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GROWER SUMMARY

Headline

- Growing cut-flowers under tunnels covered with clear polythene film protects flowers from weather and eases cropping.
- Standard clear polythene films showed a stability of light transmission over a four-year test period.
- More expensive specialist films should be used only where there are clearly demonstrated benefits.

Background and expected deliverables

The UK cut-flower market is currently very strong, but is supplied by growing imports while at the same time there is declining UK production. The production of cut-flowers under glass in the UK is expensive, compared with production abroad. However, an economical alternative to glasshouse production is using low-cost polythene tunnels, as already adopted by soft-fruit growers. Polythene tunnels offer the possibility of cheaper cut-flower production compared with using glasshouses, ensuring fresher produce compared with imported goods and improvements in quality and seasonal availability compared with production in the field. This is clearly an opportunity for the home production of suitable species such as the range of seed-raised, summer annuals that enjoy considerable popularity. Polythene tunnel design has been improved considerably by manufacturers.

A further development has been the introduction of specialist polythene films. While standard, clear polythene films provide crops with physical protection from the effects of weather, more specialised films could offer growers a number of potentially useful properties, such as:

- Thermal barriers (blocking incoming infra-red (IR) radiation to give lower summer growing temperatures)
- Light diffusion films (improving the distribution of photosynthetically active radiation (PAR) so that light penetrates better into the crop canopy);
- Anti-condensation films (reducing problems due to condensation and humidity);
- Disease control films (the control of pathogens is possible by changing the balance of ultra-violet (UV) wavelengths)
- Growth control films (altering the ratio of red to far-red light (R:FR) to make crops taller or shorter).

There has been little or no assessment of these specialist films from the viewpoint of cut-flower growers.

The expected deliverables from this project include:

- Assessment of the physical properties of several films and of the quality of cut-flower obtained using them. The project has provided useful information on the physical properties and extent of degradation of the films over four years. This information will help inform growers on the characteristics of different films, putting them in a better position to interpret sales literature. It will also show the most suitable films for growing cut-flower crops generally.
- Data on the performance of four very different crops - spray chrysanthemums, godetia, column stock and spray carnations – under various types of polythene film will be provided.
- This information should lead directly to more cost-effective purchases of polythene films for tunnels.

Of course, such a project cannot include the testing of all available films, nor can it cover all relevant crops. Also, new and improved films are coming onto the market place. Further development work may, therefore, be needed as polythene film technology develops.

Summary of the project and main conclusions

Scope

Tunnels were set up and covered with the following films:

- Standard clear films: Visqueen Clear and XL SuperClear;
- Light diffusing film: White (reduced PAR);
- Thermal barrier film: Luminance THB;
- Condensation reducing film: Politherm AF;
- UV films: Anti-*Botrytis* and SteriLite;
- Growth control films: Solatrol (high R:FR), and Steel Blue, SuperBlue and SuperGreen (low R:FR).

In addition, other tunnels were covered with Luminance THB film for the early and (or) late part of the growing season only. The following crops were grown in each tunnel in 1999 and 2000: spray chrysanthemum (*Chrysanthemum morifolium*) cv ‘Ellen’, spray carnation (*Dianthus caryophyllus*) cv ‘Westek Westpearl Cerise’, column stock (*Matthiola incana*) cv ‘Operetta’, and godetia (*Godetia amoena*) cv ‘Grace’. For comparison, these crops were also grown in equivalent non-covered plots.

Film properties

Summary of film characteristics

All films, including the standard clear films, affected (generally raised) temperatures, reduced the levels of PAR and blocked some UV light. Table A summarises the main properties of the specialist films observed during this project.

Table A. Summary of the properties of specialist films

Film type	*Film*	*Air temp.*	*Soil temp.*	*Plant temp.*	*R:FR*	*PAR*	*UV*	*IR*
UV	SteriLite			Lower		Lower (year 2)	Blocks UV	
UV	Anti-*Botrytis*		Cooler than outside				Blocks UV (all wave-lengths)	
IR	Luminance THB	Cooler than outside		Higher		Lower	Low	Low
R:FR	Solatrol			Lower	High	Lower (year 2)	Blocks UV	
R:FR	Steel Blue			Higher	Low	Lower	Blocks UV	
R:FR	SuperBlue				Low	Lower (year 2)	Blocks UV	
R:FR	SuperGreen	Cooler than outside	Day temperatures like outside	Lower	Low	Lower	Blocks UV	
AC	Politherm AF			Higher			Low	
LD	White (reduced PAR)			Higher	Slightly reduced	Lower	Blocks UV	

- *Spectral characteristics of films.* UV wavelengths were blocked by all films at around 320nm, while the two specific UV films (Solatrol and Anti-*Botrytis*) and the standard film Visqueen Clear (but not SuperClear) blocked UV over a wider range of wavelengths. The Anti-*Botrytis* film blocked all UV wavelengths, with a very sharp cut off at 400nm. There was effective blocking of red light by the SuperGreen film and of far-red light by Solatrol film. The Luminance THB film blocked some 50% of IR radiation, with some blocking in the upper end of the PAR region.
- *Air temperatures* in the canopy were generally increased under a polythene film. However, SuperGreen and Luminance THB films gave air temperatures consistently 2-3°C cooler than in the open. Other specialist and standard films generally resulted in temperatures that were 1-2°C warmer than outside.
- *Soil temperatures* in tunnels covered with the standard film Visqueen Clear and SteriLite film were about 2°C higher than in the open. Anti-*Botrytis* and SuperGreen films gave soil temperatures about 1°C cooler than outside plots. Luminance THB and Politherm AF films resulted in soil temperatures similar to those of outside plots.

- *Plant temperatures* (assessed by monitoring chrysanthemum leaves) were lower under SteriLite and Solatrol films and higher under Luminance THB, Steel Blue and Politherm AF films, compared with standard clear films.
- *The red : far red ratio* was altered by several films. The far red-reducing Solatrol film measured in 1999 gave a R:FR of 1.2, lower than expected and indicating that some degradation of properties had occurred in what was then an experimental film; with a new supply of Solatrol film in 2000, a ratio of about 2.0 was expected and was confirmed. The R:FR of 0.4-0.5 under the blue films and of 0.7-0.8 with SuperGreen film demonstrated reduced levels of red light compared with far-red. The White diffusing (reduced PAR) film slightly lowered R:FR, to 1.0.
- *The transmission of PAR* measured in 1999 was 77-89% for most films, but was lower for Luminance THB, Steel Blue, SuperGreen and White diffusing (reduced PAR) films (50-61%). As a result of deterioration of the films, this percentage had fallen for most films by the next year, although transmission through Politherm AF and Steel Blue films remained more or less stable. This loss of transmission was greatest for SteriLite, Solatrol and SuperBlue films (54-57%). All films can be expected to reduce PAR, and, in general, a 1% loss in transmission will result in a 1% loss of dry weight production.
- *UV transmission.* SuperClear film transmitted 66% of UVA, and Visqueen Clear 47%. All other films considerably reduced the proportion of UVA radiation entering the tunnel, with SteriLite, Solatrol and Steel Blue films cutting out virtually all UV. Anti-*Botrytis* UV film was less effective in blocking UV wavelengths than SteriLite, the other UV film tested. Most films reduced UVB somewhat more than UVA.
- *The deterioration of film properties* was measured over a four-year period of normal exposure. The transmission spectra of two standard clear films (XL SuperClear and Visqueen Clear) showed only a small, gradual loss of transmission over this period, but their initial UV-blocking was lost after one year. An anti-condensation film, Politherm AC, maintained its transmission properties over four years, apart from partly losing its UV-blocking property after two years. Of two UV-blocking films tested, one (Anti-*Botrytis* film) lost this property gradually over four years, while the other (SteriLite film) maintained its UV-blocking. A red light blocking film, Solatrol, partly lost this property after two years of use. Two far-red light blocking films, SuperBlue and SuperGreen, maintained this blocking over four years, while another filter (Lee Filters Steel Blue, not designed for horticultural use, but useful experimentally) lost its red-blocking property by the third year of use and at this stage had also degenerated physically. Two other films, an experimental white diffusing film and an IR-blocking film (Luminance THB), lost much of their transmission after one year's use, and the former was not considered suitable for testing after three years.

Responses of crops

Spray chrysanthemum

- There was a large year-to-year difference: in 1999 sprays were longer and heavier than in 2000.
- All films increased spray length compared with non-covered controls, and significantly so in the case of SuperClear, Anti-*Botrytis*, Steel Blue, SuperGreen, Politherm AF and White diffusing (reduced PAR) films. Since, however, none of the specialist films increased or decreased spray length significantly from that found under the standard clear films, no effects due to changes in R:FR were evident.
- Only growing under Solatrol film produced a significant effect on spray weight, sprays being lighter under this film compared with controls. Only SuperGreen film had a significant effect on the number of flowers per spray, with fewer flowers than in controls. No distinctive property of either Solatrol or SuperGreen film that might result in this weaker growth could be determined.
- Compared with controls or using an all-season cover, no significant effects of using a part-season Luminance THB cover were seen, except that an early-season cover resulted in lower flower numbers.

Godetia

- There were large year-to-year effects on all the variables recorded. In 1999 stems were shorter, heavier, produced more flowers and branches, and had fewer leaves per stem, compared with 2000.
- The films used significantly affected plant length and weight. Only the two standard clear films (Visqueen Clear and SuperClear) and SteriLite and Solatrol films increased plant length, compared with non-covered controls. Anti-*Botrytis*, SuperBlue, SuperGreen, Politherm AF and Luminance THB films all decreased plant length compared with both two standard clear films. Some of these effects on plant length were contrary to expectations: Solatrol film would be expected to produce shorter stems, and SuperBlue and SuperGreen films longer stems.
- Plant weight was significantly reduced, compared with non-covered controls, by Anti-*Botrytis*, Steel Blue and White diffusing (reduced PAR) films.
- Therefore, as found for chrysanthemum, the varied properties of these groups of films did not indicate a common mechanism responsible for stem shortening, nor an effect due to the varying R:FR ratio.
- Overall, the films used did not have significant effects on the numbers of flowers per stem, stems per plant, or leaves per stem. However, White diffusing (reduced PAR) film significantly reduced the number of flowers, compared with the controls, while SuperGreen film increased leaf numbers.
- Using a part-season Luminance THB cover increased plant weight, compared with an all-season treatment.

Column stocks

- There were large year-to-year effects on all the variables recorded except the number of stems per plant. In 1999 stems were shorter and heavier, with more flowers and fewer leaves, compared with 2000.

- Several films (Anti-*Botrytis*, Steel Blue, SuperBlue, SuperGreen, Politherm AF and Luminance THB) significantly increased stem length compared with non-covered controls.
- Several films (the two standard clear films and Steel Blue, SuperBlue, SuperGreen and White diffusing (reduced PAR) films) significantly decreased stem weight, compared with non-covered controls.
- None of the films significantly changed stem length or weight compared with the two standard clear films.
- There were no significant effects of films on the numbers of flowers per plant, stems per plant, or leaves per stem.
- Using a part-season Luminance THB cover (either early- or late-season) increased stem weight, compared with an all-season treatment.

Spray carnations

- There were significant year-to-year effects on spray length, but not on spray weight or number of flowers. Sprays were shorter in 1999 than in 2000, as found for the two previous species.
- There were no significant effects of film on the variables measured.
- Using an early-season Luminance THB cover increased spray length, compared with an all-season treatment.

Pest and disease levels

Pests and diseases were monitored as part of a separate project (PC 170). There was a suggestion of lower pest levels, especially aphids, under the UV-absorbing films (SteriLite and Anti-*Botrytis*). There were significant differences in the incidence of downy mildew (*Peronospora destructor*) infections on stocks under different films: disease incidence was low in non-covered control plots and under Solatrol and Steel Blue films, and higher under all other films. There were no clear differences in the incidence of other pests and diseases under different films.

Conclusions

- At least for the four cut-flower species used in this project, the current results suggest that a standard clear polythene film would be a good, if conservative, choice for covering tunnels. Such films are relatively cheap, provide adequate protection from weather, transmit a high proportion (80-90%) of incident PAR, and in the first year blocked a significant proportion of incident UV radiation. Visqueen Clear film was effective in blocking a wide range of UV wavelengths.
- The chief disadvantage of standard clear films is the heat gain in the tunnels, which demands good ventilation in warm weather. Of the specialist films used in this project, the effects of Luminance THB, Anti-*Botrytis* and SuperGreen films were effective in reducing soil and air temperatures to those outside the tunnels. Luminance THB film blocks a high proportion of IR wavelengths. Luminance THB and Anti-*Botrytis* films also exhibit reasonable transmission of PAR (about 60 and 80%, respectively, compared with 50% for SuperGreen film), and all three films exhibited good UV-blocking (10-30% transmission). Where a UV-blocking film is needed, Anti-*Botrytis* film blocks UV across a wide range of wavelengths. Spectral filter films blocking particular red, far-red wavelengths maintained this property for four years in two cases, and for two years in two other cases. Two

films, a diffusing film and an IR-blocking film, showed a large loss of transmission after one year's use.
- Only where there is a demonstrated advantage to manipulating the R:FR ratio, reducing soil temperatures, altering the UV input (e.g., to reduce pest and disease incidence), etc., is known, should the use of more expensive specialist films be considered. In particular crops, some of these effects may be very important.
- This project was carried out using small 'French tunnels', but the findings should be equally applicable to large, multi-span 'Spanish tunnels'. While polythene tunnels are relatively cheap, compared with glasshouses, they do present a number of problems compared with growing in the open, which must be taken into account. There are significant costs of irrigating, weeding and ventilating, and the labour involved in generally checking and maintaining the structures should not be underestimated. The tunnel environment can be uneven, for example due to excess water alongside gutters or tunnel sides, or wind from raised tunnel sides. Finally, the overall strength of the structure needs to be considered, in relation to the overall exposure of the site and any provision of natural or artificial windbreaks.

Financial benefits

Up to now, little independent, comparative information has been available on the properties and performance of the range of horticultural polythene films used for covering tunnels, nor on the performance of cut-flower crops under these films.

Films
The project demonstrated that, unless there are clear reasons for choosing a specialist film, standard clear films are adequate for protecting cut-flower crops, and may last for up to four years. Using a standard film should enable growers to save money when buying films: as a rough guide, specialist films may be 5 – 20% more expensive than basic clear films.

Crops
The project demonstrated the value of growing cut-flower species in polythene tunnels, with protection from adverse weather and cropping that can be carried out seven days a week regardless of weather. This will lead to the advantages of more consistent crop quality and continuity of supply, so even if there is no direct price advantage, contracts should be easier to negotiate. As polythene technology advances, advantages from spectral filtering and other effects will also become more readily available. Cut-flower growing under polythene tunnels is a useful opportunity for UK producers.

Action points for growers

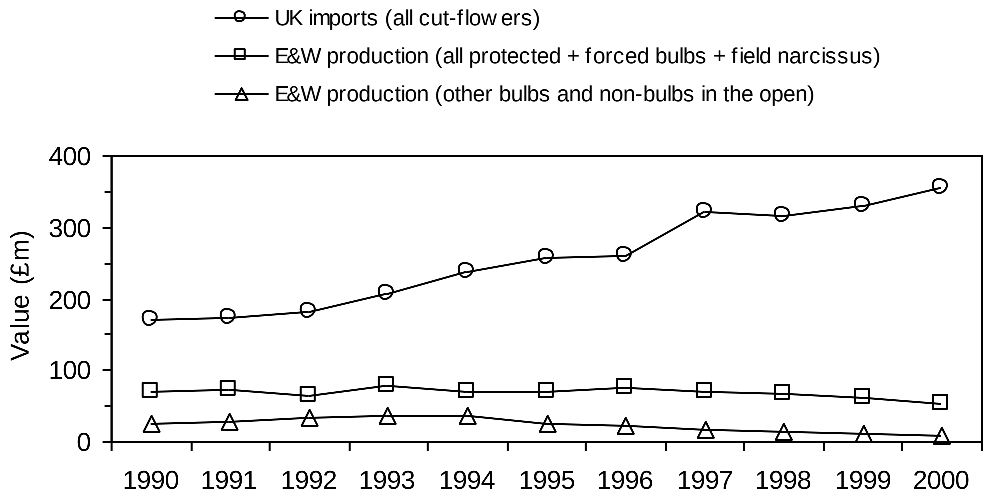
It is important for growers to understand what various polythene films do and what they cannot do, and how long they last, if they are to achieve cost-effective, high-quality production. Then, the responses of their crops need to be understood – to temperature, humidity, light (amount and quality), etc., so that the requirements of crops can be matched to the properties of films. Many text books are available that describe the growing and physiology of floral crops, but regrettably, at present, practical information for UK growers is not necessarily drawn together in a convenient form, and for many specialist or novel crops little information is available. Until specific needs for specialist films are better understood, it is likely that the emphasis will be on using tough, durable, clear films. In any case and regardless of special properties, such 'basic' films provide the advantages of protection from adverse weather, seasonal extension and 24/7 cropping.

SCIENCE SECTION

INTRODUCTION

The UK cut-flower market is currently very strong. This continuing growth is driven by demand from the supermarkets, so quality and reliability of supply are essential. However, there is strong import growth and a decline in UK production. Figure 1 illustrates the stark divergence between the two. While UK production cannot substitute for all the imported crop, there is clearly an opportunity for home production of suitable species.

Figure 1. Changes in the value of UK imports and production of cut-flowers between 1990 and 2000 (Source: DEFRA Basic Horticultural Statistics for the United Kingdom, Calendar and Crop Years 1990/91 – 2000/01; figures for 2000 provisional).



This expanding cut-flower market therefore presents opportunities for UK growers who can produce blooms of high quality on schedule. As an economical alternative to glasshouses, French (single-span) and Spanish (multi-span) tunnels, already adopted by the soft fruit sector, offer the possibility of improvements in quality and season extension for cut-flower growers. There are obvious benefits for crop protection and environmental modification, but little, if any, development work has been conducted on their use for cut-flower crops. Tunnels could be used either as shelters for the whole growing season, or as temporary covers at specific periods for seasonal extension.

Standard, clear polythene films provide crops with physical protection (from wind, hail, rain, etc.) and allow the possibility of seasonal extension (by protecting crops from cold and frost, allowing earlier planting or later production). These 'basic' films such as Visqueen Clear film, are composed of polyethylene with added UV inhibitors and vinyl acetate, the latter increasing film strength in cold conditions. Many of the more specialised films are UVI/EVA films modified by the inclusion of other additives, while some of the newer films may use novel materials or additives.

Specialist films may offer growers a number of properties:

- *Thermal barrier*
  Temperatures in plastic structures can be lowered by reducing the entry of infrared (IR) radiation (wavelengths above 700nm), giving cooler growing temperatures in summer (e.g., 'Luminance THB' film).
- *Light diffusion*
  Diffusing films improve the distribution of photosynthetically active light (PAR; 400-700nm), giving better penetration of light into the crop canopy (e.g., 'White (reduced PAR)' film).
- *Condensation reduction*
  Anti-condensation films reduce problems due to condensation and humidity (e.g., 'Politherm AF' film).
- *Disease control*
  The control of pathogens is possible by changing the ultraviolet (UV) light balance between UVA (320-400nm) and UVB (300-320nm) wavelengths. The films tested were 'Visqueen Anti-*Botrytis*' and 'XL SteriLite'.
- *Growth control*
  Taller or shorter stems can be obtained by changes in the ratio of red (670nm) to far-red (730nm) light (R:FR). The films tested were 'Solatrol' (high R:FR), and 'Steel Blue', 'SuperBlue' and 'SuperGreen' (low R:FR). The proportion of blue light also affects plant height in some species.

The properties summarised above may be present singly in a plastic film, or may be provided in some combination. A range of films is commercially available, and it is important to determine how their properties might be exploited in practical growing. The physical properties of different films examined in this project were:

- Spectral properties (effects on R:FR, IR, UV and PAR levels in the tunnels)
- Effects on other environmental factors - air, soil and plant temperature
- Stability of the plastics over time (photo-degradation).

