Project title:	Growth of a range of nursery stock subjects under different coloured and spectral filter plastic films	
Report:	Final report, January 2003	
Project number:	HNS 108	
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Location:	Main trial:	Dove Associates, Weggs Farm, Dickleburgh, Diss, Norfolk IP21 4PJ
	Propagation work:	HRI East Malling, West Malling, Kent ME19 6BJ
Start date:	May 2001	
Duration:	14 months	
Keywords:	Spectral filters, plastics, light transmission, protected cropping, tunnel structures, hardy nursery stock, plant growth, propagation	

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GROWER SUMMARY

Headline

Plastic films with different spectral transmission characteristics show potential for the manipulation of growth, flowering and foliage colour within a range of hardy nursery stock (HNS) species.

Background and expected deliverables

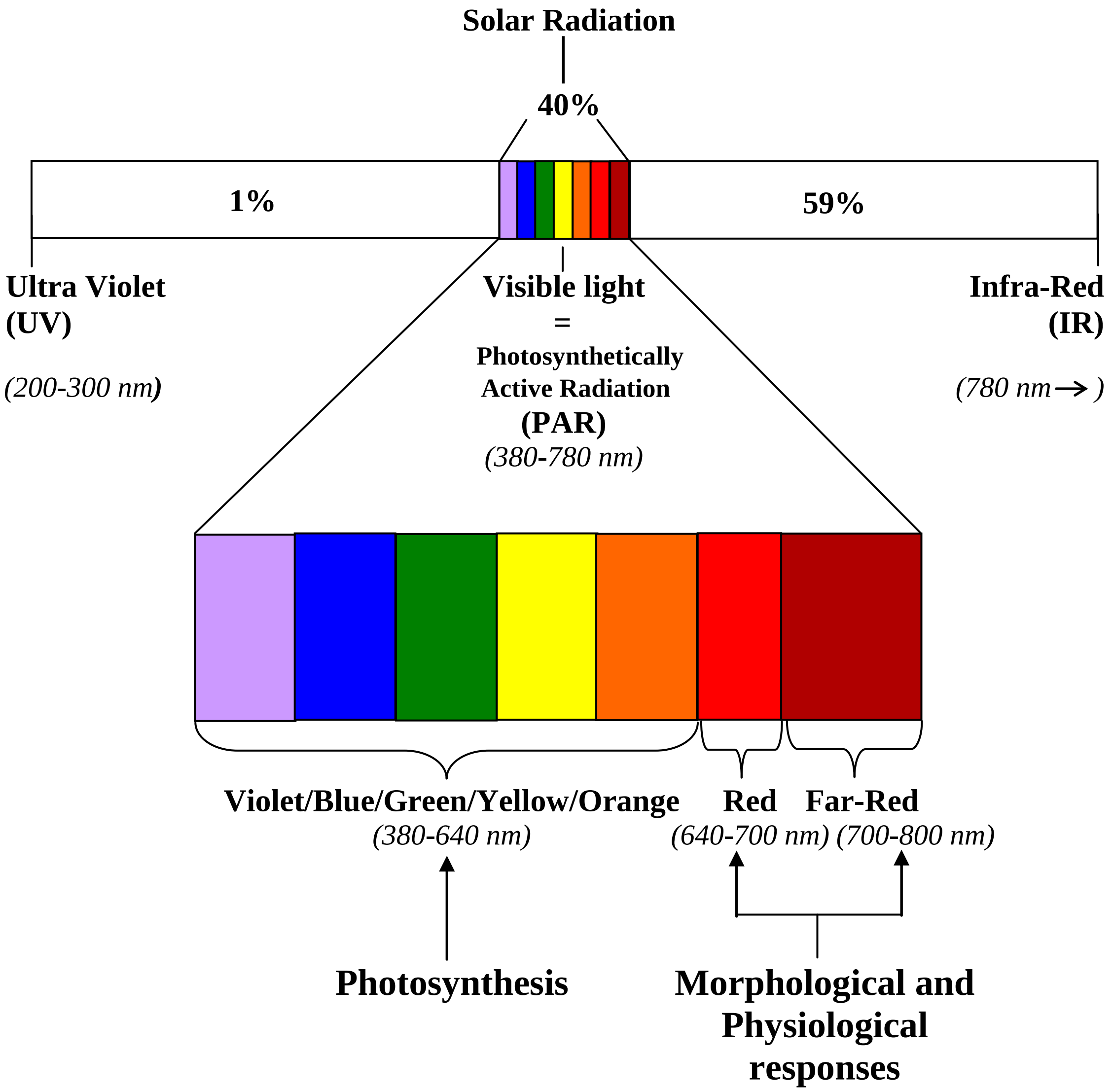
There has been a marked increase in protected cropping of HNS over the past decade, and while glass provides one of the more favoured production environments, there is still a significant proportion of plastic clad tunnel structures in use. Heat build up from incoming solar radiation can be a problem under plastic, and has led to softer, stretched growth with some species, which also results in increased disease susceptibility.

Solar radiation can be divided into 3 distinct bands, encompassing the ultra-violet (UV) component, visible light, and infra-red (IR) wavelengths (see diagram). UV has the lowest wavelength/highest energy and makes up 1% of the spectrum. IR has the highest wavelengths, which provide 59% of the spectrum, and can be detected as heat radiated from any warm body in the structure (e.g. paths, pots, plants). Visible light, comprising 40% of the spectrum, incorporates the rainbow colours from violet through blue, green, yellow and orange, to red, and provides the energy for all plant functions, including photosynthesis, morphogenesis and physiological responses. The interest here, in terms of influencing plant growth, is the red:far-red:blue ratio of light, with the higher level of red light producing more compact growth, while increasing the far-red component enhances extension growth.

Spectral filters can have a range of effects depending on which wavelengths are admitted or blocked out. Recent developments in plastic technology have brought a number of specialised spectral films from a number of manufacturers onto the market which need assessing to quantify their potential for manipulating plant growth under UK conditions. Many of the reported benefits have come from work abroad, or with protected crops in the UK, but little objective work has been done on HNS.

The project reported here was set up at the Dove Associates site in south Norfolk, with the objective of observing the response of a range of HNS species to cladding materials with different spectral transmission properties of UV, near-red, far-red and near-infra-red. In a separate study at HRI East Malling the rooting of cuttings taken from plants grown under the spectral films was also examined. Although only materials from XL Horticulture were included in this trial, the intention was to test a representative range of plastics from those available and readers should be aware that other manufacturers produce spectral films. Mentions of products should not be seen as an endorsement of them and non-inclusion of others is not intended to imply criticism.

Diagram of the electromagnetic spectrum



Summary of the project and main conclusions

The project was set up as a screening trial, with the objective of observing the response of a range of HNS species to cladding materials with different spectral transmission properties. In this preliminary screening a range of 54 species of shrubs, conifers, heathers, herbaceous and alpines were grown under five tunnels clad in different plastic films.

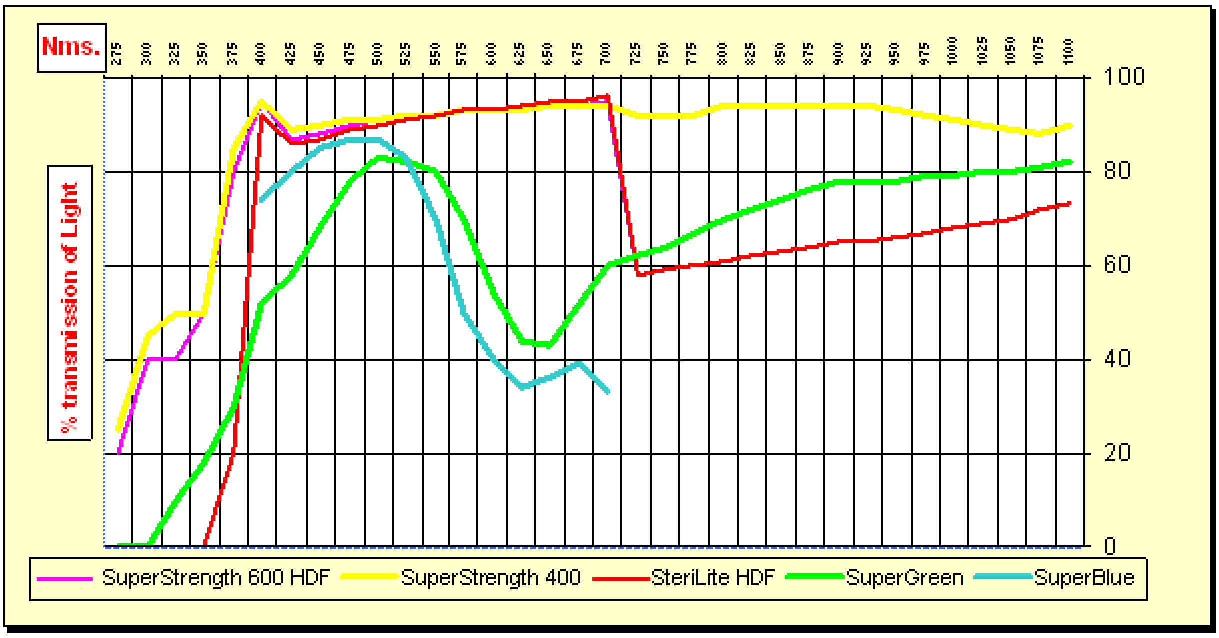
In addition to the finished plant trials a secondary trial was designed to provide information on the effects of light quality on root initiation in cuttings. Cuttings taken from 5 species under each of the cladding materials were rooted and observed.

Cladding materials

The cladding materials used in this trials were al provided by XL Horticulture and were intended to represent the range of materials currently available from a number of manufacturers.

1. SuperStrength 400 (No UVA/UVB filters, maximum light transmission)
2. SteriLite HDF (thermic anti-fog film with UVA and UVB filters, plus near-infra-red filter)
3. SuperBlue (modifies PAR light in near-red/far-red/blue wavelengths)
4. SuperStrength 600 HDF Control (near-infra-red filter)
5. SuperGreen (alters ratio of blue:red wavelengths in PAR to give only 65% global light transmission)

Manufacturers' data for the 5 films used



List of plants included in the trial

Conifers

Chamaecyparis lawsoniana 'Broomhill Gold'
Chamaecyparis lawsoniana 'Ellwoodii'
Chamaecyparis lawsoniana 'Little Spire'
X Cupressocyparis leylandii
X Cupressocyparis leylandii 'Castlewellan Gold'
Juniperus horizontalis 'Blue Chip'
Juniperus x media 'Sulphur Spray'
Picea glauca albertiana 'Conica'
Thuja plicata 'Rogersii'

Herbaceous

Anemone x hybrida 'Richard Ahrens'
Euphorbia amygdaloides 'Purpurea'
Heuchera hybrids
Lamium maculatum 'Chequers'
Primula vulgaris
Sedum atuntsuese 'Autumn Joy'
Stokesia laevis 'Blue Star'
Veronica gentianoides 'Variegata'

Alpines

Ajuga reptans 'Burgundy Glow'
Aubretia albomarginata 'Astolat'
Geranium cinereum 'Splendens'
Lithospermum diffusum 'Heavenly Blue'
Phlox subulata 'McDaniel's Cushion'
Saxifraga deorum 'Stansfieldii'
Thymus x citriodorus 'Aureus'

Stock plants

Cotinus coggygria 'Royal Purple'

Woody shrubs

Aucuba japonica 'Variegata'
Berberis atropurpurea 'Red Pillar'
Berberis darwinii
Ceanothus thrysiflorus repens
Chaenomeles speciosa 'Nivalis'
Choisya 'Aztec Pearl'
Choisya ternata 'Sundance'
Cistus x pulverulentus 'Sunset'
Convolvulus cneorum
Cotoneaster 'Coral Beauty'
Cotoneaster horizontalis
Elaeagnus pungens 'Maculata'
Escallonia illinita 'Iveyi'
Forsythia giraldiana 'Golden Times'
Hebe pinguifolia 'Pagei'
Helianthemum umbellatum 'Wisley Pink'
Hydrangea macrophylla 'Madame Emile Mouilliére'
Hypericum henryi 'Hidcote'
Ilex aquifolium 'Argentea Marginata'
Philadelphus tomentosus 'Virginal'
Physocarpus opulifolius 'Diabolo'
Potentilla fruticosa 'Red Ace'
Pyracantha gibbsii 'Orange Glow'
Spiraea japonica 'Shirobana'
Viburnum tinus 'Eve Price'
Weigela florida 'Variegata'

Heathers

Calluna vulgaris 'Tib'
Erica carnea
Erica carnea 'Vivellii'
Erica x darlyensis
Erica erigena

Outline results

Filter	Principle characteristics	Environmental effect	Plant growth disadvantages	Plant growth advantages	Other notes
SuperStrength 400	Maxiumum light transmission 10% light reduction 18% diffusion	Average air temperature, higher root temperature, average leaf temperature, higher water consumption	Conifer tip scorching, earlier leaf drop.	Good quality, faster re-growth, slight growth compaction, good coloured leaf intensity, earlier flowering.	
SteriLite HDF	Antifog, Heat retaining, 12% light reduction, 0% diffusion with upper and lower spectrum filters	Higher air temperature, higher root temperature, average leaf temperature, higher water consumption	Red foliage not bright, tip scorch on conifers.	Good quality, good root development, slight growth compaction, good coloured leaf intensity, earlier flowering.	
SuperBlue	30% light reduction 30% diffusion with upper spectrum filter	Lower air temperature, higher root temperature, low leaf temperature, lower water consumption	Slower growing, shorter jointed, smaller leaf size, flowering reduction, coloured foliage weak, reduced root growth, some uneven growth.	Compacted growth, poor root development, larger leaves.	Human eye effect.
SuperStrength 600 HDF	12% light reduction, 60% diffusion, slight red filter	Control	Control	Control	
SuperGreen	28% light reduction, 30% diffusion, blue filter	Lower air temperature, lower root temperature, average leaf temperature, average water consumption	Uneven growth, elongated growth, poor coloured leaf intensity.	Earlier growth, suit forest floor plants.	

Environmental influences

Air temperatures

Daytime air temperatures under both SuperBlue and SuperGreen covers were consistently lower by several degrees C than SuperStrength 600 (the control), Temperatures under SuperBlue and SuperGreen covers did not exceed 30 °C, whilst under the SuperStrength 600 it was, on average, 5 °C higher.

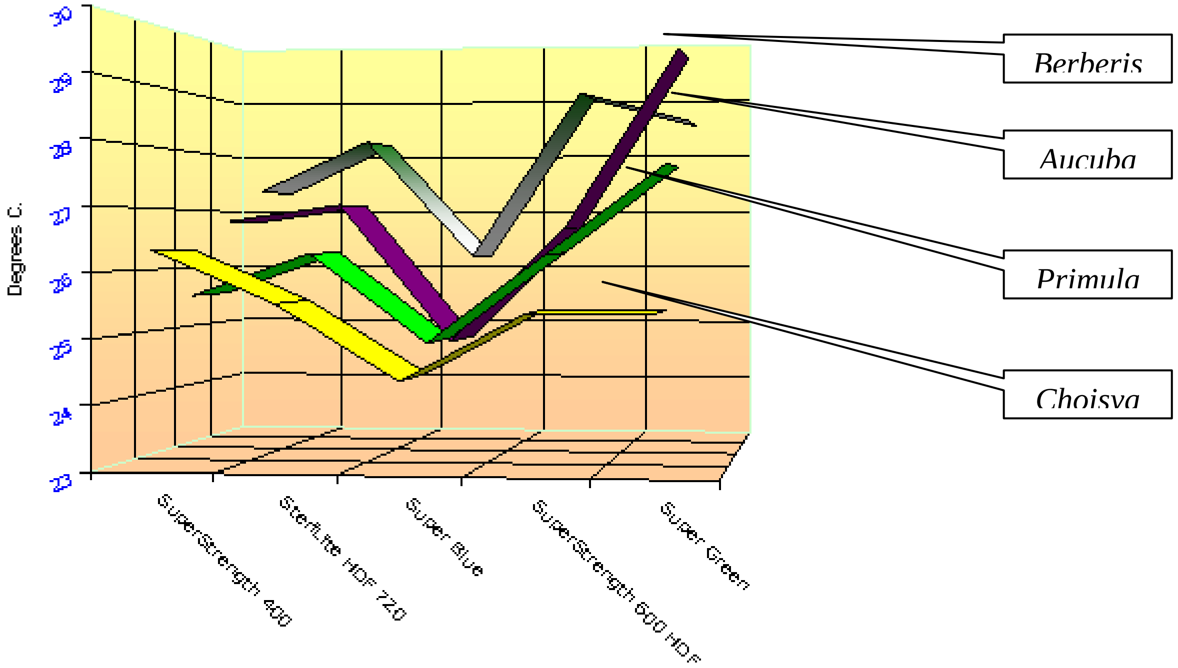
Nighttime air temperatures under SuperStrength 600 (the control) were the lowest. When considering the wintertime temperatures over a 24-hour period, the SuperStrength 400 and SteriLite covers were cooler at night and warmer during the day than the SuperStrength 600 and SuperBlue covers.

Media temperature

Growing media under the SuperGreen cover achieved similar temperatures during the night those under the SuperStrength 400 and SteriLite covers. Daytime temperatures of the growing media did not exceed those under the SuperBlue or SuperStrength 600 either.

Leaf temperature

Plants with different leaf colour characteristics and texture were selected for leaf temperature measurements. These were *Aucuba* as a representative of waxy, variegated foliage, *Choisya* as yellow and *Primula* as soft green foliage, plus a purple leafed, deciduous *Berberis.* There was a 5 °C difference registered between yellow and purple leafed plants.



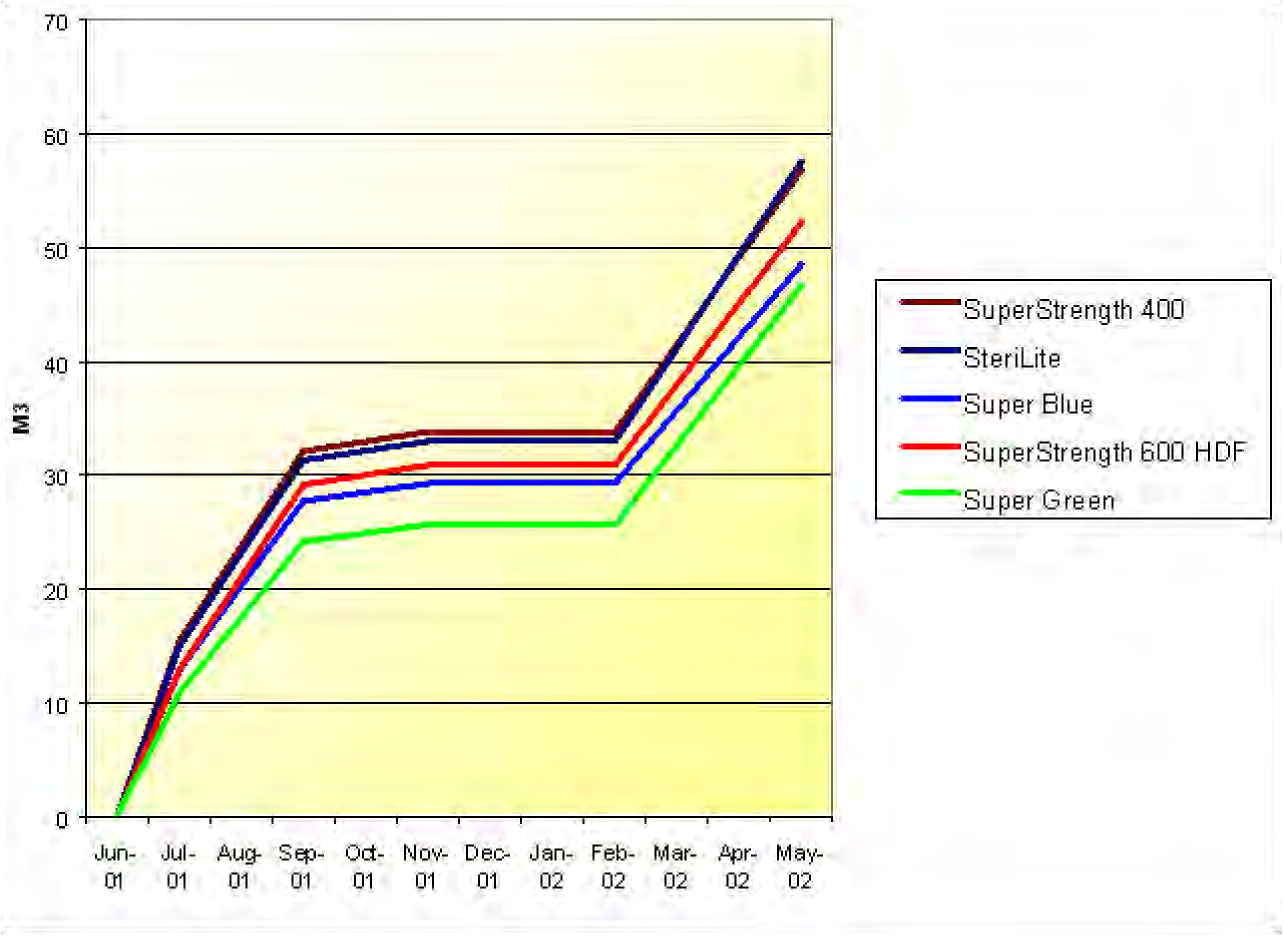
Humidity

Humidity appeared similar under all five covers increasing towards 100% overnight. A major difference, however, was observed under the SteriLite cover where the anti-condensation coating on the underside of the sheet created a noticeable fine "fog" in the atmosphere when the tunnels were opened in the morning. Under the other films condensation formed on the under- side of the cover which dripped onto the crop

Water utilisation

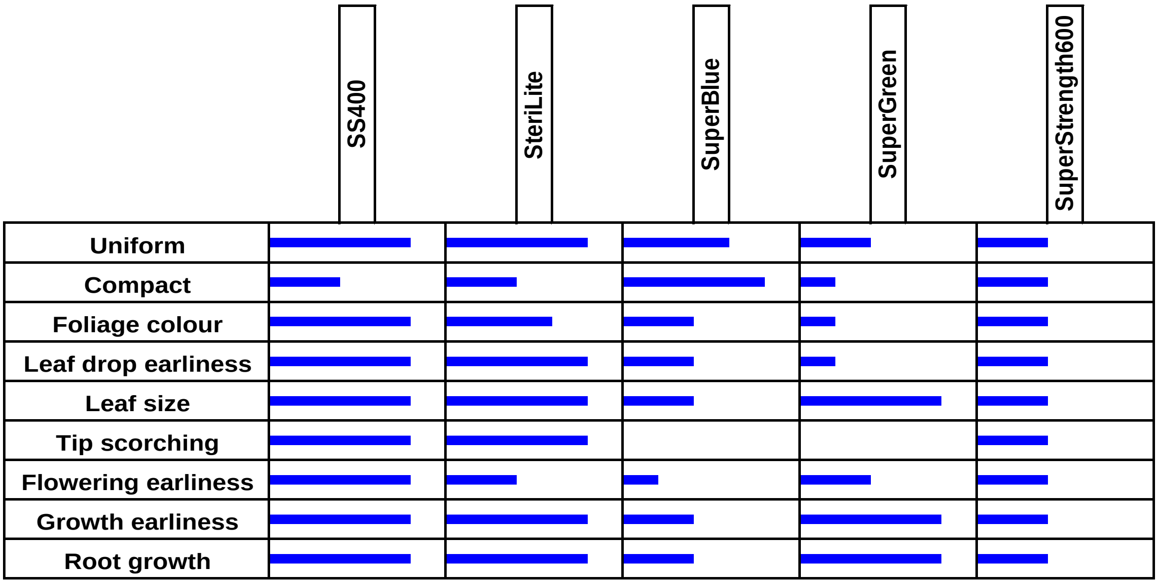
Water utilisation closely followed the temperature trends of each film with plants under the SuperGreen cover using 25% less water than the SuperStrength 400 or SteriLite.

