done by Bio-Bee in six commercial greenhouses (Steinberg, per. comm.). It was found that 1½ to 2 times more hives were required under UV-blocking films than under non UV-absorbing films, to achieve acceptable levels of pollination (90% of flowers pollinated within 24 hours).

The possible effects of UV absorbing films on chemical control

The near-UV component of sunlight is absorbed by many pesticides leading to photodegradation of some pesticides, such as abamectin and pyrethroids (Klier *et al.*, 1994). It is possible that UV-absorbing films may reduce photodegradation so altering the residual effect of some pesticides. This may impact on the efficacy of the pesticides, on resistance management and on the duration of any residual effect on natural enemies. This aspect has not yet been studied.

Effects of UV-absorbing films on IPM

The information above suggests that UV-absorbing films can significantly reduce pest numbers without adversely affecting biological pest control. Because more hives of bumblebees are required for pollination of tomato crops, there may be cost implications. However, this is not currently the case in Israel where pollination is priced on an area basis rather than on the numbers of hives sold. Overall, in Israel, the use of UV-absorbing plastic films has reduced the numbers of chemical insecticides required and made the use of biological pest control more feasible. Throughout the country, approximately 10% of vegetable growers use UV-absorbing plastics (Ginegar, pers. comm.). Uptake in spice crops is higher because the use of UV-absorbing films on commercial nurseries has reduced insecticide use by approximately 50% and a reduction in insecticide use is demanded by the export market (Antignus, per. comm). Israeli tomato growers reported a 20-25% reduction in insecticide use under UV-absorbing greenhouses. The savings were mostly in the winter when pest numbers were lower. UV-absorbing films cost approximately 10% more than normal films and the extra cost was recouped by saving a single spray treatment (The cost of chemicals is relatively high in Israel e.g. Vertimec = $200 / litre).

There are a number of reasons why it may not be possible to transfer this technology directly from Israel to the UK. In Israel, it is not possible to grow tomato crops outdoors because of the high number of whiteflies and the lack of effective insecticides to control the pest (Horowitz *et al.*, 1994). The high infection rates with TYLCV normally result in total loss of yield in tomatoes, lisianthus and beans, which are susceptible hosts of the virus. In the UK there are fewer invasive pests, therefore the benefits may be reduced.

Although UV-absorbing films show some promise, there may be some effects on plants that prevents their uptake in certain crops or crop stages. These may be exacerbated under UK conditions.

The effect of UV-absorbing films on plants and plant products

UV radiation increases the production of the red pigments such as anthocyanin and carotenoids in plants like nectarines, roses, cotinus and anygozanthus. High temperatures leads to their partial degradation but in low temperatures there is an accumulation of pigments in leaves/flowers and fruits. This “effect” can increase or decrease the commercial value of the final product. The following colour changes have been noted in Israeli crops:

- Delayed ripening in strawberry and aubergine.
- Colour changes in purple varieties of lisianthus.
- Colour changes in rose flowers.

Pepper and tomato crops have not been affected. Different ornamental species must be tested before UV-absorbing films can be recommended.

Etiolation – A plant propogator in Israel does not use UV-absorbing films because they cause etiolation in young seedlings. A similar effect has been observed in lettuce seedlings where the plants become etiolated, weak and fall over.

4.2 Other films

There is no information on the effects of other types of spectral filter that are being used on pest control.

5. METHODS OF USING SPECTRAL FILTERS

5.1 Polytunnels

The greatest potential use of spectrally-modified film for pest control is in polytunnels. A number of factors must be considered before deciding whether a specific film would be cost effective for specific cropping systems.

- Although spectral films protect crops against insects, they may reduce air ventilation and movement, and elevate temperatures. Expensive air circulation and cooling systems may be required. Israelis have compromised by using UV-absorbing plastic roofs and net sides. Nets provide some blocking effect while maintaining some airflow. If sides are opened to improve ventilation, unfiltered light is let in and the effects of spectral filters are reduced.

- UV-absorbing plastics cost at least 10% more than standard films, but the life of the films will vary according to their thickness and the light intensity. In Israeli light conditions, the spectral qualities of UV-absorbing filters may only last for one to two seasons (Steinburg, pers. comm.). Similar plastics now come with a four year guarantee when used under North European conditions. The stability of the films should be considered in any cost:benefit analysis.

- The size of the polytunnels affects the impact on insect numbers. Larger tunnels have a greater effect as they have a greater proportion of filtered light.

5.2 Soil mulches

Mulches with repelling and attracting qualities have been used.

Attraction
In warmer climates, yellow mulches protected cucumber and tomato crops from infection with the whitefly-borne viruses cucumber vein yellowing virus (CVYV) and TYLCV respectively (Cohen & Melamed-Madjar, 1978). It was suggested that *B. tabaci* were attracted to the yellow mulch in preference to the plants, where they died due to the reflected heat. Soil mulching with yellow polythene sheets delayed the spread of TYLCV by at least 20 days. Orange plastic mulches also delayed infection with the whitefly transmitted Tomato mottle virus and improved tomato yields compared to white or black mulches (Csizinski *et al.*, 1995).

Repellance
Aluminium foil reflects light in the UV B and near ultraviolet (395 nm) region (Csizinszky *et al.*, 1997). Aluminium foil mulches reduced insect-transmitted viruses and their vectors in a range of crops. These included thrips and Tomato Spotted Wilt Virus TSWV infection in pepper, tomato and tobacco (Greenough *et al.*, 1990) as well as aphids (especially *Myzus persicae*) and aphid transmitted viruses in watermelons (Adlerz and Everett, 1968), tomatoes and peppers (Kring & Schuster, 1992; Loebenstein *et al.*, 1975). Virus incidence was delayed by 5 days and 20 days in separate tests and virus incidence reduced from 45% to 5%. Aluminium repelled aphids more effectively when all, rather than half, the rows were mulched and the effect was reduced as soon as crop canopies covered the mulch surface.

Mulching with silver plastic also delayed infection and reduced the spread of TYLCV in tomato in Jordan, maintaining the incidence at a low level (20%) throughout the season when the incidence reached 97% in the non-mulched control (Suwwan *et al.*, 1988). In most cases, the differences in numbers of insects and virus-infected plants between treatments when using mulches were too small to be statistically significant when compared each week, but the cumulative values were significant. The use of mulches is therefore considered a useful component of an integrated control programme rather than an overall control.