The effects of different films on plant growth will be due to (possibly complex) combinations of all these properties. Novel plastic films also offer scope for the reduced use of pesticides and plant growth regulators. In this project the qualities of four contrasting cut-flower species – spray chrysanthemums, spray carnations, column stocks and godetia - were determined growing under each film. They were also grown in tunnels covered with a standard film for the early and (or) late parts of the season only. Pest and disease levels were assessed as part of a separate project (PC 170, see summary in Appendix D).

If successful, the project would strengthen the case for using polythene tunnels for cut-flower production. The building of new glass (at approximately £30/m^2) is not likely to be an economic proposition for many cut-flower crops, when competing with better overseas climates. However, the use of temporary plastic structures, with costs less than £2/m^2, may offer the UK grower the opportunity to compete to the required standard.

MATERIALS AND METHODS

Tunnels and films

The work was carried out at HRI Kirton, Lincolnshire, the field soil being a medium silty marine alluvium. The site was deep-ploughed, harrowed and sterilised before use. Sterilisation was by an experimental reduced-rate treatment of metam-sodium (as Metam Sodium 400, 650 litre/ha, incorporated to 35cm) and dazomet (as Basamid, 200 kg/ha, incorporated to 12cm), which was applied by a contractor (Sands Agricultural Services Ltd.). Following soil sampling and analysis in spring 1999, the land was fertilised as required (75kg N per ha applied as Nitrapril, 34.5% N) and cultivated.

Fourteen single-span polythene tunnels ('French' tunnels; Fordingbridge Ltd.) were erected in a north-south orientation for maximum uniformity of light. The tunnels were 20m long, 4.5m wide and 10m high, except for those used with four experimental films, which were only 10m long. The 20m-tunnels consisted of 11 hoops, 2m apart, mounted on 22 flighted ground anchors. Diagonal braces were bolted between the end pairs of hoops. Plastic film was secured over the top of the tunnels by 4mm-diameter three-strand rope passed over the plastic and around the ground anchors. Tunnel ends were formed by tensioning the plastic sheet onto anchors at the ends of the tunnels. Details of the film covers used on each tunnel are given in Table 1. In addition to the tunnels, there was an equivalent area among the tunnels that was used as a non-protected (outside) control. Three, 1m-wide beds were formed in each tunnel or non-covered area, with pathways 0.3m wide between. Plots 4m long (2.5m long in small tunnels) were marked in along the beds. Two low-level irrigation lines (T-tape) were lain along each bed.

The tunnels were ventilated by raising the polythene along the tunnel sides between 08:00 and 18:00 hours. Only the western side was raised until 12:00 hours (to allow maximum spectral filtering through the polythene on the eastern side), and then the eastern side was raised in its place.

Unlike the other films, the Steel Blue film (produced as a theatrical, rather than a horticultural, filter) was brittle and easily damaged *in situ*, so from 29 August 1999 onwards it was held in place by covering it with a layer of SuperClear film. After the first growing season (in November 1999) the plastic films were removed and stored in a cool, dark shed for re-use in 2000, when they were replaced as before. However, the Solatrol film showed signs of physical deterioration and was replaced with a new sheet for 2000.

The ‘treatments’ provided in the tunnels were in two groups (see Table 1):

- *Evaluation of flower crop production grown under a range of plastic film covers*
  Crops were planted in 11 tunnels covered with the range of plastic films, further ‘control’ plots being planted in an equivalent, non-covered area.
- *Evaluation of crop covers for season extension*
  Crops were also planted in tunnels covered with Luminance THB film for:
  - The start of the season (until the end of July)
  - The end of the season (from the beginning of September)
  - The start and end of the season (uncovered in August)

Table 1. Treatments and films used			
Tunnel no.	*Film type*[1]	*Film description*	*Film supplier*
Group 1			
2	-	No cover (outside control)	-
14	Std	SuperClear	XL Horticulture
1	Std	Visqueen Clear	Visqueen
8	UV	Anti-*Botrytis*	Visqueen
3	UV	SteriLite	XL Horticulture
4[2]	R:FR	Solatrol (experimental growth control film, low far red, height suppressing film)	Reading University & Visqueen
6a[2]	R:FR	Steel Blue (blue theatrical film ref. 117, low red, height extension film)	Lee Filters
6b[2]	R:FR	SuperBlue (blue experimental growth control film, low red, height extension film)	XL Horticulture
11	R:FR	SuperGreen (green film, low red, height extension film)	XL Horticulture
13	AC	Politherm AF (anti-condensation)	Visqueen
5[2]	LD	White (reduced PAR) (experimental growth control film)	Reading University & Visqueen
10	IR	Luminance THB (pale white)	Visqueen
Group 2			
12	IR	Luminance THB (early cover only)	Visqueen
9	IR	Luminance THB (late cover only)	Visqueen
7	IR	Luminance THB (early and late cover only)	Visqueen

[1]Film types: Std, standard high transmission film; UV and IR, ultra-violet and infra-red absorbing; R:FR, growth modifying; AC, anti-condensation; LD, light diffusing. Film colour was clear unless stated otherwise. Films were obtained in 1999 (the Solatrol film was replaced in 2000), and specifications may have changed subsequently.
[2]10m-long tunnels

Determining the properties and deterioration of films

Light measurements were made during mid-August under clear skies, between 12:00 and 14:00 hours. In each tunnel, five readings were taken at canopy height at standard positions in the middle of each bed, avoiding shadows from the tunnel structure, averaging the 15 readings. Before and after taking these readings, 'control' readings were made in full sun outside the tunnels.

UVA and UVB measurements were made using a 'SpectroSense' meter. Mean values inside and outside the tunnels were used to calculate the percentage of UVA entering the tunnels. Red and far red light were measured using a 'Skye' meter at 660 and 730nm, respectively, hence calculating the red:far red ratio. Photosynthetically active radiation (PAR) was measured using a 'Skye' quantum sensor at midday during periods of clear skies. The mean values inside and outside the tunnels were used to calculate the percentage of PAR entering the tunnel. In each tunnel, the temperatures of 15 chrysanthemum leaves (in 1999) or buds (in 2000) were recorded in full sun 15cm below the canopy top at the same times, using a 'Calex' infra-red thermometer.

Air and soil temperatures were recorded and logged by sensors in all tunnels, and the temperatures presented are the average reading of two sensors positioned centrally in the middle of three beds. Air temperature was measured at canopy height, and soil temperature at 10-15cm depth equidistant between irrigation tapes.

General meteorological data for the site were taken from the Kirton met station, *ca*. 100m from the trial site, and some key weather variables are summarised in Appendix Table C1.

The spectral properties and stability of the films were determined. Initially, and at about monthly intervals during summer and autumn in 1999 and 2000, pieces (*ca*. A4-size) of each plastic film were removed from the tunnels and analysed by spectroradiometry. At the conclusion of the field experiments in 2000, pieces of film (*ca*. 1m x 1m) were taken from each tunnel and stored in a cool, dark shed. In April 2000 the film pieces were fixed on wooden frames and placed in the field at an angle of 45° until September 2000, taking samples for spectrometry at about monthly intervals. Storage and sampling were repeated in 2001 and 2002.

Film samples were wiped clean after collecting, but it was impractical to ensure removal of all surface deposits, while some scuffing of films during handling and use was unavoidable. Each year's samples were placed individually in manilla envelopes and stored away from light at room temperature until about October, when they were despatched for transmission spectra to be obtained.

Initially, spectrometry over the range 300-1200nm was carried out by Mr. S. Carter (Department of Horticulture, Reading University). Due to staffing changes, after 1999 this work was instead carried out by Prof. J. Hardie (Department of Biology, Imperial College at Silwood Park). In this case spectrometry was carried out over the range 300-750nm. Although in the Results section the spectra are collated onto single graphs for each film, it should be noted that, strictly speaking, since different instrumentation was used in 1999 and in the subsequent years, the 1999 spectra are not strictly comparable with the others. Results are generally presented over the range 350-700nm, the most responsive range of the Imperial College instrumentation; in some other cases the 1999 spectra shown covered a wider range.

Care should be exercised in interpreting some of the measurements reported here. For example, it has been pointed out that measurements of light intensity are difficult to make accurately inside structures with diffusing covers: some instruments may underestimate light levels compared with direct measurements made on the covers using instruments such as spectroradiometers. Unavoidably, different spectroradiometers were used in 1999 and 2000, and it appears the device used in 2000 may have been more affected by the diffusing nature of films than the one used in 1999. 'Spot' measurements inside structures can always be affected by minor local variations, but measurements were replicated as described above in order to reduce this variation.

Determining plant responses

Four flower crops were chosen for the project:

- *Chrysanthemum morifolium* (spray chrysanthemum) cv Ellen (mid-season (September) flowering). Chrysanthemums are a widely grown crop offering a useful reference point for growers and scientists.
- *Dianthus caryophyllus* (spray carnation) cv 'Westek Westpearl Cerise'. Spray carnations are another crop that is well understood by growers and scientists. Summer production in the UK may offer a good opportunity to fill a window where imported produce falls in quality.
- *Matthiola incana* (column stock) cv 'Operetta'. Stocks were chosen to test the strategy of plastic as an alternative to glasshouse production, because of the commercial popularity of stocks and its problem with high temperature ‘clubbing’ of the flower spike.
- *Godetia amoena* (godetia) F1 cv 'Grace'. Godetia was included as a ‘novel’ crop that has been highlighted as having strong market potential as a cut-flower.

The chrysanthemums and spray carnations were obtained as rooted cuttings from Frank Rowe Ltd. Seeds of stock and godetia were obtained from Vegmo and Hamer Seeds, respectively, raised in cellular trays and transplanted. Following the usual practice, stocks were selected for double-flowered plants as young plants prior to transplanting, by placing the trays at 10°C for two days and keeping only those with light green leaves. Planting densities and planting or transplanting dates for 1999 and 2000 are given in Table 2. The 1999 planting of carnations was over-wintered and used again in 2000. The chrysanthemum plants were ‘pinched’ at the appropriate stage.

Table 2. Planting distances and dates

	Planting distance	*Planting date*	
		1999	*2000*
Spray chrysanthemum	20 x 20 cm	2 June	5 June
Godetia	14 x 14 cm	9 June	12 June
Column stock	14 x 14 cm	16 June	31 May
Spray carnation	20 x 20 cm	22 June	(over-wintered)

There were three beds in each tunnel (or non-covered control area), along each of which plots of each of the four crops were arranged in a balanced row and column design. It was not practical to replicate tunnels (films), however replication between years constitutes an effective form of replication, since any measure of difference between tunnels (films) is judged against the year-to-year variation for the crop.

During growth, individual crops received a foliar feed (N:P:K 3:1:1) as required. Over-wintered carnations received a nitrogen top-dressing (50 kg/ha N) in spring. Crops were inspected for pests and diseases at intervals, and pesticides were applied as appropriate. Fungicides applied included myclobutanil (three treatments in July 1999) and iprodione (August 1999). Insecticides applied included deltamethrin (August 1999), pirimicarb (August 1999), malathion (July 2000), and pirimicarb +

deltamethrin (July 2000). All pesticides were applied according to label recommendations or specific off-label approvals current at the time.

Flower sprays (or whole plants, see below) were cropped from each tunnel when they reached the stage of development appropriate for the commercial marketing of each species. Plants at the edges of the plots were regarded as 'guards' and were not used when recording. At cropping the following records were made on each of 15 healthy, pest-free but otherwise randomly selected sprays or plants from each plot:

- Length and weight of main spray[1] (not godetia)
- Length and weight of whole plant for godetia (and chrysanthemums in 1999)
- Number of branches for godetia and stocks (and chrysanthemums in 1999)
- Number of leaves on main spray (stocks) or stem (godetia)
- Number of flowers[2] on the spray (or plant, in the case of godetia)[3]

No pest and disease monitoring was included in this project, but some observations were carried out under the associated HDC Project PC 170 (see Appendix D).

Where appropriate, data were subjected to the analysis of variance, both for the individual years and for the combined data for the two years (see page 22). Some data (particularly those for flower numbers) were transformed to square roots before analysis, but in no case did this alter the conclusions based on non-transformed data, and hence the non-transformed data are presented throughout this report.

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[1] The terms length and weight are used throughout to mean the total weight or length of the stem or spray, with its flowers

[2] Flower counts include all flowers, whether open or in bud

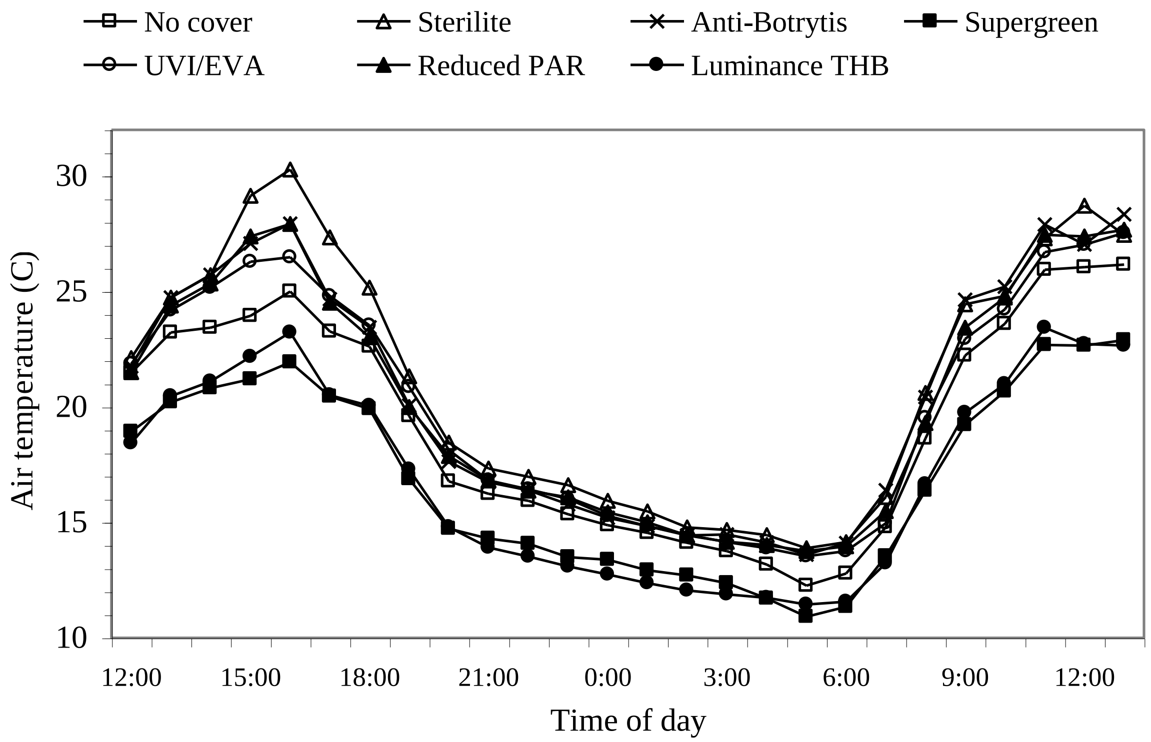
RESULTS

Properties of films

Air temperature in the canopy

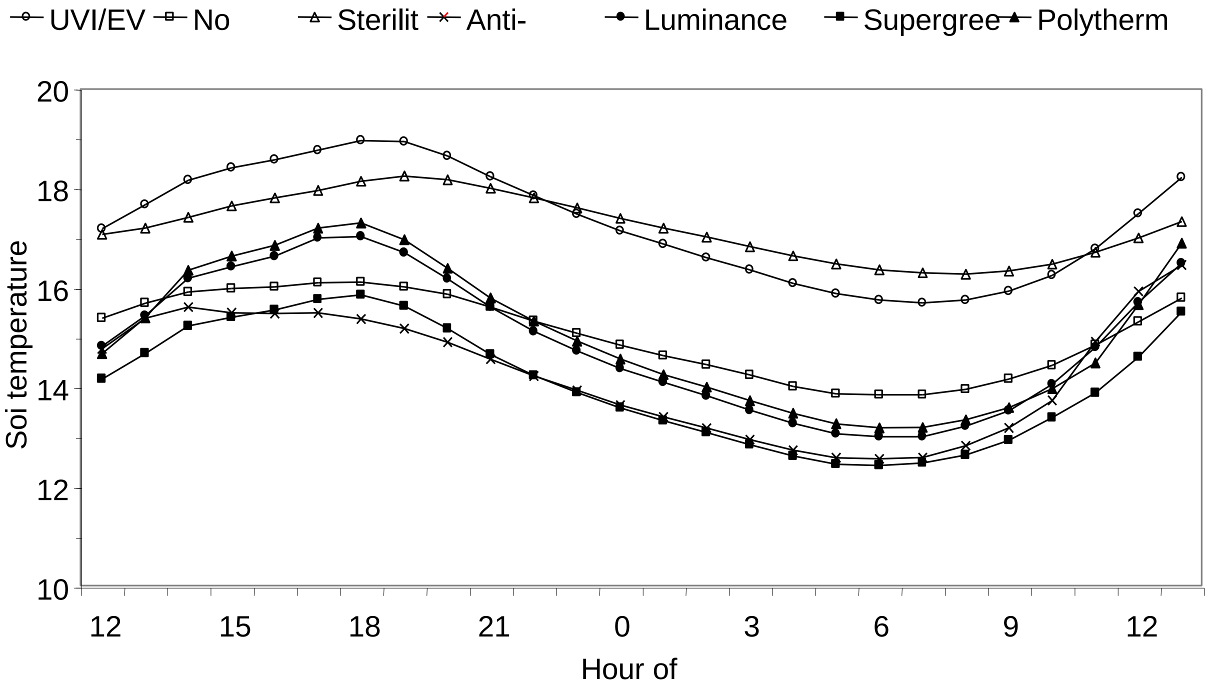
Figure 2 shows a typical profile of air temperatures for key plastic films over a cloudless 24-hour period of high light levels in August 1999. Using SuperGreen and Luminance THB films resulted in air temperatures consistently 2-3°C cooler than in the open. The standard film Visqueen Clear, and other specialist films (SteriLite, Anti-*Botrytis* and White (reduced PAR)) resulted in temperatures that were usually 1-2°C warmer than outside temperatures.

Figure 2. Canopy air temperature in summer under key films



Soil temperature
Figure 3 shows a typical range of soil temperatures for commercial films over a 24-hour period in August 1999. The standard film Visqueen Clear and SteriLite resulted in similar soil temperatures, about 2°C higher than in non-covered plots. Anti-*Botrytis* and SuperGreen films gave soil temperatures about 1°C cooler than outside plots. Some films – Luminance THB and Politherm AF – gave soil temperatures about the same as for outside plots. Some films (e.g., SteriLite) reduced the diurnal range of temperatures, producing lower day and higher night soil temperatures. Films do not necessarily have the same effects on air and soil temperatures: Anti-*Botrytis* film, for example, gave warmer air but cooler soil temperatures.

Figure 3. Soil temperatures in summer under some key films



Plant temperature
Chrysanthemum leaf temperature measured in August 1999 under full sun in non-covered plots was 15.6°C (Table 3). Under most films leaf temperatures were 19-20°C, although with SteriLite and Solatrol films they were lower (18°C), and under Luminance THB, Steel Blue and Politherm AF films they were higher (about 21°C). The higher leaf temperature recorded under Luminance THB, an IR-absorbing film, was unexpected. Leaf temperatures will be moderated from air temperature by the ability of the plant to control its temperature through transpiration. Non-transpiring organs, such as flower buds and the apical meristem have no direct cooling mechanism. Bud temperatures were assessed in 2000 (under warmer conditions) (Table 3). In this case the non-covered plots gave a bud temperature of 20.4°C, bud

temperature was lower under SuperGreen film (19°C) and higher under all other films (usually 21-22°C) and especially under White (reduced PAR) film (23.6°C).

