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CONTENTS

GROWERS' SUMMARY[1]

PC 168

Cut-flowers: Evaluation and development of plastic films and low-cost growing structures

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).

[1] This summary repeats the information from the Final Report, with the addition of additional information from the supplementary report on the stability of polythene films.

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

- *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.

INTRODUCTION

The main aim of this project was to examine the effects on cut-flower crops (spray chrysanthemum, spray carnation, column stock and godetia) of growing in polytunnels clad with the range of polythene films available at the time (1999). These results were presented in a Final Report in April 2002. A secondary aim of the project was to test the stability of the spectral properties of the films used; this exercise was carried out over an extended period of four years, and the results are presented in the present supplementary report.

MATERIALS AND METHODS

Full details of the methods employed were presented in the Final Report. Briefly, small polythene tunnels ('French tunnels') were erected in spring 1999 and clad with the plastic films shown in Table 1. After the conclusion of cropping, in autumn 1999, the plastic films were removed from the tunnels and stored over the winter in a cool, dark shed. Samples (*ca*. A4 in size) of the films were taken at about monthly intervals from erection to removal. The Solatrol film was replaced for 2000. This process was repeated in 2000, but at the end of the growing season only a piece of each film (*ca*. 1m x 1m) was retained. During the June to September period in 2001 and 2002, the film samples were fixed to wooden frames and placed in the field in an unobstructed position at an angle of 45°. Samples were again taken at about monthly intervals and the frames with the plastic films were stored over winter as before.

Table 1. Films used

Tunnel no.	*Film type*[1]	*Film description*	*Film supplier*
14	Std	SuperClear	XL Horticulture
1	Std	Visqueen Clear	Visqueen
8	UV	Anti-*Botrytis*	Visqueen
3	UV	SteriLite	XL Horticulture
4	R:FR	Solatrol (experimental growth control film, low far red, height suppressing film)	Reading University & Visqueen
6a	R:FR	Steel Blue (blue theatrical film ref. 117, low red, height extension film)	Lee Filters
6b	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	DF	White (reduced PAR) (experimental growth control film)	Reading University & Visqueen
10	IR	Luminance THB (pale white)	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; DF, light diffusing. Film colour was clear unless stated otherwise. Films were obtained in 1999, but the Solatrol film was replaced in 2000; film specifications may have changed subsequently.

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 presented over the range 350-700nm, the most responsive range of the Imperial College instrumentation; spectra covering a wider range for the 1999 determinations can be seen in the Final Report published previously.

RESULTS

The spectra of film samples taken in 1999 – 2002 are shown in the following figures. 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.

- <u>Visqueen Anti-*Botrytis* film</u>
  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.

- <u>XL SteriLite film</u>
  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.

- <u>Reading University/Visqueen Solatrol film</u>
  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.

- <u>Steel Blue filter (Lee Filters)</u>
  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.

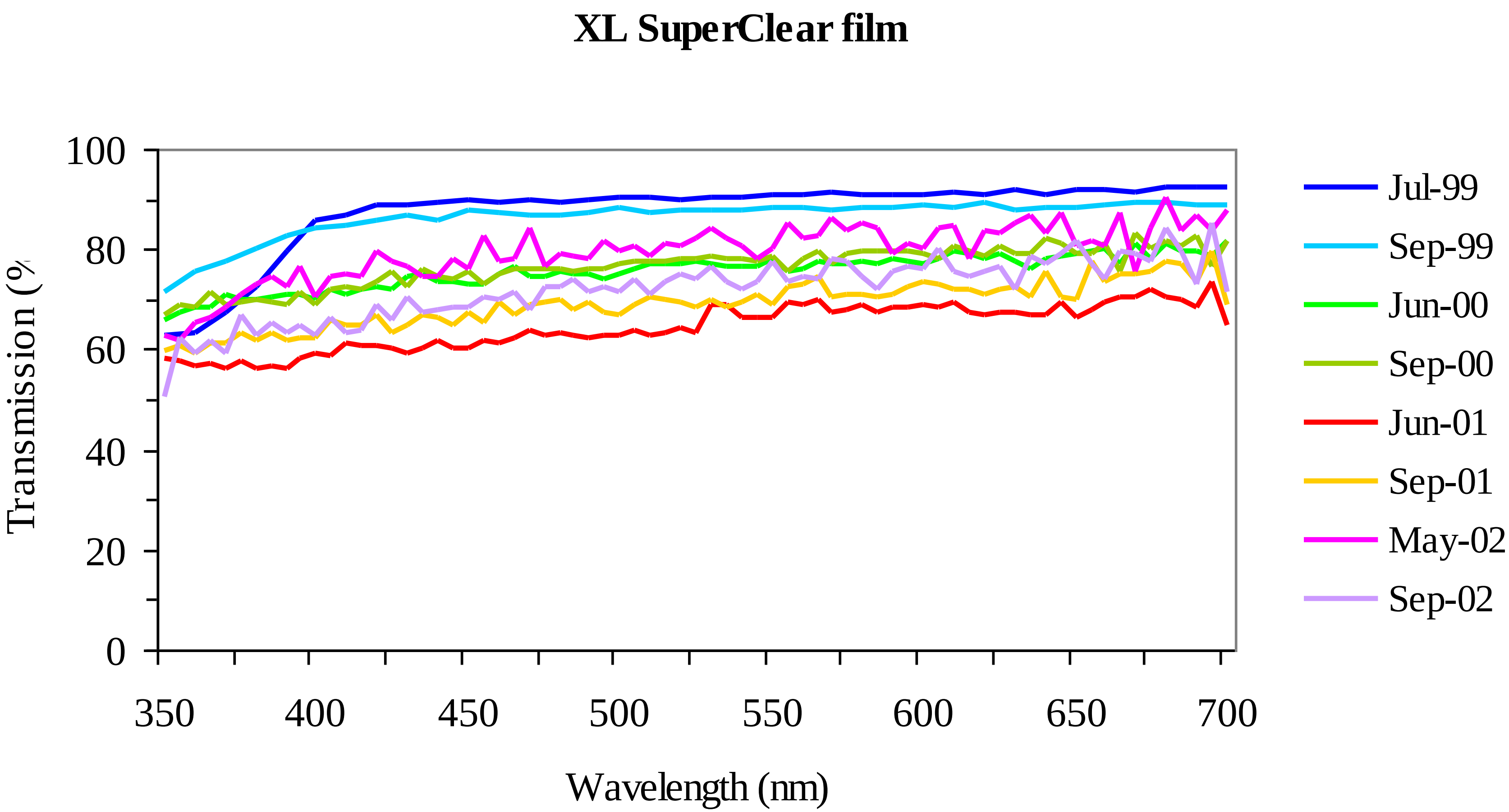
- <u>XL SuperBlue film</u>
  There was a marked loss of percentage transmission in wavelengths <500nm after the first year, but in years 2 to 4 the spectra were more or less stable. The film blocked red light transmission (around 650nm), and this was largely maintained over the four-year period.