Cumulative water consumption



Plant responses

Plant responses can be grouped into 9 categories as shown in the table below.



Action points for growers

The trials demonstrate that differing spectral filter cladding on tunnel structures can be beneficial through the modification of the plant environment. With much of the emphasis in the past being on the pest and disease reduction these trials have shown that crop growth characteristics can be harnessed to good effect.

The cladding with the best overall result for a range of crops grown on to saleable maturity was the SuperStrength 400. The high light transmission of this film provided a balanced plant structure with good foliage and flower colour. The degree of winter protection was limited.

Sterilite also has a high light transmission but the light is diffused. Under this spectral filter foliage colour was less, flowering was earlier and there was a small amount of plant compaction. Root development after potting was noticeably faster and was more advanced going into the winter. This cladding is most suitable for liner and young plant production and provides a good all-round growing environment with the added benefit of a reduced need for shading.

The SuperBlue filter resulted in a compaction of the plant growth on many of the trialed species. Winter growing media temperatures were higher by several degrees making it ideal for over wintered stock. The reduced leaf size, delayed growth and lower root density make this cladding suitable for over-winter liner production and late potted perennials. Variegated crops performed less well. High summer temperatures reduce the range of crops that can be grown through the summer months but spring and autumn crops would be very suitable. Two litre perennials potted in late summer for autumn sales would do well under this cladding.

The SuperGreen filter creates an environment suitable for certain specific crops, notably ferns and other shade crops. However, most shrubs produced rather stretched growth and plants with variegated foliage being less than satisfactory. Early cropping may be possible with selected species although non-uniformity can be a problem. A stretched growth of many shrub species would require more trimming to get a saleable compact growth excessive. Variegated foliage does not perform well.

SuperStrength 600

Sterilite

SuperBlue

Spiraea japonica ‘*Shirobana*’

X Cupressocyparis leylandii ‘*Castlewellan Gold’*

Primula vulgaris

SCIENCE SECTION

Introduction

The project was set up as a screening trial with the objective of observing the response of a range of HNS species grown under cladding materials with different spectral transmission properties for UV, near-red, far-red, and near-infra-red. This work was prompted by reports that suggested these materials had the potential to affect not only growth but also to reduce pest and disease problems.

In this preliminary screening a range of 54 species of shrubs, conifers, heathers, herbaceous and alpines were grown under five 25x5 m tunnels clad in different plastic films, with the aim of monitoring plant growth and environment characteristics.

The trial, funded by the HDC, has been financially supported by XL Horticulture, who provided the cladding materials, and Clover Peat Products, who provided the growing media.

Objectives

1. Review current knowledge on use of spectral filters in horticultural crops.

2. Compare spectral transmission of 5 different films used for cladding tunnel structures.

3. Monitor environmental parameters of air temperature, humidity and solar radiation, together with root and leaf temperatures and water consumption.

4. Measure plant growth under the different covers during a full growing season (2001) and after the following spring flush of growth (2002).

5. Observe any pest and disease occurrence.

6. Examine the rooting characteristics of cuttings taken from plants grown under the different covers.

Work on the first five objectives was carried out at Dove Associates, Diss, Norfolk. The review / bibliography (Objective 1) is presented in Appendix 9.

Work for Objective 6 was carried out at HRI East Malling, Kent.

Light and plants

The worldwide use of plastic as a greenhouse cladding material has increased rapidly in the last decade and with improvements being made in plastic technology it is now possible to change the spectrum of radiation that enters the structure. There are now possibilities to block incoming infra-red (heat), or prevent its escape, from the structure.

Although glass holds a dominant position as a covering material in Northwest Europe, improvements in glass technology are occurring relatively slowly. The acreage of glass covered greenhouses on a worldwide basis has remained more-or-less static at approximately 30,000 ha for the last 25-years. However, the amount of plastic cladding used is increasing rapidly and has expanded from zero in the early 1950s to 60,000 ha in 1976. It is now approaching 200,000 ha and is still increasing.

Solar radiation has an influence on the culture of nursery stock. Solar radiation is divided into three parts: ultra violet radiation (UV), visible light and infra-red radiation (IR). Visible light makes-up around 40% of the total radiation, with UV at 1% and IR at 59%. UV radiation is the part of solar radiation with the shortest wavelength and the highest energy. This radiation can have a damaging effect on many living organisms and is responsible for the degradation of polythene. The second part of solar radiation is visible light and this is important for the growth and development of plants. Visible light has a wavelength of 380–780 nm, which equates closely to the spectrum that can be utilised by plants for photosynthesis, called PAR-light (photosynthetic active radiation), with a wavelength of 400–700 nm. Blue and red light form the main components of PAR-light and chlorophyll absorbs light at these wavelengths more efficiently than any other. Near-infra-red (NIR), with a wavelength of 780-2,500 nm, is not used by plants for photosynthesis, but it does produce heat. Finally, there is far-infra-red (FIR). This radiation is not the direct result of solar radiation, but does play a significant role in the so-called ‘greenhouse effect’, being produced by any warm body such as gravel, pots, compost, plant leaves, etc. Since polyethylene does not absorb FIR radiation, a lot of energy in the form of FIR is lost through the sheet to the outside environment, especially during cold nights. EVA copolymers have a lower transmission in this part of the spectrum and their use in polyethylene films reduces thermal radiation to the outside.

Over the past few years cladding materials have become more complex. Nearly all are manufactured in 3 layers thick (even though they look like only 1 layer to the eye) and in the U.K. the majority of films use HALS (Hindered Amine Light Stabilisers) that gives a clear look to the film. Formerly NQ (Nickel Quench) was used, but this was identified to be a class 1 Carcinogenic compound. NQ gives a yellowish tinge to the film and is still used in some countries. HALS is a more expensive UV stabiliser, but without any potential health risks. The move to co-extruded films has enabled cladding manufacturers to add different compounds to the films, which can cut or even fluoresce from one part of the light spectrum to another.

IR absorbing compounds can be added to the polymers as they are manufactured and are normally mixed into the outer layer of the film. Current compounds also scatter the light so that more light gets to the lower leaves of a plant, increasing the photosynthetic potential of the plant as a whole. The absorbing compound not only reflects part of the NIR spectrum giving a temperature reduction in bright sunlight, but will also give a degree of heat retention in cold weather. There is also a suggestion that diffusion films are better at transmitting light than non-diffuse films, or glass, particularly in the winter months when the sun is striking the structure at a low angle of incidence. To lower the temperature in the summer is desirable because high levels of IR can cause heat build up and have undesirable consequences, including increased nutrient release from CRF's, and softer stretched growth. However even though they give a greater degree of heat transfer than clear films by retaining heat within the structure, they will also exclude an important portion of the NIR energy required to heat the structure in the winter period.

Table 1 **Classification of light wavelengths**

Type of Radiation	Type of Light	Wavelength in nm .	Notes
UV C	Black Light	190-280	Harmful to humans. Normally absorbed by the atmosphere.
UV B		280-380	Lower levels (280-300 nm) are absorbed by the atmosphere.
Violet	Visible Light and the PAR range	380-425	The PAR range which plants use, mostly occurs within the range of 400-800 nm although UV down to 300 nm is used by some plants.
Blue		425-490	
Green		490-560	
Yellow		560-585	
Orange		585-640	The red /far red for plant growth manipulation occurs between 600-700 for red and 700-800 for far red
Red		640-780	
Near Infra Red	Heat	780-2500	On all but the very hottest days 1300 nm is the maximum radiation that we receive in Northern Europe.
Middle range Infra Red	Heat	2500-4000	Frequently received near the equator.
Far Infra Red	Heat	4,000-50,000	Radiation in this band never reaches the Earth.

Materials and methods

Tunnel cladding materials

Five different films were used in the trial, each chosen for a specific spectral characteristic.

In this work each 26m tunnel was fully clad in one type of cover. Ventilation was achieved by opening the doors at either end of the tunnels.

1. SuperStrength 400 (No UVA/UVB filters, maximum spectrum transmission)

2. SteriLite HDF (thermic anti-fog film with UVA and UVB filters, plus near-infra-red filter)

3. SuperBlue (modifies PAR light in far-red wavelengths)

4. SuperStrength 600 HDF (near-infra-red filter) - control

5. SuperGreen (alters ratio of blue:red wavelengths in PAR to give only 65% global light transmission. Reduced near-red wave length more than far-red)

Table 2 Physical properties of various films

	Thickness in microns	**Strength along roll**	**Strength across roll**	**Elongation along roll before breaking**	**Elongation across roll before breaking**	**Tear strength along roll**	**Tear strength across roll**
SuperStrength 400	100	27	31	540%	670%	13.4	18.9
SteriLite HDF	180	23	23	520%	700%	6.1	9.3
SuperBlue	180	23	21	480%	650%	4.8	8.6
SuperStrength 600 HDF	150	25	33	525%	720%	95	16.2
SuperGreen	180	23	21	480%	650%	4.8	8.6

	Thickness in microns	**Antifog**	**UV inhibitor**	**Vinal acetate**	**Global light transmission**	**Diffusion**
SuperStrength 400	100	No	2%	5%	90%	18%
SteriLite HDF	180	Yes	9%	8%	88%	60%
SuperBlue	180	No	7%	4%	70%	30%
SuperStrength 600 HDF	150	No	7%	5%	88%	60%
SuperGreen	180	No	7%	4%	72%	30%

Light transmission properties

SuperStrength 400

This was the clearest cladding in this trial and gave the maximum visible light transmission. It is a co-extruded thin film with a high level of metallocene co-polymer to give added strength. The strength of the film is said to be as strong as other 600/720 gauge films but is designed for Spanish Tunnels and has a 3-year life span. It has no spectral filters and allows all spectrums of light into the structure, particularly in the UV band where it allows UV down to 200nms to enter the structure. Glass and conventional polythene's normally cut the UV out below 350 nms. It therefore followed most closely the outside light spectrum and gave us a benchmark, which showed us what a covered protection would do without any filters. Themicity of the film is around 26%.

SteriLite HDF

This is a UV blocking film, which cuts all spectral transmissions to 380 nms. This is known to interfere with the sporulation of a wide range of fungal diseases including both downy and powdery mildew, botrytis etc. Unfortunately this could not be looked at specifically in this preliminary investigation. In addition it has a diffusion additive in the film to reduce the NIR, scatter the light and reduce temperatures inside the tunnel in bright sunlight. It is also a thermic film with 86% thermicity and has an anti drip coating on the inside surface.

Since this film was trialled SteriLite HDF has been changed to SteriLite Premium + with the addition of an additive in the outside layer to inhibit green fungal growth and the AF additive on the inside of the film has been changed to diminish the fog effect associated with thermal films.

SuperBlue

The Blue film has an inversion effect which fluoresces a proportion of the Far Red wavelengths down into the Near Red wavelengths. Under outside conditions the ratio of FR: NR would be 1fr to 1.15nr. Under SuperBlue the ratio is 1.15fr:1.45nr. Under a normal film the ratio would be 1.15fr:0.95nr. The manufacturers suggest that this film has the potential ability to reduce internode length, thus producing more compact growth. Because it is blocking a part of the spectrum the average percentage of transmitted light is brought down to an average of 62% over the PAR range. Since this film was trialled SuperBlue is now SuperBlue + with the addition of an anti Green Algae inhibitor in the outer layer, 86% thermicity and the new anti fog/anti condensation layer on the inside.

<u>SuperStrength 600 HDF</u>

This is one of the simpler SMART films with the only additive being a diffusion additive, as used in SteriLite HDF, to reduce the NIR, scatter light and reduce tunnel temperatures in bright sunlight. Thermicity of this film is around 66%.

Since this film was trialled the Anti Green algae inhibitor has been included in the outer layer. This film is one of the standards used within the industry and as such has been used as the control for comparison in this trial.

SuperGreen

This film lowers the orange/red light and reduces the average of PAR transmitted light to 65%. There is also some reduction in the U.V levels reaching the crop. Thermicity of this film is around 36%.

Manufacturers recommendations are that this film is designed for shade loving plants, mimicking as it does the woodland light spectrum.

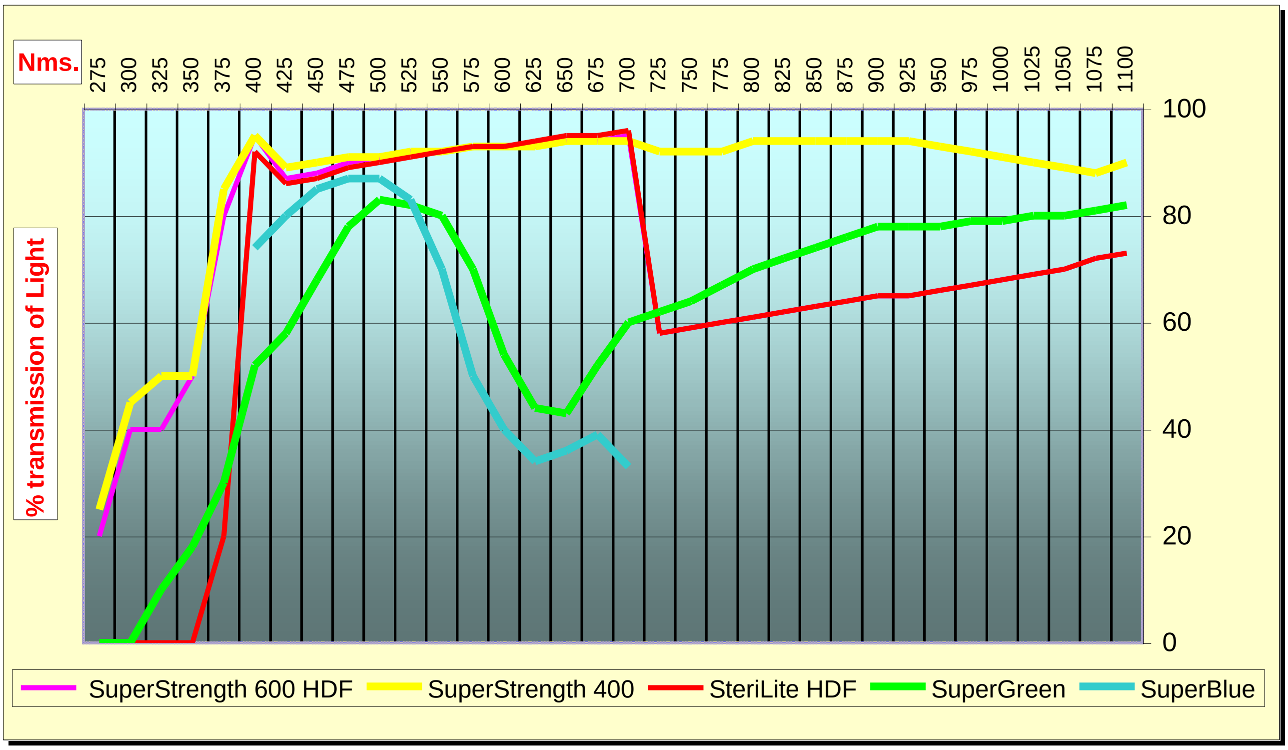
Other products

Comparing films from different manufacturers is difficult and is best shown in the table below. Other films were available at the time but the suppliers were unable to provide any data on the spectral modifications that take place.

Table 2 **Comparison between different commercial films available**.

	Thermic	Anti Drip	NIR reflector	UV open below 350nm	UV blocking	NR/FR modifier	UVI guarantee
SteriLite	√	√	√		√		5 years
SuperStrength 600 MDF	√		√				5 years
SuperBlue	√	√				√	5 years
SuperGreen						√	5 years
SuperStrength 400				√			3 years
Luminance THB AF		√	√				5 season
Politherm +	√	√			√		5 season
UVI/EVA							5 season
White							5 season
Solatrol						√	1 season

Figure 1 Manufacturer's spectral transmission data.



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Primula vulgaris
Sedum atuntsuese ‘Autumn Joy’
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Veronica gentianoides ‘Variegata’

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Ajuga reptans ‘Burgundy Glow’
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Geranium cinereum ‘Splendens’
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Cotoneaster horizontalis
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Hebe pinguifolia ‘Pagei’
Helianthemum umbellatum ‘Wisley Pink’
Hydrangea macrophylla ‘Madame Emile Mouilliére’
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Potentilla fruticosa ‘Red Ace’
Pyracantha gibbsii ‘Orange Glow’
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Viburnum tinus ‘Eve Price’
Weigela florida ‘Variegata’

Heathers

Calluna vulgaris ‘Tib’
Erica carnea
Erica carnea ‘Vivellii’
Erica x darlyensis
Erica erigena

Trial layout

This was an un-replicated, preliminary observation with a single 5 m x 26 m tunnel clad for each film (see Appendix 1 for layout). The 54 species used were laid out in the same order in each tunnel, (see Appendix 2), with a block of 50 plants of each species. Only 6 of the middle plants of each block were used for detailed recording.

Cultural details

The trial was set up in late May 2001, when rooted plugs were potted-on into 3 litre containers, (heathers and alpines in 90 mm pots), in a standard peat-based mix incorporating Multicote 12 month, and stood out on gravel beds. No supplementary liquid feeding was given to any of the crops, but a top dressing of Sincron was applied in February 2002 to all pots. Where appropriate, plants were cut hard back in the winter of 2001/2002. Ideally, the crops should have had a second stop in the spring of 2002, but were left to allow the effects of the cladding materials to be seen. Similarly, dead or damaged plants were left *in-situ* as many of the effects appeared to relate to tunnel cladding. No moss or liverwort treatments were applied.

Pest and disease control (P&D)

No P&D control was applied until problems occurred. When these were observed standard commercial products were applied. (See results section.)

Irrigation

All irrigation was by hand watering to achieve a better water balance between differing crop requirements. Each structure had a water meter fitted to record the total volume applied.

Assessments

A wide range of observations and records were taken throughout the summer and autumn months of 2001, including internode length, stem diameter, leaf size, foliage colour and flowering. Because of the difficulty in comparing actual growth directly between tunnels at any given time, as opposed to stage of development, the assessments were repeated over time to obtain general trends. The experience gained here allowed more targeted, detailed results to be taken in spring 2002, following the flush of growth after plants had been hard cut back in the winter.

Results

Spectral transmission of films

The spectrum characteristics and the intensity of irradiance reaching the plant canopy under each film was quantified using a spectro-radiometer (SR 3000B, Macadam Photometrics, Livingston, UK) attached to a quantum sensor (QS1) as a reference, with data recorded via a T3000 logger. (Both instruments were from Delta-T Devices Ltd, Cambridge, UK.) While measurements were only taken on a single day in July 2001, they were repeated a minimum of six times under each film between 10 a.m. and 11.30 a.m. Any readings where there was obvious cloud cover were excluded from the data sets. Data sets from each tunnel were then evaluated for consistency and a representative profile selected. For any given tunnel the patterns were almost identical after each run, although the intensities could vary. These profiles were then re-calibrated to take account of variations in irradiance intensity and a wavelength x relative intensity spectrum produced for each treatment.

The data obtained is shown in Figure 2. Essentially, these measurements were not at variance with the manufacturers' published literature.

Outdoor measurements of light quality were also taken for comparison with the different films.

SuperStrength 400: This film gave the highest light transmission, which translated into around a 5% increase over the other films in the trial.

SteriLite HDF: *This film had a lower level of transmission than the SuperStrength 400, and its property of diffusing incoming light made a better working environment.*

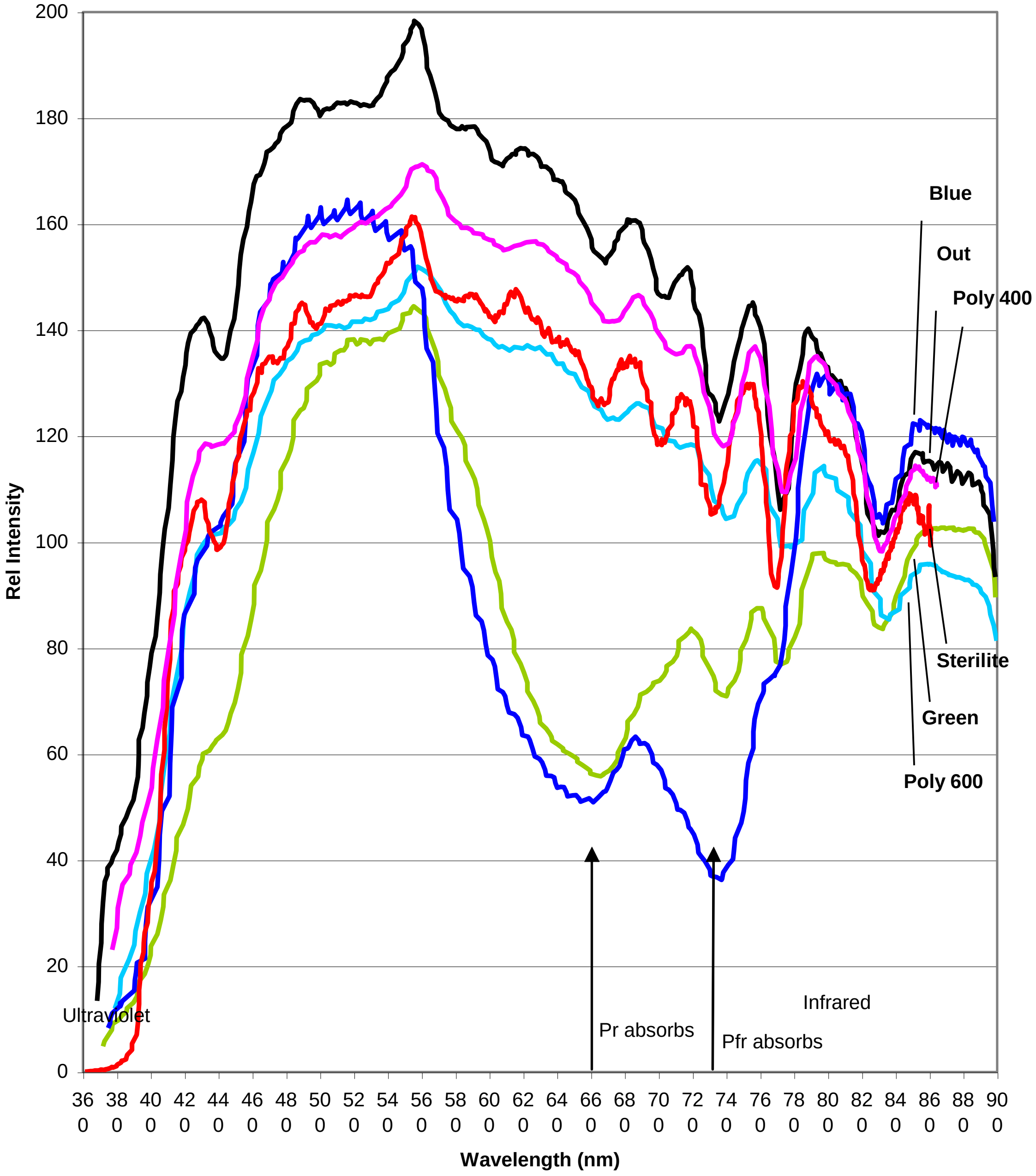
SuperBlue: *The property of this cover to block wavelengths 600 to 740 nm is shown clearly in the graph. Air temperatures were consistently lower than average at night and mostly higher during the day. At midday on some occasions this cladding was the hottest! Staff and visitors have remarked on the strange effect the light has on vision. After emerging from the house to outside sunlight the balance of colour has to be re-arranged by the eye. During this period the environment looks a somewhat strange colour. It is unlikely to need a government health warning! After working under the material for some time this effect disappears.*

SuperStrength 600 HDF: This film is visually similar to the SteriLite, using the same level of diffusion additives, but also uses the mettalocene technology to give an increased strength/gale resistance, which is far higher than a conventional 720 gauge film. A transmission property followed a similar pattern to the SuperStrength 400 within the PAR range but gives a slightly lower proportion of UV and NIR than SuperStrength 400.