Table 3. Chrysanthemum leaf temperature (in August 1999) and bud temperatures (in August 2000)

Tunnel no.	*Film type*	*Film*	*Mean leaf or bud temperature (°C)*	
			Leaf, 1999	*Bud, 2000*
2	-	No cover (outside control)	15.6	20.4
1	Std	Visqueen Clear	20.1	20.8
14	Std	SuperClear	19.4	21.4
3	UV	SteriLite	17.9	21.9
8	UV	Anti-*Botrytis*	19.3	22.0
10	IR	Luminance THB	21.2	21.7
4	R:FR	Solatrol (film replaced in 2000)	17.9	21.5
6a	R:FR	Steel Blue	21.4	21.0
6b	R:FR	SuperBlue	19.3	21.2
11	R:FR	SuperGreen	20.7	19.0
13	AC	Politherm AF	21.1	21.6
5	LD	White (reduced PAR)	20.4	23.6

Red:far red ratio

R:FR ratios were recorded in each tunnel in 1999 and 2000, and are shown in Table 4. A ratio of 1.1, for example, reflects a 10% higher level of energy at 660nm (red) than at 730nm (far red), some of the 730nm radiation having been blocked by the film. The films expected to have growth-modifying effects were Solatrol (higher red, shortening stems), and the two blue films and SuperGreen (higher far red, extending stems). Table 4 confirmed that these films made a substantial difference to the R:FR ratio. The ratio of 1.2 for the far red-reducing Solatrol film in 1999 indicated some degradation in what was an experimental film; these data were recorded in August, and the R:FR ratio at the start of the season would have been higher. A ratio of about 2.0 was expected in a new production version of Solatrol, and in 2000, using a replacement film, a R:FR ratio of 2.2 was obtained. The ratios of 0.4-0.5 under the blue films (this effect had been lost in the SuperBlue film by 2000) and of 0.7-0.8 with SuperGreen film demonstrated reduced levels of red light compared with far-red. The White (reduced PAR) film slightly lowered the R:FR ratio (to 1.0).

Table 4. Red: far red ratio under tunnel films (recorded in August 2000)

Tunnel no.	*Film type*	*Film*	*R:FR ratio*	
			1999	*2000*
2	-	No cover (outside control)	1.1	1.1
1	Std	Visqueen Clear	1.1	1.1
14	Std	SuperClear	1.1	1.1
3	UV	SteriLite	1.1	1.1
8	UV	Anti-*Botrytis*	1.1	1.1
10	IR	Luminance THB	1.1	1.1
4	R:FR	Solatrol (film replaced in 2000)	1.2	2.2
6a	R:FR	Steel Blue	0.5	0.4
6b	R:FR	SuperBlue	0.5	1.2
11	R:FR	SuperGreen	0.7	0.8
13	AC	Politherm AF	1.1	1.2
5	LD	White (reduced PAR)	1.0	1.0

Level of PAR

The relative loss of PAR for each film can be seen in Table 5, which shows PAR as the percentage of the natural level measured in the uncovered plots. In 1999, most films transmitted 77-89% of incoming PAR. By 2000 the percentage had fallen for most of these films, although Politherm AF and Steel Blue films were stable (at 77% and 51-53%, respectively). Transmission had fallen considerably for SteriLite, Solatrol and SuperBlue films, to 54-57%. Luminance THB film transmitted less PAR, 61% for both years. Steel Blue and SuperGreen films transmitted about 50% of PAR in both years. The White (reduced PAR) film transmitted 51% of PAR in 1999, falling to 38% in 2000.

Table 5. Proportion of PAR entering tunnels (% of outside value, recorded in August)

Tunnel no.	*Film type*	*Film*	*% PAR*	
			1999	*2000*
1	Std	Visqueen Clear	83	73
14	Std	SuperClear	89	77
3	UV	SteriLite	78	57
8	UV	Anti-*Botrytis*	83	73
10	IR	Luminance THB	61	61
4	R:FR	Solatrol (film replaced in 2000)	80	57
6a	R:FR	Steel Blue	51	53
6b	R:FR	SuperBlue	88	54
11	R:FR	SuperGreen	49	53
13	AC	Politherm AF	77	77
5	LD	White (reduced PAR)	51	38

UVA / UVB balance

Of the two standard clear films, SuperClear transmitted 66% of UVA and Visqueen Clear 47%. All other films considerably reduced the proportion of outside UVA entering the tunnel, but particularly the two UV films, the four growth-modifying films and the White (reduced PAR) film (Table 6). Most films reduced UVB somewhat more than UVA. SteriLite, Solatrol and Steel Blue cut out virtually all UV light.

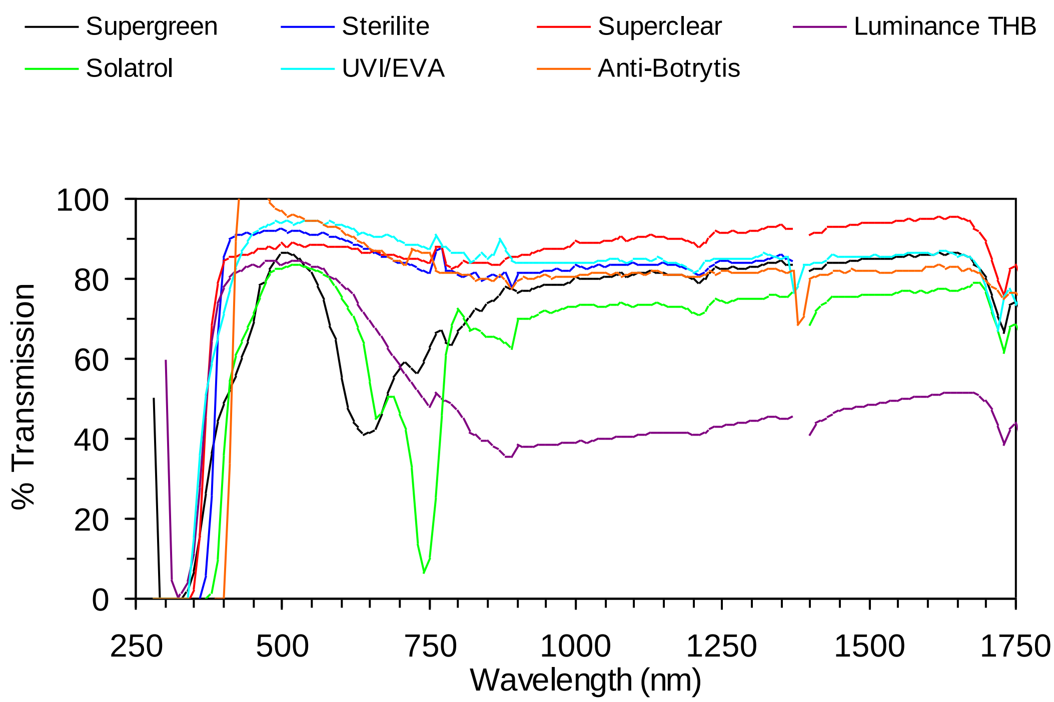
Table 6. Proportion of UVA and UVB entering tunnels (% of outside value, recorded in August 2000)

Tunnel	*Film type*	*Film*	*% UBA*	*% UVB*
1	Std	Visqueen Clear	47	38
14	Std	SuperClear	66	61
3	UV	SteriLite	1	1
8	UV	Anti-*Botrytis*	8	6
10	IR	Luminance THB	28	18
4	R:FR	Solatrol (film replaced in 2000)	1	<1
6a	R:FR	Steel Blue	0	0
6b	R:FR	SuperBlue	5	2
11	R:FR	SuperGreen	11	7
13	AC	Politherm AF	20	9
5	LD	White (reduced PAR)	6	6

Spectral characteristics of films

Figure 4 shows the spectra of the commercial films at the start of the growing season in 1999. UV wavelengths (300-400nm) were blocked by all films at around 320nm, while the two specifically UV-blocking films (Solatrol and Anti-*Botrytis*) and the Visqueen Clear standard film (but not SuperClear) blocked UV over a wider range of wavelengths. The Anti-*Botrytis* film blocked all UV wavelengths, with a very sharp cut off at 400nm. The figure clearly shows the blocking of red light (670nm) by the SuperGreen film and of far red light (730nm) by Solatrol film. The Luminance THB film blocked some 50% of IR radiation (>700nm), with some blocking in the upper end of the PAR region (400-700nm).

Figure 4. Spectra of commercially available films as received



Summary of film characteristics

All films, including the standard clear films, affected (generally raised) temperatures, reduced the levels of PAR and blocked some UV light. Table 7 summarises the main properties of the specialist films observed during this project.

Table 7. Summary of the properties of specialist films

Film type	*Film*	*Air temp.*	*Soil temp.*	*Plant temp.*	*R:FR*	*PAR*	*UV*	*IR*
UV	SteriLite			Lower		Lower (year 2)	Blocks UV	
UV	Anti-*Botrytis*		Cooler than outside				Blocks UV (all wave-lengths)	
IR	Luminance THB	Cooler than outside		Higher		Lower	Low	Low
R:FR	Solatrol			Lower	High	Lower (year 2)	Blocks UV	
R:FR	Steel Blue			Higher	Low	Lower	Blocks UV	
R:FR	SuperBlue				Low	Lower (year 2)	Blocks UV	
R:FR	SuperGreen	Cooler than outside	Day temperatures like outside	Lower	Low	Lower	Blocks UV	
AC	Politherm AF			Higher			Low	
LD	White (reduced PAR)			Higher	Slightly reduced	Lower	Blocks UV	

<u>Deterioration of films</u>

The spectra of film samples taken over the period 1999 to 2002 are shown in Appendix A. To avoid confusion, only results from the start and end of each growing season are included. Due to degeneration of the White diffusing (reduced PAR) and Steel Blue films, only the first three years results are available for these products.

In several cases, there appeared to be minor discrepancies from the results expected. For example, while overall transmission was expected to fall over the four-year period due to the accumulation of deposits on the films, in some cases the percentage transmission for year 4 were slightly greater than those for year 3. This could represent minor variations across the films or variations in spectrometer performance, or, very likely, effects of the preceding weather (accumulation or removal of surface deposits, tear-to-year variation of sunlight profile, etc). Such variations were frequent, but are not repeated with the main findings for each film which are presented below.

- <u>XL SuperClear film</u>
  There was a small loss of transmission across the range over the four-year period of testing. There was a minor blocking of UV wavelengths (<400nm) by the new film, but this was lost during the first year's use.
- <u>Visqueen Clear film</u>
  The results were similar to the previous film, with a small, gradual loss of transmission across the range. Blocking of UV wavelengths (<400nm) by the new film was partly lost over the first year's use.

- Visqueen Anti-*Botrytis* film
  There was a marked loss (10-20%) of transmission above the UV band (>420nm) after the first year, thereafter there was a gradual loss of transmission across these wavelengths. This film, when new, produced a sharp cut-off in transmission at wavelengths <410nm, this blocking of UV being lost only gradually over the next three years.
- XL SteriLite film
  There was a slow loss of transmission over the four years in wavelengths >400nm. This film effectively blocked UV wavelengths (<400nm), and this characteristic was not lost over the four years of the observations.
- Reading University/Visqueen Solatrol film
  There was a slow loss of transmission in wavelengths >400nm, but note that the original film was replaced for the second year. The UV blocking effect (<400nm) was somewhat lost after the second year of use. There was also some loss of blocking >650nm (far-red wavelengths) in the second year of use. The last samples taken in year 4 were observed to be somewhat more scuffed than for other samples, perhaps because of some property of the film.
- Steel Blue filter (Lee Filters)
  This material showed a marked loss of transmission over the growing period of year 2, across the range of wavelengths tested. However, in the third year there was an increase in percentage transmission in wavelengths >500nm including red light. This material, which is designed as a theatrical filter rather than as a horticultural film, was too brittle to be used after the third year.
- XL SuperBlue film
  There was a marked loss of percentage transmission in wavelengths <500nm after the first year, but in years 2 to 4 the spectra were more or less stable. The film blocked red light transmission (around 650nm), and this was largely maintained over the four-year period.
- XL SuperGreen film
  There was a gradual loss of transmission, especially over the range 450-550nm, the lower end of photosynthetically-active radiation (PAR), over the four-year period. the blocking of red light was maintained during the test period.
- Visqueen Politherm AF
  There was a gradual loss of transmission >380nm over the four years, though the loss in the third year was larger than in other years. The blocking of UV wavelengths <370nm was slightly lost after the second year.
- Reading University/Visqueen White difusing (reduced PAR) film
  There was a huge loss of transmission by this film after the first year, across the range of wavelengths, including the loss of the blocking effect of UV wavelengths (<400nm). This film was not tested after the third year as it was considered too fragile.
- Visqueen Luminance THB film
  There was a marked loss of transmission >370nm after one year, effectively blocking all wavelengths to the same extent as the initial blocking of UV below 370nm. This loss of transmission continued more slowly over years 2-4.

Crop responses

The crop data obtained in this project could be analysed either individually for each year, or combined across both years. Two factors involved in this choice were:

- The often large year-to-year differences in crop growth, presumably resulting from crop responses to differing weather patterns. Selected weather data for 1999 and 2000 are given in Appendix C. These show that, while the annual figures for 1999 and 2000 were not very dissimilar from each other and from the long-term means (except for rainfall, where both years were wetter than average), there were some marked differences in the monthly patterns of weather. For example, June was abnormally dry in 2000, whereas July was in 1999. June 2000 was also markedly warmer than June 1999.
- The deterioration of film properties over the two year period. In broad terms, however, most films exhibited reasonably stable transmission spectra in each year. The exceptions were where films showed rapid changes in transmission of its key wavelengths, such as SuperClear and SuperBlue films, where there was a rapid loss of blocking of UV or red wavelengths, respectively, in 1999, but thereafter the spectra were more or less stable. In the case of Solatrol film, which showed a rapid loss of far red blocking, the film was replaced for the second year, so its properties were effectively similar over both years.

The results presented below are based on an analysis of data across *both* years. On balance, it was considered better to take this approach and seek the major experimental effects of the films, rather than to risk confusion due to minor effects or interactions appearing significant in individual years. This approach also gives some useful information on year-to-year differences in growth, as well as increasing the number of observations on individual films. Replication across years will be a robust indication of the consistency of the effects of films. For completeness, however, the crop data for individual years are presented in Appendix B, and these additional analyses are referred to below in appropriate instances.

For each crop described below, the following factors have been considered in turn:

- The effect of year (year-to-year effects);
- The effect of films (tunnels) on crop growth, mainly stem length and weight and flower numbers, comparing:
  - The effects of films compared with non-covered controls
  - The effects of specialist films compared with standard, clear films (including whether specific effects from films altering the R:FR ratio were found)
  - The effects of using a part-season Luminance THB cover compared with a full-year cover;
- The effect of bed position within tunnels (west, central or east).

Chrysanthemum morifolium
The data for chrysanthemum are given in Table 8 (see also Appendix Tables B1-2 for the separate years' data).

There were large year-to-year effects. In 1999 sprays were longer ($P<0.001$) and heavier ($P<0.05$) than in 2000. The large difference in flower numbers between 1999 and 2000 was due to differences in the way the sprays were cropped.

The effect of films (tunnels) was not significant, overall, for the plant variables recorded, although some individual treatment comparisons were, nevertheless, significantly different. All films increased spray length compared with non-covered controls, and significantly so using SuperClear, Anti-*Botrytis*, Steel Blue, SuperGreen, Politherm AF and White (reduced PAR) films. No common property of these films (see Table 7) can be determined that would explain the apparent effectiveness of this diverse group of films in increasing spray length. However, none of the specialised films increased or decreased spray length significantly from that obtained using the standard clear films, so no effects due to manipulating R:FR were found. Only Solatrol film produced a significant effect on spray weight, compared with the controls, sprays being lighter as well as shorter under this film. Only SuperGreen film had a significant effect on the number of flowers per spray, compared with the controls, with fewer flowers. No distinctive property of either Solatrol or SuperGreen film that might result in this weaker growth could be determined, although both blocked UV effectively and White (reduced PAR), though not more than other films. In these crops generally it was noted that growth of the peduncles led to uneven sprays, and that stem length was obtained at the expense of stem thickness, detracting from the marketability of the sprays.

In the case of the three films where the spectral characteristics had been shown to have changed most between the two years of the project - SuperClear, SuperBlue and Solatrol - crop responses to each film were similar in each year. This implies that any changes in spectral filtering properties were not significantly affecting growth.

In 1999 only, some additional variables were recorded (see Appendix Table B1). The effects of films on whole plant weights and lengths corresponded with the results for sprays. The number of stems per plant was significantly lower under Steel Blue and SuperGreen films (though not under SuperBlue film) than under other films ($P<0.05$), suggesting that branching patterns were affected via the R:RF ratio. A lower R:FR ratio would be expected to result in less branching.

Compared with controls or using an all-season cover, no significant effects of using a part-season Luminance THB cover were seen, except that an early-season cover resulted in lower flower numbers.

The effects of position within the tunnel had a significant effect only on spray length ($P<0.005$). The tallest growth occurred in the central bed.

Table 8. The results of growing *Chrysanthemum* under different films over two years. Only the main effect means are presented.

Factor		*Treatment*	*Spray length (cm)*	*Spray weight (g)*	*No. of flowers / spray*
Year					
		1999	92.4	53.8	28.4
		2000	66.8	47.7	6.6
		SED (14 d.f.)	2.25	2.25	0.57
Film type and name					
2	-	No cover (outside control)	69.4	51.2	18.8
14	Std	SuperClear	81.6 y	54.8	17.9
1	Std	Visqueen Clear	79.4	53.9	16.8
8	UV	Anti-*Botrytis*	84.1 y	52.3	16.9
3	UV	SteriLite	80.1	46.8	16.9
4	R:FR	Solatrol	68.2	40.3 z	17.5
6a	R:FR	Steel Blue	88.1 y	53.0	17.3
6b	R:FR	SuperBlue	75.3	46.0	17.7
11	R:FR	SuperGreen	87.0 y	50.7	15.4 y
13	AC	Politherm AF	85.3 y	58.4	16.8
5	PAR	White (reduced PAR)	81.6 y	45.4	18.1
10	IR	Luminance THB	76.7	56.0	18.7
12	IR	Luminance THB (early cover only)	79.4	47.3	15.5 xy
9	IR	Luminance THB (late cover only)	79.1	58.2	19.7
7	IR	Luminance THB (early and late cover only)	79.2	47.1	18.2
		SED (14 d.f.)	6.17	6.15	1.57
Position					
		West	78.7	50.2	17.5
		Centre	81.4	52.4	17.5
		East	78.8	49.3	17.4
		SED (58 d.f.)			
Significance of factors					
		Year	*** (P<0.001)	* (P=0.016)	*** (P<0.001)
		Film	NS (P=0.172)	NS (P=0.258)	NS (P=0.407)
		Position	** (P=0.003)	NS (P=0.191)	NS (P=0.956)

The letters following film means indicate that there were significant differences (P<0.05) between specified comparisons:

- Part-time cover treatment means marked x are significantly different from the mean for all-season Luminance THB film
- Treatment means marked y are significantly different from the mean for 'no cover'
- Treatment means marked z are significantly different from means for both 'standard' films

NS, not significant; (*), *, ** and ***, significant at the 10, 5, 1 and 0.1% levels of probability

Godetia amoena

The data for *Godetia* are given in Table 9 (see also Appendix Tables B3-4).

There were large year-to-year effects ($P<0.001$) in all the variables recorded. In 1999 stems were shorter, heavier, produced more flowers and branches, and had fewer leaves per stem, compared with 2000.