It is likely that some of the new range of spectrally-modified films that have high reflectance may repel insects in a similar way to the aluminium films. This requires testing, and a cost benefit analysis done, to determine the best option. UV-absorbing films were tested in Israel in tomato crops but no significant reduction in whitefly numbers was observed (Antignus, pers. comm.).

5.3 Screened vents and doors

Highly reflective materials, such as aluminized fabric can be used to deter insects from entering entrances to greenhouses such as vents and doorways. McIntyre *et al.* (1996) applied aluminium around the entrances to green houses as a border trim, as solid aluminet, in a checkerboard or as strips of tape. All treatments reduced the numbers of WFT entering the greenhouses. Numbers of WFT increased by as much as 55%. The aluminium tape was the most successful in reducing thrips numbers and its effect improved, the closer the fabric was placed around the entrance.

5.4 Traps or baits

Yellow and blue sticky traps are used routinely in greenhouses around the world to monitor aphids, leaf miners, whiteflies and thrips. Larger traps have been successful in reducing pest numbers and virus disease in some crops. The use of 203 m long sticky polythene sheets placed around the outside of a field of seed potatoes reduced the incidence of potato leafroll virus (PLRV) by half (Zimmerman-Gries, 1979). However, this method has also seen some failures. No protection from TYLCV occurred when a tomato field was surrounded by a strip of yellow plastic (Cohen, 1982). These methods are most successful when used against insect species such as *M. persicae* that rely mainly on visual rather than olefactory cues (see section 3).

5.5 Internal screening

It is unlikely that spectral films would be effective as an internal overhead screen in glasshouses to reduce pest numbers as there would be too much unfiltered light.

6. ASSESSMENT OF UV-ABSORBING SCREENS

6.1 Polytunnels at HRI Kirton

Objective

To determine whether there were different pest and disease levels in the range of polytunnels at HRI Kirton (PC 168).

Methods

The tunnels were erected in 1999 at HRI Kirton as part of an HDC project to evaluate the production of cut flower crops under a range of plastic film covers (PC 168). The tunnels were single span French tunnel structures (Fordingbridge Ltd.) of approximately 20m x 4.5m. Plastic film was secured over the top of the tunnels by ropes and the tunnel ends were formed by tensioning the plastic sheet onto plastic anchors at the ends of the tunnels. During hot weather, the sides of the tunnels were lifted to improve ventilation.

Three one-metre beds were formed in each tunnel with irrigation pipes laid in each bed. The experimental design was a balanced row and column design with three replicates of each crop in each tunnel plot. Tunnels and plastic films were not replicated within the same experimental year. Four flower crops were grown in each structure, these were chrysanthemum (cv Westek Westpearl Cerise), spray carnation (cv Ellen), column stocks (cv Caesar) and Godetia (cv Grace).

Before monitoring began, the crops were sprayed with malathion on 10th July 2000 and pirimicarb + deltamethrin on 12th July 2000. Crops were monitored for the presence of pests from 25th July 2000 to 25th September 2000. The crops were fully grown when monitoring began and had started to flower.

The following tunnels with plastic films were used for monitoring pests:

- Visqueen Standard control (tunnel 1)
- XL Sterilite (tunnel 3)
- Lee Filters Steel Blue (tunnel 6)
- Visqueen Anti-Botrytis (tunnel 8)
- Visqueeen Luminance THB (tunnel 10)

The wavelength specfication of the films used are shown in Part 7.

Pests were monitored at two weekly intervals. On each assessment date, three shoots were selected at random from each plot (nine shoots of each crop per tunnel). On each shoot, the numbers of pests of each species were counted and the presence of pest damage recorded. One yellow sticky trap (25 cm x 20 cm) was placed near the centre of each tunnel approximately 15 cm above chrysanthemum flowers. The numbers of each pest species per trap were counted every two weeks and traps were replaced. After the first assessment, the godetia plots were not assessed further, as there were no pests on them.

Note: Monitoring of insect populations with yellow sticky traps was also done in a multi-span tunnel where each bay was clad in a different film. However, monitoring was stopped when the wind removed the film cladding. There were insufficient results to present.

In addition, the selected tunnels listed below were assessed for the presence of a range of diseases on 25 July 2000 and 19 September 2000.

- Control (No cover: Tunnel 2)
- UV1/EVA (Control: Tunnel 1)
- XL Sterilite (Tunnel 3)
- Visqueen Solatrol (Tunnel 4)
- Balanced PAR (Tunnel 5)
- Lee Filter Steel Blue (Tunnel 6)
- Visqueen Anti-Botrytis (Tunnel 8)
- Visqueen Luminance THB (Tunnel 10)
- XL Super Green (Tunnel 11)
- Politherm Anti-Condensation (Tunnel 13)
- XL Super Clear (Tunnel 14)

To assess the presence of downy mildew on stocks, 10 random plants were assessed per plot and scored for the level of symptom expression on a scale of 0-3:

0	No downy mildew sporulation present
1	Yellowing of the lower leaves with a low levels of sporulation on the under sides of the leaves (<5% of leaf area)
2	Yellowing of leaves with moderate levels of sporulation on the undersides of the leaves developing up the plant (between 5-20% of leaf area)
3	Yellowing of leaves with high levels of sporulation on the undersides of the leaves over the whole plant (>20%)

To assess the presence of Sclerotinia on stocks, the total number of plants displaying aerial lesions were counted per plot.

Results

Pest Numbers

Pest numbers were low throughout the monitoring period and there were insufficient numbers to compare statistically (Tables 5 and 6). The numbers of pests on the different crops were combined.

Table 5. Average numbers of pests on 27 shoots per assessment in different tunnel types.

Tunnel	Aphids	Leaf miners	Thrips	Caterpillars
Control	201	2.5	5.3	3.0
XL Sterilite	0	1.2	8.6	1.8
Visqueen AB	0	1.8	11.8	1.2
Luminance	0.4	2.6	1.6	1.8
Steel Blue	2.4	6.6	1.8	2.4

Table 6. Average numbers of pests caught on sticky traps per assessment in different tunnel types.