.

SuperGreen: *This film gave the lowest light transmission of all the covers, with only 65% transmission overall, having been designed for plants requiring a shadier environment. As with the SuperBlue there was a marked blocking of light in the 600 to 740 nm, though this was somewhat less than the blue cover.*

Figure 2 Spectral properties of the different films measured July 2001



Influence of the environment

The environment was recorded in each structure and outside at ½ hour intervals. Measurements included:

Air temperature
Root temperature
Leaf surface temperature
Humidity
Water consumption

Air and growing media temperatures

The air and growing medium records were taken over the period of the trial and can be seen in Appendix 3.

The maximum and minimum temperatures recorded under the various films are shown below in Table 3.

Whilst these maximum temperatures only represent a short period in the 24-hour day, it is interesting to note that while an apparent reduction of 3 ^oC was achieved under the SuperStrength 400 and SuperStrength 600 covered structures, this would have had little effect in terms of overall ambient temperatures as they were still peaking at over 40 ^oC.

On average, the covers gave frost protection of 3 ^oC.

Of greater interest were the growing media temperatures. Here, with media under the green cover, maximum temperatures appeared cooler, which would be expected due to less infra-red radiation reaching it. In the colder weather media under the SuperBlue and SuperStrength 600 covers were approximately 2 ^oC warmer than the rest.

Table 4 Maximum and minimum air and growing media temperatures over the period of the trial. (^{o}C)

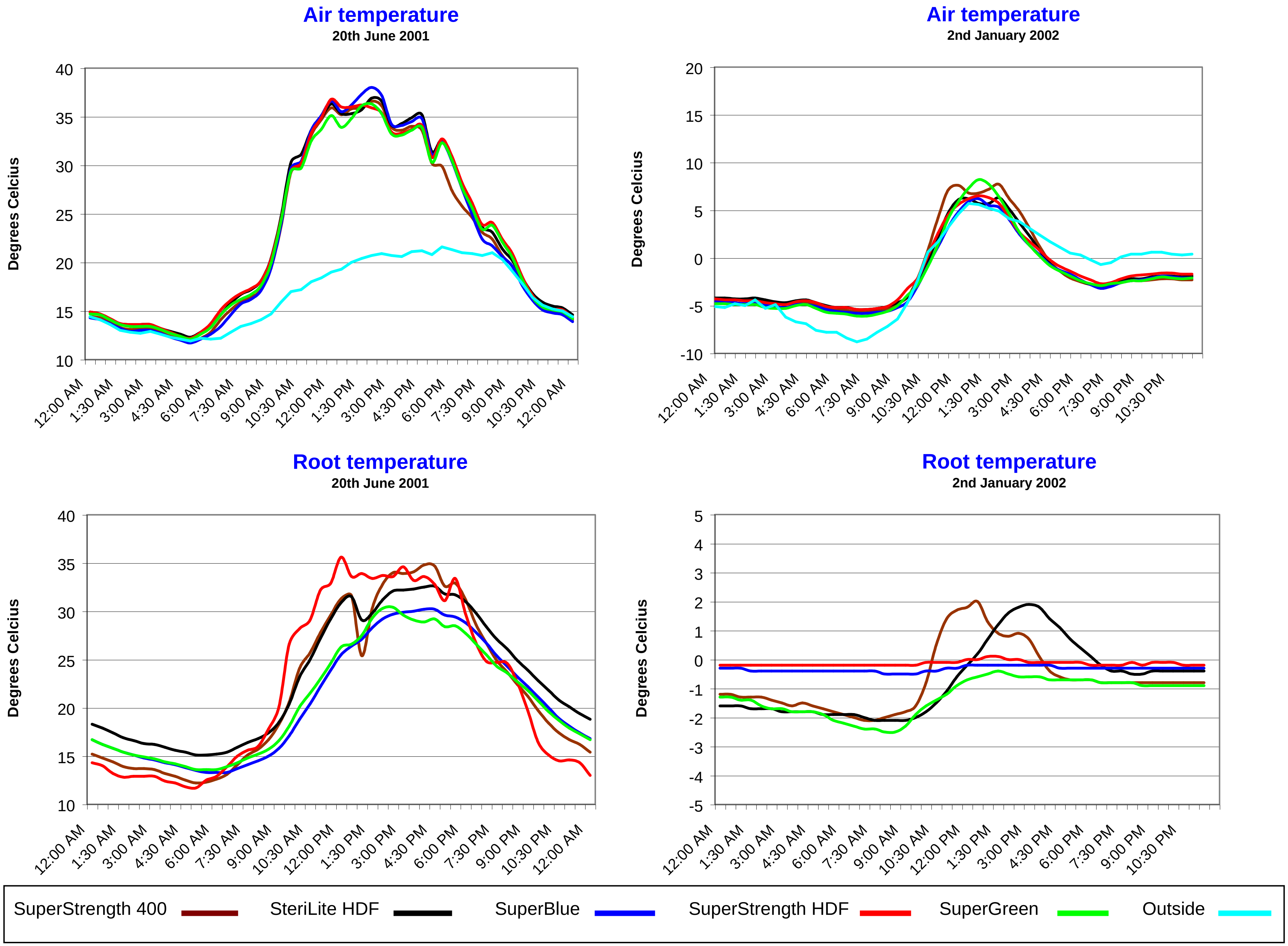
Location	Air temperature		Growing medium temperature	
	Max	Min	Max	Min
Outside	30.6	-8.8		
SuperStrength 400	41.8	-5.7	40.4	-2.1
SteriLite HDF	45.4	-5.4	39.0	-2.1
SuperBlue	44.0	-5.8	39.7	-0.5
SuperStrength 600 HDF	41.6	-5.4	35.6	-0.2
SuperGreen	43.0	-6.1	31.4	-2.5

A sample of air and root temperatures were also extracted from the data in Appendix 3 for a 24 hour period during the warmest and coldest days of the year. (Figure 3)

The summer air temperature clearly shows the temperature lift under all covers compared to outside. During the colder weather in winter the outdoor and tunnel temperature were much closer.

In contrast to the maximum media temperatures recorded, air temperatures under both SuperBlue and SuperGreen covers were consistently lower by several degrees C, compared to those under the other covers. Over this period the SuperStrength 600 generally had the higher temperature. Overall, temperatures under the SuperBlue and SuperGreen covers did not exceed 30 ^{o}C, whilst under the SuperStrength 600 it was, on average, 5 ^{o}C higher. In contrast, the SuperStrength 600 cover produced the lower temperature during the night period. When considering the 24-hour temperatures, during the cold period the SuperStrength 400 and SteriLite covers were cooler at night and warmer during the day than the SuperStrength 600 and SuperBlue covers, which remained consistent over the recording period.

The SuperGreen cover achieved similar media temperatures during the night to the SuperStrength 400 and SteriLite covers, but while day temperatures lifted they did not exceed those under the SuperBlue or SuperStrength 600.

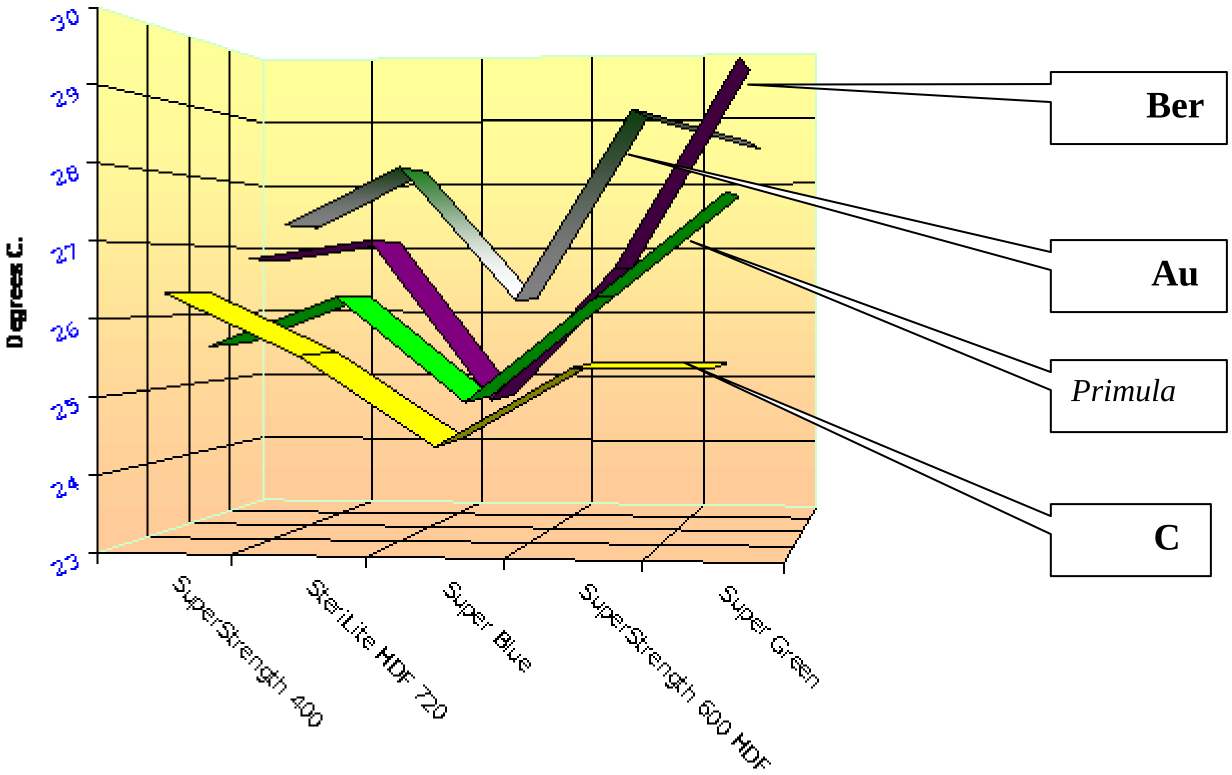

Air temperature
20th June 2001
Degrees Celcius
40
35
30
25
20
15
10
12:00 AM
1:30 AM
3:00 AM
4:30 AM
6:00 AM
7:30 AM
9:00 AM
10:30 AM
12:00 PM
1:30 PM
3:00 PM
4:30 PM
6:00 PM
7:30 PM
9:00 PM
10:30 PM
12:00 AM
Air temperature
2nd January 2002
Degrees Celcius
20
15
10
5
0
-5
-10
12:00 AM
1:30 AM
3:00 AM
4:30 AM
6:00 AM
7:30 AM
9:00 AM
10:30 AM
12:00 PM
1:30 PM
3:00 PM
4:30 PM
6:00 PM
7:30 PM
9:00 PM
10:30 PM
Root temperature
20th June 2001
Degrees Celcius
40
35
30
25
20
15
10
12:00 AM
1:30 AM
3:00 AM
4:30 AM
6:00 AM
7:30 AM
9:00 AM
10:30 AM
12:00 PM
1:30 PM
3:00 PM
4:30 PM
6:00 PM
7:30 PM
9:00 PM
10:30 PM
12:00 AM
Root temperature
2nd January 2002
Degrees Celcius
5
4
3
2
1
0
-1
-2
-3
-4
-5
12:00 AM
1:30 AM
3:00 AM
4:30 AM
6:00 AM
7:30 AM
9:00 AM
10:30 AM
12:00 PM
1:30 PM
3:00 PM
4:30 PM
6:00 PM
7:30 PM
9:00 PM
10:30 PM
SuperStrength 400
SteriLite HDF
SuperBlue
SuperStrength HDF
SuperGreen
Outside

Leaf temperatures

Leaf temperatures were recorded by the use of an infra-red thermometer (Raytek Model Raynger ST 20 Pro Standard) on 15 occasions for each species over the summer period. Care was taken to ensure that temperatures were measured on a similar area of leaf in each tunnel, avoiding midribs and main veins. The thermometer measures reflected heat. The average of these records is presented in Figure 4. The species chosen included a plant with 4 different leaf colour characteristics and texture. *Aucuba* was selected as a representative of waxy, variegated foliage, *Choisya* as yellow and *Primula* as soft green foliage, plus a purple leafed, deciduous *Berberis.*

The data clearly shows the lower leaf temperature under the blue cover for each species. The red leaved B*erberis* and variegated *Aucuba,* despite their differences in foliage type were consistently warmer than the, *Choisya* cv 'Sundance' and green *Primula.*

Figure 4 Average of leaf temperatures over the summer period



Humidity

A capacitance device, mounted in the air space 1.25 m above the crop, measured humidity. It was calibrated by a hand held hygrometer and maintained calibration throughout the trial very well. Results of humidity measurements are presented in Appendix 3.

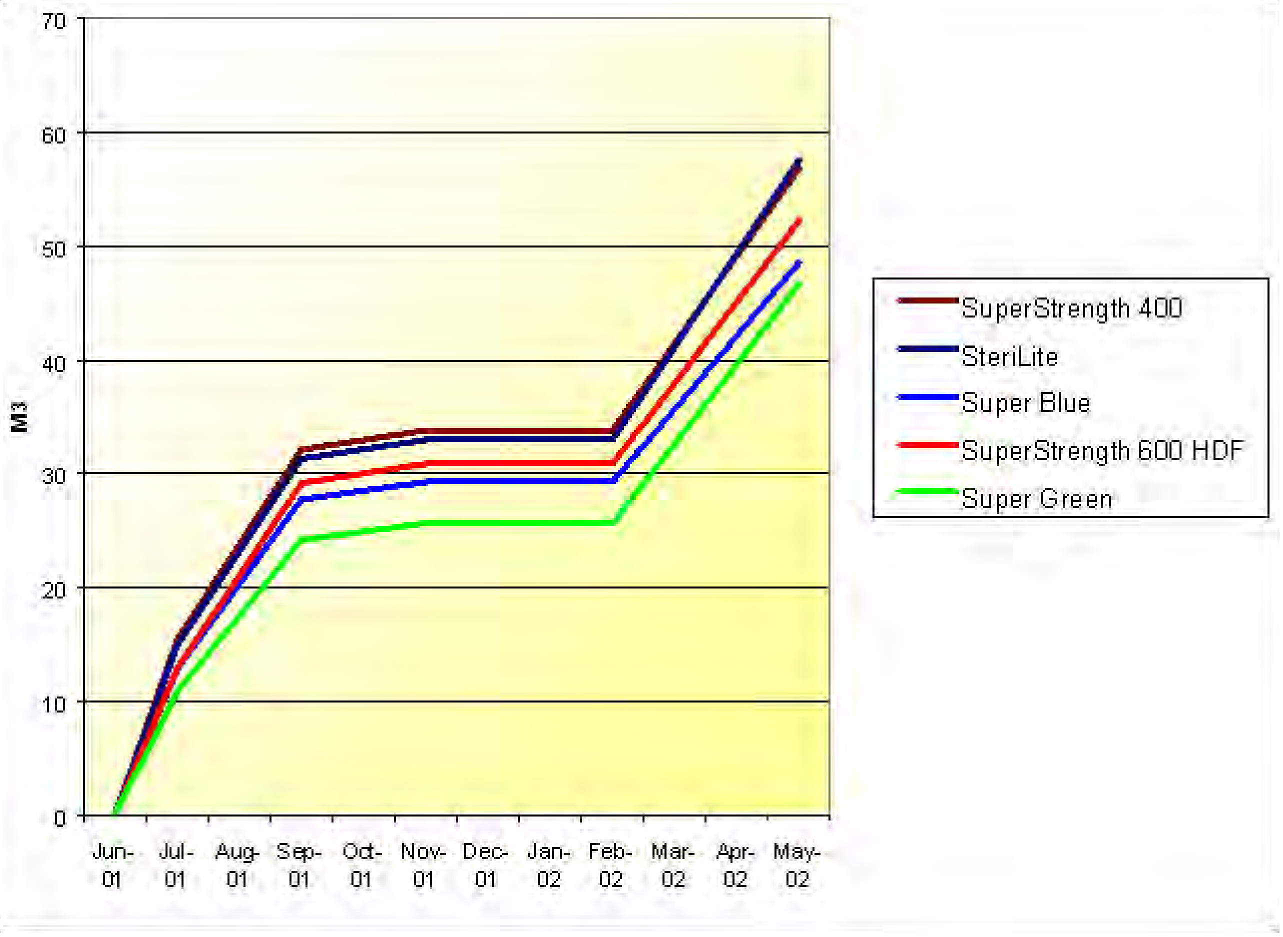
Overall, humidity appeared similar under the five covers with all lifting towards 100% overnight. A major difference, however, was observed under the SteriLite cover where the anti-condensation coating on the underside of the sheet created a noticeable fine "fog" in the atmosphere when the tunnels were opened in the morning. Under the other films condensation formed on the under- side of the cover which dripped onto the crop.

Water consumption

Water meters recorded the amount of irrigation applied to each structure individually. Water was applied by hand to accommodate the needs of each species. This has been plotted cumulatively in Figure 5.

Water utilisation closely followed the temperature trends of each film with plants under the SuperGreen cover using 25% less water than the SuperStrength 400 or SteriLite.

Figure 5 Cumulative water consumption over the period of the trial



Effects on plant growth

In this preliminary trial the decision was taken to include a wide range of species (54), in order to improve the chances of identifying those responsive to varying spectral transmissions. This limited time available for detailed records of everything on each occasion, but a range of assessments and observations were taken over the period of the trial, which commenced in May 2001 and completed by June 2002.

Detailed records on 6 plants in the centre of each block of 50 plants included:

1. Plant growth assessments over the summer of 2001, involving measurement of an expanded internode, stem calliper in the centre of this internode, root density over the pot-ball, leaf length of the first expanded leaf from the tip, and number of breaks. (see Appendix 4)

These assessments highlighted the problems associated with identifying which internode and leaf to take as ‘fully expanded’ for comparison of growth between the covers, as opposed to stage of development, though general trends were observed. As a result the trial was extended to May 2002, and plants cut back hard, where appropriate, over the winter of 2001/2002, with subsequent growth assessed a number of ways depending on species.

2. As 1. above for selected species (see Appendix 5).

3. Measurement of plant height also included (see Appendices 4 & 5).

4. Assessment of plant quality, where appropriate (see Appendix 5).

5. Number of dead plants (out of the block of 50) (see Appendix 5).

6. A more detailed record was undertaken on 14 species, chosen as having marked stem extension characteristics, in order to obtain a more accurate assessment of effects of the different covers on internode length. Here the longest shoot on the plant was selected and its length and number of expanded internodes recorded. This data allowed the calculation of mean internode length per shoot (see Appendix 7).

7. A number of qualitative assessments were also taken over the block of 50 plants including:
    - Notes on earliness of growth
    - Degree of flowering, where appropriate
    - Uniformity of growth / flowering
    - Foliage colour

Main results, and/or any obvious trends are summarised below for each cover, with the detailed results presented in the Appendices. The performance of the specialised sheets is compared against the SuperStrength 600 HDF sheet, which is widely used in the industry, and was used as the control

SuperStrength 400

- All species produced good quality plants, with greater uniformity within each block than under the standard SuperStrength 600 HDF sheet.

- Particularly notable was the re-growth of *Berberis atropurpurea* ‘Red Pillar’ following the winter prune. Here virtually the whole block of plants were growing away strongly by the following May, as opposed to those under the SuperStrength 600 HDF cover, where they were obviously struggling, with relatively few growing away.

- With some species a more compact growth was noted under this cover: which, in the main, appeared to be related to a reduction in internode length, rather than fewer internodes..

  Berberis
  Cotoneaster
  Elaeagnus
  Hydrangea
  Philadelphus
  Spiraea
  Weigela

- A striking result, (and unique to this cover in the trial), was the retention of foliage colour in the red leafed species, *Cotinus coggygria*, (see Plate 6, Appendix 9), and increased intensity of autumn colour in *Cotoneaster* 'Coral Beauty'. (see Plate 7, Appendix 9).

- Gold and variegated subjects maintained excellent colour under this cover, e.g. *Spiraea*, (see Plate 4, Appendix 9), *Elaeagnus* and *Weigela.*

- Some tip scorching of conifers, particularly in the *C. lawsoniana* group, was recorded under this cover.

- In general, autumn leaf drop occurred earlier under this tunnel, compared with that under the SuperStrength 600 HDF control sheet. (See *Hydrangea*, Plate 5, Appendix 9).

- Flowering was earlier in this tunnel by 7-10 days. With some of the species a higher proportion of plants in each block flowered, and density of flowering was greater, than in the standard clad SuperStrength 600 HDF tunnel. These included:

  Aubretia (increased density of flowering)
  Ceanothus
  Cistus (increased density of flowering)
  Erica erigena
  Geranium (increased density of flowering)
  Lithospermum
  Potentilla
  Primula (see Plate 8, Appendix 9)
  Sedum 'Autumn Joy' (see Plate 9,Appendix 9)
  Weigela (increased density of flowering)
  Heuchera

- Plants grown under this cover received a high rating overall, along with those in the SteriLite HDF tunnel, by visitors to the Autumn 2001 Open Day, and the highest rating by the Spring 2002 Open Day.

SteriLite HDF

- Essentially, similar results were obtained under this cover to the SuperStrength 400 for earliness of growth and flowering, uniformity of growth, degree of flowering, and earlier autumn leaf drop. Hence its' high rating by visitors at the Autumn Open Day.

- Density of foliage colour, however, while better than under the control cover, SuperStrength 600 HDF, was not as good as that observed with the SuperStrength 400 sheet. The red coloured foliaged species were more severely affected than the gold, *Cotinus coggygria* colour being considerably poorer under the SteriLite HDF than SuperStrength 400 (Plate 6, Appendix 9), whereas the gold *Spiraea* was only slightly duller (Plate4, Appendix 9).

- Vigorous root development occurred after potting.

- Tip scorch of conifers also occurred under this cover.

SuperBlue

- Plants under this cover were, in general, slower to grow away in the spring than under the non-coloured sheets. The delay appeared to be around 2 weeks, on average.

- Growth within the block of 50 plants was less even for many species than under the control tunnel, SuperStrength 600 HDF. This was particularly noticeable with:
  Choisya
  Cistus
  Potentilla
  Weigela
  Heathers
  Lithospermum
  Phlox
  Thymus

- More compact growth was also produced under this cover for a range of species:
  Conifers
  Berberis
  Ceanothus
  Chenomeles
  Choisya
  Cistus
  Cotoneaster
  Hydrangea
  Ilex
  Pyracantha
  Viburnum
  Weigela
  Ajuga
  Lithospermum

- With a range of species leaf size was also noticeably smaller under the SuperBlue cover, though this proved difficult to quantify for some from the single leaf measurement. Examples here included:
  Ceanothus
  Forsythia
  Chaenomeles
  Euphorbia
  Choisya
  Sedum 'Autumn Joy'
  Cistus

- Foliage colour of the red, gold and variegated species was poor under this cover (see Plates 4, 6 & 7, Appendix 9).

- There was a marked reduction in flowering in this tunnel, although the occasional flower appeared first here, followed later by the main flush. (Plates 8 & 9, Appendix 9).

- In contrast to the non-coloured plastics, no conifer tip scorch was seen with this cover.

- A small, but noticeably consistent reduction in amount of root growth visible over the root-ball was measured in this environment.

SuperGreen

- Some of the earliest growth was seen in this tunnel.

- Growth within the blocks of species tended to be more uneven than that under the non-coloured films.

- A number of species produced softer, more stretched growth under this cover, especially:

X. C. Leylandii	*Chenomeles*	*Philadelphus*	*Anemone*
Thuja	*Forsythia*	*Physocarpus*	*Aubretia*
Ceanothus	*Hydrangea*	*Viburnum*	*Geranium*

- Growth of *Cotoneaster horizontalis* and *Philadelphus* were more upright here compared with the other films.

- Both *Euphorbia* and *Geranium* had larger leaves under this film.

- Gold, variegated and red foliaged plants had poor colour under this environment.

- As with the SuperBlue cover, no tip scorch was seen on conifers.

<u>Pest and disease incidence</u>

Remedial sprays were applied when pests or diseases occurred.