The films (tunnels) used significantly affected plant length and weight (although only at $P<0.05$). Only the two standard clear films (Visqueen Clear and SuperClear), SteriLite and Solatrol increased plant length, compared with non-covered controls. On the other hand, Anti-*Botrytis*, SuperBlue, SuperGreen, Politherm AF and Luminance THB films all decreased plant length compared with both two standard clear films. Plant weight was significantly reduced, compared with non-covered controls, by Anti-*Botrytis*, Steel Blue and White (reduced PAR) films. Thus, as found for chrysanthemum, the varied properties of these groups of films did not indicate a common mechanism responsible for stem shortening, nor an effect due to the varying R:FR ratio. Indeed, Solatrol film would have been expected to reduce stem extension, and SuperBlue and SuperGreen to have increased it.

Overall, the films used did not have significant effects on the numbers of flowers per stem, stems per plant, or leaves per stem. However, White (reduced PAR) film significantly reduced the number of flowers, compared with the controls, while SuperGreen film increased leaf numbers.

In the case of SuperClear, SuperBlue and Solatrol films, where the spectral characteristics had most changed between the two years of the project, stem length responses to each film were similar in each year. However, for both SuperClear and SuperBlue films, plant weights were heavier than in non-covered controls in 1999, but lighter than controls in 2000.

Using a part-season Luminance THB cover increased plant weight, compared with an all-season treatment. Flower numbers were reduced by using an early, rather than an all-season cover.

Position in the tunnel had a significant effect on plant length only, with the tallest plants in the central bed and the shortest in the western.

Table 9. The results of growing *Godetia* under different films over two years. Only the main effect means are presented.

Factor		*Treatment*	*Plant length (cm)*	*Plant weight (g)*	*No. of flowers / plant*	*No. of stems / plant*	*No. of leaves / stem*
Year							
		1999	56.2	125.4	53.8	13.8	7.2
		2000	74.2	103.8	39.1	10.9	10.7
		SED (14 d.f.)	1.06	4.28	2.10	0.67	0.43
Film type and name							
2	-	No cover (outside control)	59.9	130.1	51.7	13.4	9.4
14	Std	SuperClear	69.8 y	134.6	50.6	12.6	8.8
1	Std	Visqueen Clear	70.4 y	112.2	46.7	13.2	8.9
8	UV	Anti-*Botrytis*	64.0 z	103.0 y	45.5	11.8	9.5
3	UV	SteriLite	68.9 y	112.3	47.4	12.5	7.4
4	R:FR	Solatrol	66.4 y	108.6	43.4	12.4	8.4
6a	R:FR	Steel Blue	65.0	103.9 y	40.4	10.6	7.5
6b	R:FR	SuperBlue	64.0 z	116.7	43.9	14.1	9.4
11	R:FR	SuperGreen	63.8 z	122.0	52.7	11.8	11.2 z
13	AC	Politherm AF	60.1 z	122.6	53.2	12.7	9.0
5	PAR	White (reduced PAR)	65.2	89.8 y	40.1 y	11.1	7.5
10	IR	Luminance THB	60.8 z	143.5	49.7	13.3	8.7
12	IR	Luminance THB (early cover only)	70.1 xy	103.5 xy	38.7 y	12.7	8.6
9	IR	Luminance THB (late cover only)	63.5 z	102.4 xy	44.8	11.5	9.7
7	IR	Luminance THB (early and late cover only)	66.2 y	113.8 x	48.4	11.8	10.1
		SED (14 d.f.)	2.90	11.71	5.76	1.82	1.16
Position							
		West	62.9	115.8	46.0	12.4	9.2
		Centre	67.6	112.1	46.6	12.2	8.5
		East	65.1	115.9	46.8	12.9	9.1
		SED (58 d.f.)	0.85	4.47	2.08	0.31	0.39
Significance of factors							
		Year	*** (P<0.001)	*** (P<0.001)	*** (P<0.001)	*** (P<0.001)	*** (P<0.001)
		Film	* (P=0.029)	* (P=0.028)	NS (P=0.316)	NS (P=0.875)	NS (P=0.207)
		Position	*** (P<0.001)	NS (P=0.638)	NS (P=0.929)	NS (P=0.597)	NS (P=0.213)

The letters following film means indicate that there were significant differences (P<0.05) between specified comparisons:

- Part-time cover treatment means marked x are significantly different from the mean for all-season Luminance THB film
- Treatment means marked y are significantly different from the mean for 'no cover'
- Treatment means marked z are significantly different from means for both 'standard' films

NS, not significant; (*), *, ** and ***, significant at the 10, 5, 1 and 0.1% levels of probability

Matthiola incana

The data for *Matthiola* are given in Table 10 (see also Appendix Tables B5-6).

There were large year-to-year effects in all the variables recorded except the number of stems per plant. In 1999 stems were shorter and heavier, with more flowers and fewer leaves (all at $P<0.001$), compared with 2000, as found for godetia.

Overall, the effects of films (tunnels) were significant only for plant weight ($P<0.005$). However, several films significantly increased stem length compared with non-covered controls (Anti-*Botrytis*, Steel Blue, SuperBlue, SuperGreen, Politherm AF and Luminance THB). Several films significantly decreased stem weight, compared with non-covered controls: the two standard clear films, Steel Blue, SuperBlue, SuperGreen and White (reduced PAR). None of the films significantly changed stem length or weight compared with the two standard clear films. There were no significant effects of films on the numbers of flowers per plant, stems per plant, or leaves per stem.

In the case of SuperBlue film, stem length was longer than in the controls in 2000, but not in 1999. There were no such year-to-year differences in response in the case of SuperClear and Solatrol films.

Using a part-season Luminance THB cover (either early- or late-season) increased stem weight, compared with an all-season treatment.

Position in the tunnel had significant effects on plant length ($P<0.001$) and plant weight and leaf number ($P<0.05$). Plants in the middle beds were taller than those in the outer beds, while those in the eastern beds were heavier and had more leaves.

Dianthus caryophyllus

The data for *Dianthus caryophyllus* are given in Table 11 (see also Appendix Tables B7-8). In 1999, crop establishment was variable, and the results for this year (Table B7) should be treated with caution because of the variable plant numbers.

There were significant year-to-year effects on spray length ($P<0.001$) but not on spray weight or number of flowers. Sprays were shorter in 1999 than in 2000, as found for the two previous species.

There were no significant effects of film (tunnel) or position on these variables.

There were no obvious differences in crop response to SuperClear, SuperBlue and Solatrol films in 1999 and 2000.

Using an early-season Luminance THB cover increased spray length, compared with an all-season treatment.

Table 10. The results of growing *Matthiola* under different films over two years. Only the main effect means are presented.

Factor		*Treatment*	*Plant length (cm)*	*Plant weight (g)*	*No. of flowers / plant*	*No. of stems / plant*	*No. of leaves / stem*
Year							
		1999	46.2	86.8	24.6	16.7	25.6
		2000	54.3	55.7	20.3	16.6	28.6
		SED (14 d.f.)	1.25	1.52	0.69	0.29	0.43
Film type and name							
2	-	No cover (outside control)	44.6	77.3	21.9	16.6	28.1
14	Std	SuperClear	48.5	67.5 y	23.1	16.7	28.1
1	Std	Visqueen Clear	50.9	68.4 y	22.6	16.8	27.9
8	UV	Anti-*Botrytis*	51.5 y	73.5	24.2	16.6	27.6
3	UV	SteriLite	50.7	71.4	23.9	16.5	27.1
4	R:FR	Solatrol	43.8	69.0	21.3	16.2	27.6
6a	R:FR	Steel Blue	52.6 y	62.9 y	19.5	17.4	28.7
6b	R:FR	SuperBlue	51.8 y	66.0 y	22.0	16.8	27.3
11	R:FR	SuperGreen	55.3 y	64.5 y	20.7	17.0	26.3
13	AC	Politherm AF	52.3 y	74.4	23.5	17.1	28.7
5	PAR	White (reduced PAR)	50.3	64.9 y	20.2	16.4	26.1
10	IR	Luminance THB	52.9 y	73.2	24.7	16.8	27.9
12	IR	Luminance THB (early cover only)	53.3 y	83.9 x z	23.8	17.0	27.7
9	IR	Luminance THB (late cover only)	44.3 x	78.8 z	23.0	15.6	26.2
7	IR	Luminance THB (early and late cover only)	50.4	73.5	23.0	16.5	28.2
		SED (14 d.f.)	3.43	4.16	1.90	0.81	1.17
Position							
		West	49.4	69.7	22.1	16.5	27.0
		Centre	51.6	69.9	22.7	16.7	27.6
		East	49.7	74.1	22.6	16.8	28.2
		SED (58 d.f.)	0.48	1.86	0.49	0.27	0.47
Significance of factors							
		Year	*** (P<0.001)	*** (P<0.001)	*** (P<0.001)	NS (P=0.684)	*** (P<0.001)
		Film	NS (P=0.101)	** (P=0.006)	NS (P=0.307)	NS (P=0.881)	NS (P=0.511)
		Position	*** (P<0.001)	* (P=0.037)	NS (P=0.493)	NS (P=0.491)	* (P=0.039)

The letters following film means indicate that there were significant differences (P<0.05) between specified comparisons:

- Part-time cover treatment means marked x are significantly different from the mean for all-season Luminance THB film
- Treatment means marked y are significantly different from the mean for 'no cover'
- Treatment means marked z are significantly different from means for both 'standard' films

NS, not significant; (*), *, ** and ***, significant at the 10, 5, 1 and 0.1% levels of probability

Table 11. The results of growing *Dianthus caryophyllus* under different films over two years. Only the main effect means are presented.

Factor		*Treatment*	*Spray length (cm)*	*Spray weight (g)*	*No. of flowers / spray*
Year					
		1999	43.2	22.3	6.3
		2000	58.2	22.9	5.8
		SED (14 d.f.)	1.62	1.46	0.39
Film type and name					
2	-	No cover (outside control)	49.1	22.3	6.2
14	Std	SuperClear	57.2	25.6	6.0
1	Std	Visqueen Clear	47.9	20.2	5.0
8	UV	Anti-*Botrytis*	49.3	21.6	5.7
3	UV	SteriLite	54.0	23.5	6.5
4	R:FR	Solatrol	53.0	26.5	6.1
6a	R:FR	Steel Blue	51.2	23.8	5.6
6b	R:FR	SuperBlue	56.0	28.9	7.8
11	R:FR	SuperGreen	50.6	21.4	6.0
13	AC	Politherm AF	51.2	22.1	6.3
5	PAR	White (reduced PAR)	44.8	17.1	5.8
10	IR	Luminance THB	44.6	22.8	6.6
12	IR	Luminance THB (early cover only)	54.4 x	20.0	5.1
9	IR	Luminance THB (late cover only)	48.5	23.2	6.9
7	IR	Luminance THB (early and late cover only)	48.8	19.8	5.6
		SED (14 d.f.)	4.42	4.00	1.05
Position					
		West	49.7	22.0	5.8
		Centre	51.7	23.1	6.5
		East	50.8	22.6	6.0
		SED (58 d.f.)	1.06	1.08	0.35
Significance of factors					
		Year	*** (P<0.001)	NS (P=0.700)	NS (P=0.188)
		Film	NS (P=0.266)	NS (P=0.445)	NS (P=0.592)
		Position	NS (P=0.180)	NS (P=0.576)	NS (P=0.148)

The letters following film means indicate that there were significant differences (P<0.05) between specified comparisons:

- Part-time cover treatment means marked x are significantly different from the mean for all-season Luminance THB film
- Treatment means marked y are significantly different from the mean for 'no cover'
- Treatment means marked z are significantly different from means for both 'standard' films

NS, not significant; (*), *, ** and ***, significant at the 10, 5, 1 and 0.1% levels of probability

DISCUSSION

Films

New films have been introduced during the course of this project, and indeed the specifications of the films tested may have changed during this time. However, the specialist films examined all demonstrated their respective properties well, whether selectively blocking UV (Anti-*Botrytis* and SteriLite films), red light (Steel Blue, SuperBlue and SuperGreen films), far red light (Solatrol film), PAR generally (White (reduced PAR) film) or IR (Luminance THB film). Most of the films used blocked UV radiation to some extent, including the 'standard' film Visqueen Clear, but the range of wavelengths blocked varied with the film. The Anti-*Botrytis* film blocked all incident UV wavelengths. The anti-condensation properties of Politherm AF film were not specifically measured, although its advertised effect was evident. Reducing leaf wetness and relative humidity should reduce the impact of fungal foliar pathogens. The results from a parallel study on pests and diseases (PC 170, see Appendix D) showed that there was insufficient evidence to recommend spectral filters for cost-effective pest reduction under UK conditions[4]. However, there were evidently some differences in the incidence of aphids and downy mildew under different films.

As well as providing crops with protection from various adverse types of weather, most of the films tested also raised temperatures, reduced incoming levels of PAR and blocked some UV radiation. As expected, most films raised temperatures, but the SuperGreen film reduced both air and soil temperatures to below outside temperatures. There were similar effects of the IR-absorbing film Luminance THB on air temperatures, and of the UV-absorbing film Anti-*Botrytis* on soil temperatures. Given the difficulties in ventilating small tunnels, even better air temperature control should be possible in larger tunnels. The effects of films on air, plant and soil temperatures was not always the same, for example, films that produced lower soil temperatures did not necessarily reduce the temperature of the air or plants. Luminance THB and SuperGreen films produced day-time air temperatures similar to those outside, but at the expense of some 50% of incoming PAR. Leaf or bud temperatures, recorded for chrysanthemums, were lower under SteriLite, Solatrol and SuperGreen films.

The stability of the eleven horticultural films used was determined over a four-year period of normal environmental exposure.

- The two standard clear films tested, XL SuperClear and Visqueen Clear, were stable in their transmission characteristics over four years, showing only a small loss of transmission across the range of wavelengths. Both films blocked some UV light and lost this property over the first year of use.
- Two UV-absorbing films were tested, Visqueen Anti-*Botrytis* and XL SteriLite. Their blocking of UV wavelengths was lost slowly over four years by the Anti-*Botrytis* film, and not at all by SteriLite film. There was a marked loss of transmission of wavelengths above the UV band over the first growing season in the case of Anti-*Botrytis* film, but otherwise the loss of transmission in these wavelengths over the three- or four-year period was only gradual.

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[4] See *HDC News*, No. 83 (June 2002), p.7.

- A far-red blocking film, Solatrol, showed some loss of blocking of these wavelengths after the first two years of use. This film also showed some UV-blocking, and this was also partly lost after the second year of use.
- Red-blocking materials tested were two horticultural films, SuperBlue and SuperGreen, and a theatrical Steel Blue filter. Both the horticultural films maintained their red light blocking effect over the four-year test period. At shorter wavelengths, SuperBlue film in particular showed some loss of transmission after the first year of use. The Steel Blue filter showed a loss of red light blocking in the third year, by which time it was too fragile for further use; while useful for experimental purposes, this material was not designed for horticultural use.
- An anti-condensation film, Politherm AF, showed only a gradual loss of transmission over the four years. This film also blocked the shorter UV wavelengths, and this property was only slightly lost after the second year of use.
- An experimental white diffusing, reduced PAR film, showed a large loss of transmission across the range of wavelengths after the first year's use, although remaining stable during the first growing season. The material was considered unsuitable for testing in the fourth year.
- An infra-red (IR) blocking film, Luminance THB, produced a large loss of transmission after the first year of use.

Crop responses

How should the properties of films be assessed in terms of plant response? In some cases the properties of films could be assessed simply and directly by the crop response, for example, stem extension or shortening in the case of a R:FR-modifying film, reduced growth in the case of White (reduced PAR) film, or changed pest and disease activity in the case of an anti-condensation or UV-modifying film. In many cases, however, a change in crop performance is likely to be the result of effects brought about by covering the crop and by various properties of the film. This might involve an interplay of reduced light transmission, alterations in spectral qualities of the transmitted light, changed soil, air and plant temperatures, and so on. It became apparent from the results of this project that the contribution of these individual components to crop response could not often easily be assessed. It could be argued that specific crop responses to environmental factors should be understood, through studies in controlled environments, before a film with the desired effect(s) can be selected for practical use. In this project, the effects of films on crops were further confounded in some cases by large year-to-year differences in crop performance and, probably to a lesser extent, by changes in the spectral qualities of films over time.

A major feature of the trials reported here was the difference in crop performance between the two years, seen in all four species. In chrysanthemums stems were longer, and in godetia, stocks and carnations shorter, in 1999 than in 2000. 1999 also produced heavier stems with more flowers in godetia, stock and carnations, than in 2000. As pointed out under Results, the weather summaries for 1999 and 2000 were not very dissimilar from each other or from the long-term means (except that rainfall was greater than average in both years), but there were some marked differences in the monthly patterns of weather. For example, June 2000 was markedly warmer than June 1999. The relatively cool June in 1999 might have led to better growth in the species mentioned. These year-to-year differences highlighted a lack of understanding of the effects of environmental factors on ornamental crop growth.

In general terms, increased red light (a high R:FR ratio) is expected to reduce stem extension, and increased far red light to increase it. Thus, in densely planted crops, red light is absorbed by foliage, reducing R:FR and leading to stem extension. Growing spray chrysanthemums under any of the films tested increased stem length compared with non-covered controls, suggesting that longer stems were likely to be a general result of growing in polytunnels – with reduced light intensities and higher temperatures - rather than to a specific film property. Compared with growing under the two standard films, Visqueen Clear and SuperClear, none of the other films used in this study significantly altered stem length, implying that no demonstrable R:FR effect was operating. In the case of godetia, some films resulted in plants taller than non-covered plants (e.g., Solatrol film, which, in fact, would be expected to produce shorter stems on the basis of its R:FR properties), while other films gave shorter plants compared with using a standard film (SuperBlue and SuperGreen films, expected to produce longer stems). With column stocks, several specialist films resulted in longer stems than obtained in non-covered plots, but none was significantly longer than when grown under the standard films. With stocks, growing under SuperBlue film gave taller stems in 2000 but not in 1999, whereas the spectra of this film – which showed faster degradation of properties in 1999 than in 2000 – would have been expected to have had the opposite effect as a result of its effects on R:FR. For spray carnations, there was no significant effect of films on plant growth. In the case of the films whose spectra changed most over the course of the two-year project - Solatrol, SuperGreen and SuperClear – there was no clear pattern of growth that reflected these changes in any of the species tested. There was no evidence for clear R:FR effects on stem extension in any of the four species under these conditions.

Relatively few significant effects of films on stem weight were found in this project, but such as were found resulted in lighter stems when compared with non-covered controls. As with stem lengths, these results were probably the results of a variety of non-specific light and temperature effects, such as lower PAR or higher temperatures. This applied to plants under Solatrol film for chrysanthemum, under Anti-*Botrytis*, SuperBlue and White (reduced PAR) films for godetia, and under the standard clear films, Steel Blue, SuperBlue, SuperGreen and White (reduced PAR) films for stocks. There was no indication of a common spectral property overarching these findings. In general, a 1% loss in transmission of PAR will result in a 1% loss of dry weight production.

The non-specific effects of reduced levels of PAR and of unfavourable temperatures may also have resulted in occasional effects on flower numbers: these were reduced in chrysanthemums under SuperGreen film, and in godetia under White (reduced PAR) film. The pattern of branching can be altered by changing the R:FR ratio, but in the present work the only significant effect observed was in chrysanthemums grown under Steel Blue and SuperGreen films (both reducing the R:FR ratio), which produced fewer stems. Cut-flower quality can be greatly and variously affected by growing under polythene film, and varietal selection will be needed in many cases to identify the most suitable cultivars for growing in tunnels.