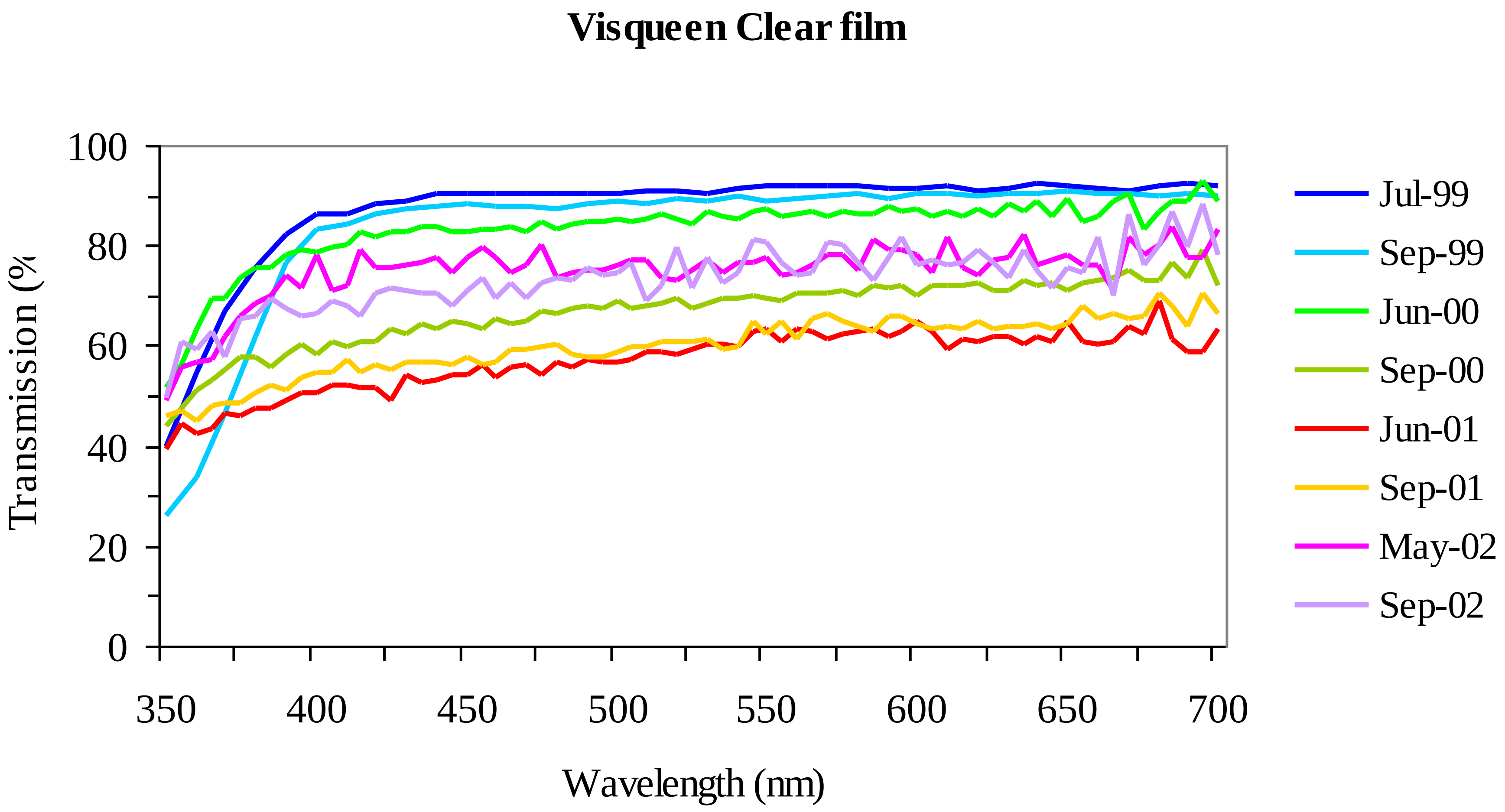
- <u>XL SuperGreen film</u>
  There was a gradual loss of transmission, especially over the range 450-550nm, the lower end of photosynthetically-active radiation (PAR), over the four-year period. the blocking of red light was maintained during the test period.