Leigh Morris, a student studying for an MSc, carried out an aphid survey and a summary of the information is shown in Table 4.

Table 5: Summary of *Myzus persicae* counts made at the HDC spectral filters trial, Weggs Farm, Dickleburgh, Norfolk. 16th May 2002. Figures represent the average number of aphids on every one of the 150 plants of each cultivar examined.

Film:	*Superstrength 400 HDF*			**Sterilite HDF**			**Superstrength 600 HDF**		
	Alatae	**Apterae**	**Infested Shoots**	*Alatae*	**Apterae**	**Infested Shoots**	**Alatae**	**Apterae**	**Infested Shoots**
***Pyracantha gibbsii* 'Orange Glow'**									
Average	0.02	1.08	0.44	0.06	4.26	1.33	0.02	0.29	0.22
***Philadelphus tomentosus* 'Virginal'**									
Average	0.8	17.47	2.39	0.22	9.16	1.57	0.04	1.98	0.61
Combined figures for both plant species									
Average	0.41	9.28	1.42	0.14	6.71	1.45	0.03	1.14	0.42

The main pests were:

- Aphids. These results showed the levels of aphid occurrence in three different tunnel claddings (see Plate 1 & 2).

- Caterpillars. An outbreak of tortrix moth occurred in July 2001 under all tunnels irrespective of colour or film.

- Mites. These only occurred at the beginning of the trial and were common to all tunnels. After spraying they did not reappear.

- Vine Weevil. Vine weevil larvae were found in the *Sedum* 'Autumn Joy' and *Saxafraga*, which caused some root damage, despite suSCon Green having been incorporated into the mix at potting. However, the plugs had not had suSCon Green incorporated during propagation. Previous work had shown the need to incorporate suSCon Green during propagation for these vine weevil sensitive species to prevent serious damage occurring in the untreated plug when potted on. (HNS 15b.)

The main diseases were:

- *Phoma*. *Ceanothus* has been given 2 applications of Octave in all tunnels to control *Phoma*, which showed up soon after potting.

CONCLUSIONS

The increased availability of different coloured tunnel film materials prompted the trial to quantify the effects on a range of container grown, hardy nursery stock subjects. The objectives of the trial were to compare spectral transmission of 5 different films; monitor the parameters of air and root environment, humidity, solar radiation and water consumption. Plant growth on a range of 54 subjects were measured under the different covers during a full growing season (2001) and the following spring flush of growth (2002) along with pest and disease occurrence. A trial to examine the rooting of cuttings taken from plants grown under the different covers was also undertaken.

The spectral transmission data of all the films measured correlated to the manufacturers' claims.

SuperStrength 400

This film had the highest light transmission, the least spectral filtering effect, and the thinnest material but was the strongest. It out performed the other films with the quality of the plant material grown in it. The winter protection qualities are good giving 3 °C. of frost protection during the coldest period of the year and average summer temperatures. Growing media temperatures were the hottest recorded in the summer months and within 0.4 °C. of the lowest.

The greatest uniformity of each plant block was achieved under this film, with most plants reaching good quality saleable standard. Spring re-growth of the *Berberis atropurpurea* was outstanding in comparison with other films and in the case of the *Cotoneaster, Eleagnus, Hydrangea philadelphus, Spiraea* and *Weigela* a more compact growth was achieved. Leaf colour was outstanding on purple and variegated golden coloured foliage. Some tip scorching was observed on conifers and leaf drop was earliest under this film. Early flowering by 7-10 days was noted under this film as well as a greater density of flowering.

This cladding offers the best all round finished plant film. Winter protection is as good as other films, so spring potted subjects would benefit the most. For overwintered plants the early production under a SuperGreen film then transferred to the SuperStrength 400 would utilise the strengths of both films.

SteriLite

This film is a co-extruded film made up of three layers. Each layer gives a specific quality to the film. The diffusing layer on the outside of the film modifies the spectral quality, which is designed to reduce *botrytis* and aphid activity. No *botrytis* was recorded in the trial, but aphid levels under this film were less than SuperStrength 400. The inner antifogging layer reduced the condensation dropping onto the foliage very well. The air temperature in the night was highest under this film both during the day and night. Growing media temperatures were higher in the summer and cooler in the winter.

This film rated equally well in respect of plant quality. Foliage density was slightly less than SuperStrength 400. Leaf colour was reduced and some conifer tip scorch was observed. There were no outstanding plant observations although the pest incidence was observed a little greater. This film is suitable for young plant production. The diffused light helps to reduce sun scorch but with a high level of light transmission good foliage and flower quality resulted. This is an ideal film for young plant production offering a good all-round balanced plant with excellent root growth, earliness and uniformity. A later flowering time would suggest that finished plant material would not fare so well under this film. Further work could be carried out on the insect effects of this film.

SuperBlue

This film modifies the infra-red segment of the spectrum. This has a dwarfing effect on stem elongation. This sheet has a low tear strength although it was one of the thicker films. The initial effect on the eyes when emerging from this film is soon overcome, but can be disconcerting to some staff at first.

Air temperatures under this film were consistently lower at night and higher during the day. Leaf temperatures were much lower on all subjects and root density was lower. Plant growth was compacted on many of the trial subjects and root density was less. Leaf colours of the red, gold and variegated species were less vivid. The spring growth was around 2 weeks later to get away and leaf size was reduced unlike the SuperGreen where in many cases it was bigger. A reduction in flowering of plants was noticeable, but in some cases flower showed up first in this tunnel but then took much longer to develop. No conifer tip scorch was seen.

Like the SuperGreen film this product offers the ability to modify plant growth on many species. Due to the high summer temperatures experienced by the crops it is more suitable to spring bedding plants and autumn herbaceous perennials. In the case of the spring bedding plants they would benefit by the first 4-5 weeks of growth under this film then moving to a clear film for finishing. A more compact plant without PGR application would be possible. The use on nursery stock subjects is limited but further work on the use of other films such as BPI Solotrol would be worth considering. Utilising this film as part of a crop blueprint should be investigated to establish the economics of crop movement against plant growth regulator use.

SuperGreen

SuperGreen film had the lowest light transmission levels and produced plants that were more elongated. The growth in this tunnel was earlier than the other films and the degrees of uneven growth within a batch were greater. The growth was stretched on most subjects and *Cotoneaster horizontalis* and *Philadelphus* were more upright. The leaf area of geranium and euphorbia was larger with gold, variegated and red leaved subjects all showing poor colour. The coldest overwinter temperatures were recorded both in the air and growing media under this film. The summer temperatures were average for the range of film materials. Surface leaf temperatures were high most leaf colours. Water consumption was 25% less than the highest consumption film.

The film is suitable for growing on plants that require a “forest floor” environment such as rhododendrons, hostas and ferns. The cooler, humid and dappled light all provide an ideal environment to this crop range.

Young plant and liner production would also be suitable. With a shorter growing period in this film young plants would reach a height specification quicker. The growth would be stretched but if trimmed once or twice during growing a more branched liner may be achieved. Further work to investigate the ability of a plant to produce new growth quickly with reduced carbohydrate and photosynthesis production is worthy of investigation.

Herbaceous perennials appear to have a larger leaf area. This is most likely due to the plant compensating for the reduced light levels. This feature could be utilised for crops like bergenia, hosta and mahonia where large leaves are a feature of the plant. Leaf colour and intensity is reduced under this cover with cotinus barely creating purple leaves throughout the whole year, green foliage however appears to be normal, albeit larger in size.

Further work should be carried out to investigate using a range of liners to establish the cost effectiveness of increased trimming against the reduction in growing time. This film has growth promoting qualities, which could be utilised as part of a crop production programme. Young plants could be established under this film with the reduced water consumption and quicker elongation growth and then placed under a clear film for finishing. A crop grown under this film and treated with a plant growth regulator would also reach maturity quicker without the elongation effect. Trials to establish the economic feasibility of these systems could be carried out.

SUGGESTIONS FOR FUTURE WORK

The trials have shown that many nursery stock subjects are subject to growth modification when grown under these spectral filters. This work has shown that the use of the spectral filters can be utilised to reduce pesticide use as well as increase production efficiency. More work is now needed to establish the economic and environmental benefits from incorporating them into a crop production programme.

These films were developed with the view of producing the crop underneath a single colour filter throughout its life. This work, however, suggests that moving the plant from one filter to another according to the type of growth effect required could be more beneficial. One could consider incorporating a series of different coloured films into the roof of a tunnel structure or even glasshouse, to manipulate the spectral quality of the light and consequently the crop.

A new product is now emerging that can be sprayed onto a clear film, similar to a whitewash coating that is a temporary spectral filter. When the effect is no longer needed it can be removed from the film. This too has possibilities in manipulating the spectral makeup according to the crops needs.

Propagation trial

Carried out at HRI East Malling by:

Dr. Ross Cameron

Rooting of cuttings after growing stock plants under different spectral filters

Introduction

This experiment was designed to provide information on the effects of light quality on root initiation in cuttings. Many nurserymen take cuttings from their current production stock. However, if a wider use of spectral filters for growing stock material is envisaged, then the effects of light quality on the rooting of cuttings obtained from such stock needs to be assessed.

Only a moderate degree of research has investigated the effects of light quality on rooting of cuttings, and the majority of these studies have focussed on altering the light spectrum on shoot tissue cultures grown *in vitro*. Relatively, few studies have evaluated the use of commercial spectral films on *in vivo* stock plants and cuttings. A number of authors report that low red to far-red ratios (i.e. the opposite effect to that encountered under copper sulphate filters) enhance rooting (Hoad and Leakey, 1996; Leakey and Storetonwest, 1992; Heins *et al*., 1980). Exposure to FR has been associated with increased endogenous auxin content in species such as tomato (Tucker, 1977). There is also anecdotal evidence to suggest that situations where there is a high incidence of FR light corresponds with shoots with enhanced rooting potential – for example, thinner, 'leggy' shoots form the base or centre of a stock plant, or shoots that have been etiolated (heavily-shaded). In contrast, some studies actually suggest that red light or a high R:FR ratio is beneficial to root formation in species such as *Prunus* (Rossi *et al*., 1993) and *Terminalia* (Newton *et al*., 1996).

In addition to the R:FR ratio, altering the amount of light transmitted in other parts of the spectrum has been cited as influencing root induction. Speed of rooting and number of roots were increased when *in vitro* cultures of *Betula* were pre-treated with blue light (Saebo *et al*., 1995), and Morini *et al*. (1990) reported that exposing olive cuttings to yellow light during propagation improved rooting percentage.

Experimental summary

Two experiments were implemented. The aim of the first was to use the light / growing environments set up at Dove Associates and to assess rooting of cuttings derived from container-grown stock plants grown under these light regimes. The second evaluated the effects of spectral films placed over sections of field-grown stock plants at HRI-East Malling and how these influenced rooting of cuttings subsequently harvested (complementing research in a current DEFRA project - HH1214SHN). The results should provide preliminary information on what sort of light spectra optimises rooting in a range of HNS species, and whether there are any 'drawbacks' associated with taking cuttings from plants grown under films that absorb far-red light.

Materials and methods

Experiment 1

Of the cultivars grown at Dove Associates, five were selected for the rooting trial: *Choisya ternata* ‘Sundance’, *Convolvulus cneorum*, *X Cupressocyparis leylandii* ‘Castlewellan Gold’, *Potentilla fruticosa* ‘Red Ace’ and *Viburnum tinus* ‘Eve Price’. In addition, container plants of a sixth subject, *Cotinus coggygria* ‘Royal Purple’ were placed in the treatments at Dove Associates on 25 June 2001 (6 x 5 litre plants per treatment). For the *Cotinus*, additional groups of plants were grown outside, either under overhead irrigation (Dove Associates) or on capillary sand beds (HRI-East Malling). Cuttings from all subjects were collected on 20 August and transported to HRI-East Malling in damp hessian sacks. These were stuck two cuttings per pot, into 9cm pots (50:50 peat:fine bark mix) and placed in an Agritech fog environment to root. No hormone treatment was applied. Each treatment per species was represented by a population of at least 40 cuttings, which were divided into positional blocks within the propagation environment. Cuttings were recorded for percentage rooted, root number per cutting, growth during the propagation period, necrosis and whether or not the cuttings formed flowers.

Speed of rooting and hence date of recording varied between the subjects, with rooting being evident after 4 weeks (*Potentilla*) compared to 20 weeks (*X C. leylandii*).

Experiment 2

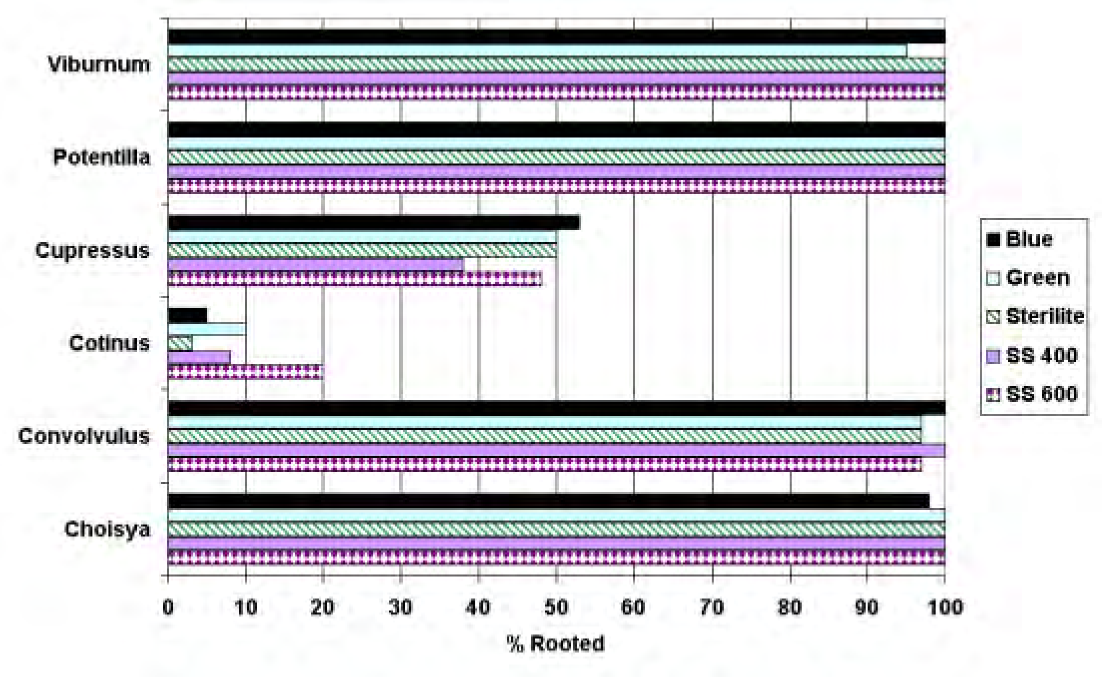
Sections of an established stock hedge of *Cotinus* at HRI-East Malling were grown under some of the spectral filters previously described. Small frames (2m x 1m) were covered with either SuperStrength 600 HDF, SuperStrength 400, SuperBlue or SuperGreen film and placed over sections of the hedge on 20 June 2001. Prior to the placement of the covers the hedge had been severely pruned during January 2001, following normal practice, and new shoots re-trimmed by 15-20 cm in early June to promote more uniform re-growth during the experimental period. Cuttings from parts of the hedge exposed to the different light regimes and to non-treated cuttings were harvested on 17 August 2001 and treated in the manner described for Experiment 1.

Results

Experiment 1

Effects of the spectral light quality that mother plants were exposed to had little influence on final rooting percentages, compared to the natural tendency for easy or difficult species to root (Figure 1). For example, those species generally classed as easy to root, still rooted well after being grown under the various light regimes. There were some more subtle effects associated with the light treatments and these are discussed on a per species basis below.

Figure 1. **Rooting percentage in a range of species after growing stock plants under SuperBlue (Blue), Super Green (Green), Sterilite HDF, SuperStrength 400 (SS 400) and Super Strength 600 HDF (SS 600) films.**



Choisya ternata 'Sundance'

Percentage rooting was very high for all treatments, although the number of roots per cutting was suppressed from stock grown under the conventional polythene cladding of SuperStrength 600 (Table 1). This may relate to lower carbohydrate levels as growth of the cuttings after excision was reduced in this treatment compared to the others. Highest root numbers were associated with the SuperStrength 400 and SuperGreen treatments. The only incidence of necrosis was evident in a small number of cuttings derived from the SuperBlue treatment.

Table 1. ***Choisya ternata* 'Sundance'. The effects of growing stock plants under different light regimes on subsequent cutting performance.**

	Super Strength 600	**Super Strength 400**	**SteriLite**	**Super Green**	**Super Blue**	***LSD***
% Rooted	100	100	100	100	98	*3.1*
Root No.	8.4	**13.8**	9.6	12.2	10.4	*1.99*
% Necrotic	0	0	0	0	**7.5**	*5.23*
Cutting Growth (mm)	33	**51**	43	46	47	*17.2*

Convolvulus cneorum

Rooting percentage and root number were similar across all treatments, with no statistically significant effects recorded (Table 2). Interestingly, greatest growth during propagation was linked to those cuttings grown under the SuperBlue film. Cuttings derived from both the SuperGreen and SuperBlue had the lowest necrosis scores, in a species that generally had a relatively high degree of basal lesions compared to other subjects.

Table 2. *Convolvulus cneorum.* The effects of growing stock plants under different light regimes on subsequent cutting performance.

	Super Strength 600	**Super Strength 400**	**SteriLite**	**Super Green**	**Super Blue**	***LSD***
% Rooted	97	100	97	97	100	*7.2*
Root No.	2.4	2.5	2.9	2.9	**3.2**	*0.74*
% Necrotic	30	**43.3**	30	13.3	20	*22.2*
Cutting Growth (mm)	19	21	19	31	**41**	*12.5*

X Cupressocyparis leylandii 'Castlewellan Gold'

Rooting percentages were lower in this subject compared to most other species, possibly reflecting the slow rate of root development in the conifer. At the time of harvest, the bases of even non-rooted cuttings were free of necrosis, and rooting may have been higher if the cuttings had been left for longer before harvesting. Regardless of speed of rooting and final percentages, there was no evidence that rooting was affected by the light treatments (Table 3). The large LSD value for percentage rooting indicates that there was greater variation due to block position within the propagation house than any treatment effect. Highest root number was recorded with the SuperStrength 400, a possible consequence of higher total radiation in this tunnel. In contrast to some other species shoot growth was poorer from stock in the SuperBlue and SuperGreen treatments.

Table 3. ***X Cupressocyparis leylandii*** **'Castlewellan Gold'. The effects of growing stock plants under different light regimes on subsequent cutting performance.**

	Super Strength 600	**Super Strength 400**	**SteriLite**	**Super Green**	**Super Blue**	***LSD***
% Rooted	48	38	50	50	53	*21.0*
Root No.	2.0	**3.1**	2.9	1.8	2.3	*0.76*
% Necrotic	0	0	0	0	0	*NA*
Cutting Growth (mm)	21.5	**23.3**	19.2	13.8	16.2	*6.43*

***Potentilla fruticosa* ‘Red Ace’**

Potentilla rooted very rapidly throughout. Marginally greater root numbers and reduced necrosis were found in the cuttings derived from the SuperGreen treatment (Table 4). During the propagation period cuttings put on a relatively large amount of shoot growth from all films except SuperStrength 400, where growth was significantly less. Generally, the coloured films appeared to reduce the number of flower buds present on the cuttings compared to the clear films.

Table 4. ***Potentilla fruticosa* ‘Red Ace’. The effects of growing stock plants under different light regimes on subsequent cutting performance.**

	Super Strength 600	**Super Strength 400**	**SteriLite**	**Super Green**	**Super Blue**	***LSD***
% Rooted	100	100	100	100	100	*NA*
Root No.	10.6	10.9	11.9	**12.7**	11.7	*1.55*
% Necrotic	7.5	**12.5**	7.5	0	2.5	*10.5*
Cutting Growth (mm)	60	32	52	61	**63**	*17.8*
% Floral	40	**58**	50	10	8	*18.7*

***Viburnum tinus* 'Eve Price'**

All cuttings rooted, bar two from the SuperGreen treatment (Table 5). Root number per cutting, however, was relatively high for this treatment, implying that there was no consistent detrimental effect associated with the SuperGreen film. Cuttings from SuperStrength 400 had the fewest roots. Growth of cuttings was marginally higher with cuttings from the SuperBlue treatment (not significant), and greater flower buds were associated with SuperStrength 600 and the SteriLite treatments.

Table 5. *Viburnum tinus* 'Eve Price'. The effects of growing stock plants under different light regimes on subsequent cutting performance.

	Super Strength 600	**Super Strength 400**	**SteriLite**	**Super Green**	**Super Blue**	***LSD***
% Rooted	100	100	100	95	100	*5.3*
Root No.	7.5	6.0	**8.0**	7.8	7.9	*1.51*
% Necrotic	0	0	0	0	0	*NA*
Cutting Growth (mm)	13.6	11.9	12.0	11.7	15.3	*4.93*
% Floral	**65**	28	60	28	30	*20.5*

Cotinus coggygria 'Royal Purple'

This was an example of a 'difficult to root' species, and the results for rooting across the treatments reflected this (Table 6). *Cotinus* cuttings rarely form roots unless there are actively expanding shoot tips or leaves present on the cutting at the time of harvest. Hence, rooting was highest in those cuttings derived from the stock plants maintained on the capillary sand bed, which had the highest proportion of cuttings with active shoot tips. None of the spectral light treatments helped retain active shoot growth, and rooting was generally poor in cuttings from the protected environments, and even those cuttings grown outdoors under overhead irrigation.

Table 6. *Cotinus coggygria* 'Royal Purple'. The effects of growing stock plants under different light regimes on subsequent cutting performance.

	Super Strength 600	**Super Strength 400**	**SteriLite**	**Super Green**	**Super Blue**	**Out Over head**	**Out Sand**	***LSD***
% Rooted	20	8	3	10	5	5	**31**	*13.3*
Root No.	3.25	1.67	2.06	2.25	3	1.51	2.83	*1.64*
% Necrotic	51	81	78	72	3	**100**	49	*18.5*
% Active at Harvest	8	3	3	8	5	0	**13**	*9.8*
Cutting Growth (mm)	1.7	1.4	0.9	0	2.5	0.9	1.4	*2.76*

Experiment 2.

Greatest shoot growth on the hedge occurred under the SuperStrength 600 film (Figure 2). Both the colour films suppressed growth, but not to any greater extent than leaving the shoots uncovered, (Natural), however, cuttings derived from the SuperStrength 600 treatment resulted in lowest rooting percentages - only 36% (Table 7). In contrast, stock plants grown outside under natural conditions, or under the SuperGreen film, resulted in cuttings with the highest rooting (74%). Why the rooting was so low in the SuperStrength 600 is unclear. It cannot be attributed to a lack of shoot activity, as both shoots on the hedge and on the excised cuttings were growing strongly. The higher level of necrosis with these cuttings from this treatment may suggest that carbohydrate levels became limiting in the cuttings.