Some crop responses to growing under different films are quoted in manufacturers' leaflets. For example, Solatrol film has been reported as giving effective height suppression in chrysanthemums, with a much smaller effect on *Dianthus*, stocks and other species. In other cases, tested mainly on species of bedding plants, the use of Solatrol film improved other quality aspects, such as producing greater dry weight and leaf area and higher numbers of leaves and buds. During the present study, the height-suppressing effect of Solatrol on chrysanthemums was not confirmed, nor were there similar effects on carnations and stocks, while in godetia plant height was increased. Many factors could result in such apparent discrepancies, however, such as varietal and environmental factors. Other information from manufacturers reported that the dry weight of five bedding plant species was increased by variable extents, but averaging 12%, by growing under Luminance THB film. Further, tomato yields were reported increased by 10% when growing under Luminance THB film, and that of strawberries by 5% when growing under a similar film, Luminance. Such yield increases were not observed with the species used in the present study.

Certain aspects of the physiology of the species grown can be related to the results obtained here. For example, the key factor in the flowering of column stocks is the inhibitory effect of high temperatures on floral initiation[5]. Column stocks do not usually initiate flowers at 16°C or higher – some 10-21 days of lower temperatures are needed for floral initiation, depending on cultivar. Also, if stocks experience high temperatures soon after floral initiation, floral abnormalities may occur. Hence the higher temperatures as a result of using polythene covers, like the warmer weather in June 2000, could be detrimental to floral initiation. Carnations are perpetual flowering, floral initiation and development occurring under most conditions[6]. Here, the rate of flower development is increased by higher temperatures, over the range of about 10 - 20°C, but higher temperatures after floral initiation can reduce flower diameter, reduce stem strength and have other adverse effects.

There were few significant effects of using Luminance THB film as a part-season, rather than as a full-year, cover. However, there were some effects of using a cover for the earlier part of the season only. As an early-season cover, this film resulted in lower flower numbers in chrysanthemums and godetia, perhaps an effect of temperatures that were made unsuitably high for floral initiation early on in the growing period. Using an early cover increased plant or stem weight in godetia and stocks, whereas in carnations the same treatment increased spray length. Any benefit of using an early cover is probably simply due to the warmer growing temperatures obtained early in the growing season.

Conclusions

Films currently available in the UK are listed in Appendix E. However, unless growing species that have a clearly understood requirement for a specific spectral modification or for the use of other specialist film, the current project suggests that a standard, clear polythene film would be a good, if conservative, choice for covering tunnels (the conclusions from Project PC 170 were similar). Such films are relatively cheap, provide adequate protection from weather, transmit a high proportion (80-90%) of incident PAR, and block a significant proportion of incident UV radiation. The chief disadvantage of this type of film is the heat gain in the tunnels, which

[5] Cockshull, K.E. (1985). *Matthiola incana*. Pp. 363-367 in *Handbook of flowering* (ed., A.H. Halevy), Volume 3. CRC Press, Boca Raton, Florida.
[6] Bunt, A.C. & Cockshull, K.E. (1985). *Dianthus caryophyllus*. Pp. 433-440 in *Handbook of flowering* (ed., A.H. Halevy), Volume 2. CRC Press, Boca Raton, Florida.

demands good ventilation. Only where a clear advantage to manipulating the R:FR ratio, reducing soil temperatures, altering the UV input, etc., is known, should the use of more expensive specialist films be considered. In this project, Visqueen Clear film was shown to block UV across a wider range of wavelengths than SuperClear film. Whether there are specific issues relating to people working in polythene tunnels under films transmitting different percentages of UV light, especially of the more damaging UVA wavelengths, has not been determined. Developed for use on strawberries, one film, not tested here, gives *total* UV transmission leading to better fruit ripening (Appendix Table E1).

Of the specialist films used in this project, the effects of Luminance THB, Anti-*Botrytis* and SuperGreen films in reducing soil and air temperatures to those outside the tunnels were notable. Luminance THB film blocks a high proportion of IR wavelengths. Luminance THB and Anti-*Botrytis* films also exhibit reasonable transmission of PAR (about 60 and 80%, respectively, compared with 50% for SuperGreen film), and all three films exhibited good UV-blocking (10-30% transmission). Where a UV-blocking film is needed, Anti-*Botrytis* film blocks UV across a wide range of wavelengths. Trials on a number of ornamentals in the Republic of Ireland, reported by one of the manufacturers, reported that the best quality produce when assessed visually, happened under SterilLite and Luminance THB films.

This project was carried out using small ‘French tunnels’, but the findings should be equally applicable to large, multi-span ‘Spanish tunnels’. While these tunnels are relatively cheap at about £17,000 per ha, compared with glasshouses, they do present a number of problems compared with growing in the open. There are significant costs of irrigating, weeding and ventilating, and the labour involved in generally checking and maintaining the structures should not be underestimated. The tunnel environment can be uneven, for example due to excess water alongside gutters or tunnel sides, or wind from raised tunnel sides. Finally, the overall strength of the structure needs to be considered, in relation to the overall exposure of the site and any provision of natural or artificial windbreaks. Many films are now guaranteed for three to five years’ use on conventional tunnels, but this may not apply to French or Spanish tunnels, where there is much more wear as the film is not secured to the same extent.

ACKNOWLEDGEMENTS

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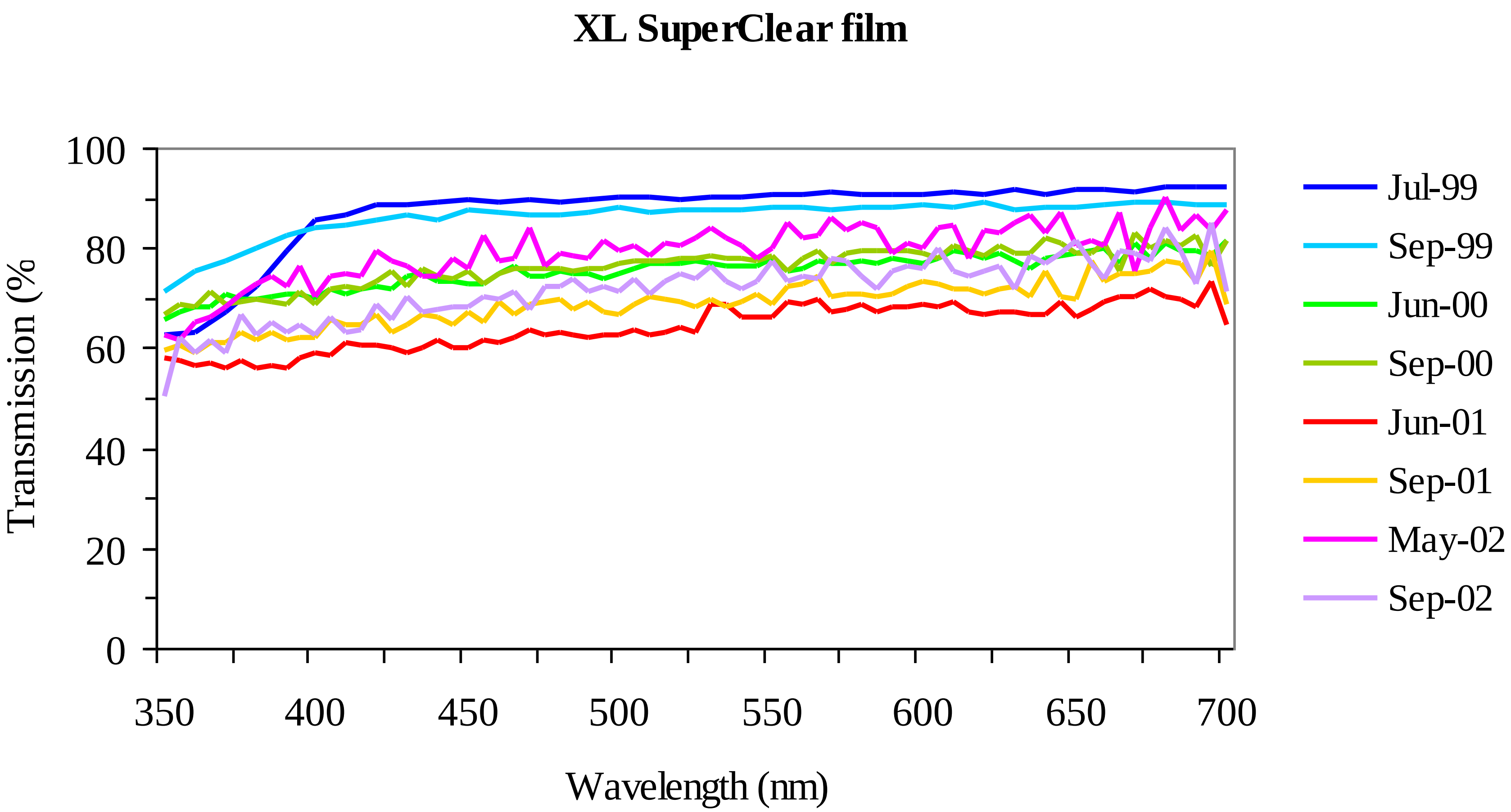
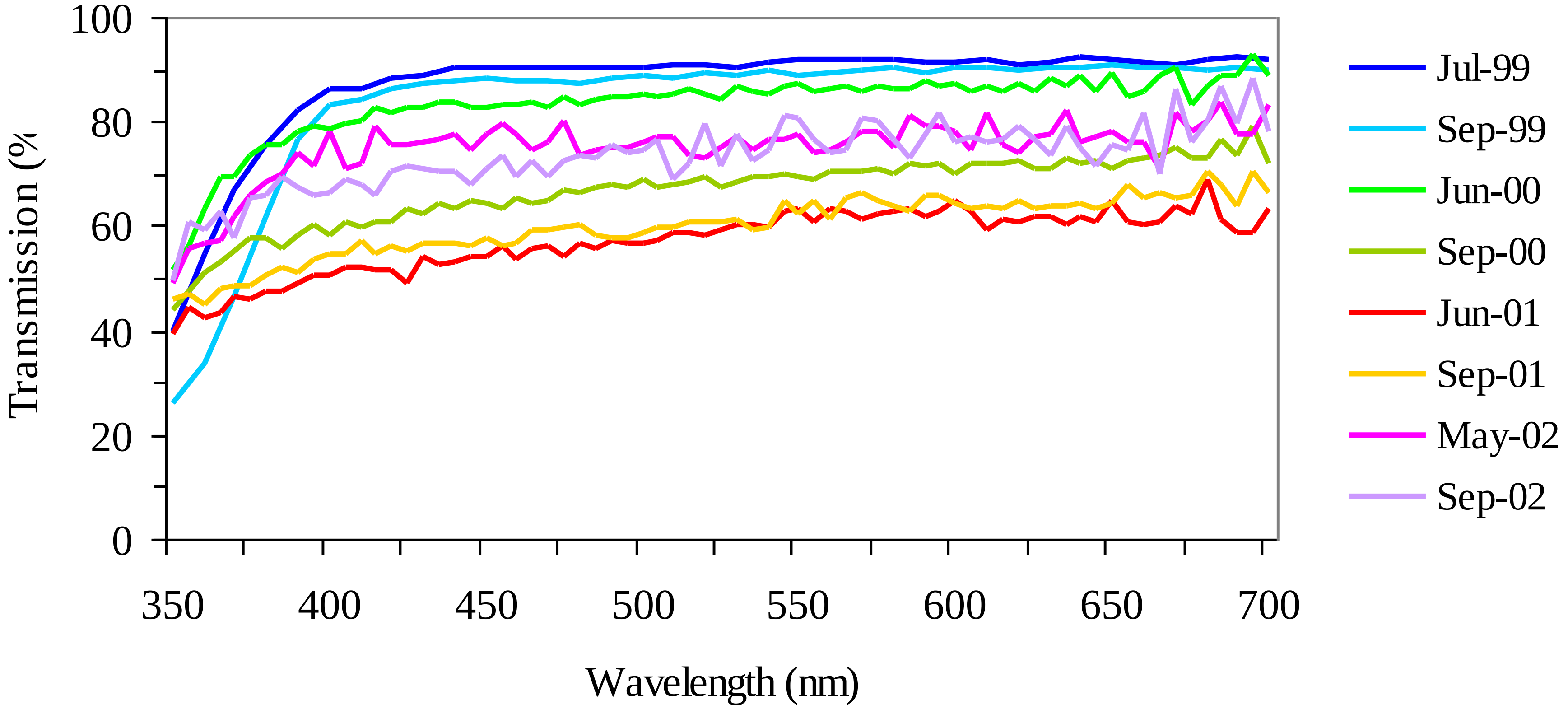
APPENDIX A: SPECTRA FOR FILMS OVER FOUR YEARS

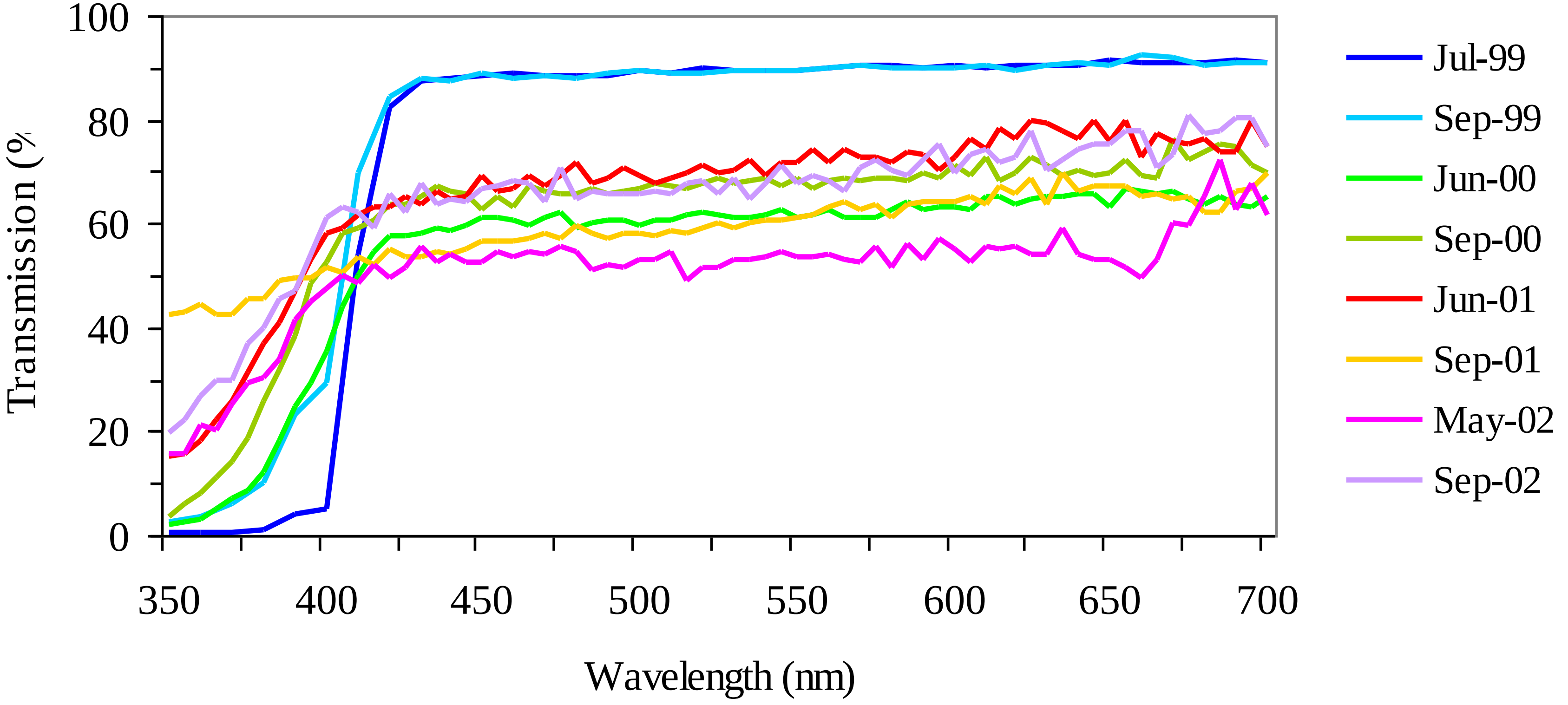


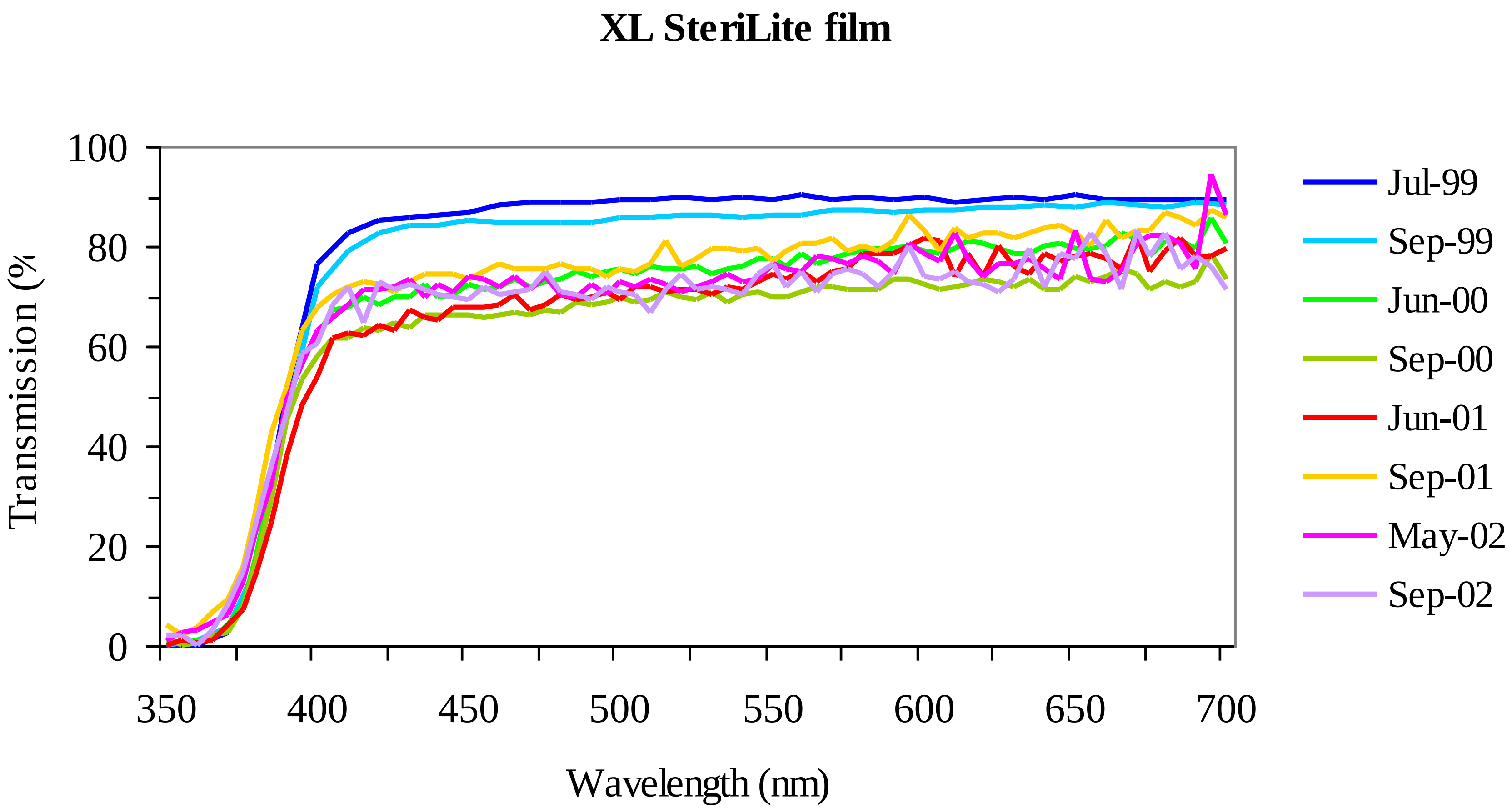
XL SuperClear film
100
80
60
40
20
0
Transmission (%
350
400
450
500
550
600
650
700
Wavelength (nm)
Jul-99
Sep-99
Jun-00
Sep-00
Jun-01
Sep-01
May-02
Sep-02