Tunnel	Aphids	Leaf miners	Thrips	Caterpillars
Control	0	0.3	11.3	4
XL Sterilite	0	0	6.5	0
Visqueen AB	0	0	7.5	0.5
Luminance	0	0	12.5	1.8
Steel Blue	0	0	19.8	1.5

The following pest species were identified on the different crops:

Stocks – *Plutella xylostella*
Chrysanthemum – *Thrips tabaci, Aphis gossypii, Phytomyza* sp.
Carnation – *Thrips tabaci, Autographa gamma*

Disease incidence

The presence of a number of diseases was noted on the assessment dates and their incidence recorded. On the first recording date (25th July 2000) there were differences in the levels of infection of downy mildew (*Peronospora destructor*) on the stocks (Table 7, Fig. 1). Analysis of variance indicates a high level of significance between the different film treatments. The levels of downy mildew recorded under the Standard Control tunnel compared with plants growing without cover were significantly higher. This is likely to be due to the increased humidity that would provide conditions more conducive to infection and sporulation. Two spectral films, Visqueen Solatrol and the experimental Lee Filter Steel B, significantly reduced the level of downy mildew when compared to the other plastic films. Reductions in levels of downy mildew were noted with some of the other film types (Balanced PAR, XL Super Green and XL Super Clear) although they were not significant.

Sclerotinia (*Sclerotinina sclerotiorum*) infection on aerial plant tissues was also noted with resulting stem dieback and collapse of the flower heads of the stocks. Only low levels of infection symptoms were recorded except under the Balanced PAR film where there was a marked increase in infection levels from the other film types.

Levels of Botrytis infection were low on the first disease assessment and there were no other diseases observed on the other plant types at this assessment. On the second assessment (19th September 2000) the plant material was in poorer health making assessments of disease more difficult. As one of the objectives of the project PC 168 was to monitor cut flower quality, only part of the plants remained for further disease assessments. Downy mildew (*P.*

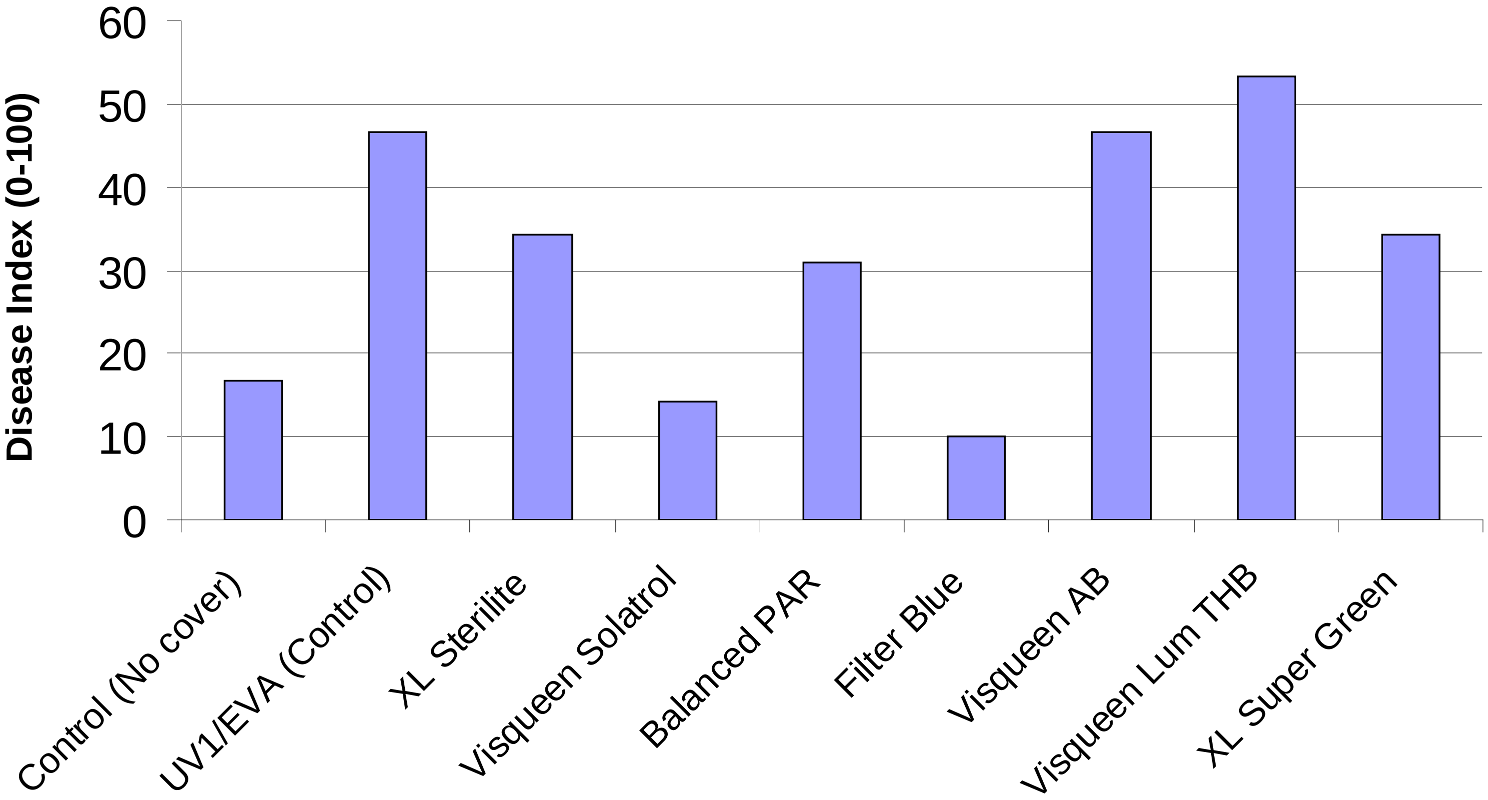
destructor) was sporulating on the stocks although assessment proved difficult due to necrosis of the lower stem foliage. Infection by the pathogen *Botrytis cinerea* was observed but at low incidence on the plants, with no obvious differences in levels of disease recorded between the spectral film types.