Figure 2. ***Cotinus coggygria*** **'Royal Purple'. The effect of shoot growth on the hedge when plants were grown under natural light (Natural) or covered with SuperStrength 600 HDF (SS 600), SuperStrength 400 (SS 400), SuperGreen (Green) or SuperBlue (Blue) films.**

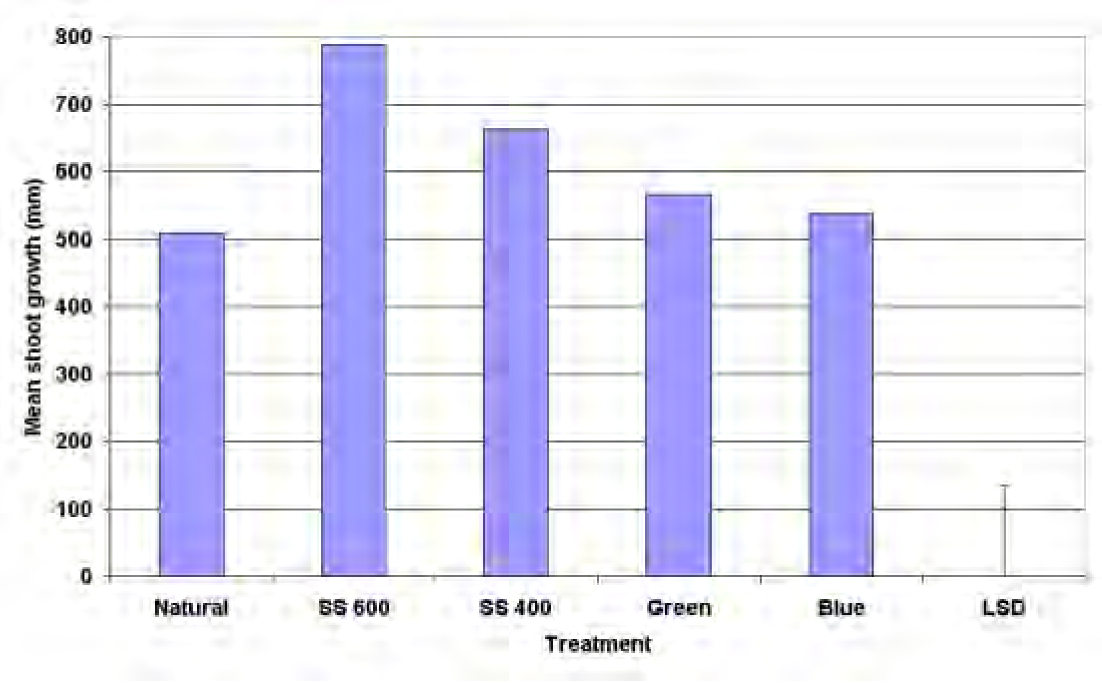


Table 7. ***Cotinus coggygria*** **'Royal Purple'. The effects of growing field stock plants under different light regimes on subsequent cutting performance.**

	Super Strength 600	**Super Strength 400**	**Super Green**	**Super Blue**	**Natural**	***LSD***
% Rooted	36	68	**74**	58	**74**	*17.8*
Root No.	3.8	4.1	**5.1**	4.5	3.9	*0.90*
% Necrotic	**74**	52	36	56	38	*18.3*
% Active at Harvest	100	98	96	98	98	*5.5*
Cutting Growth (mm)	12.9	10.1	**13.7**	8.9	8.3	*3.77*

Conclusions

The main point to be drawn from these experiments is an encouraging one – for the majority of the species tested, altering the light spectrum over the stock plants appeared to have very little effect on the percentage of cuttings rooting. With the exception of the difficult to root *Cotinus* and the slow rooting conifer, X *C leylandii*, rooting percentages tended to be ≥ 95% regardless of treatment.

The effects on the *Cotinus*, however, appeared to be more complex. Rooting was generally low when cuttings were taken from the container stock plants, largely reflecting less shoot vigour in these plants compared to the more mature stock plants grown in the field. Even in the container grown stock plants though, greatest rooting (30%) corresponded to the treatment with the highest number of active cuttings at collection. The situation with the cuttings derived from field-grown material, however, was more intriguing. Here greatest shoot growth did not correspond with rooting percentage. Indeed the shoots that had the strongest growth (under the SuperStrength 600 film) produced cuttings with a relatively poor rooting performance. It is possible that reduced carbohydrate levels due to the excessive shoot growth may explain this. Certainly light levels were comparably low under this film compared to outside and this may contribute to the lower carbohydrate reserves. However, it is interesting to note that light intensity was even lower in the SuperGreen treatment and this in contrast, corresponded with good rooting rates. It is feasible that there is some positive factor associated with the SuperGreen film (or detrimental associated with the SuperStrength 600) that cannot be explained by growth rates or carbohydrate availability alone.

At a more subtle level, placement of some other species under the SuperGreen regime also resulted in relatively positive findings – in *Choisya* and *Potentilla* the treatment resulted on good root numbers per cuttings and reduced the incidence of necrosis. From a propagation point of view both the SuperGreen and SuperBlue treatment were beneficial in that there was reduced number of flower buds found on the cuttings of *Potentilla* and *Viburnum* under these treatments, thereby reducing the competition for assimilates to the new roots. Although the purpose of the SuperBlue film is to reduce internode extension on crop plants, it was noteworthy that shoot growth on the cuttings (i.e. once the shoot has been removed from the blue light) was often quite large. Shoot growth on *Convolvulus*, *Potentilla* and *Viburnum* cuttings was greater after the SuperBlue treatment than any other treatment. A notable exception to this rule was the X *C. leylandii*, where growth was reduced after exposure to the SuperBlue and SuperGreen light spectra, although rooting percentage was unaffected.

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APPENDICIES

APPENDIX 1: Tunnel layout

Tunnel covers left to right

SuperStrength 400 **SuperBlue** **SuperGreen**
SteriLite HDF **SuperStrength 600 HDF**

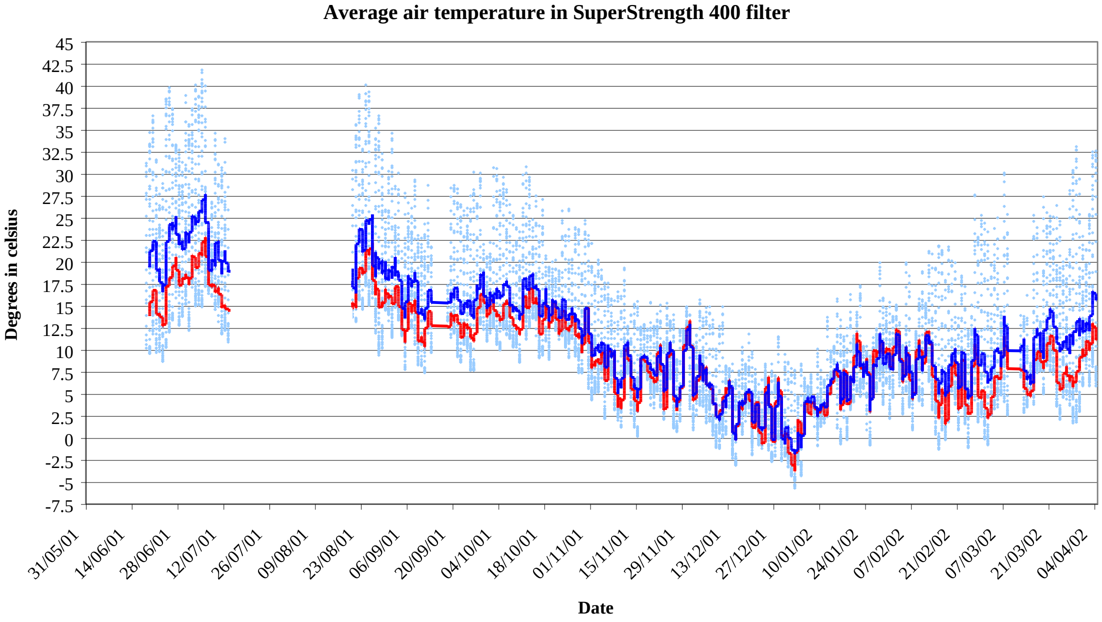
APPENDIX 2: Crop layout in each tunnel

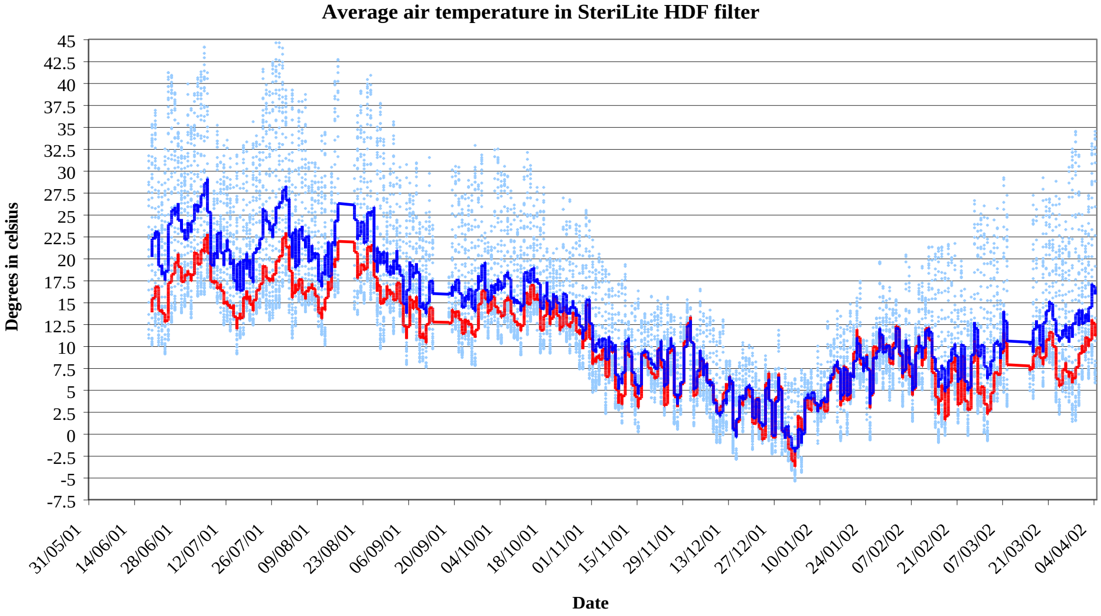
Lithospermum *diffusum* 'Heavenly Blue'	28		29	*Veronica gentianoides* 'Variegata'
Forsythia giraldiana 'Golden Times'	27		30	*Saxifraga deorum* 'Stansfieldii'
Choisya 'Aztec Pearl'	26		31	*Aubretia albomarginata* 'Astolat'
Spiraea japonica 'Shirobana'	25		32	*Helianthemum umbellatum* 'Wisley Pink'
Weigela florida 'Variegata'	24		33	*Primula vulgaris*
Pyracantha gibbsii 'Orange Glow'	23		34	*Geranium cinereum* 'Splendens'
Ilex aquifolium 'Argentea Marginata'	22		35	*Thymus* x *citriodorus* 'Aureus'
Escallonia illinita 'Iveyi'	21		36	*Philadelphus tomentosus* 'Virginal'
Chaenomeles speciosa 'Nivalis'	20		37	*Cistus* x *pulverulentus* 'Sunset'
Acuba japonica 'Variegata'	19		38	*Berberis darwinii*
Physocarpus opulifolius 'Diabolo'	18		39	*Cotoneaster* 'Coral Beauty'
Anemone x *hybrida* 'Richard Ahrens'	55		40	*Ceanothus thyrsiflorus repens*
Erica carnea 'Vivellii'	17		41	*Hypericum henryi* 'Hidcote'
Calluna vulgaris 'Tib'	16		42	*Elaeagnus pungens* 'Maculata'
Erica carnea	15		43	*Hebe pinguifolia* 'Pagei'
Erica erigena	14		44	*Cotoneaster horizontalis*
Erica x *darlyensis*	13		45	*Berberis atropurpurea* 'Red Pillar'
Phlox subulata 'McDaniel's Cushion'	12		46	*Choisya ternata* 'Sundance'
Ajuga reptans 'Burgundy Glow'	11		47	*Potentilla fruticosa* 'Red Ace'
Viburnum tinus 'Eve Price'	10		48	*Hydrangea macrophylla* 'Madame Emile Mouilliére'
Thuja plicata 'Rogersii'	9		49	*Convolvulus* cneorum
X Cupressocyparis leylandii	8		50	*Euphorbia amygdaloides* 'Purpurea'
Picea glauca albertiana 'Conica'	7		51	*Sedum atuntsuense* 'Autumn Joy'
X Cupressocyparis leylandii 'Castlewellan Gold'	6		56	*Cotinus coggygrea* 'Royal Purple'
Juniperus horizontalis 'Blue Chip'	5		52	*Heuchera* hybrids
Chamaecyparis lawsoniana 'Little Spire'	4		53	*Stokesia laevis* 'Blue Star'
Juniperus x *media* 'Sulphur Spray'	3		54	*Lamium maculatum* 'Chequers'
Chamaecyparis lawsoniana 'Ellwoodii'	2			
Chamaecyparis lawsoniana 'Broomhill Gold'	1			

→ North

Each species represents a plot of 50 plants.

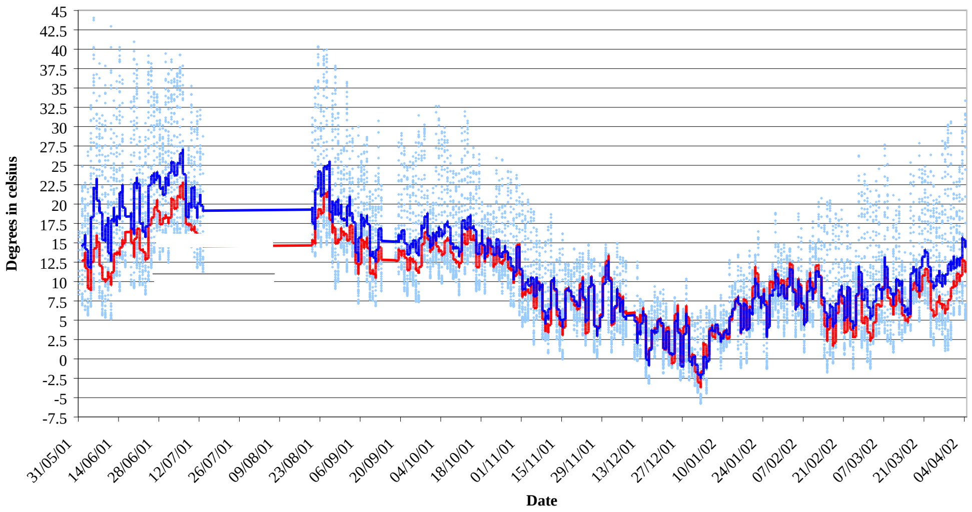
APPENDIX 3: Environmental Data


Average air temperature in SuperStrength 400 filter

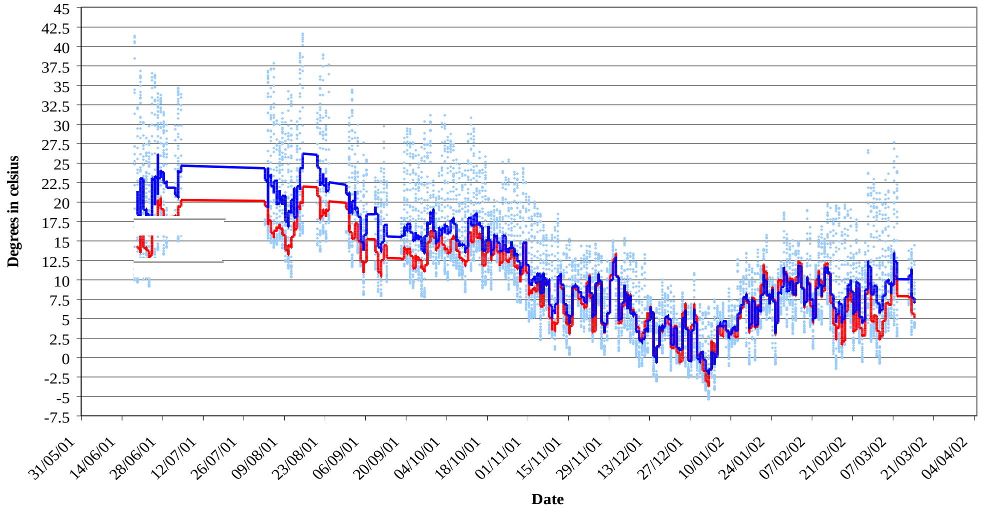

Average air temperature in SteriLite HDF filter

\+ Actual air temperature in tunnel — Average air temperature in tunnel — Average outdoor air temperature

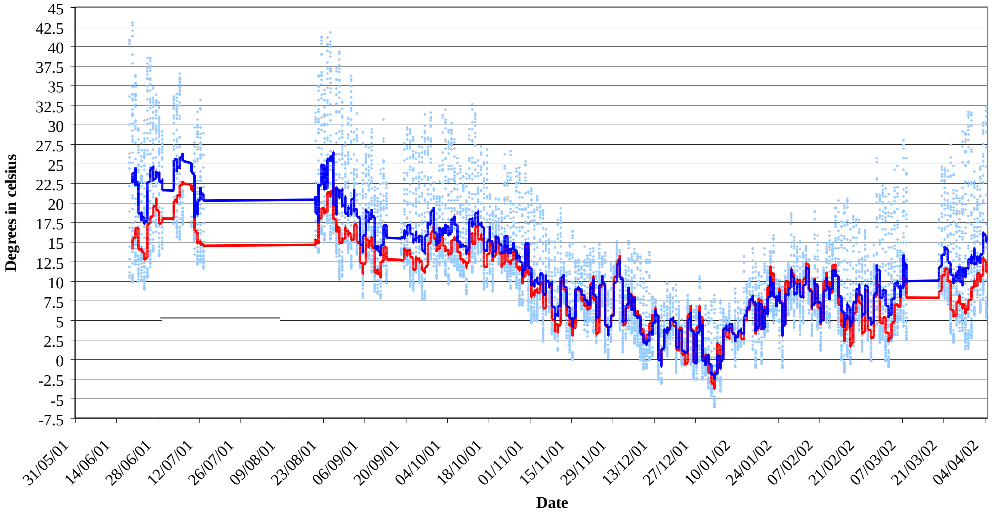
Average air temperature in SuperBlue filter



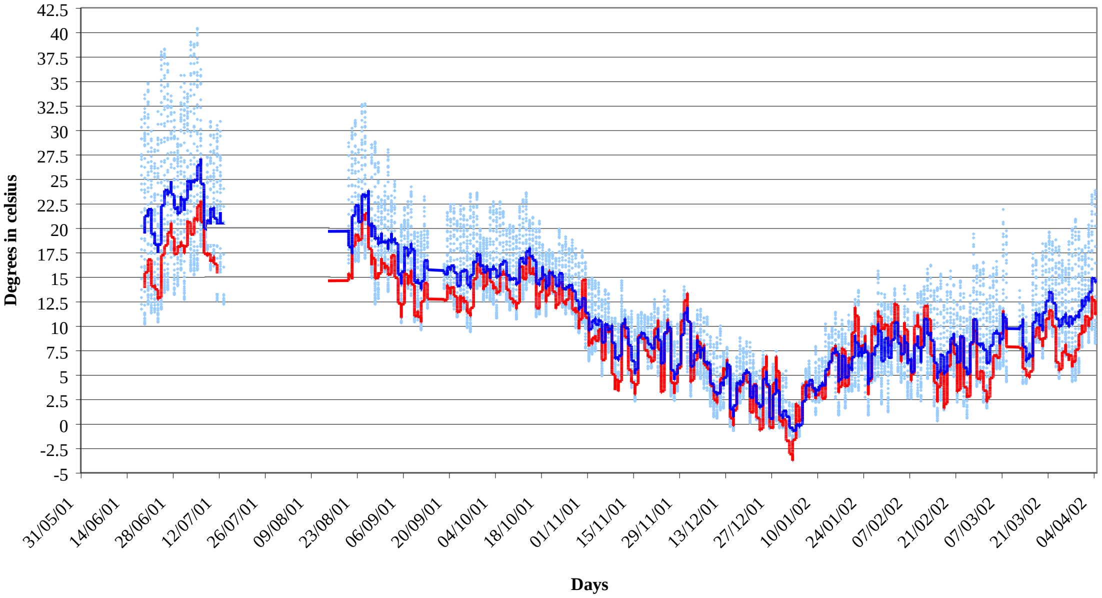
Average air temperature in SuperStrength 600 HDF filter



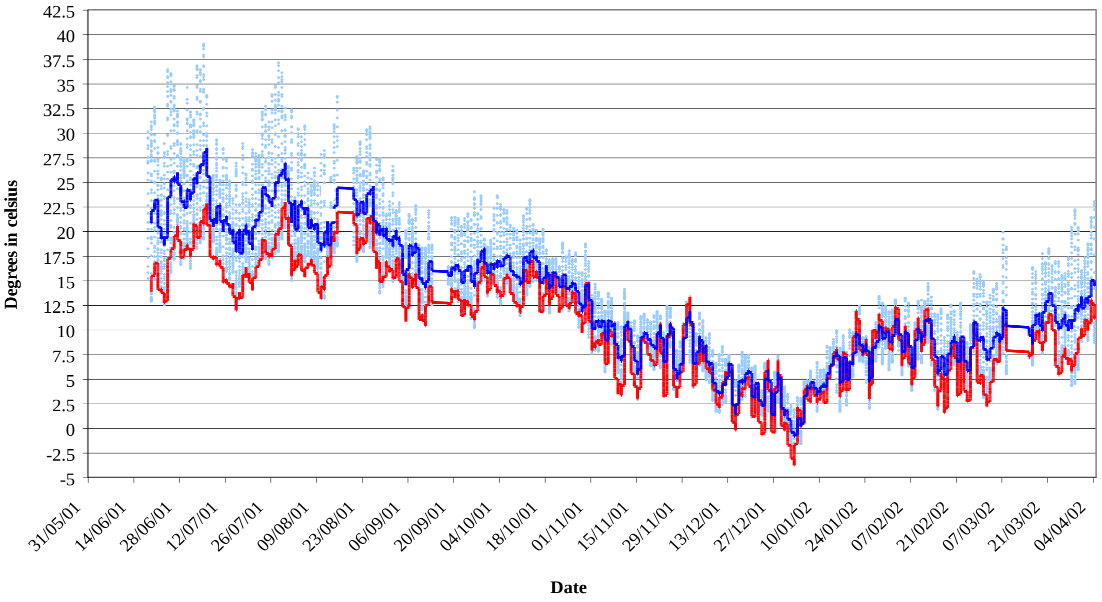
Average air temperature in SuperGreen filter



\+ Actual air temperature in tunnel ━ Average air temperature in tunnel ━ Average outdoor air temperature



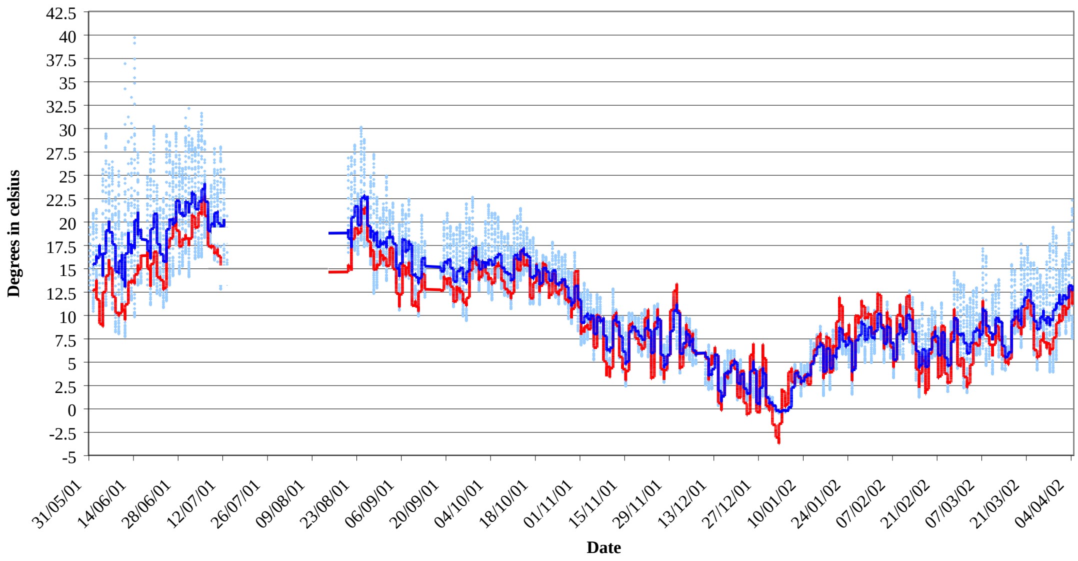
Average growing media temperature in SuperStrength 400 filter