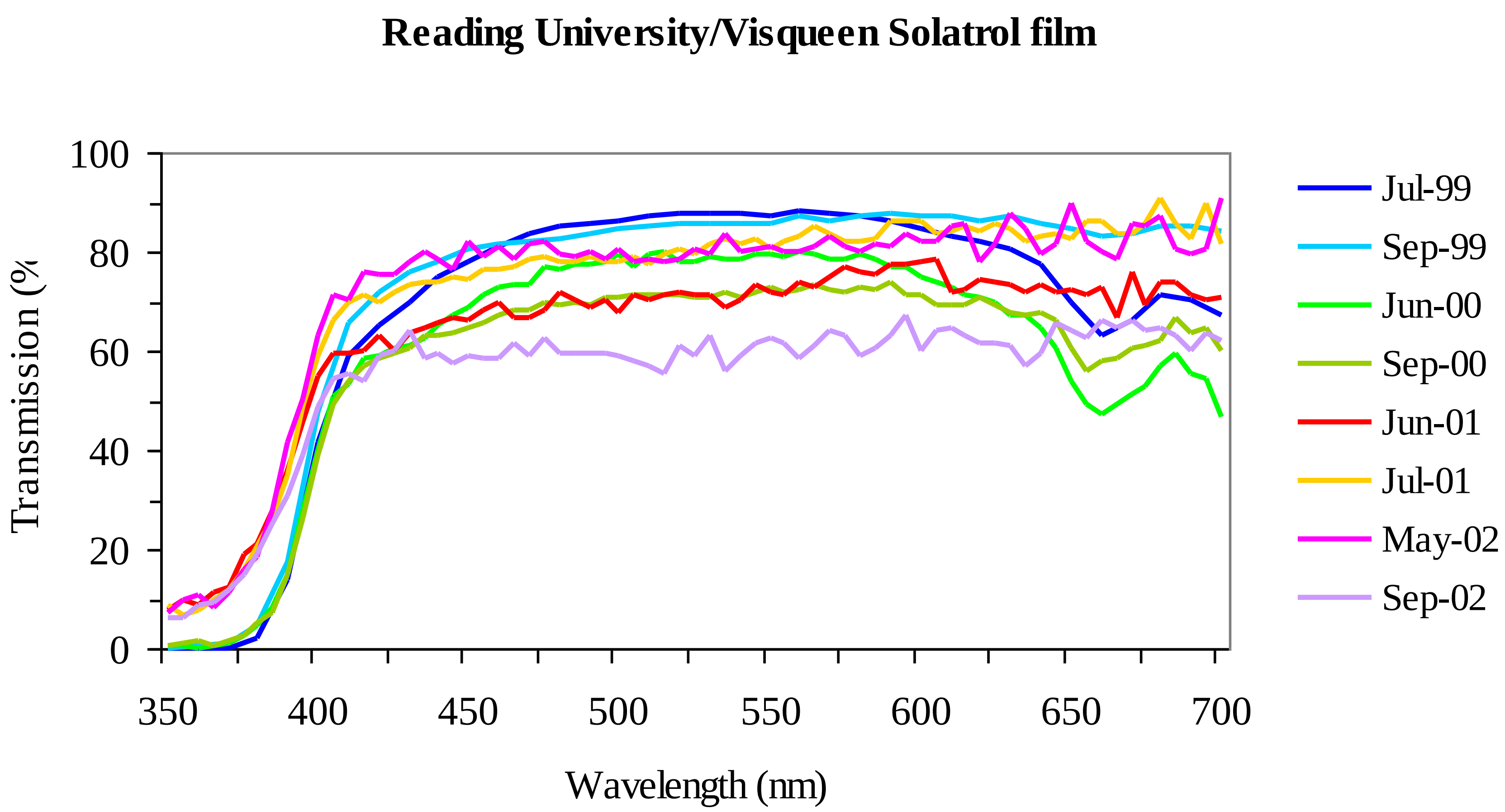
Visqueen Clear film



Visqueen Anti-*Botrytis* film

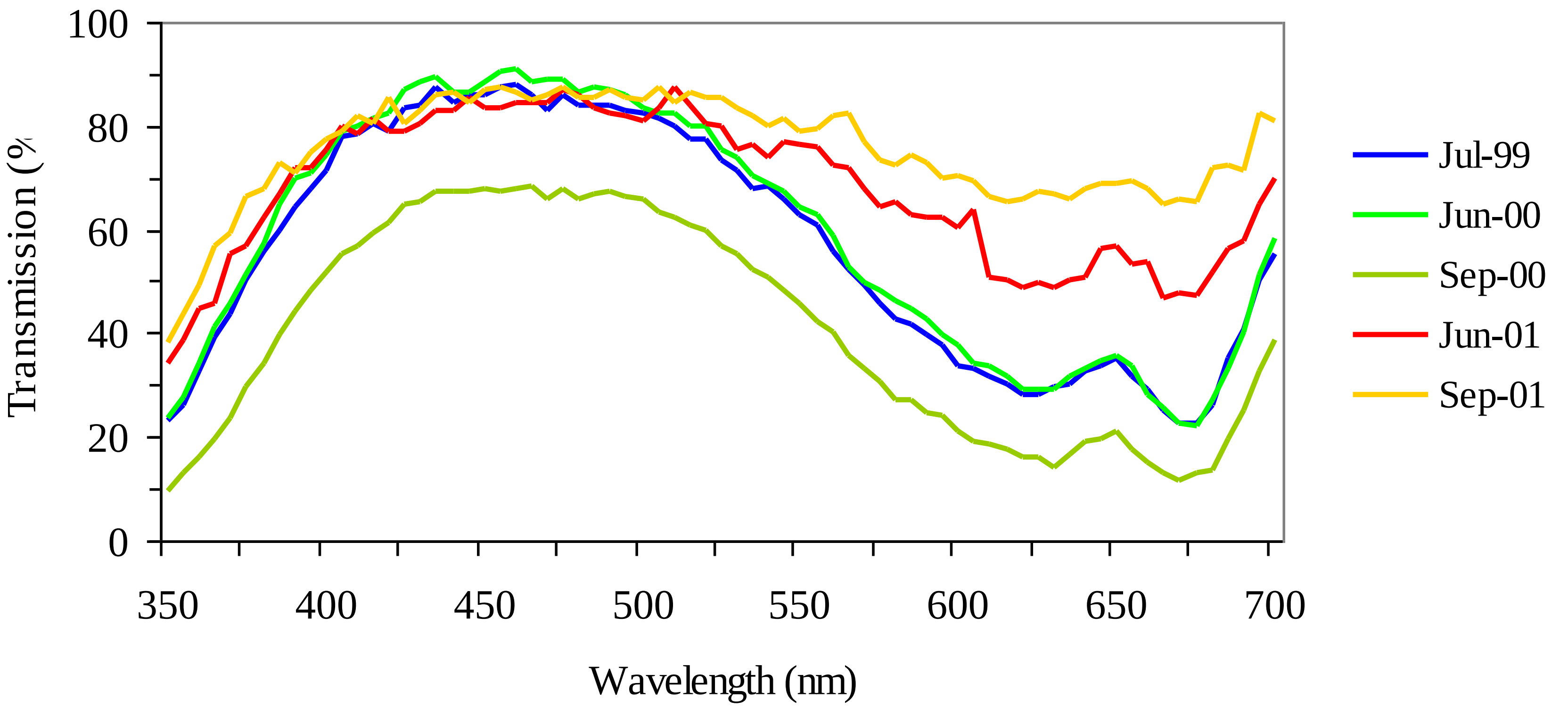


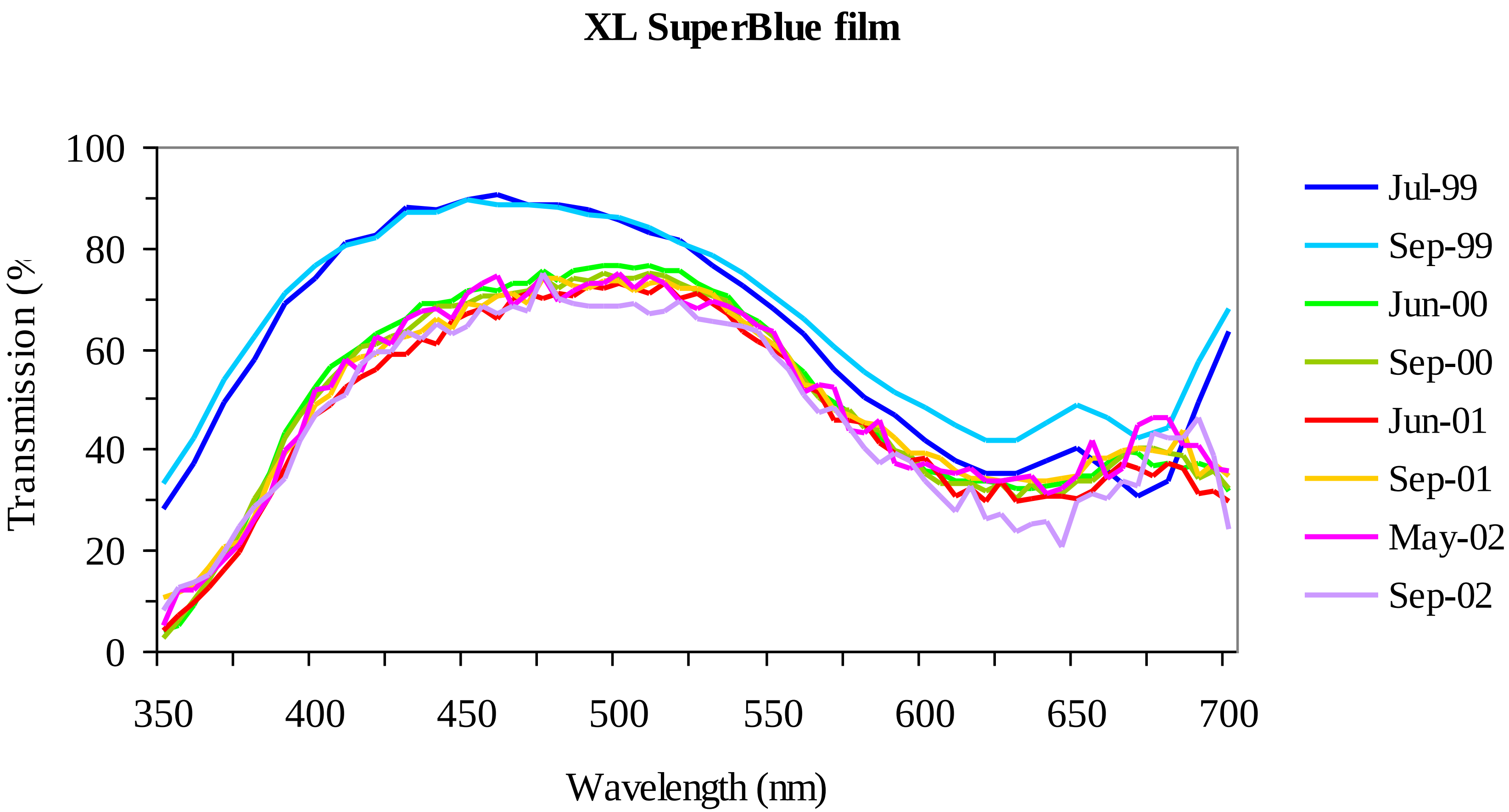

XL SteriLite film
Transmission (%
Wavelength (nm)
0
20
40
60
80
100
350
400
450
500
550
600
650
700
Jul-99
Sep-99
Jun-00
Sep-00
Jun-01
Sep-01
May-02
Sep-02

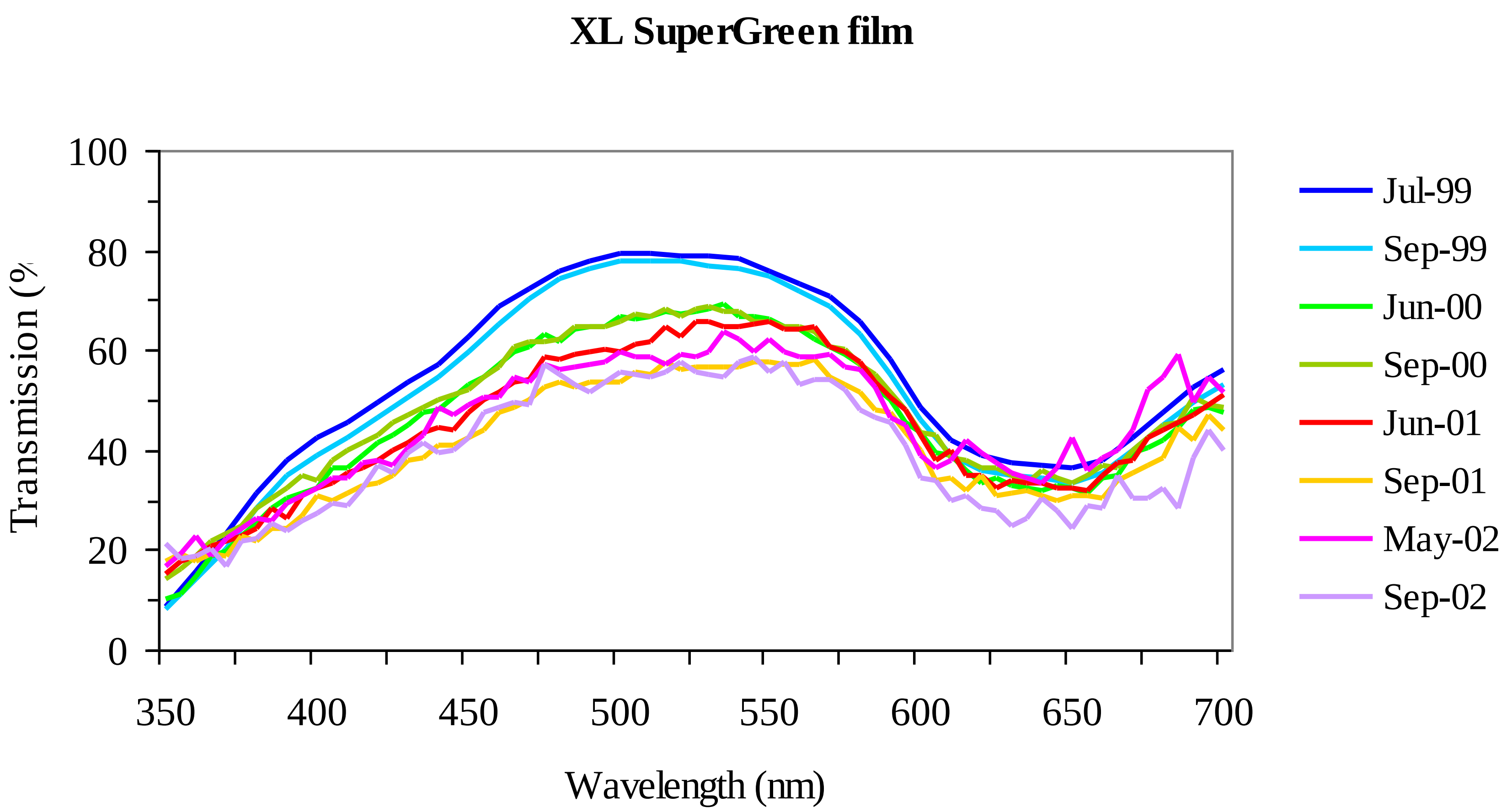


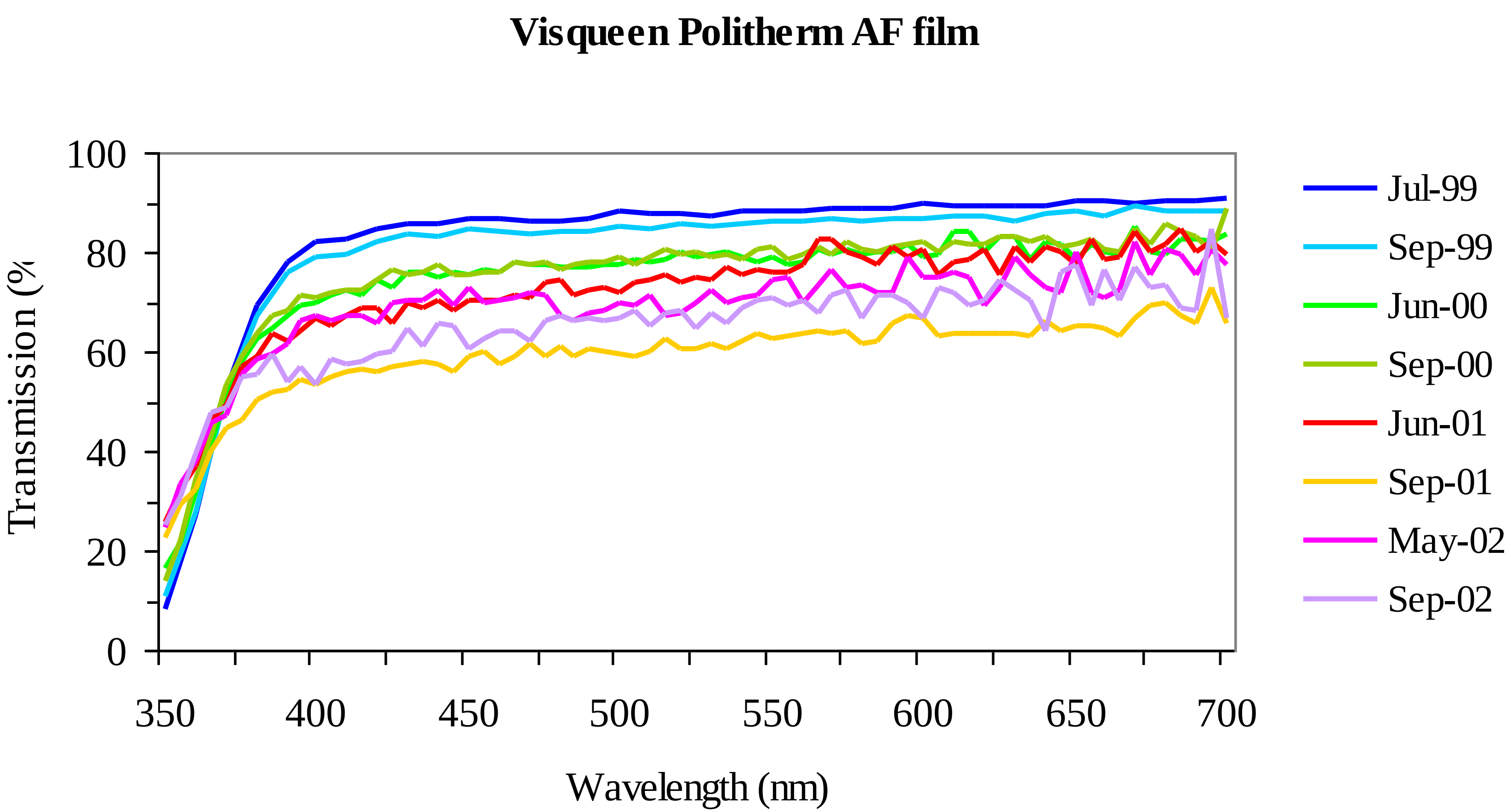
Reading University/Visqueen Solatrol film
100
80
60
40
20
0
Transmission (%
350
400
450
500
550
600
650
700
Wavelength (nm)
Jul-99
Sep-99
Jun-00
Sep-00
Jun-01
Jul-01
May-02
Sep-02