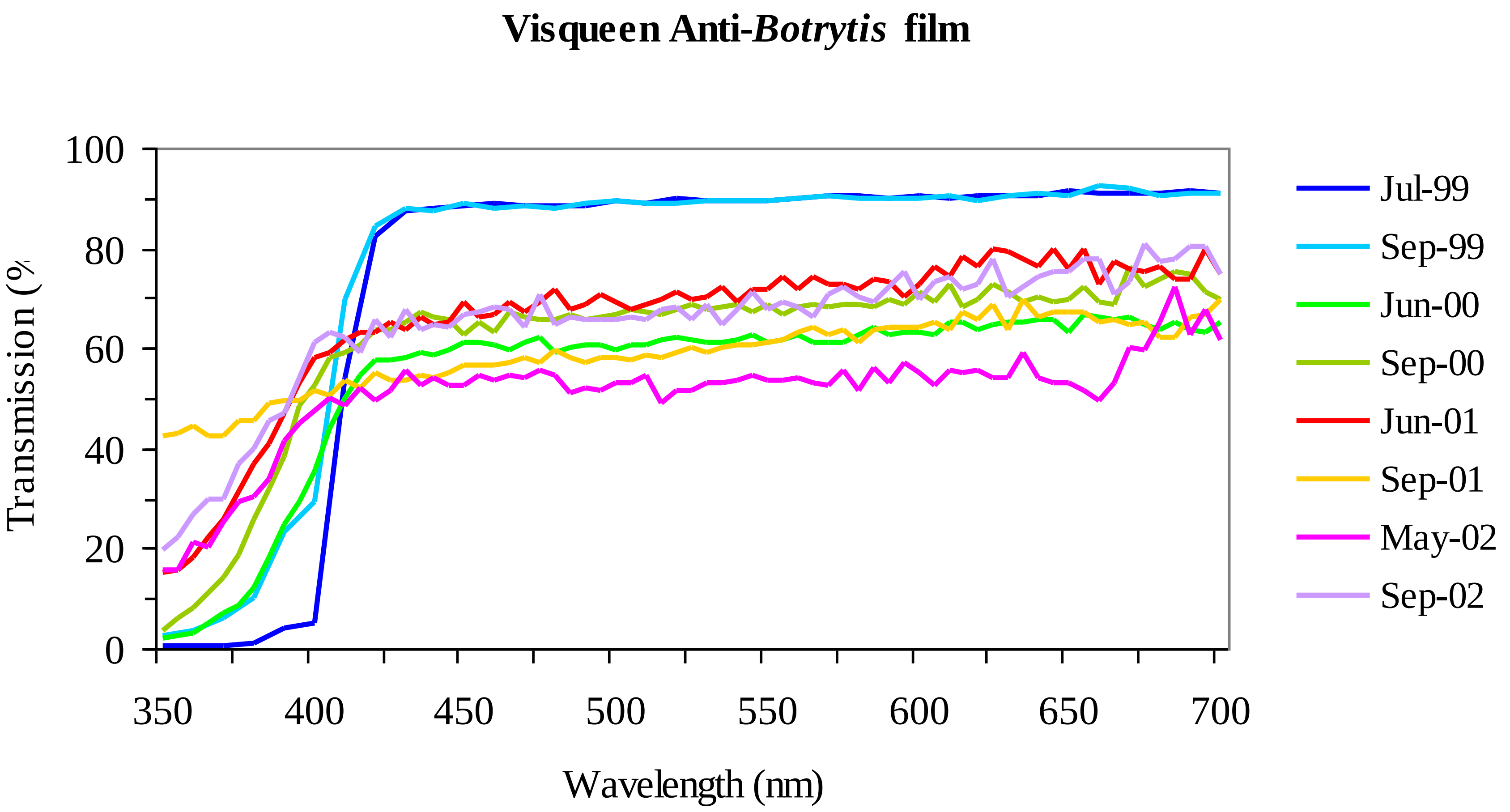
- <u>Visqueen Politherm AF</u>
  There was a gradual loss of transmission >380nm over the four years, though the loss in the third year was larger than in other years. The blocking of UV wavelengths <370nm was slightly lost after the second year.

- <u>Reading University/Visqueen White dissusing (reduced PAR) film</u>
  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.

- <u>Visqueen Luminance THB film</u>
  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.


XL SuperClear film
Transmission (%)
100
80
60
40
20
0
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
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