Table 7. Disease incidence recorded on Stocks (*Matthiola* cv Caesar) under different spectral filters at HRI Kirton on 25 July 2000

Treatment **(plastic type)**	Downy mildew infection [Disease Index (0-100)]*	Sclerotinia infection[1] [No of plants per plot]
Control (No cover)	16.7	0.0
Control (UV1/EVA)	46.7	2.0
XL Sterilite	54.3	0.3
Visqueen Solatrol	14.3	0.3
Balanced PAR	31.0	6.7
Lee Filter Steel Blue	10.0	0.0
Visqueen AB	46.7	0.0
Visqueen Luminance	53.3	0.0
XL Super Green	34.3	0.3
Anti-condensation	44.3	0
XL Super Clear	36.7	0
Significance	***	-
SED (22 df)	8.396	-

[1] Statistical analysis was not carried out on data on the number of plant infected with Sclerotinia.

* Disease Index for downy mildew infection; 0 = no infection, good quality; 100 = severe infection, plants dead or of very poor quality.



Note: Disease index for downy mildew infection
0 = no infection, good quality; 100 = severe infection, plants dead or of very poor quality

Discussion

The work was not set up as a proper statistically designed experiment but merely as a monitoring exercise to ascertain any major discernible differences in pest invasion for several different spectral filters under semi-commercial conditions. Unfortunately, overall pest levels were low. However, it could be determined that crops under the UV-absorbing films (XL Sterilite and Visqueen AB) had fewer aphids, leaf miners, leaf hoppers and caterpillars than the control tunnel. Thrips numbers were lower on the trap but not on the plants. The greatest differences were in aphid numbers, which parallels observations in tunnel grown crops in Israel. The results warrant further investigation.

Although only a few pathogens were monitored at HRI Kirton, significant differences in levels of downy mildew (*P. destructor*) were recorded between spectral film types in 2000. The results recorded on stocks confirm previous studies carried out in Israel (Reuveni & Raviv, 1997) where the use of plastics with blue pigments were shown to reduce the colonisation and sporangial production of downy mildew infection of cucumbers. In addition, other small scale studies in the UK have identified the potential of a number of spectral films to control downy mildew (*P. parasitica*) on Brassica transplants (Mowat, 2000). Downy mildew diseases require blocking of UV-B wavelengths (280-320nm) to inhibit sporulation, and hence blue filters controlled disease levels in the stocks. The film Visqueen Solatrol significantly alters the ratio of red to Far red light received, which may improve plant quality. This in turn could have lead to a reduction in infection and sporulation of downy mildew on the stocks.

There was no obvious difference between levels of *Botrytis cinerea* under different films during this period. Previous research in the UK has found that blocking out UV-A wavelengths (320-400nm) has led to significant reductions in development of Botrytis (West et al., 2000). However, during this work infector plants were used to introduce a number of strains of *B. cinerea* to the crop. The spectral films XL Sterilite and Visqueen AB both have claimed activity to reducing sporulation of Botrytis by blocking out UV-A light up to 400nm. The low levels of Botryis infection within the crops could be the reason for no difference between the spectral films under test. Research work conducted in other countries has shown marked reductions in sporulation of *Botrytis cinerea* under similar filters (Elad, 1997; Reuveni et al., 1989) although there is little data under commercial growing conditions on Botrytis control with UV filters.

These initial results obtained under the experimental blue film are encouraging emphasising that such filters under UK light conditions might lead to significant reductions in disease levels and thus further investigation is warranted. Pathogens of particular interest include Botrytis cinerea, Powdery and downy mildews, Sclerotinia and leaf spotting pathogens.

6.2 Cloches at HRI Stockbridge House

Objective

To determine whether a UV-absorbing film (Visqueen AB) can reduce pest numbers under cloches.

Methods

Six cloches (1.75 m x 1.4 m) were placed in a randomised complete block at a 2 m spacing at HRI-Stockbridge House. Half the cloches were covered in Visqueen AB (anti-botrytis) film, which blocks 99% of UV light to 350 nm. The controls were covered in standard horticultural film which blocks 10% of UV light. The cloches were fully enclosed in the films except for a six cm gap along the bottom edge at each end, to allow air exchange and insect entry. This gap was covered in netting (mesh size: max 0.6 x 0.6) which prevented the plants from being fully exposed to the outside but allowed insect entry. On 19th July, 18 lettuce plants (cv. Loretta, at the 5 leaf stage) and 18 flowering Viola plants (cv Wiittrockiana), were planted in grow bags under each cloche. On 24th August, all the viola plants were replaced with geranium plants, as the viola (all treatments) were infected with black root rot, *Thielaviopsis basicola*, and were dying. One grow bag containing six lettuce plants and six viola plants was placed beside each cloche. These plants were infested with aphids, whiteflies and leaf miners to ensure that pests were in the vicinity of the cloches. On each assessment date, nine lettuce plants and nine viola plants per cloche were examined and the numbers of each insect species counted. Assessments were made twice a week for the first 2 weeks, then weekly, for up to seven weeks after planting.