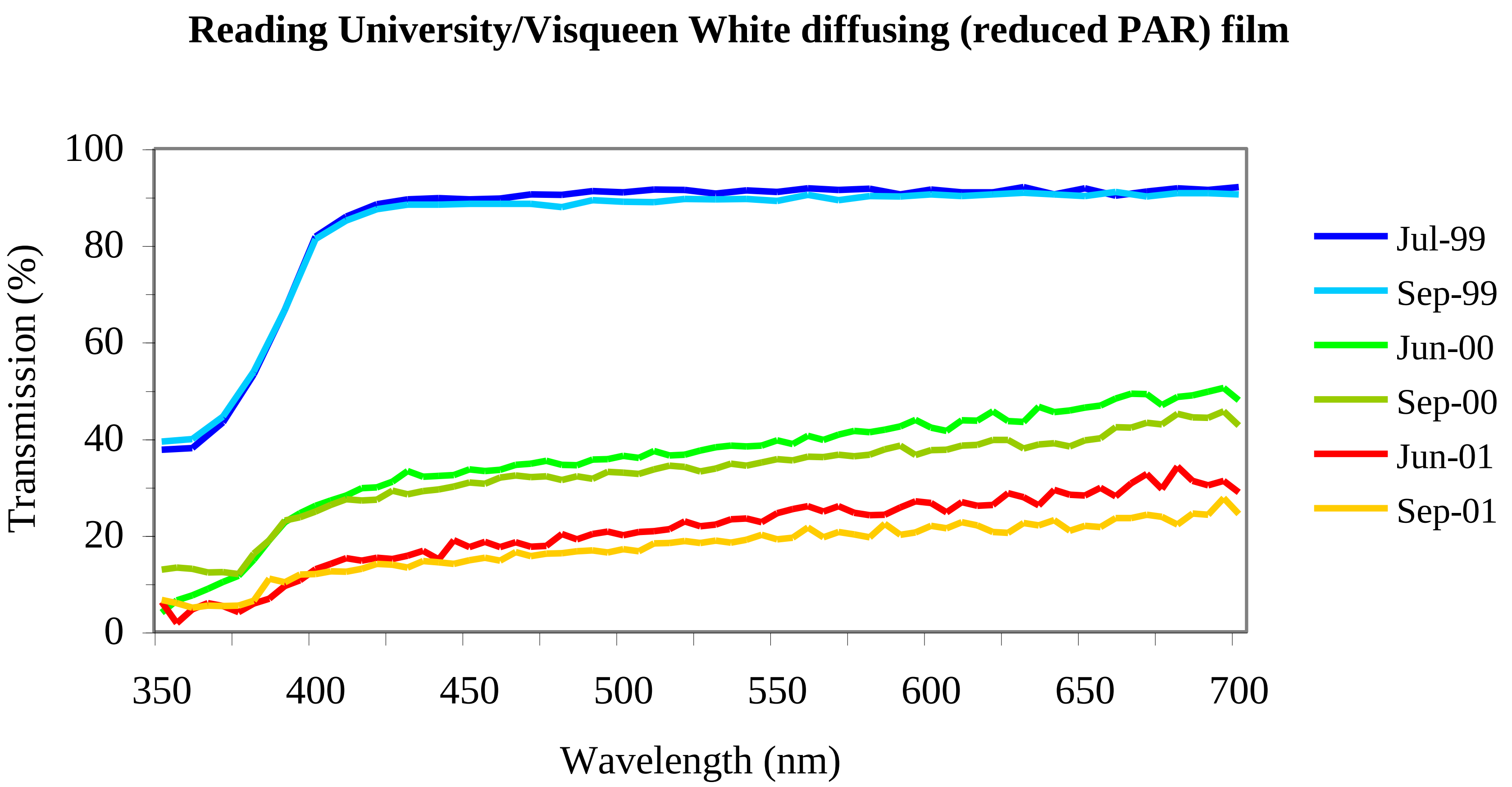
Steel Blue filter (Lee Filters)



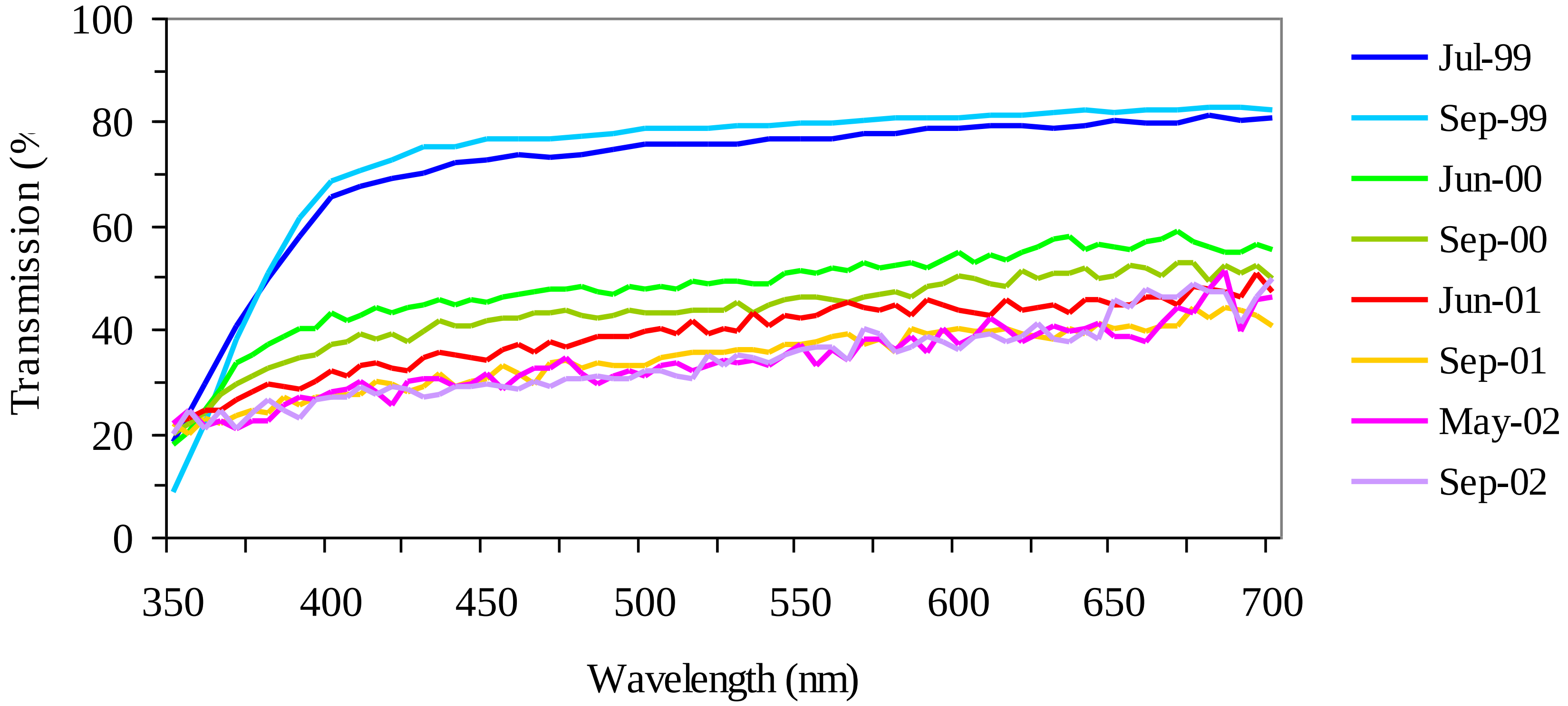

XL SuperBlue film
Transmission (%
Wavelength (nm)
100
80
60
40
20
0
350
400
450
500
550
600
650
700
Jul-99
Sep-99
Jun-00
Sep-00
Jun-01
Sep-01
May-02
Sep-02


XL SuperGreen film
Transmission (%)
Wavelength (nm)
100
80
60
40
20
0
350
400
450
500
550
600
650
700
Jul-99
Sep-99
Jun-00
Sep-00
Jun-01
Sep-01
May-02
Sep-02


Visqueen Politherm AF film
Transmission (%
Wavelength (nm)
100
80
60
40
20
0
350
400
450
500
550
600
650
700
Jul-99
Sep-99
Jun-00
Sep-00
Jun-01
Sep-01
May-02
Sep-02


Reading University/Visqueen White diffusing (reduced PAR) film
100
80
60
40
20
0
Transmission (%)
350
400
450
500
550
600
650
700
Wavelength (nm)
Jul-99
Sep-99
Jun-00
Sep-00
Jun-01
Sep-01

Visqueen Luminance THB film



APPENDIX B: CROP RESULTS FOR 1999 AND 2000

Table B1. The results of growing *Chrysanthemum morifolium* under different films in 1999. Only the main effect means are presented.

Tunnel no.	*Film type*	*Film name*	*Plant length (cm)*	*Plant weight (g)*	*Spray length (cm)*	*Spray weight (g)*	*No. of flowers / spray*	*No. of stems / plant*
Film type and name								
2	-	No cover (outside control)	87.8 z	297.2	84.1 z	53.5	31.1	12.3
14	Std	SuperClear	95.4 y	296.6	90.7 y	52.1	28.5	11.7
1	Std	Visqueen Clear	96.8 y	288.2	91.8 y	56.4	27.9	11.7
8	UV	Anti-*Botrytis*	100.6 y	284.5	95.4 y	48.2	26.5	11.5
3	UV	SteriLite	100.5 y	288.6	95.8 y	48.9	27.9	11.7
4	R:FR	Solatrol	88.8 z	269.4	85.5	46.4	29.1	12.4
6a	R:FR	Steel Blue	101.0 y	313.0	94.9 y	58.9	28.5	10.9 y
6b	R:FR	SuperBlue	91.6	263.3	88.0	44.9	29.2	12.1
11	R:FR	SuperGreen	109.1 yz	267.5	103.4 yz	55.0	23.7 y	10.8 y
13	AC	Politherm AF	105.5 yz	299.5	101.4 yz	66.4 yz	29.5	12.0
5	PAR	White (reduced PAR)	93.4	257.0	89.3	41.3 yz	29.5	12.6
10	IR	Luminance THB	103.5 yz	343.7 yz	99.5 yz	65.0 yz	30.2	11.6
12	IR	Luminance THB (early cover only)	93.4	258.2	88.2	51.1	24.8 y	11.3
9	IR	Luminance THB (late cover only)	92.3	325.6	88.0	66.1 yz	31.7	11.6
7	IR	Luminance THB (early and late cover only)	95.1	276.0	90.6	53.2	30.2	12.3
		SED (28 d.f.)	2.50	23.57	2.77	4.88	2.33	0.50
Position								
		West	97.1	291.4	95.6	55.1	28.5	11.8
		Centre	98.1	289.9	93.7	55.0	28.5	11.7
		East	95.7	284.3	91.0	51.3	28.2	11.8
		SED (28 d.f.)	1.12	10.54	1.24	2.18	1.04	0.22
Significance of factors								
		Film	*** (P<0.001)	* (P=0.032)	*** (P<0.001)	*** (P<0.001)	(*) (P=0.091)	* (P=0.040)
		Position	NS (P=0.114)	NS (P=0.778)	NS (P=0.102)	NS (P=0.155)	NS (P=0.957)	NS (P=0.739)

The letters following film means indicate that there was significant differences (P<0.05) between specified comparisons:

- Part-time cover treatment means marked x are significantly different from the mean for all-season Luminance THB film
- Treatment means marked y are significantly different from the mean for 'no cover'
- Treatment means marked z are significantly different from means for both 'standard' films

NS, not significant; (*), *, ** and ***, significant at the 10, 5, 1 and 0.1% levels of probability

Table B2. The results of growing *Chrysanthemum morifolium* under different films in 2000. Only the main effect means are presented.

Tunnel no.	*Film type*	*Film name*	*Spray length (cm)*	*Spray weight (g)*	*No. of flowers / spray*
Film type and name					
2	-	No cover (outside control)	54.7 z	48.9	6.5
14	Std	SuperClear	62.6 y	47.1	7.3
1	Std	Visqueen Clear	66.9 y	51.6	5.8
8	UV	Anti-*Botrytis*	70.6 y	50.8	7.3
3	UV	SteriLite	64.5 y	44.8	6.0
4	R:FR	Solatrol	51.0 z	34.2 y	5.9
6a	R:FR	Steel Blue	81.2 yz	47.1	6.1
6b	R:FR	SuperBlue	67.8 y	40.9	6.2
11	R:FR	SuperGreen	70.6 y	43.5	7.0
13	AC	Politherm AF	72.5 y	57.5	6.4
5	PAR	White (reduced PAR)	74.0 yz	49.5	6.8
10	IR	Luminance THB	70.6 y	46.4	7.2
12	IR	Luminance THB (early cover only)	69.2 y	50.5	6.2
9	IR	Luminance THB (late cover only)	53.9 z	47.0	7.8
7	IR	Luminance THB (early and late cover only)	72.7 yz	56.3	6.1
		SED (28 d.f.)	2.49	5.68	0.61
Position					
		West	66.8	46.1	6.6
		Centre	69.2	49.7	6.6
		East	66.6	47.8	6.6
		SED (28 d.f.)	1.11	2.54	0.27
Significance of factors					
		Film	*** (P<0.001)	(*) (P=0.053)	* (P=0.042)
		Position	** (P=0.002)	NS (P=0.362)	NS (P=0.978)

The letters following film means indicate that there were significant differences (P<0.05) between specified comparisons:

- Part-time cover treatment means marked x are significantly different from the mean for all-season Luminance THB film
- Treatment means marked y are significantly different from the mean for 'no cover'
- Treatment means marked z are significantly different from means for both 'standard' films

NS, not significant; (*), *, ** and ***, significant at the 10, 5, 1 and 0.1% levels of probability

Table B3. The results of growing *Godetia amoena* under different films in 1999. Only the main effect means are presented.

Tunnel no.	*Film type*	*Film name*	*Plant length (cm)*	*Plant weight (g)*	*No. of flowers / plant*	*No. of stems / plant*	*No. of leaves / stem*
Film type and name							
2	-	No cover (outside control)	48.7	129.4	56.6	15.0	7.5
14	Std	SuperClear	54.0 y	133.1	61.4	14.8	7.0
1	Std	Visqueen Clear	61.4 y	119.1	51.0	15.3	7.0
8	UV	Anti-*Botrytis*	57.2 y	107.8	48.9	11.1 yz	7.3
3	UV	SteriLite	58.9 y	124.4	54.6	13.9	6.5
4	R:FR	Solatrol	57.2 y	120.6	47.5	12.6 yz	6.7
6a	R:FR	Steel Blue	54.7 y	132.0	53.7	14.8	6.8
6b	R:FR	SuperBlue	56.2 y	136.4	56.8	14.9	7.3
11	R:FR	SuperGreen	59.0 y	113.8	42.7	14.1	7.1
13	AC	Politherm AF	60.6 y	146.3	65.2	12.4 yz	7.5
5	PAR	White (reduced PAR)	53.6 y	108.5	41.0	14.4	6.8
10	IR	Luminance THB	58.6 y	134.2	61.8	13.2	7.7
12	IR	Luminance THB (early cover only)	54.7 y	127.0	61.9	13.6	7.1
9	IR	Luminance THB (late cover only)	51.6	141.8	59.3	14.6	7.9
7	IR	Luminance THB (early and late cover only)	56.6 y	107.1	51.2	12.8	7.3
		SED (28 d.f.)	2.57	15.90	8.09	1.11	0.58
Position							
		West	54.0	127.6	54.5	14.2	7.2
		Central	58.6	120.8	52.8	13.5	7.1
		East	56.0	127.9	55.5	13.8	7.2
		SED (28 d.f.)	1.15	7.11	3.62	0.50	0.26
Significance of factors							
		Film	** (P=0.002)	NS (P=0.316)	NS (P=0.145)	* (P=0.027)	NS (P=0.628)
		Position	** (P=0.002)	NS (P=0.536)	NS (P=0.750)	NS (P=0.432)	NS (P=0.955)

The letters following film means indicate that there were significant differences (P<0.05) between specified comparisons:

- Part-time cover treatment means marked x are significantly different from the mean for all-season Luminance THB film
- Treatment means marked y are significantly different from the mean for 'no cover'
- Treatment means marked z are significantly different from means for both 'standard' films

NS, not significant; (*), *, ** and ***, significant at the 10, 5, 1 and 0.1% levels of probability

Table B4. The results of growing *Godetia amoena* under different films in 2000. Only the main effect means are presented.

Tunnel no.	*Film type*	*Film name*	*Plant length (cm)*	*Plant weight (g)*	*No. of flowers / plant*	*No. of stems / plant*	*No. of leaves / stem*
Film type and name							
2	-	No cover (outside control)	71.1 z	130.8	47.7	11.9	11.3
14	Std	SuperClear	74.1	100.2 y	29.4 y	13.4	11.8
1	Std	Visqueen Clear	79.4 y	105.3 y	42.3	11.1	10.8
8	UV	Anti-*Botrytis*	69.7	96.6 y	40.5	11.7	12.2
3	UV	SteriLite	78.9 y	100.1 y	40.1	11.1	8.2
4	R:FR	Solatrol	75.6	96.6 y	40.7	12.3	10.0
6a	R:FR	Steel Blue	75.4	75.8 yz	29.0 y	6.3 yz	8.2
6b	R:FR	SuperBlue	76.3	91.1 y	40.0	8.8 yz	12.9
11	R:FR	SuperGreen	81.2 y	93.3 y	34.6 y	11.2	10.1
13	AC	Politherm AF	79.0 y	122.8	36.1 y	12.9	10.1
5	PAR	White (reduced PAR)	76.7 y	71.2 yz	39.1	7.9 yz	8.2
10	IR	Luminance THB	69.0	109.8	43.6	10.4	14.7
12	IR	Luminance THB (early cover only)	65.4	118.3	44.5	11.9	10.9 x
9	IR	Luminance THB (late cover only)	70.0	145.2	40.2	12.0	9.5 x
7	IR	Luminance THB (early and late cover only)	71.3	98.8 y	39.9	10.9	11.6
		SED (28 d.f.)	2.89	12.46	4.80	0.79	1.66
Position							
		West	71.8	103.9	38.2	10.6	11.2
		Central	76.6	103.5	41.2	10.9	9.9
		East	74.2	103.8	38.1	11.2	11.0
		SED (28 d.f.)	12.94	5.57	2.15	0.35	0.74
Significance of factors							
		Film	*** (P<0.001)	*** (P<0.001)	* (P=0.034)	*** (P=<0.001)	* (P=0.023)
		Position	** (P=0.004)	NS (P=0.997)	NS (P=0.279)	NS (P=0.254)	NS (P=0.215)

The letters following film means indicate that there were significant differences (P<0.05) between specified comparisons:

- Part-time cover treatment means marked x are significantly different from the mean for all-season Luminance THB film
- Treatment means marked y are significantly different from the mean for 'no cover'
- Treatment means marked z are significantly different from means for both 'standard' films

NS, not significant; (*), *, ** and ***, significant at the 10, 5, 1 and 0.1% levels of probability

Table B5. The results of growing *Matthiola incana* under different films in 1999. Only the main effect means are presented.