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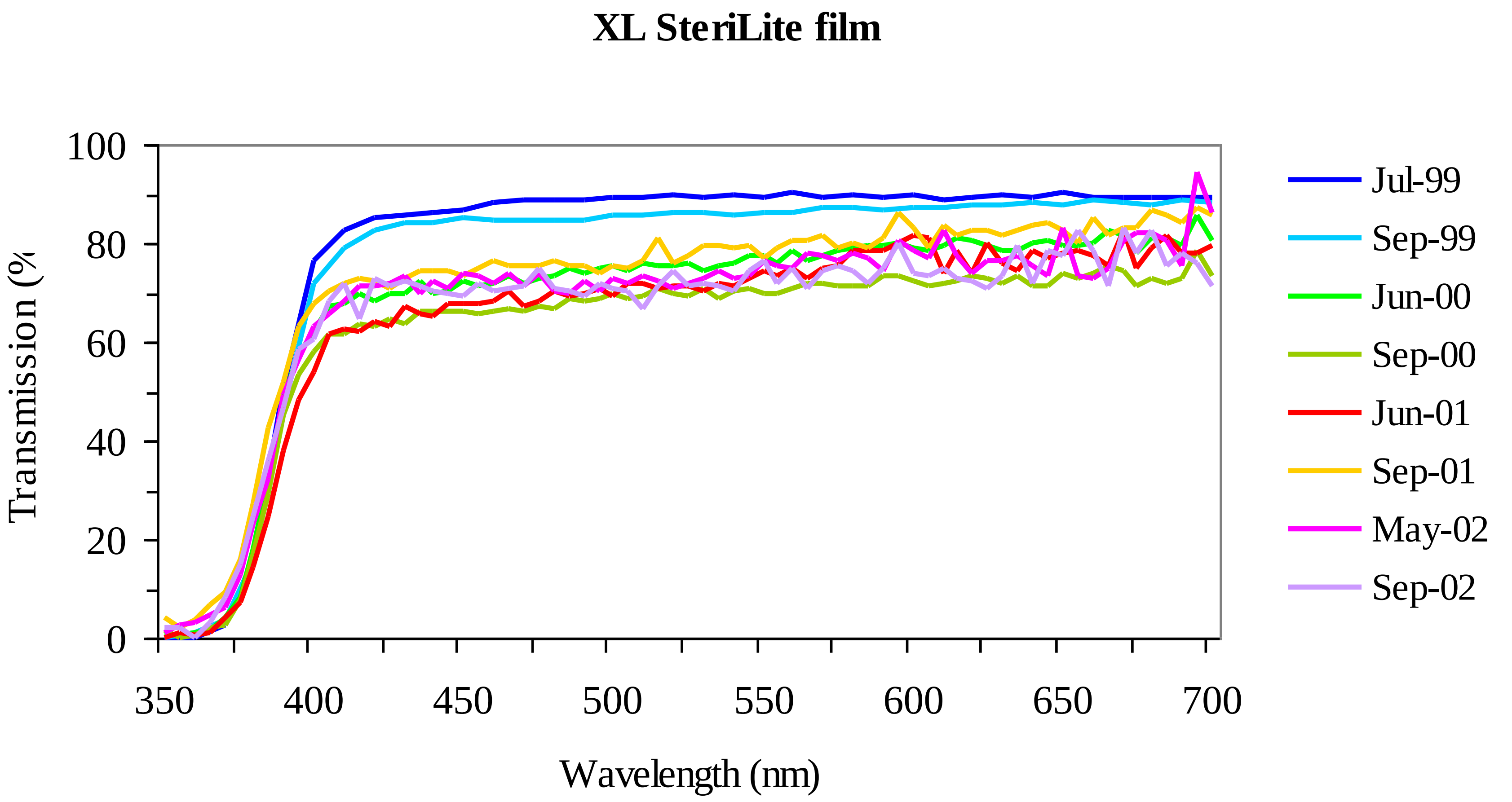
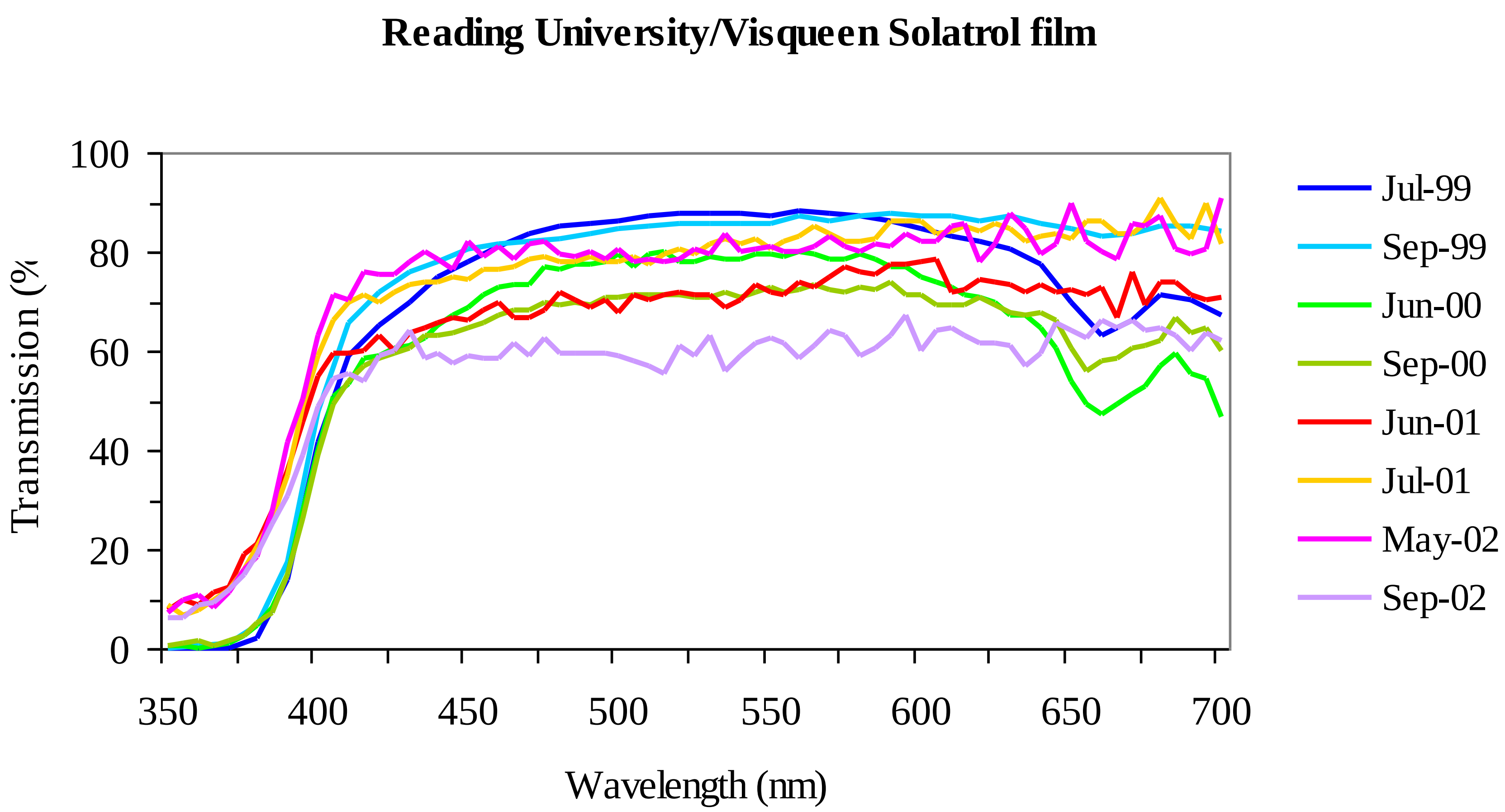
650
700
Jul-99
Sep-99
Jun-00
Sep-00
Jun-01
Sep-01
May-02
Sep-02