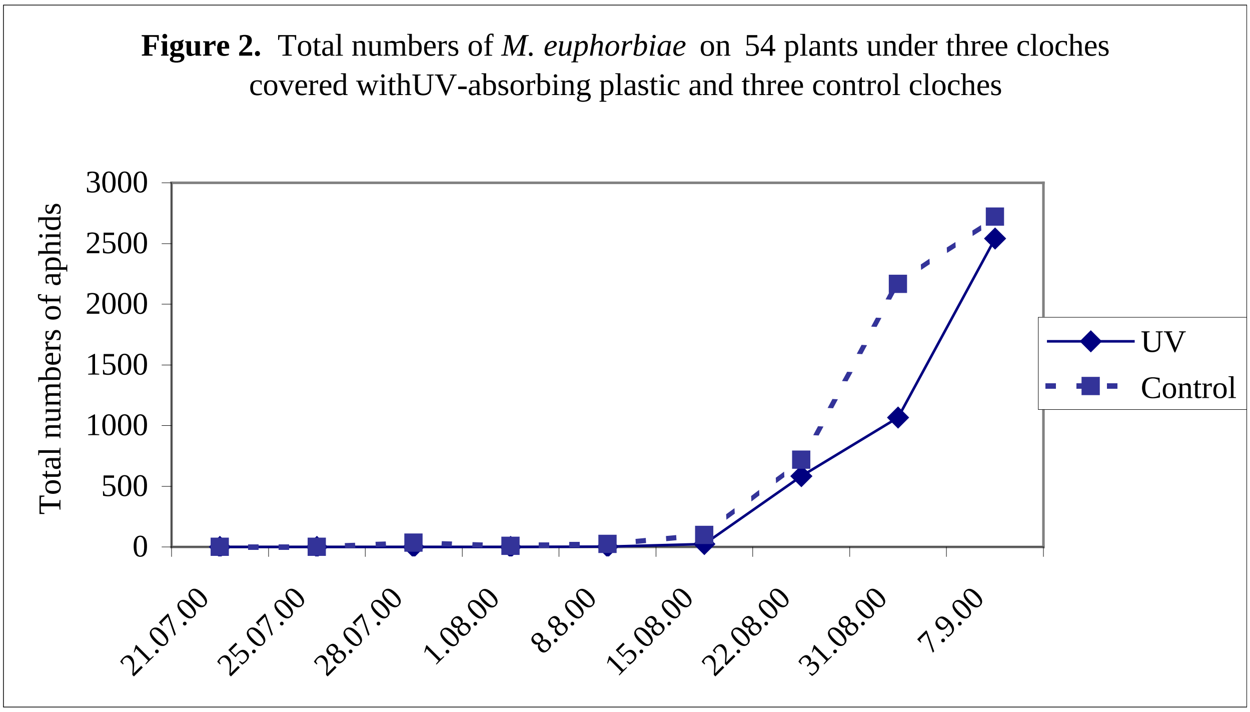
Results

Macrosiphum euphorbiae accounted for over 95% of all pests recorded. The first *M. euphorbiae* were observed under the UV-blocking cloches about two weeks later than under the control cloches (Table 8). However, once *M. euphorbiae* had invaded, numbers built up rapidly under both types of cloche and there was no significant difference between the numbers of aphids between treatments by the end of the experiment (Figure 2).

Table 8. Total numbers of *M. euphorbiae* recorded under each cloche, up to four weeks from the start of the experiment.

	Assessment date					
Treatment - Cloche No.	**21.07**	**25.07**	**28.07**	**01.08**	**08.08**	**15.08**
UV 1	0	0	0	0	3	18
UV 2	0	0	0	0	0	0
UV 3	0	0	0	0	0	5
Control 1	0	1	0	1	0	78
Control 2	0	0	35	7	25	16
Control 3	0	0	0	0	0	4

Figure 2. Mean numbers of *M. euphorbiae* under UV-absorbing and control films throughout the experiment.



A number of other pest and beneficial species invaded the UV-blocking and control cloches in small numbers (Table 9).

Table 9. Total numbers of insects of different species under UV-absorbing and control cloches.

Species	UV-blocking	Control
Thrips, tabaci	0	14
Lettuce root aphid	0	5 *
Trialeurodes vaporariorum	10	7
Sciarid flies	0	3
Macrolophus caliginosus	4	12
Aphidius colemani	5	23

* = numbers of plants infested by lettuce root aphid

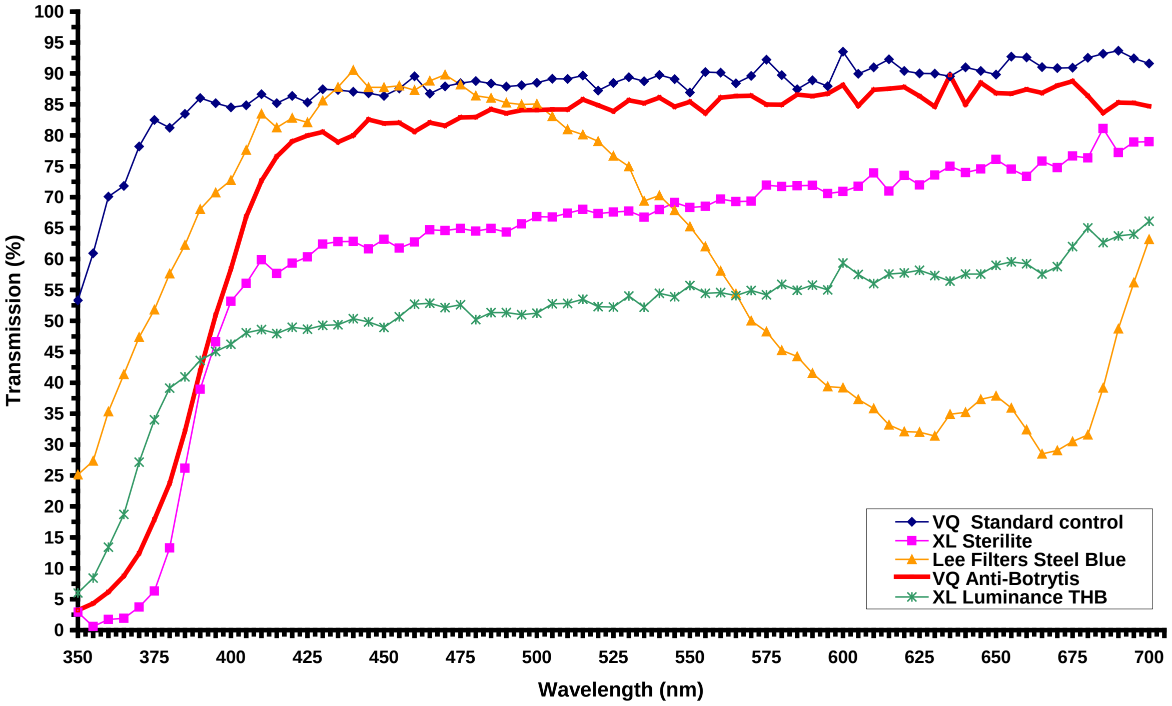
Discussion

Macrosiphum euphorbiae invaded the UV-blocking cloches later than the control cloches, but then built up to similar numbers. Delayed invasion may help pest management in some situations. It is likely that pest numbers would have been lower under the UV-absorbing film if the cloches had been larger, as there would have been a greater proportion of unfiltered light. There were three pest species which were found under control cloches that were not found under the UV-absorbing film. In conclusion, there is enough evidence to suggest that UV-absorbing films would help to reduce pests under UK conditions and further work is recommended.