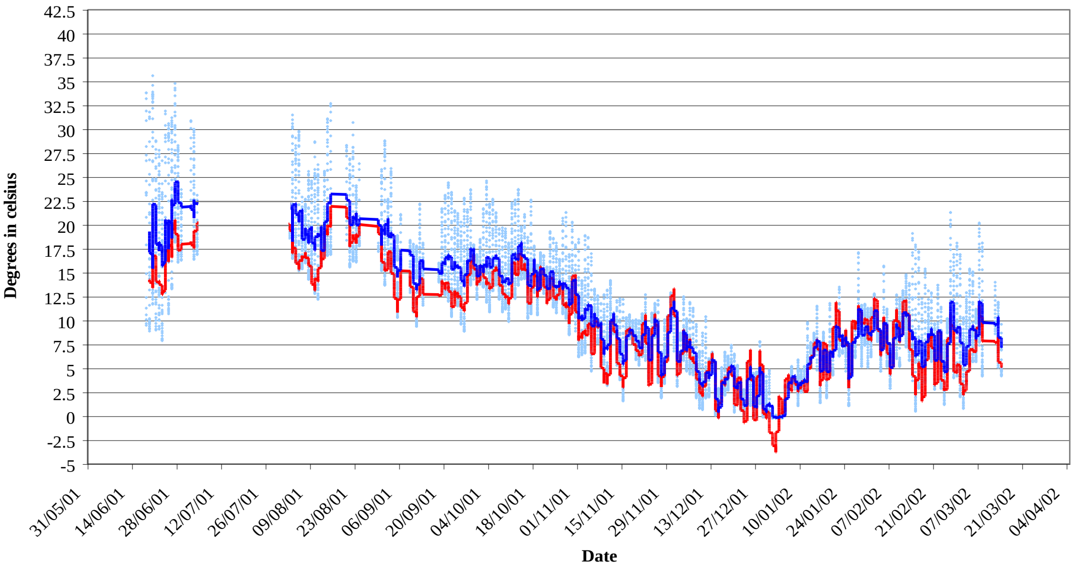
Average growing media temperature in SteriLite HDF filter

\+ Actual growing media temp in tunnel — Average growing media temp in tunnel — Average outdoor air temp

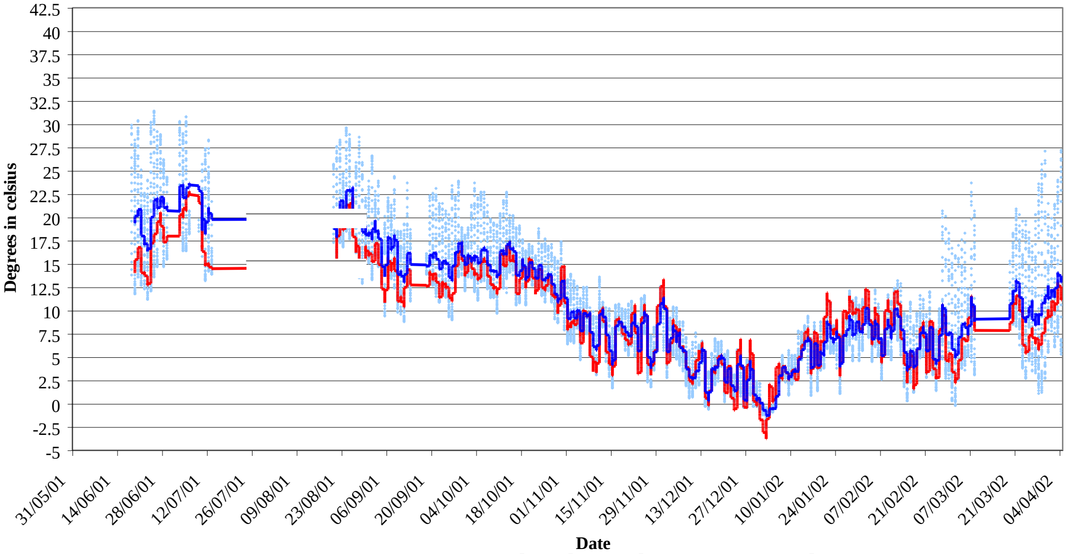
Average growing media temperature in SuperBlue filter



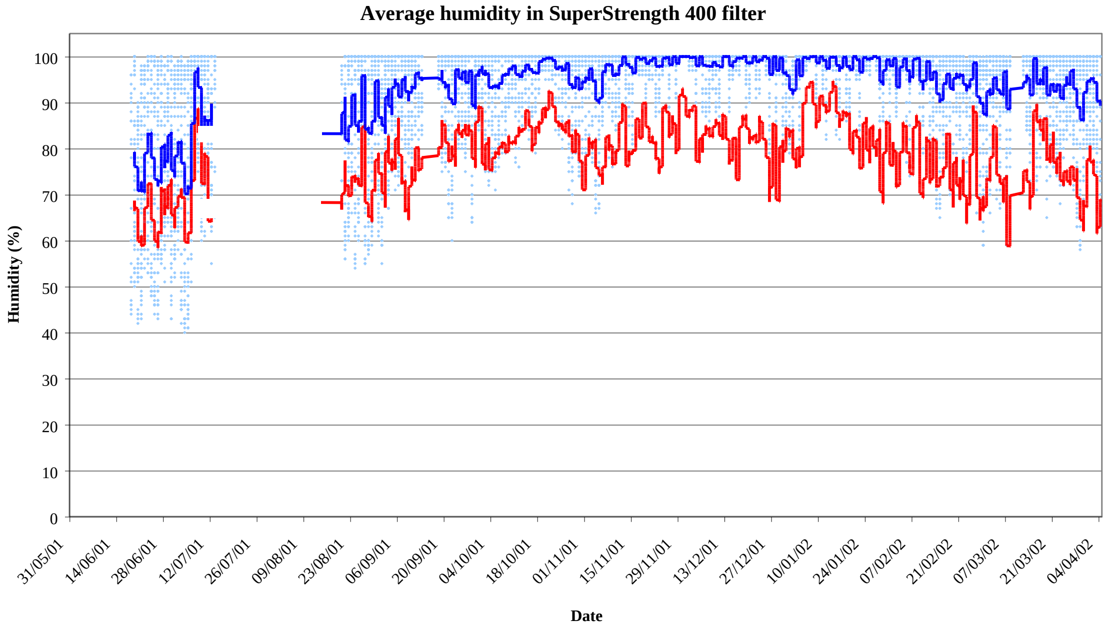
Average growing media temperature in SuperStrength 600 HDF filter

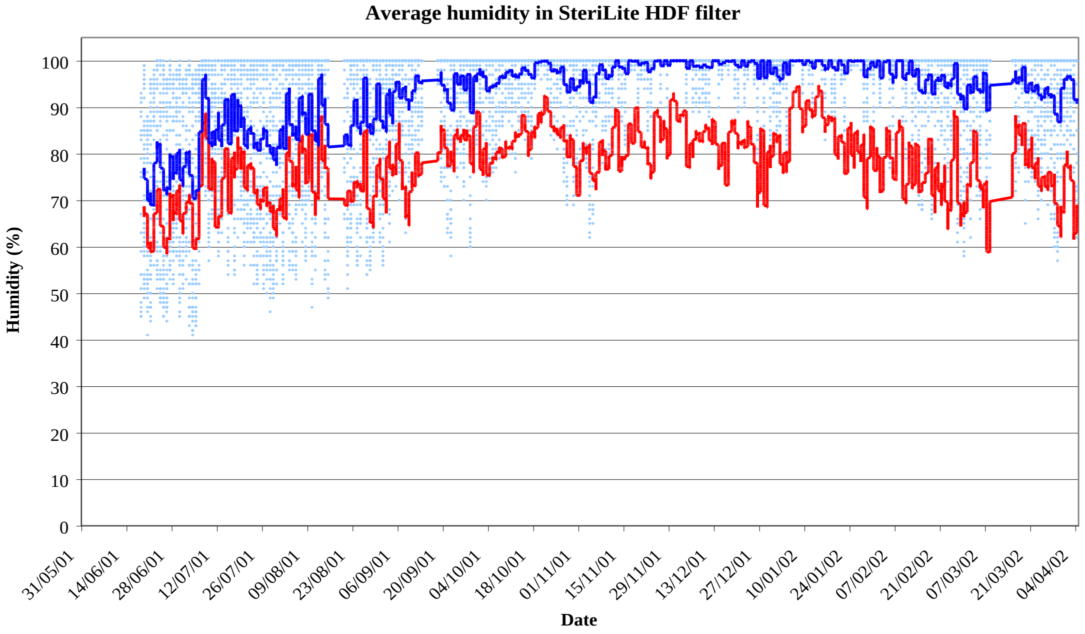


Average growing media temperature in SuperGreen filter

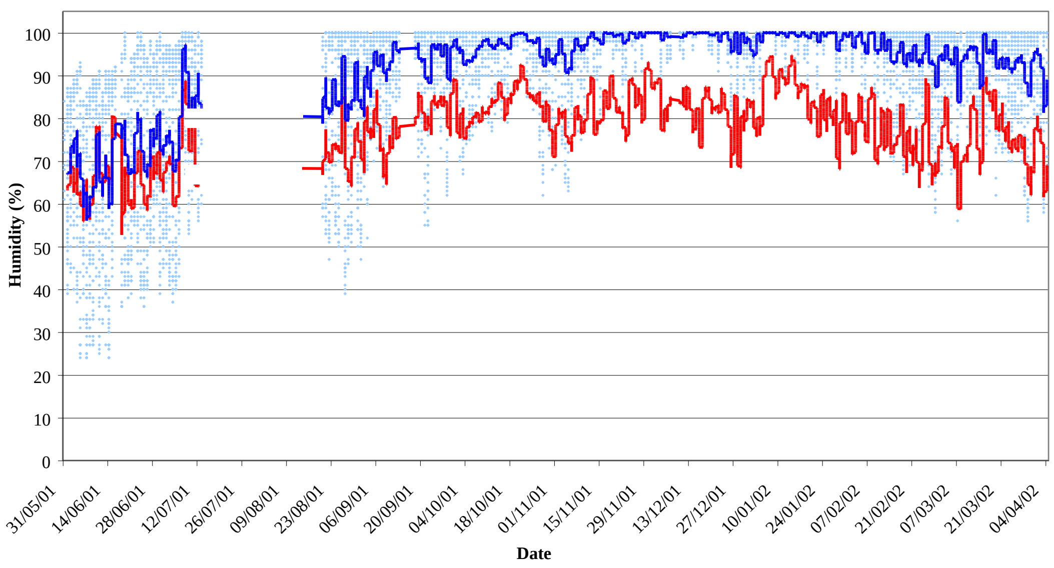


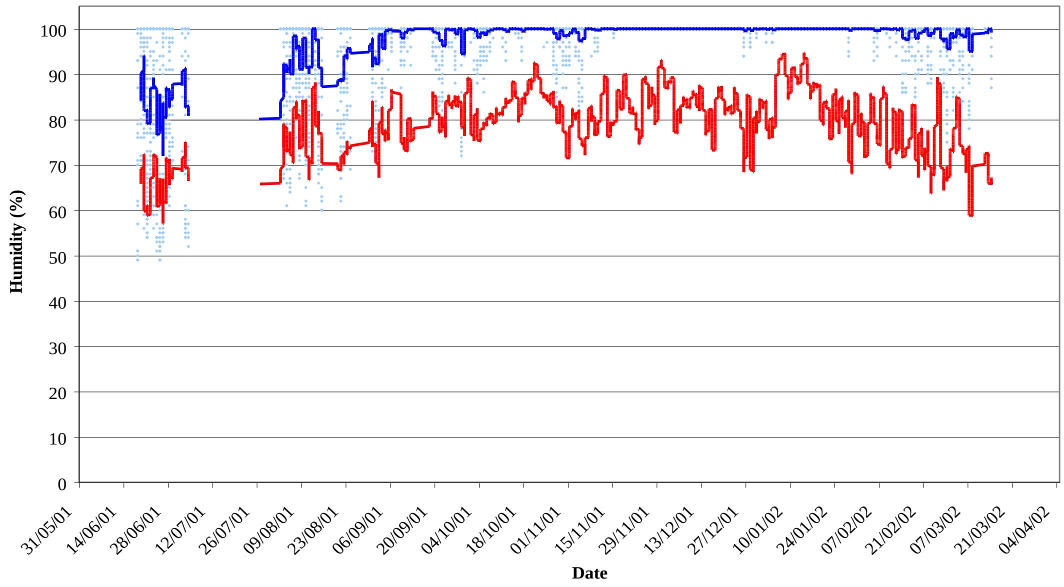
\+ Actual growing media temp in tunnel ━ Average growing media temp in tunnel ━ Average outdoor air temp

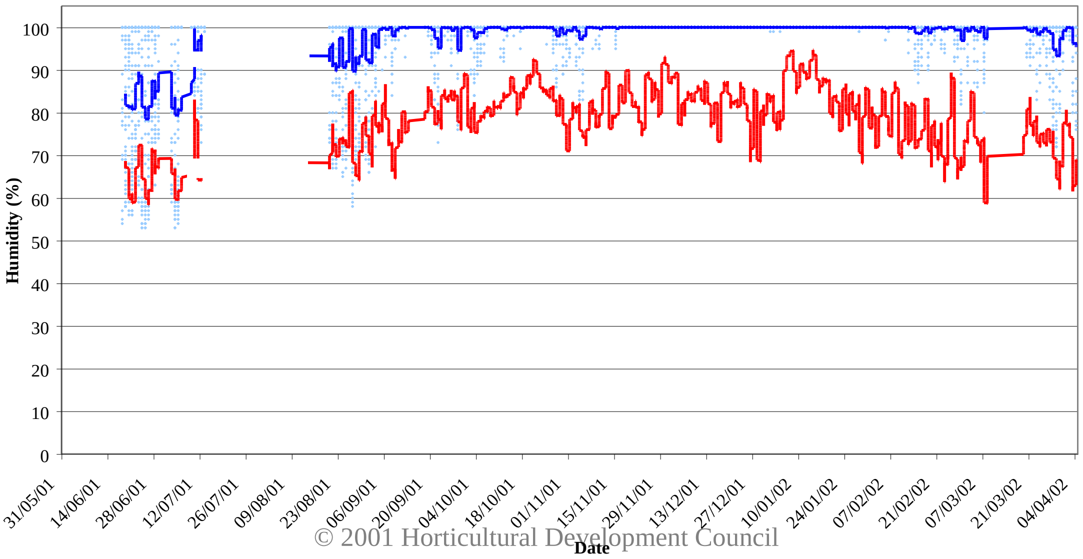

Average humidity in SuperStrength 400 filter


Average humidity in SteriLite HDF filter

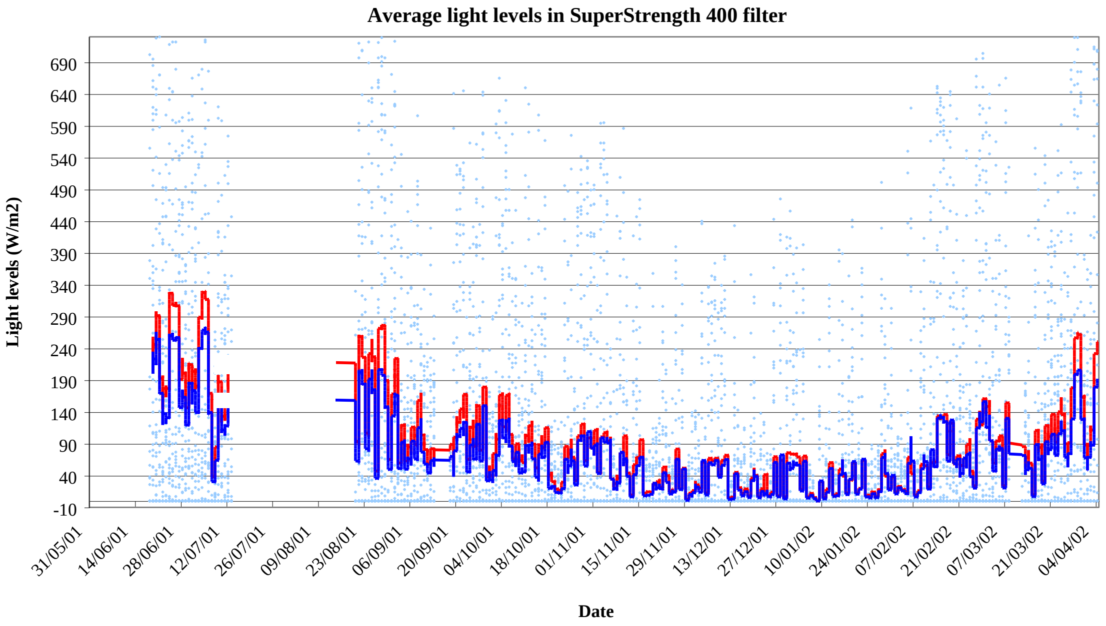
+ Actual humidity in tunnel ▬ Average humidity in tunnel ▬ Average outdoor humidity

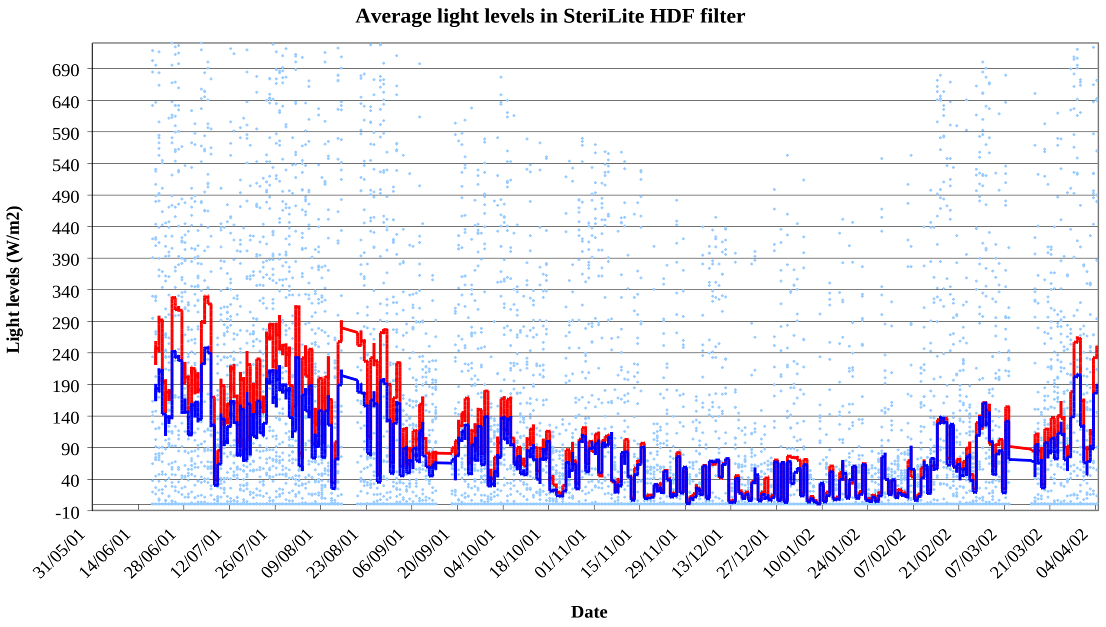

Average humidity in SuperBlue filter


Average humidity in SuperStrength 600 HDF filter


Average humidity in SuperGreen filter

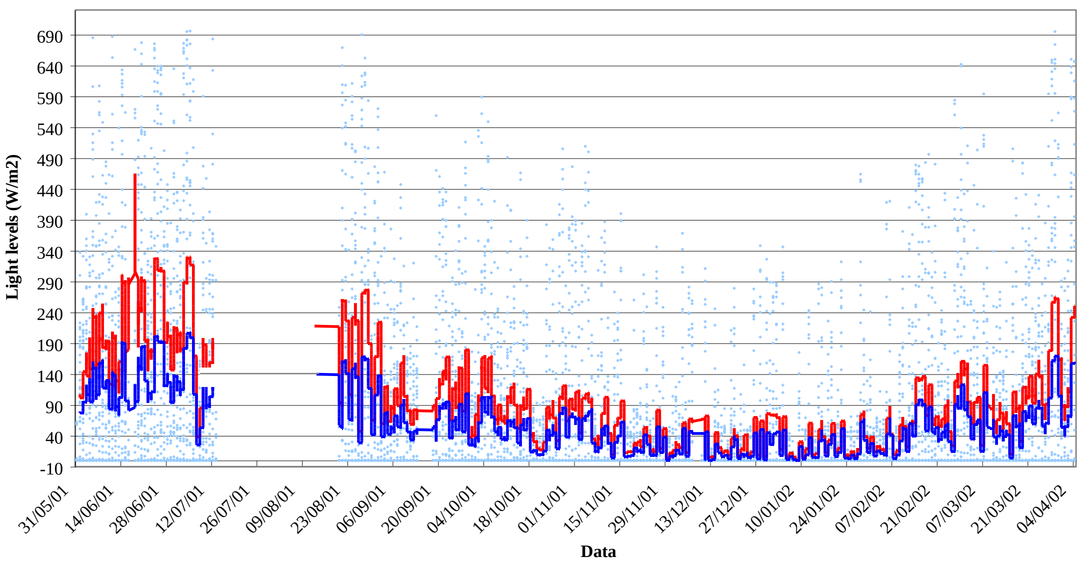
+ Actual humidity in tunnel ▬ Average humidity in tunnel ▬ Average outdoor humidity


Average light levels in SuperStrength 400 filter

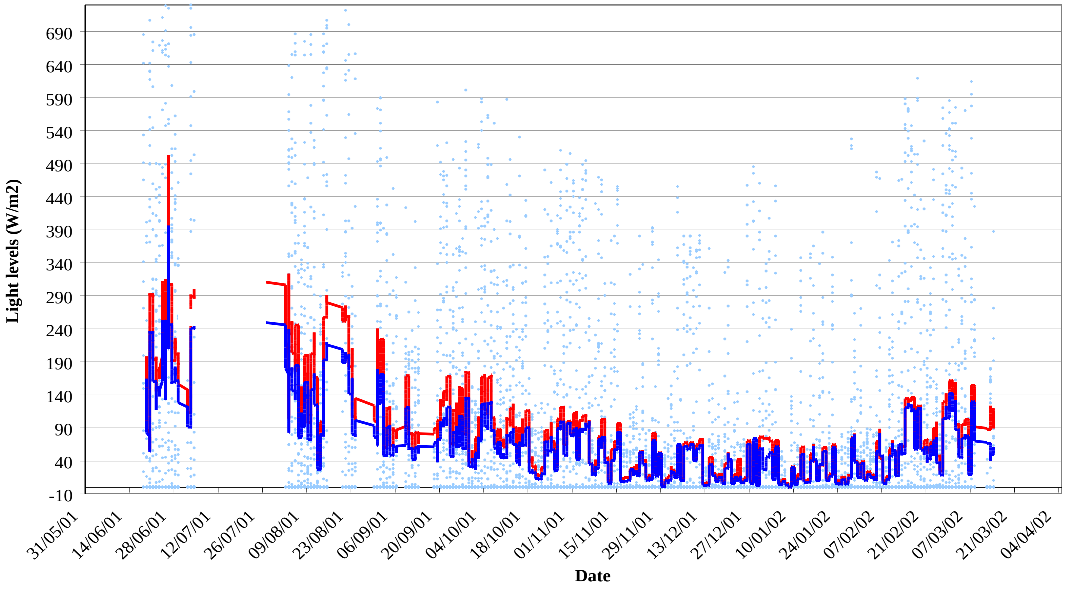

Average light levels in SteriLite HDF filter

\+ Actual solar radiation received in tunnel — Average light levels in tunnel — Average outdoor light levels