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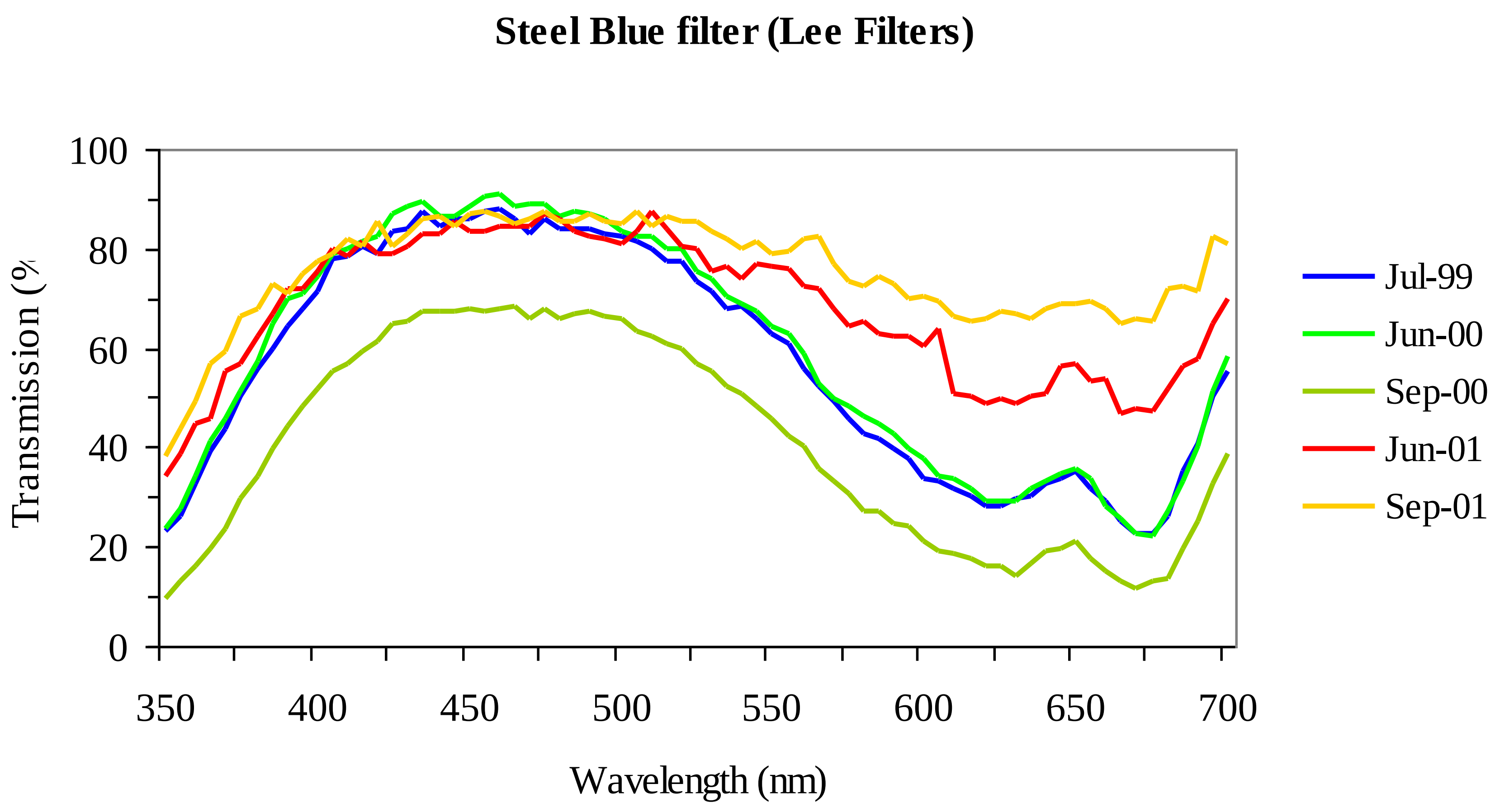
Jun-01
Jul-01
May-02
Sep-02


Steel Blue filter (Lee Filters)
100
80
60
40
20
0
Transmission (%
350
400
450
500
550
600
650
700
Wavelength (nm)
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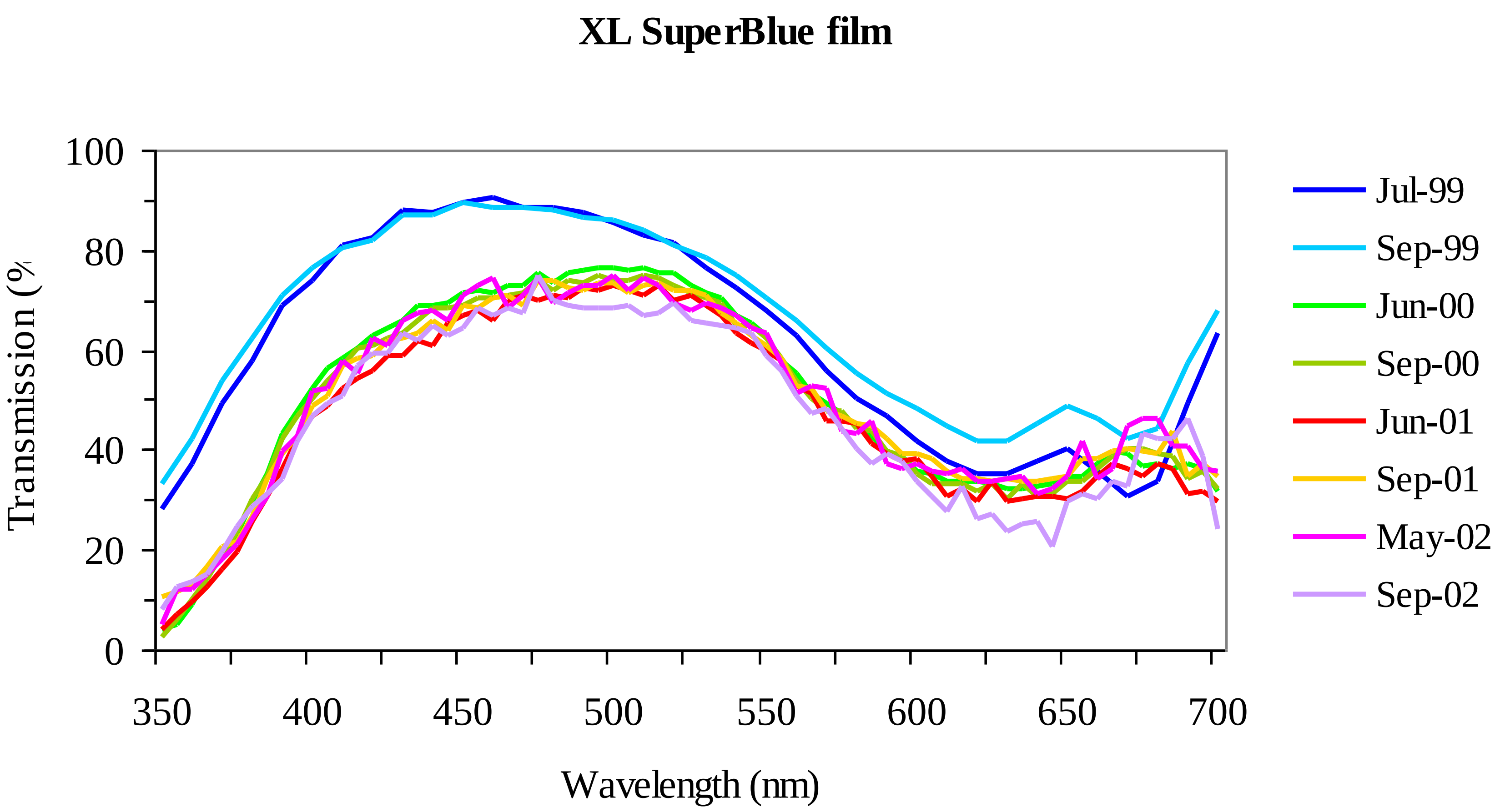
Jun-00
Sep-00
Jun-01
Sep-01