7. DIFFERENT WAVELENGTHS OF PLASTICS ON THE MARKET

The transmission of light wavelengths between 350 and 700 nm (the insect visible spectrum) was measured using a Bentham Dual-Beam spectrophotometer. The spectral filters used during the monitoring trials in Section 6, i.e. Visqueen Standard control, XL Sterilite, Lee Filters Steel Blue, Visqueen Anti-Botrytis and Visqueen Luminance THB, are shown in Figure 3.

Figure 3. Transmission data for spectral filters used for observations in Section 6.



Results and Discussion

The major differences between the spectral films used to undertake the preliminary monitoring of pests and disease incidence in cut flower crops reported in section 6 were the amount of UV light transmitted and the transmission of longer wavelengths. Transmission of light for Lee Filters Steel Blue film peaks in the blue region of the spectrum, c. 450 nm and is depressed at longer visible wavelengths in the red region, 600-675 nm. The data also confirm the very much reduced UV transmission by XL Sterilite and Visqueen Anti-Botrytis films. UV transmission was also slightly reduced for XL Luminance and Steel Blue compared to the Visqueen control.

8. RECOMMENDATIONS FOR USING SPECTRAL FILMS

8.1 CROPPING SYSTEMS

There is insufficient evidence to recommend unequivocally spectral filters as a cost-effective method of reducing pest numbers under UK conditions and further work is required. However, the monitoring results indicate there may be a benefit in terms of delayed pest invasion and reduced pest numbers (especially of aphids).

The following crop: pest combinations have been identified as most likely to benefit from the technology in the UK:

- Aphids on lettuce, nursery stock and cut flowers
- Leafhoppers on herbs and primroses
- Leaf miners on a range of crops

8.2 PRIORITIES FOR FUTURE RESEARCH

The top priority is to investigate the potential use of UV-absorbing films for pest control under UK conditions. Investigations should:

- Identify the mode of action.
- Determine the pest control effect for key pest species.
- Determine the effect on bumblebee pollination.
- Confirm that there are no adverse effects on biological pest control.
- Test whether there are adverse effects on a range of target crops.
- A cost:benefit analysis should determine the overall benefits. Costs should include any modifications that are needed to improve ventilation in the polytunnels.

It is also important to determine whether the full range of filters (e.g. high reflectance and red-blocking filters) on the market and in development have an affect on pest control. Specifically:

- To study the effects of different spectral filters on the flight and feeding behaviour of important pest and beneficial species of protected crops.
- To study the effects of specific spectral filters on the biology of the above species.
- Determine the effects of selected films on the incidence and build up of pests.
- Provide recommendations for growers on how to use spectral films as part of an integrated pest and disease management system and whether existing pest and disease programmes need to be modified.

Further work may include:

- Identify the proportions of invasive pest (e.g. *Frankliniella occidentalis*) in different cropping systems in order to determine which crops would benefit most from UV-absorbing films.
- To determine the effect of different spectral films of specified wavelengths on the trapping efficacy of yellow and blue sticky traps for the target pest species.

- Study the effects of different application methods on pest control (e.g. greenhouse design, critical timing of covers for moveable screens, use as cloches etc).

9. REFERENCES

Adlerz, W.C. and Everett, P.H. (1968). Aluminium foil and white polyethylene mulches to repel aphids and control watermelon mosaic. *Journal of economic entomology*. 61 (3) 1276-1279.

Affeldt, H.A., Thimijan, R.W., Smith, F.F. and Webb, R.E. (1983). Response of the Greenhouse Whitefly (Homoptera: Aleyrodidae) and the Vegetable Leafminer (Diptera: Agromyzidae) to Photospectra. *Journal of Economic Entomology*, 76: 1405-1409.

Antignus, Y., Mor, N., Ben Joseph, R., Lapidot, M. and Cohen, S. (1996a). Ultraviolet-absorbing plastic sheets protect crops from insect pests and from virus diseases vectored by insects. *Environmental Entomology*, 25(5): 919-924.

Antignus, Y., Cohen, S., Mor, N., Masika, Y. and Lapidot, M. (1996b). The effects of U.V-blocking greenhouse covers on insects and insect-borne virus diseases. *Plasticulture*. No 112: 15-20.

Antignus, Y., Mor, N., Masika, Y., Lapidot, M., and Cohen, S. (1997). The use of UV-absorbing plastic sheets against insects and spread of virus diseases. *CIPA International Congress*, 23-33.

Antignus, Y., Lapidot, M., Hadar, D., Messika, Y. and Cohen, S. (1998). Ultraviolet absorbing screens serve as optical barriers to protect crops from virus and insect pests. *Journal of Economic Entomolgy*. 91 (6): 1401-1405.

Battaglia, D., Poppy, G., Powell, W., Romano, A., Tranfaglia, A. and Pennachio, F. (2000). Physical and chemical cues influencing the oviposition behaviour of *Aphidus ervi*. Ent exp. appl. 94, 219-227.

Cartier, J.J. and Auclair, J.L. (1964). Pea aphid behaviour, colour preference on a chemical diet. Can. Ent. 96, 1240-1243.

Castilla, N. and Jarret, P. (1995). Protected cultivation in the Mediterranean area. *Plasticulture* 107, 13-20.

Cohen, S., (1982). Control of whitefly vectors af viruses by colour mulches. In Harris, K.F., Maramorosch, K. (Eds.), Pathogen, Vectors, and Plant Diseases, Approaches to Control. *Academic Press*, New York, pp 45-56.

Cohen, S. and Melamed-Madjar, V. (1978). Prevention by soil mulching of the spread of tomato yellow leaf curl virus transmitted by *Bemisia tabaci* (Gennadius) (Hemiptera: Alyrodidae) in Israel. *Bulletin of Entomological Research.* 68, 465-470.

Coombe, P.E., (1981). Visual behaviour of the whitefly *Trialurodes vaporarium* (Westwood) (Homoptera: Aleyrodidae). J. comp. Phsyiol. 144, 83-90.

Costa, H.S. and Robb, K.L. (1999). Effects of Ultraviolet-absorbing greenhouse plastic films on flight behavior of *Bemisia argentifolii* (Homoptera: Aleyrodidae) and *Frankliniella occidentalis* (Thysanoptera: Thripidae). *Journal of Economic Entomology*, 92(3): 557-562.