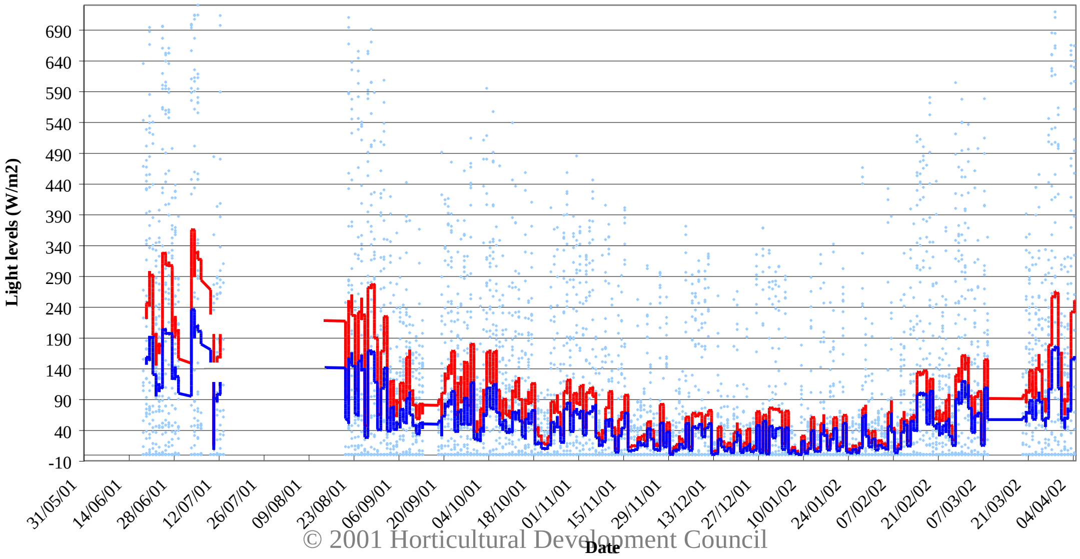
Average light levels in Super Blue filter



Average light levels in SuperStrength 600 HDF filter

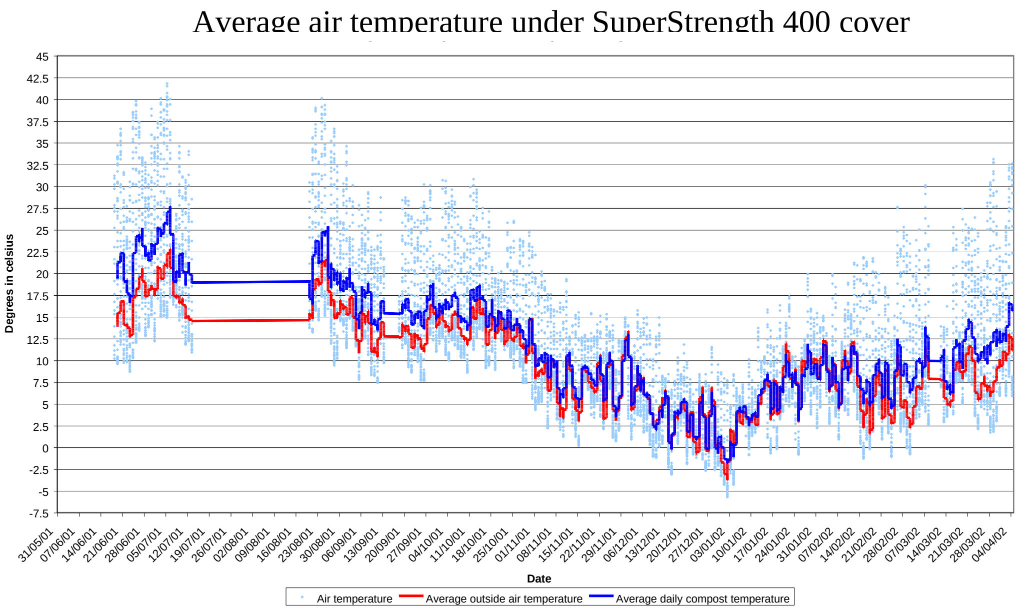


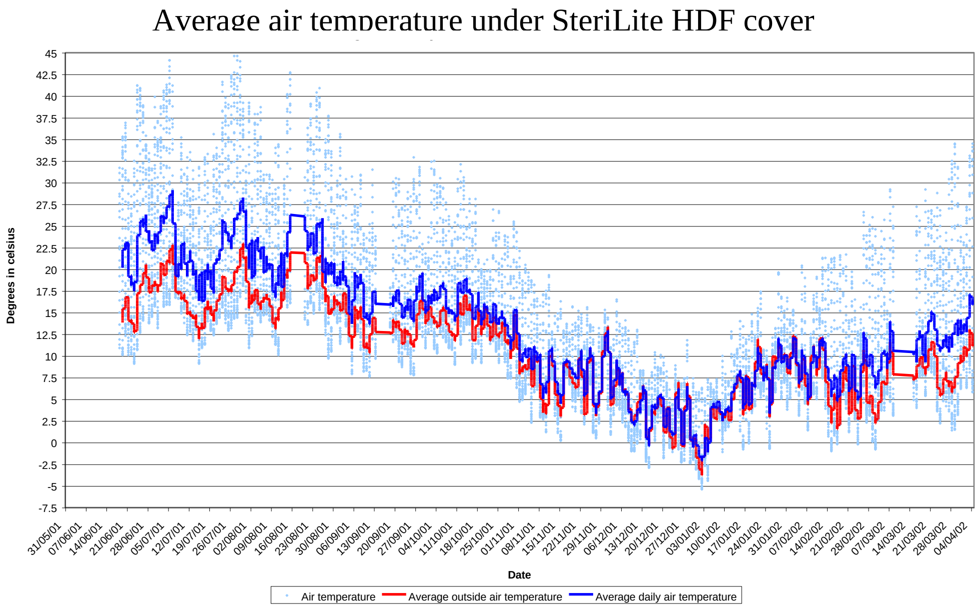
Average light levels in SuperGreen filter



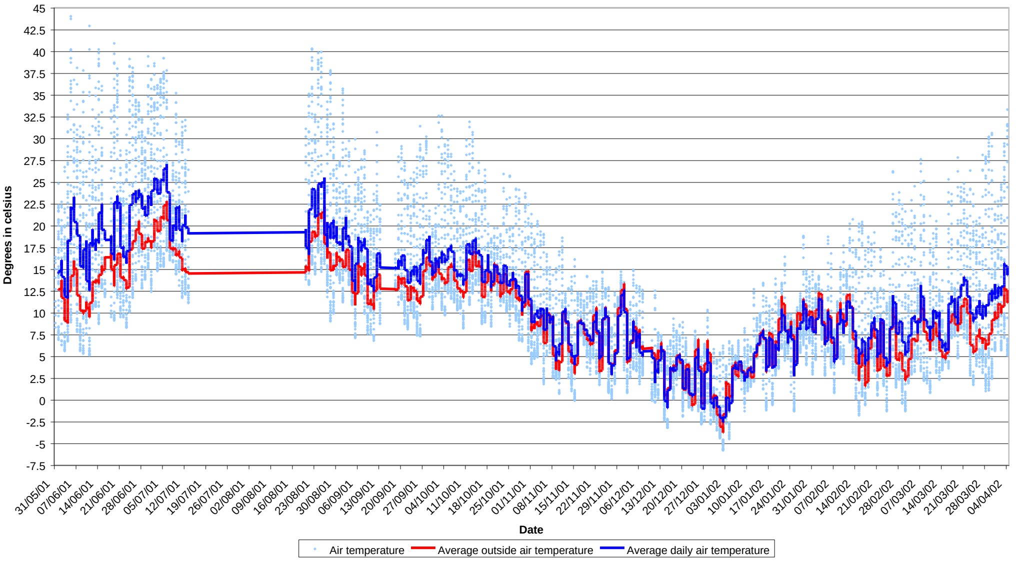
+ Actual solar radiation received in tunnel ▬ Average light levels in tunnel ▬ Average outdoor light levels

APPENDIX 3 Environmental Data

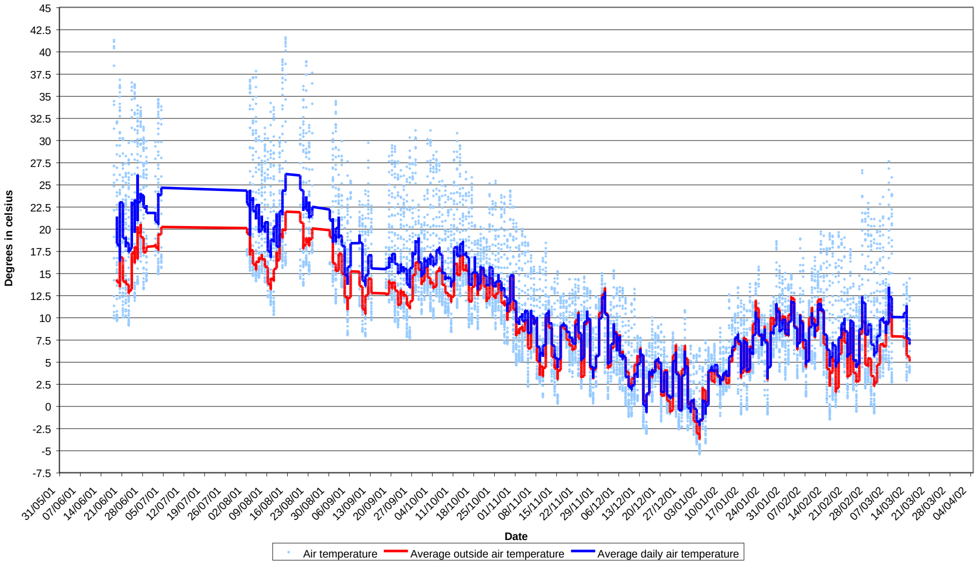

Average air temperature under SuperStrength 400 cover


Average air temperature under SteriLite HDF cover

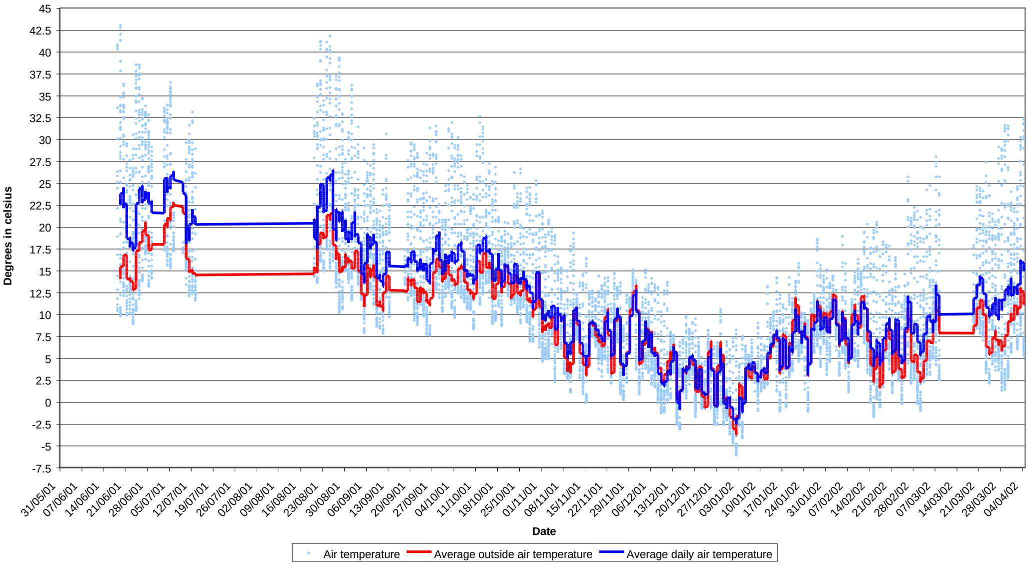
Average air temperature in SuperBlue filter



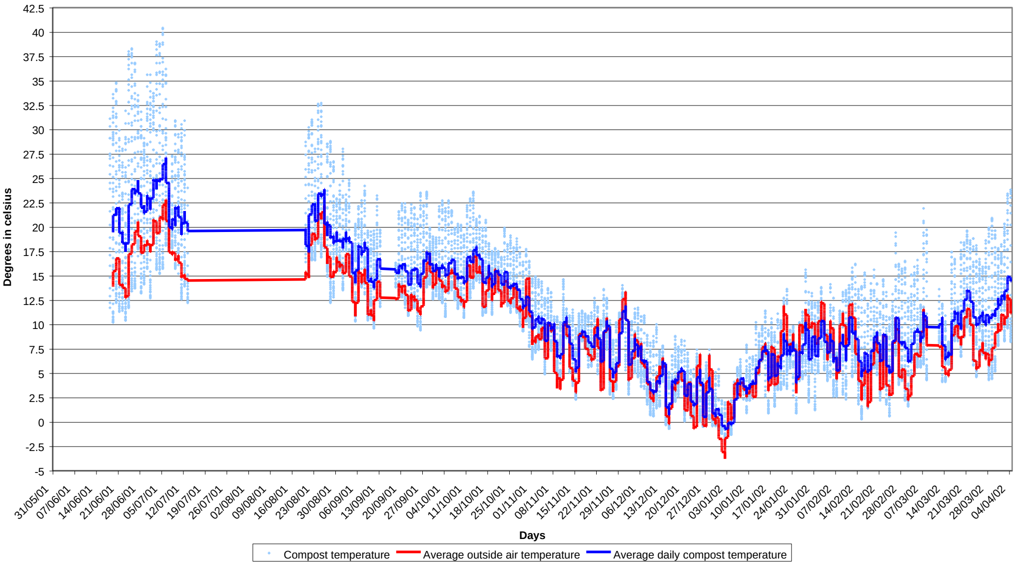
Average air temperature in SuperStrength 600 HDF filter



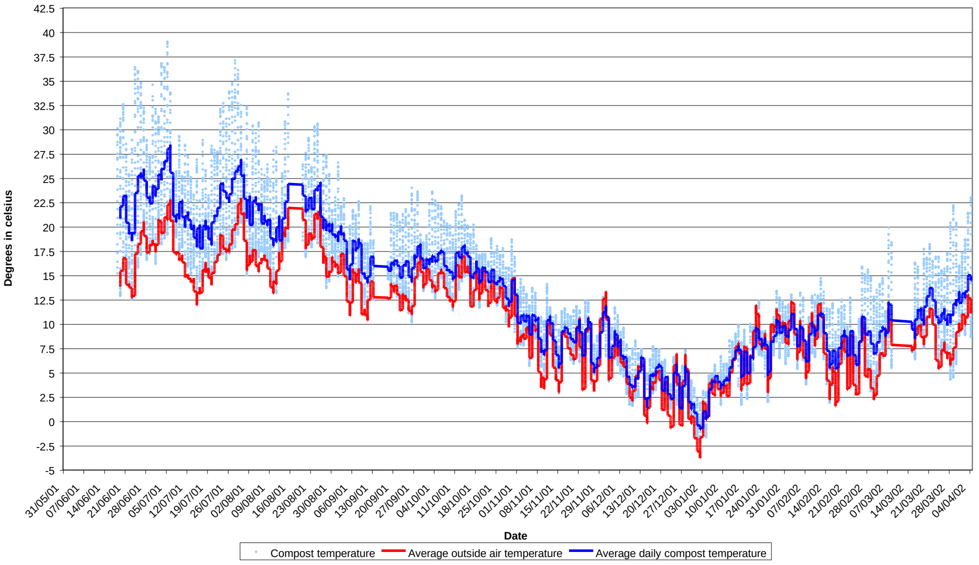
Average air temperature in SuperGreen filter



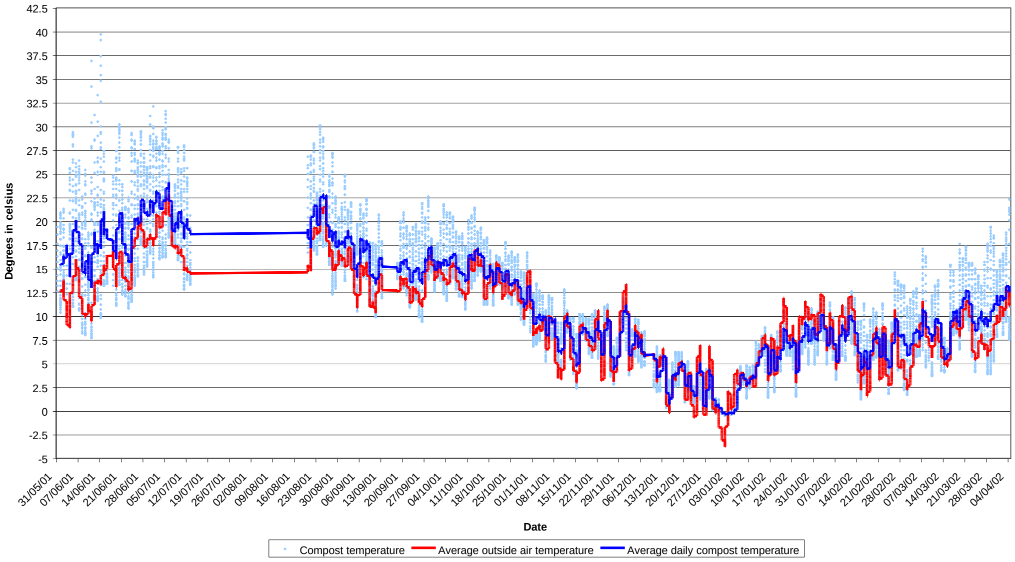
Average growing media temperature in SuperStrength 400 filter



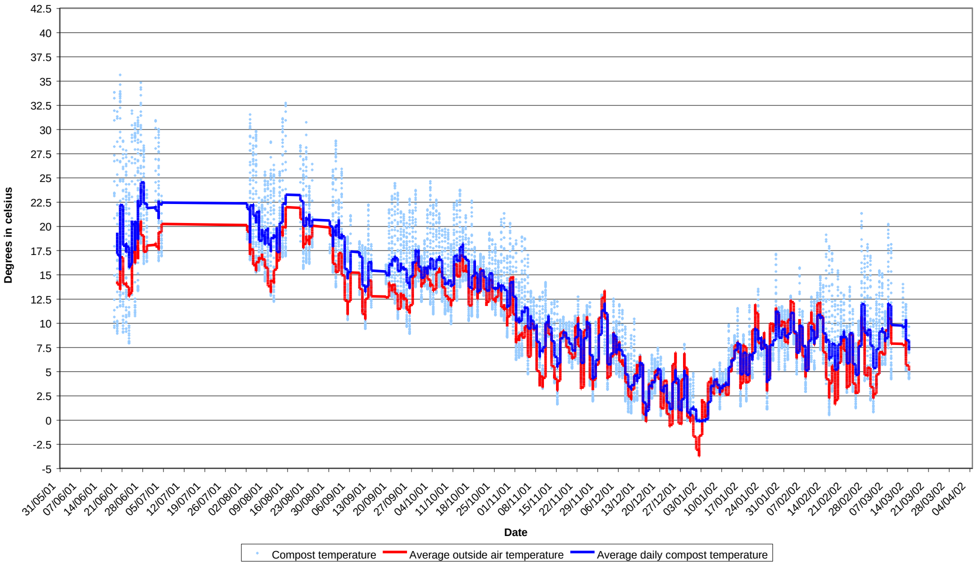
Average growing media temperature in SteriLite HDF filter



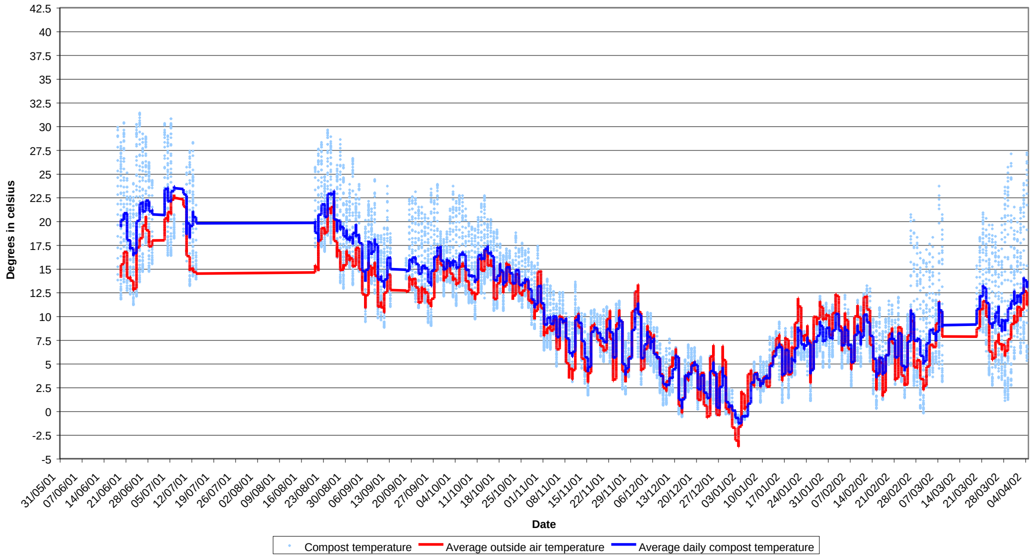
Average growing media temperature in SuperBlue filter

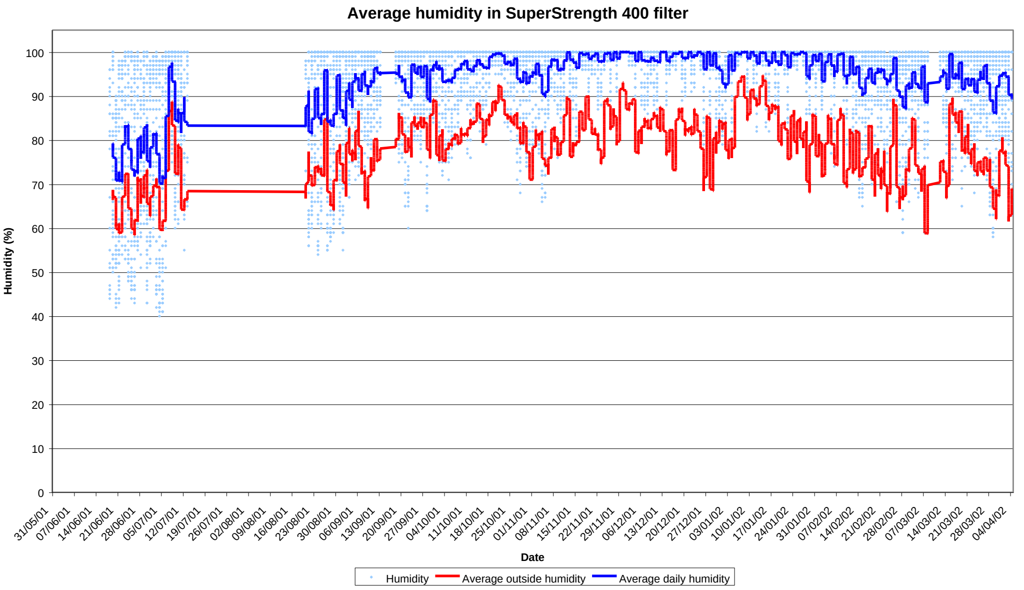


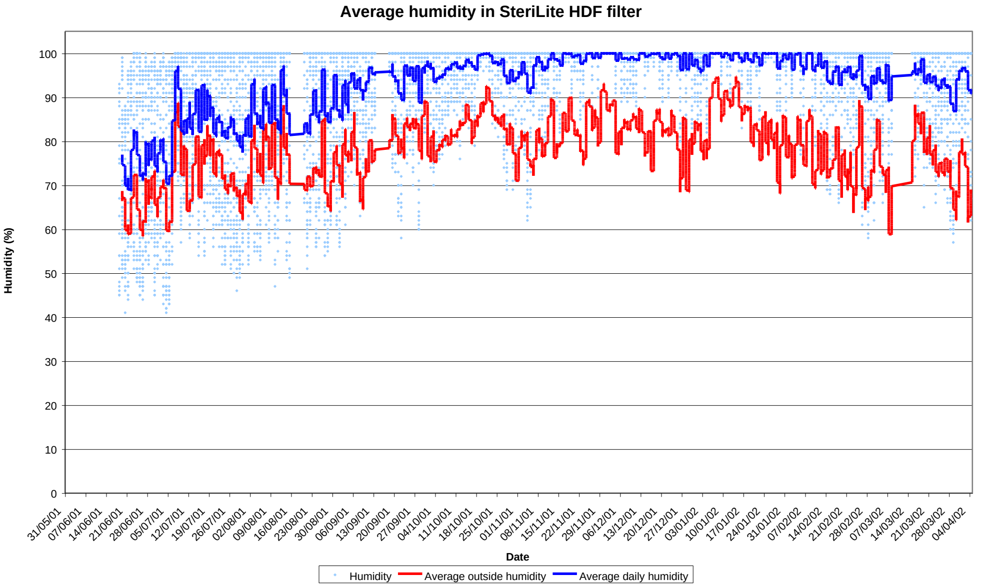
Average growing media temperature in SuperStrength 600 HDF filter