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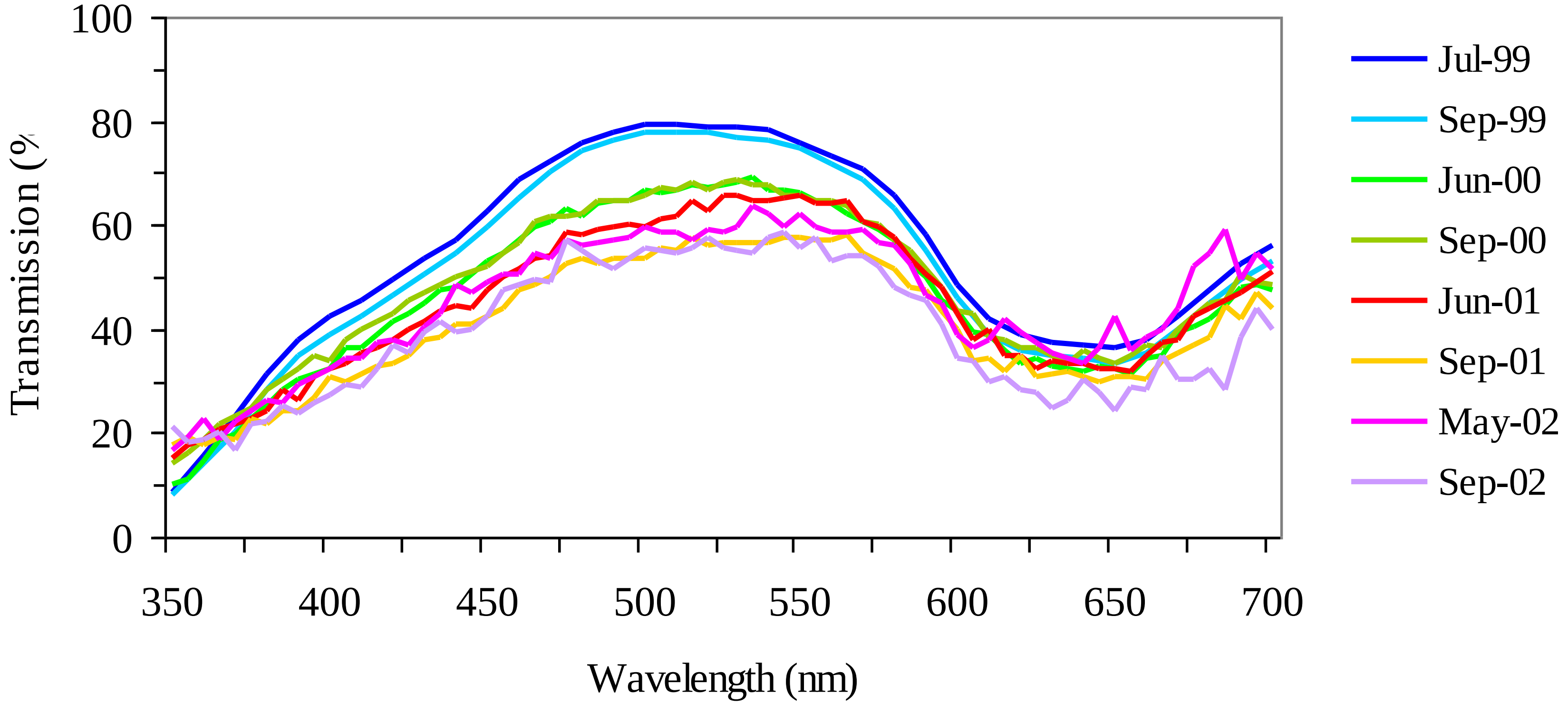
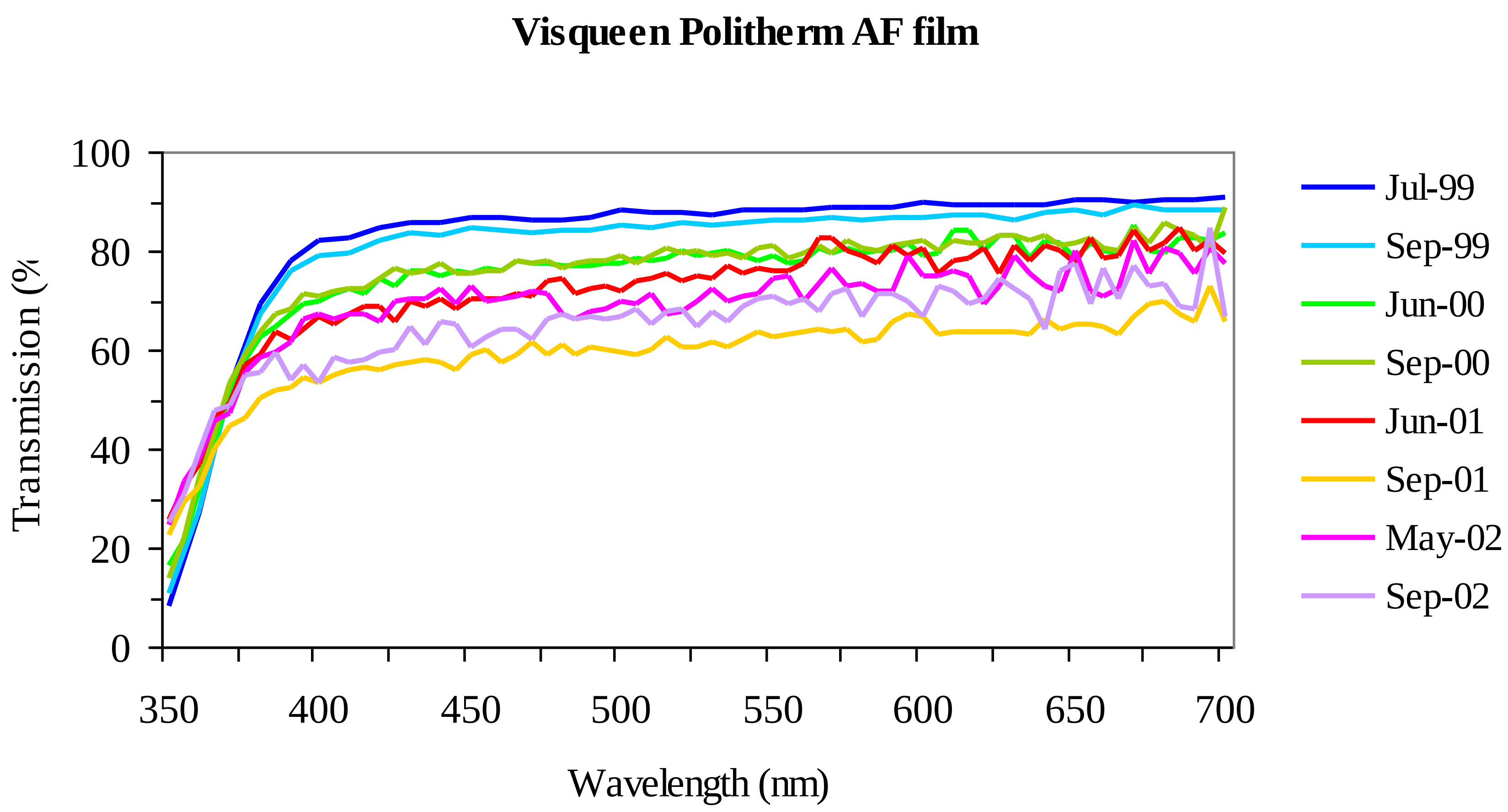
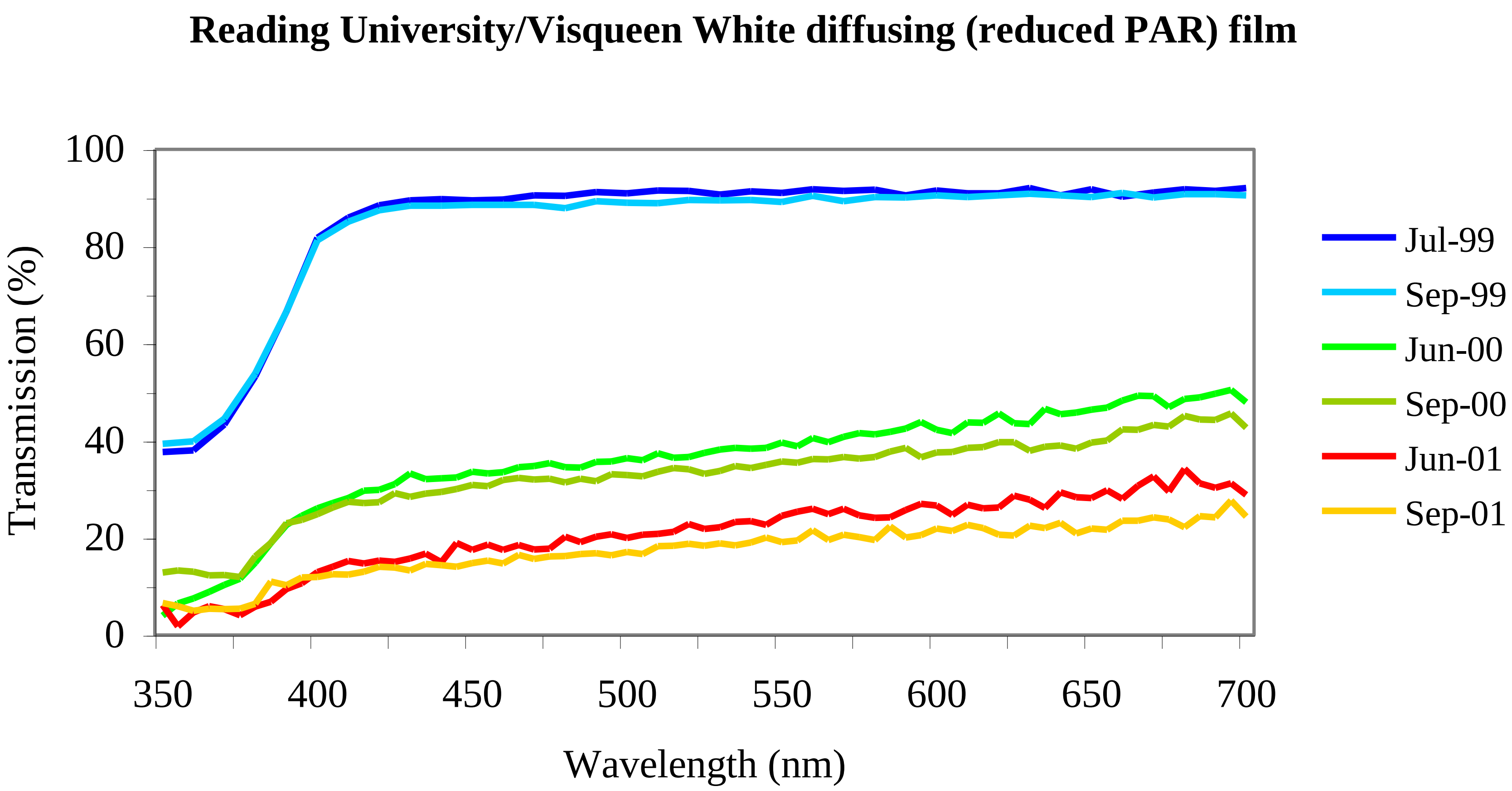
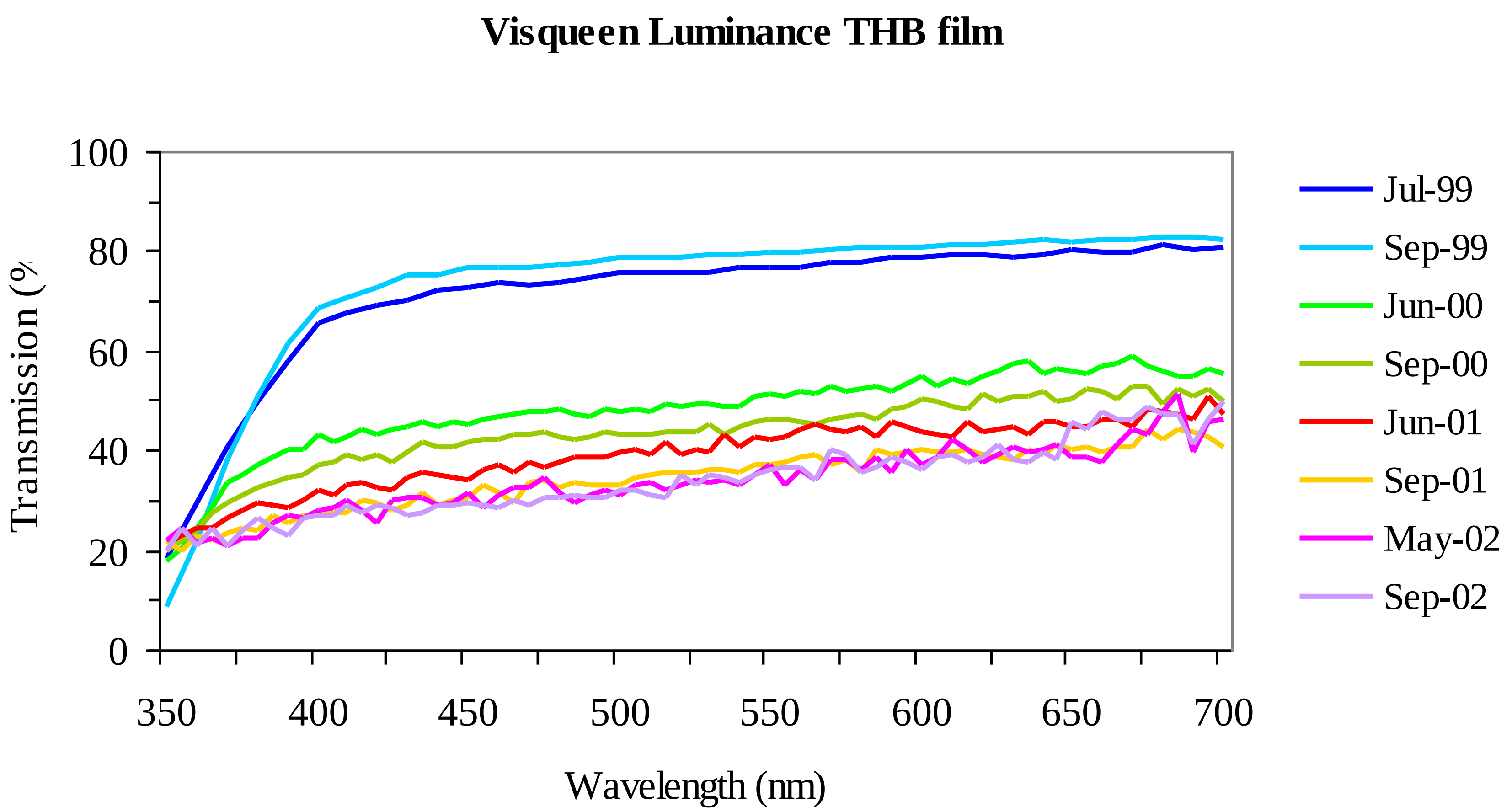
80
60
40
20
0
350
400
450
500
550
600
650
700
Jul-99
Sep-99
Jun-00
Sep-00
Jun-01
Sep-01
May-02
Sep-02

XL SuperGreen film




Visqueen Politherm AF 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 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
Transmission (%)
100
80
60
40
20
0
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

CONCLUSIONS

This report examined the stability of eleven horticultural films over a four-year period of normal environmental exposure. The main conclusions are listed below.

1. The two <u>standard clear films</u> 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.

2. Two <u>UV-absorbing films</u> were tested, Visqueen Anti-*Botryti*s 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.

3. A <u>far-red blocking film</u>, 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.

4. <u>Red blocking materials</u> 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.

5. An <u>anti-condensation film</u>, 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.

6. An <u>experimental white diffusing, reduced PAR film</u>, 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.

7. An <u>infra-red (IR) blocking film</u>, Luminance THB, produced a large loss of transmission after the first year of use.

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