Costello, M.J. (1994). Spectral reflectance from a broccoli crop with vegetation or soil as background: influence on immigration by Brevicoryne brassicae and Myzus persicae. *Entomologia Experimentalis et Applicata*, 75: 109- 118.

Csizinski, A.A., Schuster, D.J. and Kring, J.B. (1995) Colour mulches influence yield and insect pest populations in tomaotes. *Journal of American Soc. Horticultural Science*. 120, 778-784.

Csizinski, A.A., Schuster, D.J. and Polston, J.E. (1997). Influence of color and reflective mulches on Tomato (*Lycopersicon esculentum* Mill.) yields and on the silverleaf whitefly (*Bemisia argentifolii* (Bellows and Perring). *CIPA international congress March*. 111-117.

De Barro, P.J. (1991). Attractiveness of four colours of traps to cereal aphids (Hemiptera: aphididae) in South Australia, *J. Aust. ent. soc.* 30, 263-264.

Degen, T. and Städler, E. (1996). Influence of natural leaf shape on oviposition in three phytophagous flies: a comparative study. *Entomologia Experimentalis et Applicata*, 80, 97-100.

Degen, T. and Städler, E., (1997). Foliar form, colour and surface characteristics influence oviposition behaviour of the carrot fly. *Entomologia Experimentalis et Applicata*, 83, 99-112.

Dubal. (1998).

Elad, Y. (1997). Effect of filtration of solar light on the production of conidia by field isolates of *Botrytis cinerea* and on several diseases of greenhouse-grown vegetables. *Crop Protection*. 16(7): 635-642.

Finch, S. and Collier, R.H. (2000). Host-plant selection by insects – a theory based on appropriate/inappropriate landings by pest insects of cruciferous plants. *Ent. exp appl*. 96, 91-102.

Goldsmith, T. (1994). Ultraviolet receptors and colour vision: evolutionary implications and a dissonance of paradigms. Vision Res. 34, 1479-1487.

Greenough, D.R., Black, L.L. and Bond, W.P. (1990). Aluminium-surfaced mulch: An approach to the control of tomato spotted wilt virus on solanaceous crops. *Plant Diseases*. 74: 805-808.

Hardie, J. (1993). Flight behaviour in migrating insects. *J. agric. Ent.* 10, 239-245.

Hardie, J. (1989). Spectral specificity for targeted flight in the black bean aphid, *Aphis fabae*. *J. Insect Physiology*, 35, 619-626.

Hatcher, P.E. and Paul, N.D. (1994). The effect of elevated UV-B radiation on herbivory of pea by *Autographa gamma*. *Entomol. exp. appl.*, 71: 227-233.

Heinz, K.M. and Parrella, M.P. (1998). Host location and utilization by selected parasitoids of *Bemisia argentifolii* (Homoptera: Aleyrodidae): implications for augmentative biological control.

Horowitz, R., Forer, G.and Ishaaya, I. (1994). Managing resistance in *B. tabaci* in Israel with emphasis on cotton. *Pesticides Science*. 42: 113-122.

Jansen, M.P.T. and Stamp, N.E. (1997). Effects of light availability on host plant chemistry and the consequences for behavior and growth of an insect herbivore. *Entomologia Experimentalis et Applicata*, 82: 319-333.

Kajita, H. (1986) Parasitism of the greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood) (Homoptera: Aleyrodidae) by *Encarsia formosa* Gahan (Hymenoptera: Aphelinidae) in a greenhouse covered with near-ultraviolet absorbing vinyl film. *Proc. Association Plant Protection Kyushu* 32, 155-157.

Kennedy, J. S., Booth, C.O. and Kershaw, W.J.S. (1961). Host finding by aphids in the field III. visual attraction. *Ann. Appl, Biol* 49, 1-21.

Kleier, D.A., Hewitt, H.G., Caseley, J., Copping, L.G. (ed), Grayson, B.T. (ed) and Tyson, D. (1994). Environmental effects on the photodegradation of pesticides. *BCPC Monograph No 59* on comparing glasshouse and field pesticide performance., 97-109.

Kring, J.B. (1964). New ways to repel aphids. Front. *Plant Sci*. 17, 6-7.

Kring, J.B. (1972). Flight behaviour of aphids. *Ann. Rev. Ent.* 17, 461-492.

Kring, J.B. and Schuster, D.J. (1992). Management of insects on pepper and tomato with UV-reflective mulches. *Florida Entomologist*, 75(1): 119-129.

Kuwai, A. (1986). Studies on the population ecology of *Thrips palmi*. Comparison of the adult movement in the plastic greenhouse depending on the covering materials. *Proceedings of the association for plant protection of Kyusha.* 32, 163-165.

Lavola, A., Julkunen-Tiitto, R., Roininen, H. and Aphalo, P. (1998). Host-plant preference of an insect herbivore mediated by UV-B and CO_2 in relation to plant secondary metabolites. *Biochemical Systematics and Ecology* 26: 1-12.

Loebenstein, G., Alper, M., Levy, S., Palevitch, D.and Menagem, E. (1975). Protecting peppers from aphid-bourne viruses with aluminium foil or plastic mulch.. *Phytoparasitica* 3(1): 43-53.

Lunau, K. (1992). A new interpretation of flower guide colouration: absorption of ultraviolet light enhances colour saturation. *Plant Systematics and Evolution*, 183: 51-65.

Marco, S. (1986). Incidence of aphid transmitted virus infections reduced by whitewash sprays on plants. *Phytopathology* 76, 1344-1348.

Matteson, N., Terry, I., Ascoli-Christiansen, A. and Gilbert, C. (1992). Spectral efficiency of the western flower thrips, *Frankliniella occidantalis*. *J. Insect Physiol.* 38, 453-459.

MacDowall, F.D.H. (1972). Phototactic action spectrum for whitefly and the question of colour vision. *Can. Ent.* 104, 299-307.

McIntyre, J.A., Hopper, D.A. and Cranshaw, W.S., (1996). Aluminized fabric deters thrips from entering greenhouses. *Southwestern Entomologist*, June, Vol. 21 No. 2: 135-140.