Tunnel no.	*Film type*	*Film name*	*Stem length (cm)*	*Stem weight (g)*	*No. of flowers / stem*	*No. of stems / plant*	*No. of leaves / stem*
Film type and name							
2	-	No cover (outside control)	41.2 z	92.9	22.3	16.7	27.1
14	Std	SuperClear	44.3 y	82.5 y	25.9	16.3	27.8
1	Std	Visqueen Clear	47.1 y	80.3 y	25.2	17.3	29.0
8	UV	Anti-*Botrytis*	47.9 y	87.5	27.9 y	16.9	26.9
3	UV	SteriLite	47.9 y	88.2	27.2 y	17.6	25.8
4	R:FR	Solatrol	41.2 z	83.8 y	22.1	16.2	25.8
6a	R:FR	Steel Blue	45.8 y	75.3 y	21.9	16.5	26.0
6b	R:FR	SuperBlue	41.8	86.8	23.5	16.0	26.6
11	R:FR	SuperGreen	53.6 yz	77.2 y	23.8	17.5	25.1 z
13	AC	Politherm AF	49.5 yz	90.2	25.5	17.4	28.2
5	PAR	White (reduced PAR)	42.5	84.0 y	19.5 z	16.1	24.8 y
10	IR	Luminance THB	51.4 yz	85.3 y	28.6 y	17.2	27.1
12	IR	Luminance THB (early cover only)	49.4 yz	104.0 z	27.2	17.6	26.8
9	IR	Luminance THB (late cover only)	43.0	97.0	24.2 x	14.9 xy	24.7 y
7	IR	Luminance THB (early and late cover only)	46.2 y	86.1 y	25.5	16.9	26.5
		SED (28 d.f.)	1.46	6.09	1.97	0.90	1.27
Position							
		West	45.4	85.5	23.7	16.5	25.9
		Central	47.7	83.3	25.4	16.6	27.2
		East	45.4	91.5	24.8	17.0	26.6
		SED (28 d.f.)	0.65	2.72	0.88	0.40	0.57
Significance of factors							
		Film	*** (P<0.001)	** (P=0.008)	** (P=0.002)	NS (P=0.227)	(*) (P=0.073)
		Position	*** (P=0.001)	* (P=0.016)	NS (P=0.178)	NS (P=0.429)	(*) (P=0.084)

The letters following film means indicate that there were significant differences (P<0.05) between specified comparisons:

- Part-time cover treatment means marked x are significantly different from the mean for all-season Luminance THB film
- Treatment means marked y are significantly different from the mean for 'no cover'
- Treatment means marked z are significantly different from means for both 'standard' films

NS, not significant; (*), *, ** and ***, significant at the 10, 5, 1 and 0.1% levels of probability

Table B6. The results of growing *Matthiola incana* under different films in 2000. Only the main effect means are presented.

Tunnel no.	*Film type*	*Film name*	*Stem length (cm)*	*Stem weight (g)*	*No. of flowers / stem*	*No. of stems / plant*	*No. of leaves / stem*
Film type and name							
2	-	No cover (outside control)	48.0	61.6	21.6	16.5	29.2
14	Std	SuperClear	52.8 y	52.5	21.4	17.1	28.4
1	Std	Visqueen Clear	54.6 y	56.6	19.9 y	16.2	26.9
8	UV	Anti-*Botrytis*	55.2 y	59.4	20.5	16.3	28.2
3	UV	SteriLite	53.6 y	54.6	20.7	15.4	28.4
4	R:FR	Solatrol	46.4 z	54.3	20.2 y	16.3	29.4
6a	R:FR	Steel Blue	59.4 yz	50.5 y	18.0 yz	18.2	31.3
6b	R:FR	SuperBlue	61.8 yz	45.2 y	20.3	17.6	27.9
11	R:FR	SuperGreen	57.0 y	49.7 y	20.8	16.6	27.6
13	AC	Politherm AF	55.1 y	58.6	19.9 y	16.8	29.1
5	PAR	White (reduced PAR)	58.1 yz	45.8 y	20.8	16.8	27.5
10	IR	Luminance THB	54.5 y	61.0	21.8	16.4	28.6
12	IR	Luminance THB (early cover only)	57.2 y	63.7	17.7 xyz	16.5	28.7
9	IR	Luminance THB (late cover only)	45.6 x z	60.4	20.9	16.4	27.3
7	IR	Luminance THB (early and late cover only)	54.7 y	60.9	20.4 x	16.0	29.8
		SED (28 d.f.)	1.60	5.36	0.69	0.82	1.59
Position							
		West	53.4	53.8	20.6	16.5	28.0
		Central	55.4	56.5	20.0	16.7	27.9
		East	54.0	56.7	20.4	16.7	29.8
		SED (28 d.f.)	0.72	2.40	0.31	0.37	0.71
Significance of factors							
		Film	*** (P<0.001)	* (P=0.024)	*** (P<0.001)	NS (P=0.275)	NS (P=0.512)
		Position	* (P=0.023)	NS (P=0.424)	NS (P=0.117)	NS (P=0.902)	* (P=0.025)

The letters following film means indicate that there were significant differences (P<0.05) between specified comparisons:

- Part-time cover treatment means marked x are significantly different from the mean for all-season Luminance THB film
- Treatment means marked y are significantly different from the mean for 'no cover'
- Treatment means marked z are significantly different from means for both 'standard' films

NS, not significant; (*), *, ** and ***, significant at the 10, 5, 1 and 0.1% levels of probability

Table B7. The results of growing *Dianthus caryophyllus* under different films in 1999. Only the main effect means are presented[1].

Tunnel no.	*Film type*	*Film name*	*Stem length (cm)*	*Stem weight (g)*	*No. of flowers / stem*
Film type and name					
2	-	No cover (outside control)	42.2	23.8	6.9
14	Std	SuperClear	42.6	25.6	8.1
1	Std	Visqueen Clear	na	na	na
8	UV	Anti-*Botrytis*	41.4	22.3	6.3
3	UV	SteriLite	49.8	29.1	6.5
4	R:FR	Solatrol	47.0	31.1	6.0
6a	R:FR	Steel Blue	48.2	30.1	7.0
6b	R:FR	SuperBlue	37.8	16.2	6.1
11	R:FR	SuperGreen	50.8	18.1	4.8
13	AC	Politherm AF	45.0	25.6	7.5
5	PAR	White (reduced PAR)	35.7	14.1	5.4
10	IR	Luminance THB	44.9	18.9	5.7
12	IR	Luminance THB (early cover only)	39.6	19.6	6.7
9	IR	Luminance THB (late cover only)	38.4	19.7	6.1
7	IR	Luminance THB (early and late cover only)	38.4	20.0	4.8
		SED[2] (24 d.f.)	5.52	6.08	2.30
Significance					
		Film	*** (P=0.001)	*** (P<0.001)	NS (P=0.251)

[1] Due to variable plant establishment analysis of variance carried out only at film (tunnel) level
[2] Average value of SED is quoted because of variable replication
na, data not available
The letters following film means indicate significant differences (P<0.05) between specified comparisons:

- Part-time cover treatment means marked x are significantly different from the mean for all-season Luminance THB film
- Treatment means marked y are significantly different from the mean for ‘no cover’
- Treatment means marked z are significantly different from means for both ‘standard’ films

NS, not significant; (*), *, ** and ***, significant at the 10, 5, 1 and 0.1% levels of probability

Table B8. The results of growing *Dianthus caryophyllus* under different films in 2000. Only the main effect means are presented.

Tunnel no.	*Film type*	*Film name*	*Stem length (cm)*	*Stem weight (g)*	*No. of flowers / stem*
Film type and name					
2	-	No cover (outside control)	56.0	21.0	5.5
14	Std	SuperClear	60.3	32.2 y	7.5 y
1	Std	Visqueen Clear	55.3	20.3	4.8
8	UV	Anti-*Botrytis*	55.8	24.4	7.2
3	UV	SteriLite	58.6	20.6	5.2
4	R:FR	Solatrol	58.6	21.7	5.9
6a	R:FR	Steel Blue	54.4	19.4	4.4
6b	R:FR	SuperBlue	55.8	19.5	4.6
11	R:FR	SuperGreen	59.0	22.5	6.0
13	AC	Politherm AF	70.2 yz	25.6 y	4.6
5	PAR	White (reduced PAR)	53.4	20.3	6.2
10	IR	Luminance THB	56.6	24.0	6.4
12	IR	Luminance THB (early cover only)	63.0 y	24.8	6.0
9	IR	Luminance THB (late cover only)	50.7	27.8 y	7.1
7	IR	Luminance THB (early and late cover only)	51.6	20.9	5.9
		SED (28 d.f.)	3.17	2.08	0.97
Position					
		West	55.8	20.9	5.2
		Central	59.8	24.8	6.4
		East	58.9	22.9	5.8
		SED (28 d.f.)	1.42	0.93	0.43
Significance of factors					
		Film	*** (P<0.001)	*** (P<0.001)	* (P=0.048)
		Position	* (P=0.025)	*** (P<0.001)	* (P=0.029)

The letters following film means indicate significant differences (P<0.05) between specified comparisons:

- Part-time cover treatment means marked x are significantly different from the mean for all-season Luminance THB film
- Treatment means marked y are significantly different from the mean for 'no cover'
- Treatment means marked z are significantly different from means for both 'standard' films

NS, not significant; (*), *, ** and ***, significant at the 10, 5, 1 and 0.1% levels of probability

APPENDIX C: METEOROLOGICAL DATA FOR KIRTON WEATHER STATION

Table C1. Selected meteorological data from Kirton weather station, 1999 and 2000

	Rain (mm)			*Days with >0.2mm rain*			*Hours of sun*		
	1999	*2000*	*LTM*[1]	*1999*	*2000*	*LTM*	*1999*	*2000*	*LTM*
January	76.3	18.5	52.7	19	11	15	33	73	57
February	22.3	45.2	34.5	11	20	13	53	96	82
March	62.7	15.7	39.8	15	6	14	92	109	106
April	34.3	94.5	47.2	14	20	14	160	140	143
May	57.8	76.3	48.6	13	16	12	195	186	198
June	77.0	12.1	45.8	16	10	12	174	168	179
July	12.6	32.7	46.5	6	10	10	224	121	205
August	99.7	39.5	55.4	16	12	11	140	205	196
September	33.7	82.6	52.4	15	15	13	150	109	132
October	78.4	89.8	54.5	11	18	14	117	97	115
November	39.1	97.9	54.9	17	17	15	62	68	68
December	48.1	53.1	48.9	21	16	15	59	49	48
Annual	642.0	657.9	581.2	174	171	158	1459	1421	1541

	Mean max. daily temperature (C)			*Mean min. daily temperature (C)*			*Mean mean daily temperature (C)*		
	1999	*2000*	*LTM*	*1999*	*2000*	*LTM*	*1999*	*2000*	*LTM*
January	8.1	8.0	6.6	0.8	1.4	1.0	4.5	4.7	3.8
February	8.1	9.3	7.2	-0.4	2.2	1.1	3.9	5.7	4.2
March	11.1	11.4	9.9	2.1	3.5	2.8	6.6	7.4	6.4
April	13.6	12.3	12.2	3.6	4.4	3.8	8.6	8.3	8.0
May	17.6	16.5	15.9	7.8	7.7	6.7	12.7	12.1	11.3
June	18.5	19.7	18.6	9.3	11.0	9.6	13.9	15.3	14.1
July	20.9	19.0	21.5	12.3	11.1	11.8	16.6	15.1	16.7
August	21.6	22.3	21.5	12.9	11.6	11.7	17.3	17.0	16.6
September	21.2	19.4	18.0	11.5	11.3	9.6	16.3	15.3	13.8
October	14.6	13.7	14.3	7.2	7.1	7.0	10.9	10.4	10.7
November	10.5	10.0	9.6	4.7	3.6	3.5	7.6	6.8	6.5
December	7.1	7.6	7.2	1.3	2.9	2.1	4.2	5.3	4.7
Annual	14.4	14.1	13.5	6.1	6.5	5.9	10.3	10.3	9.7

[1]LTM =long-term (20 years) mean

APPENDIX D: SUMMARY OF HDC PROJECT PC 170

P&D levels in tunnels at Kirton

Materials and methods

Crops growing under the following films were monitored for pests at two-week intervals from 25 July to 25 September 2000: Visqueen Clear, SteriLite, Steel Blue, Anti-*Botrytis* and Luminance THB. On each assessment 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 (25cm x 20cm) was placed near the centre of each tunnel approximately 15cm above chrysanthemum flowers. The numbers of each pest species per trap were counted every two weeks and traps were replaced. No pests were found on the godetia plots at the first assessment, so these were not assessed further.

Crops growing under all films (except SuperBlue) were assessed for a range of diseases on 25 July 2000 and 19 September 2000. To assess 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. To assess *Sclerotinia* on stocks, the total number of plants displaying aerial lesions were counted per plot.

Results

Pest Numbers
Pest numbers were low throughout and there were insufficient numbers to compare statistically (Tables D1 and D2). The numbers of pests on the different crops were combined.

Table D1. Average numbers of pests on 27 shoots per assessment under different films.

Film	*Aphids*	*Leaf miners*	*Thrips*	*Caterpillars*
No cover	201.0	2.5	5.3	3.0
SteriLite	0	1.2	8.6	1.8
Anti-*Botrytis*	0	1.8	11.8	1.2
Luminance THB	0.4	2.6	1.6	1.8
Steel Blue	2.4	6.6	1.8	2.4

Table D2. Average numbers of pests caught on sticky traps per assessment.

Film	*Aphids*	*Leaf miners*	*Thrips*	*Caterpillars*
No cover	0	0.3	11.3	4.0
SteriLite	0	0	6.5	0
Anti-*Botrytis*	0	0	7.5	0.5
Luminance THB	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

On the first recording date there were differences in the levels of infection of downy mildew (*Peronospora destructor*) on stocks (Table D3). Analysis of variance indicated a significant effect due to the different films. In non-covered plots, and under Solatrol and Steel Blue films, the incidence of downy mildew was low when compared with crops growing under other films.

Also on stocks, sclerotinia (*Sclerotinina sclerotiorum*) infection on aerial plant tissues was noted with resulting stem die-back and collapse of the flower heads. Only low levels of infection symptoms were recorded, except under White (reduced PAR) film, where there was a marked increase in infection levels compared with the other films.

Levels of *Botrytis* infection were low on the first assessment and there were no other diseases observed on the other plants at this time.

At the second assessment 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 and with no obvious differences in levels between the films.

Table D3. Disease incidence on stocks under different films (25 July 2000).

Film	*Downy mildew infection[1]* (disease index 0-100)	*Sclerotinia infection[2]* (no. plants per plot)
Non-covered	16.7	0
Visqueen Clear	46.7	2.0
SteriLite	54.3	0.3
Solatrol	14.3	0.3
White (reduced PAR)	31.0	6.7
Steel Blue	10.0	0
Anti-*Botrytis*	46.7	0
Luminance THB	53.3	0
SuperGreen	34.3	0.3
Politherm AF	44.3	0
SuperClear	36.7	0
Significance	***	-
SED (22 d.f.)	8.40	-

[1]Disease index from 0, no infection, good quality, to 100, severe infection, plants dead or of very poor quality.
[2] Statistical analysis was not carried out on these data.

Discussion

Unfortunately, the overall pest levels were low and no clear conclusions about the effects of spectral filters on pest incidence could be drawn. There was a suggestion that crops under the UV-absorbing films (SteriLite and Anti-*Botrytis*) had fewer aphids than non-covered crops.

Although only a few pathogens were monitored, significant differences in levels of downy mildew (*Peronospora destructor*) were recorded between films. The results recorded on stocks confirm previous studies carried out in Israel where the use of plastics with blue pigments was shown to reduce the colonisation and sporangial production of downy mildew infection of cucumbers. In addition, small-scale studies in the UK have identified the potential of a number of films to control downy mildew (*P. parasitica*) on brassica transplants. Downy mildew diseases require blocking of UV-B wavelengths to inhibit sporulation, and hence blue filters controlled disease levels 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 UV-A wavelengths (320-400nm) has led to significant reductions in development of *Botrytis*, although in that work infector plants were used to introduce a number of strains of *B. cinerea* into the crop. SteriLite and Anti-*Botrytis* films have both claimed activity in reducing sporulation of *Botrytis* by blocking UV-A radiation. The low levels of *Botryis* infection within the crops could be the reason that no difference were found between the films under test. Research conducted elsewhere has shown marked reductions in sporulation of *Botrytis cinerea* under similar filters, 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 might lead to significant reductions in disease levels under UK light conditions, and further investigation is warranted. Pathogens of particular interest include *Botrytis cinerea*, powdery and downy mildews, *Sclerotinia* and leaf spotting pathogens.

APPENDIX E: AVAILABILITY OF FILMS FOR COVERING TUNNELS

The 49 suppliers of 'Plastic film and sheeting' or 'Polyhouses and accessories' listed in 'Grower' magazine directories[1] were contacted by fax in 2002, asking for information on polythene films for covering tunnels. Of these, 37 contacts are known to have successfully received the fax, of which 18 replied (49%). Thirteen suppliers provided the information requested, while five reported that they did not supply this type of product.

The literature supplied covered the films listed in Table E1, excluding films for mushroom houses and housing livestock. Tabulated information was extracted from this literature, and is not intended to be exhaustive or a full description of the materials. Information on the various weights (gauges) of films available has not been included.

Table E1. Polythene tunnel covering materials listed as at May 2002

Maker	*Name or description*	*Properties*	*Uses*
BPI Agri (Visqueen)	Clear poly	Standard UVI/EVA film. Economical	
	Politherm AF	Good thermic properties (heat retention), anti-condensation (anti-fogging)	Plants that respond to high light levels and warm temperatures
	Luminance THB	Good thermic properties, high transmission, high diffusion, reduced risk of scorch	Ornamental plants and HONS. Improved yield of tomatoes.
	Luminance THB AF	Combines previous two properties	
	White tint	Reduced light transmission evenly through PAR spectrum, lower temperatures	Holding HONS. Plants at risk of scorching (ferns, conifers)
	Lumitherm	For strawberries in Spanish or French tunnels. High light transmission, good thermic properties.	Strawberries
	Luminance	For strawberries in Spanish or French tunnels. High diffusion.	Strawberries
	AB (anti-*Botrytis*)	High light transmission. *Botrytis* control through UV filtering.	Strawberries
	Solatrol	As internal screen in glasshouses or tunnels, or for short-term tunnel cover. Growth control film (reduced stem extension, more leaves and branches, greener leaves) through increased R:FR ratio.	Many bedding plants (response varies).
	New Concept, Lumitherm 2/3, 4STD	Thinner but tough.	

[1] The Horticultural Directory 2001 and 2002.

Unspecified by supplier (Northern Polytunnels)[1]	Politherm Plus	As Politherm AF with UV-blocking	
XL Horticulture (Opico Ltd)	SteriLite HDF	UV-blocking, IR-blocking, high diffusion, heat retention, anti-condensation, anti-algae	Organic crops. Propagation houses. Heated structures with: bedding and basket annuals, over-wintered vegetables, sun-loving, variegated and frost-susceptible HONS, sun-loving and frost-susceptible alpines, heathers and herbaceous plants, early strawberries and strawberry runners.
	SuperGreen	Reduced R:FR, anti-algae, growth control for shade-loving plants	Shade-loving plants (e.g. camellias, rhododendrons, hostas, ferns, bedding like *Impatiens*, some alpines and herbaceous plants).
	SuperBlue	Reduced R:FR, low FR, growth control (dwarfing, increased basal shooting, improved leaf colour).	Bedding and most HONS
	SuperStrength 600 HDF	Strong, IR-blocking, high diffusion, heat retention, anti-algae	Non-heated structures with: bedding and basket annuals, spring/summer vegetable production, sun-loving and variegated HONS, sun-loving or frost-susceptible alpines, heathers and herbaceous plants, strawberries.
	SuperStrength 400	Strong (for Spanish or French tunnels), total UV transmission (better strawberry quality)	Strawberries, other soft- or top-fruit, field-grown flowers and vegetables.
Unspecified by supplier (First Tunnels Ltd)[2]	SuperClear	Standard UVI/EVA film. High light transmission.	Over-wintered HONS, hardy herbaceous perennials, summer vegetables and flowers.
	Thermal Anti-fog	Anti-condensation, UV-blocking, good thermic properties	Bedding, annual plants, propagation, over-wintered vegetables, sun-loving or variegated HONS.
	SuperWhite	Reduced light transmission (less scorch)	Shade-loving plants (e.g. camellias and *Impatiens*)
Unspecified by supplier (National Polytunnels)	Plastlucent HD Multieva Thermic AF	Not available. Not available.	
Elpeflex-Keder	3-ply sandwich of polythene and ethylene vinyl acetate with 1,000 bubbles m^{-3}	Insulating, diffusing, long-life	

[1] Presumed to be BPI (Visqueen)
[2] Presumed to be Opico (XL)