Mellor, H.E., Bellingham, J. and Anderson, M. (1997). Spectral efficiency of the glasshouse whitefly *Trialeurodes vaporarium* and *Encarsia formosa* its hymenopteran parasitoid. Ent. exp. appl. 83, 11-20.

Michaud, J.P. and Mackauer, M. (1994). The use of visual cues in host evaluation by aphidiid wasps. *I.* Comparison between three Aphidius parasitoids of the pea aphid. *Entomol. exp. appl.*, 70: 273-283.

Moericke, V. (1950). Uber das Farbsehen der Pfirsichblattlaus (*Myzodes persicae* Sulz.). *Z. fur Tier*, 7, 265-274.

Moericke, V. (1952). Farben als Landereize für geflügelte Blattlaüse (Aphidoidea). Z. Naturf. 7, 304-309.

Moericke, V. (1955). Uber die Lebensgewohnheiten der grflugelten Blattlaüse (Aphidina) unter besonderer Berucksichtigung des Verhaltens beim Landen. Z. Ang. Ent. 27, 29-91.

Moericke, V. (1969). Hostplant specific colour behaviour by *Hyalopterus pruni* (Aphididae). *Ent. exp. appl.* 12, 524-534.

Mowat, H. (2000). Investigating the control of downy mildew in organic brassica transplants by manipulating spectral quality of light. Undergraduate Thesis, University College Worcester/Pershore College, May 2000, 42pp.

Nakagaki, S., Sekiguchi, K. and Onuma, K. (1982). The growth of vegetable crops and establishment of insect and mite pests in a plastic greenhouse treated to exclude near UV radiation-establishment of insect and mite pests. *Bulletin of Ibaraki Ken horticultural experimental station*. 10, 39-47.

Nakagaki, S., Amagai, H. and Onuma, K. (1984). The growth of vegetable crops and establishment of insect and mite pests in a plastic greenhouse treated to exclude near UV radiation-establishment of insect pests on tomatoes. *Bulletin of Ibaraki Ken horticultural experimental station*. 12, 89-94.

Pelletier, Y. (1990). the role of colour of the substratum on the initiating of the probing behaviour in *Myzus persicae* (Sulzer) and *Macrosiphon euphorbiae* (Thomas) (Homoptera: Aphididae). *J. Can. Zool* 68, 694-698.

Prokopy, R.J. and Owens, E.D. (1983). Visual detection of plants by herbivorous insects. *Ann. Rev. Ent.* 28, 337-364.

Rautapaa, J. (1980). Light reactions of cereal aphids (Homptera, Aphididae). *Ann. Ent. fenn*. 46, 1-12.

Reuveni, R. and Raviv, M. (1997). Control of downy mildew in greenhouse-grown cucumbers using blue photoselective polyethylene sheets. *Plant Disease*. 81: 999-1021.

Reuveni, R., Raviv, M. and Bar, R. (1989). Sporulation of *Botrytis cinerea* as affected by photoselective polyethylene sheets and filters. *Annals of Applied Biology*. 115: 417-424.

Scholze, P. (1993). Das Körperwachstum bei Blattläusen (Homoptera, Aphididae) als Ausdruck des Nährstoffangebots in der Wirtspflanze: III. Untersuchungen an Blattsscheiben von *Vicia faba* L. *Beitr. Ent*., 43(1): 141-147.

Shibao, M. (1996). Effects of a vinyl film cover on the population density of the Chillie Thrips, *Scirtothrips dorsalis* Hood (Thysanoptera: Thripidae), on grape. *Appl. Entomol. Zool*. 31(1): 174-177.

Smith, F.F., and Webb, R.E. (1969). Repelling aphids by reflective surface a new approach to the control of insect transmitted viruses. In: Maramorosch, K. (Ed) Viruses, Vectors and Vegetation. *Interscience publishers, New York,* pp 631-639.

Steinberg, S., Prag, H., Gouldman, D., Antignus, Y., Pressman, E., Asenheim, D., Moreno, Y. and Shnitzer, M. (1997). The effect of ultraviolet-absorbing plastic sheets on pollination of greenhouse tomatoes by bumblebees. *In CIPA proceedings, International Congress for plastics in agriculture.*

Suwwan, M.A., Akkawi, M., Al-Musa, A.M. and Mansour, A. (1988). Tomato performance and the incidence of tomato yellow leaf curl (TYLC) virus as affected by type of mulch. *Sci. Hortic*. 37, 39-45.

Turlings, T.C.J., Loughrin, J.H. and McCall, P.J. (1995). How caterpillar-damaged plants protect themselves by attracting parasitic wasps. *Proc. Natl. Acad. Sci. USA* 92, 4169-4174.

Vaishampayan, S.M., Kogan, M., Waldbauer, G.P., and Wooley, J.T. (1975). Spectral specirfic responses in the visual behaviour of the greenhouse whitefly, *Trialeurodes vaporarium* (Homoptera: Aleyrodidae). *Exp. Ent. Appl.* 18, 344-356.

West, J.S., Pearson, S., Hadley, P., Wheldon, A.E., Davis, F.J., Gilbert, A., and Henbest, R.G.C. (2000). Spectral filters for the control of *Botrytis cinerea*. *Annals of Applied Biology*. 136, 115-120.

Wiktelius, S. (1981). Diurnal flight periodicities and temperature thresholds for flight for different migrant forms of *Rhopalosiphum padi L. (*Hom.Aphididae) *S. Angew. Ent.* 93, 449-457

Zdarek, J. and Pospisil, J. (1962). On the visual orientation of *Aphis fabae* Scop. To coloured lights. *Acta ent. Bohemslov* 63, 17-24.

Zimmerman-Gries, S. (1979). Reducing the spread of potato leaf roll virus and potato virus Y in seed potatoes by trapping aphids on sticky yellow polythene sheets. *Potato Research*. 22, 123-131.

Appendix 1 – Wavelength of different light spectra

Spectra	**Wavelength**
Ultra violet - C	100-280 nm
Ultra violet - B	280-320 nm
Ultra violet - A	320-380 nm
Blue	400-455 nm
Green	515-550 nm
Yellow	550-590 nm
Red	660 nm
Infrared	780-2500 nm
Thermal	> 2500nm