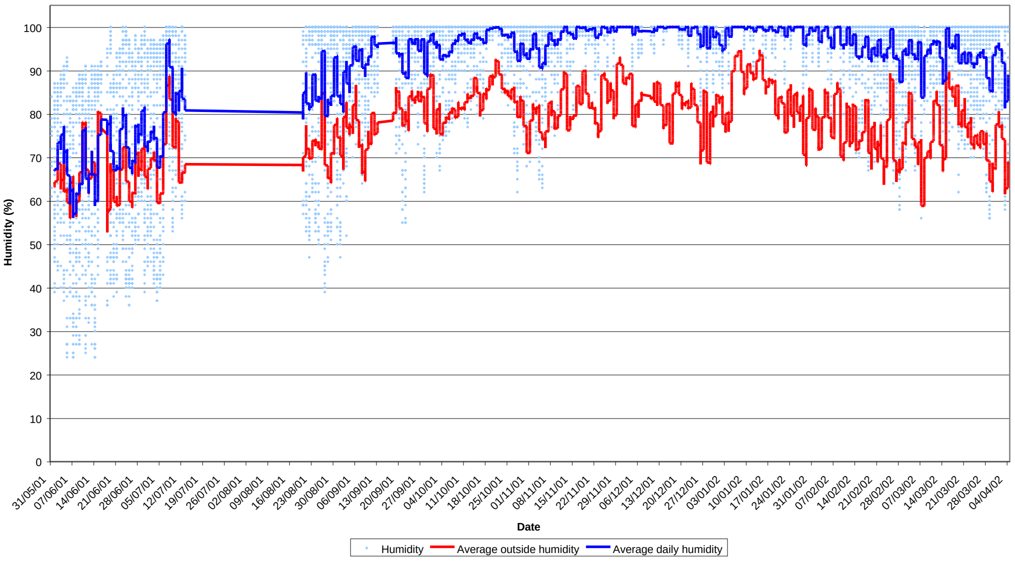
Average growing media temperature in SuperGreen filter



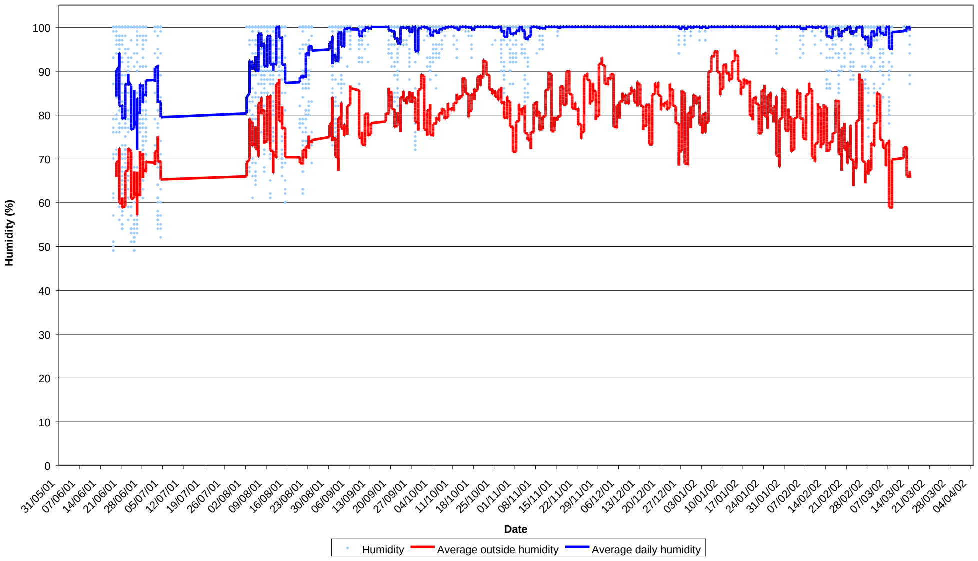

Average humidity in SuperStrength 400 filter


Average humidity in SteriLite HDF filter

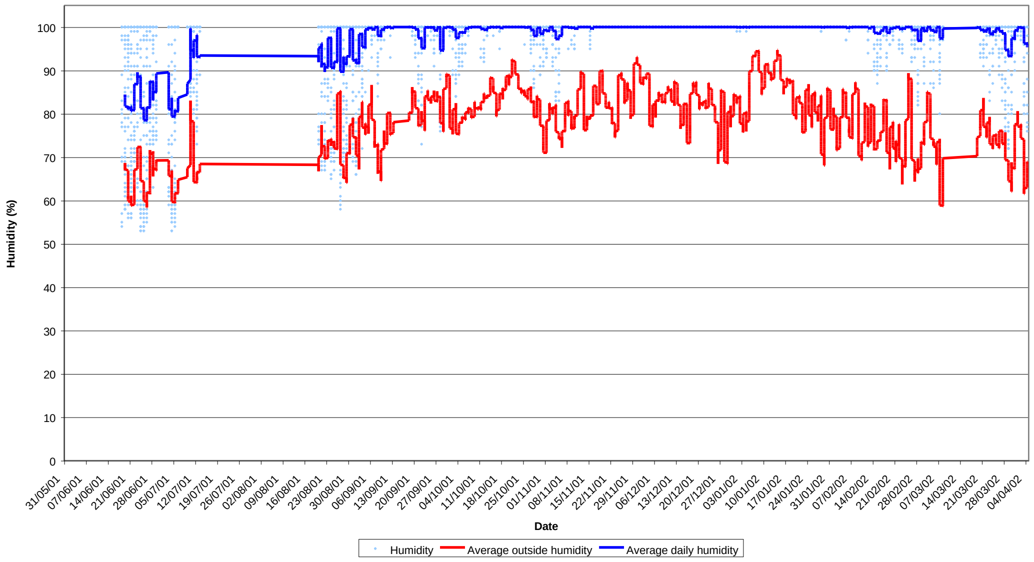
Average humidity in SuperBlue filter

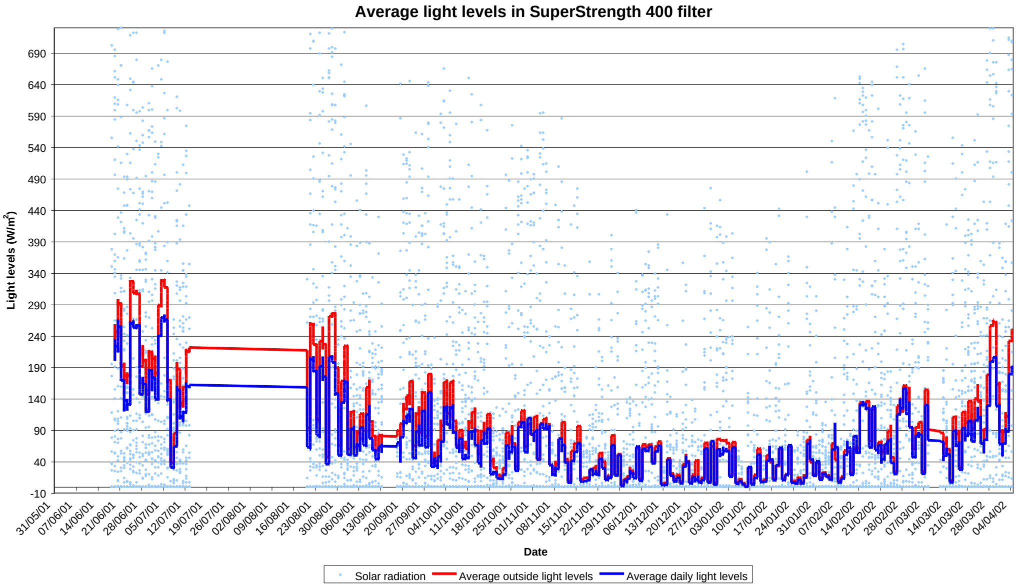


Average humidity in SuperStrength 600 HDF filter

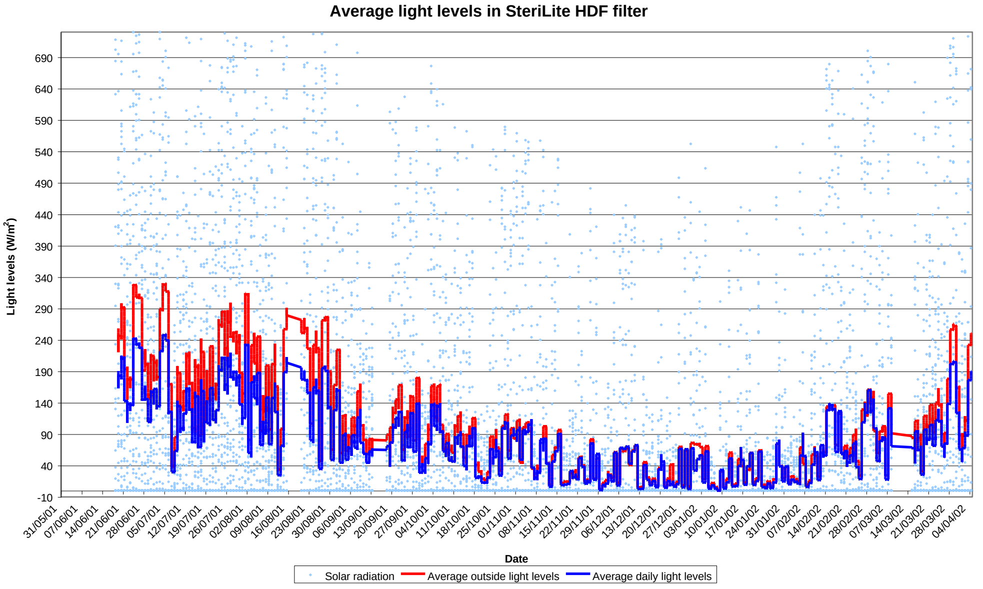


Average humidity in SuperGreen filter



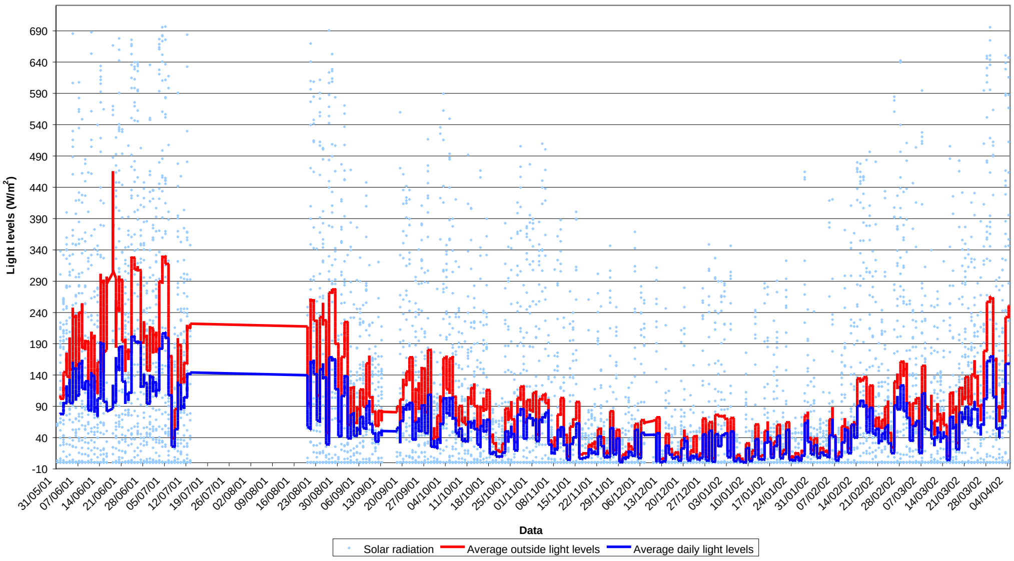


Average light levels in SuperStrength 400 filter

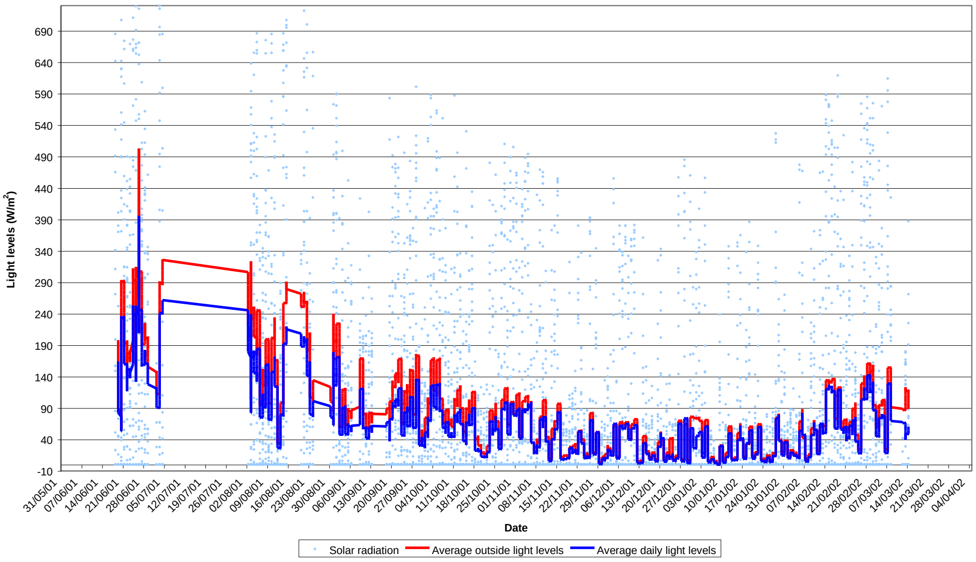


Average light levels in SteriLite HDF filter

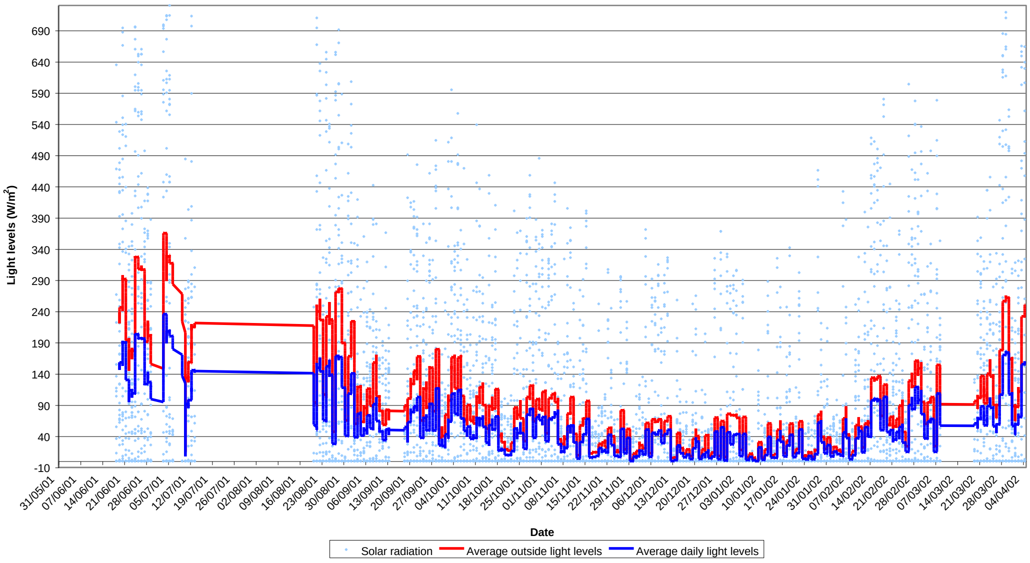
Average light levels in Super Blue filter



Average light levels in SuperStrength 600 HDF filter



Average light levels in SuperGreen filter



APPENDIX: 4

Table 1

Plant growth records - Summer 2001

(Figures are an average of 12 plants from assessments on two occasions, July and August 2001))

	Cover	**Mean Internode length** (mm)	**Stem thickness** (mm)	**Root density over pot-ball** Score 1-5, 5 = most	**Leaf size** (mm)	**No. breaks**
CONIFERS						
***Chamaecyparis lawsoniana* 'Broomhill Gold'**	**400**	4.8	2.2	0.7	2.2	31
	SteriLite	4.3	2.3	0.4	2.8	31
	Blue	5.5	2.1	0.3	2.3	29
	600	6.0	2.5	0.3	2.3	31
	Green	5.4	2.2	0.4	2.8	26
***Chamaecyparis lawsoniana* 'Ellwoodii'**	**400**	2.8	1.5	1.0	4.1	23
	SteriLite	2.6	1.9	0.5	4.3	20
	Blue	3.8	1.7	0.7	4.0	29
	600	3.0	1.9	0.9	4.0	29
	Green	5.3	2.5	0.8	4.8	9
***Chamaecyparis lawsoniana* 'Little Spire'**	**400**	5.7	2.8	1.2	2.1	>50
	SteriLite	4.1	2.5	1.3	2.1	>50
	Blue	5.3	2.3	1.0	2.1	>50
	600	4.8	2.9	1.1	1.8	48
	Green	6.3	3.0	1.2	2.1	>50

Table 1 (cont'd)

	Cover	Mean Internode length (mm)	Stem thickness (mm)	Root density over pot-ball Score 1-5, 5 = most	Leaf size (mm)	No. breaks
X Cupressocyparis leylandii	**400**	5.7	2.2	0.3	2.7	35
	SteriLite	4.6	2.4	0	2.7	35
	Blue	3.5	1.8	0	2.8	31
	600	5.8	2.6	0.4	2.6	29
	Green	6.1	2.3	0.2	3.1	26
***X Cupressocyparis leylandii* 'Castlewellan Gold'**	**400**	6.0	2.4	0.7	3.3	25
	SteriLite	5.7	2.4	0.6	2.8	25
	Blue	3.5	2.0	0.1	2.5	24
	600	5.1	2.3	0.8	3.0	24
	Green	6.0	2.2	0.5	3.3	21
***Juniperus horizontalis* 'Blue chip'**	**400**	5.2	1.6	0.8	5.3	>50
	SteriLite	4.6	1.9	0.8	5.8	>50
	Blue	3.3	1.3	0.3	5.2	>50
	600	5.5	1.8	1.1	5.0	>50
	Green	5.8	1.9	0.9	4.9	29
***Juniperus x media* 'Sulphur Spray'**	**400**	4.2	1.5	0	5.3	27
	SteriLite	3.5	1.9	0	5.3	26
	Blue	3.5	1.5	0.1	4.9	50
	600	3.6	1.9	0	4.2	36
	Green	4.3	1.9	0.1	4.2	20

Table 1 (cont'd)

	Cover	Mean Internode length (mm)	Stem thickness (mm)	Root density over pot-ball Score 1-5, 5 = most	Leaf size (mm)	No. breaks
***Picea glauca albertiana* 'Conica'**	**400**	2.0	1.5	0.2	12.3	14
	SteriLite	2.2	1.7	0	12.3	15
	Blue	2.3	1.6	0	10.8	12
	600	6.0	2.4	0	9.5	15
	Green	6.8	2.2	0.1	9.8	11
***Thuja plicata* 'Rogersii'**	**400**	5.2	1.8	0	2.7	13
	SteriLite	5.1	1.7	0	3.3	11
	Blue	3.0	1.7	0	2.9	8
	600	3.5	1.8	0	3.0	9
	Green	4.3	2.3	0	5.0	11
WOODY SHRUBS						
***Aucuba japonica* 'Variegata'**	**400**	9.0	4.3	0.2	64.3	1
	SteriLite	15.8	4.2	0	69.8	1
	Blue	15.3	4.7	0	75.8	1
	600	15.1	3.7	0	64.3	1
	Green	15.3	4.1	0	66.0	2
***Berberis atropurpurea* 'Red Pillar'**	**400**	16.3	1.4	0.1	23.9	3
	SteriLite	16.5	1.6	0	22.6	2
	Blue	13.3	2.1	0	24.0	1
	600	17.8	1.5	0	21.9	2
	Green	16.3	2.2	0	23.3	1

Table 1 (cont'd)

	Cover	Mean Internode length (mm)	Stem thickness (mm)	Root density over pot-ball Score 1-5, 5 = most	Leaf size (mm)	No. breaks
Berberis darwinii	**400**	10.3	1.1	0	13.8	2
	SteriLite	12.9	1.1	0	14.8	3
	Blue	16.3	1.3	0	18.6	2
	600	12.8	1.1	0	15.8	3
	Green	15.1	1.1	0	17.9	4
Ceanothus thyrsiflorus repens	**400**	15.4	2.3	1.2	20.6	19
	SteriLite	17.3	2.0	0.4	20.3	6
	Blue	15.8	1.9	0.7	20.7	9
	600	17.9	2.1	1.0	24.9	10
	Green	18.7	2.0	1.0	22.5	10
Chaenomeles speciosa **'Nivalis'**	**400**	22.6	1.8	0.4	41.6	3
	SteriLite	21.0	1.7	0.6	45.9	2
	Blue	14.9	1.6	0.1	36.2	2
	600	16.4	1.6	0.3	41.4	2
	Green	22.9	2.0	0.2	43.8	2
Choisya **'Aztec Pearl'**	**400**	24.2	2.3	0.8	52.9	4
	SteriLite	24.2	2.3	0.6	50.4	3
	Blue	21.1	1.6	0.3	52.7	2
	600	24.8	1.9	0.5	50.2	3
	Green	26.7	2.0	0.9	53.5	3

Table 1 (cont'd)

	Cover	**Mean Internode length** (mm)	**Stem thickness** (mm)	**Root density over pot-ball** Score 1-5, 5 = most	**Leaf size** (mm)	**No. breaks**
***Choisya ternata* 'Sundance'**	**400**	18.3	2.7	0.5	39.9	6
	SteriLite	21.8	2.4	0.3	38.9	3
	Blue	15.3	2.2	0	36.7	1
	600	17.9	2.3	0	33.8	5
	Green	16.1	2.3	0	33.2	4
***Cistus x pulverulentus* 'Sunset'**	**400**	27.8	2.4	2.3	51.7	7
	SteriLite	27.4	2.3	2.3	45.8	8
	Blue	25.4	2.1	1.3	42.3	5
	600	28.3	2.2	3.2	47.0	6
	Green	32.5	2.4	2.8	47.9	7
Convolvulus cneorum	**400**	12.6	1.9	1.2	36.2	7
	SteriLite	12.8	1.7	0.7	30.5	6
	Blue	11.3	1.7	0.2	30.6	4
	600	9.3	2.4	0.5	30.8	4
	Green	8.2	1.9	0.5	25.9	4
***Cotoneaster* 'Coral Beauty'**	**400**	11.5	1.7	1.4	18.0	12
	SteriLite	12.2	1.9	1.2	19.1	13
	Blue	10.8	1.8	0.5	18.8	6
	600	11.5	1.7	0.6	18.4	5
	Green	11.5	1.5	0.7	17.8	6

Table 1 (cont'd)

	Cover	Mean Internode length (mm)	Stem thickness (mm)	Root density over pot-ball Score 1-5, 5 = most	Leaf size (mm)	No. breaks
Cotoneaster horizontalis	**400**	7.7	1.7	1.1	13.1	13
	SteriLite	8.0	1.6	0.5	12.6	13
	Blue	7.6	1.3	0.3	11.8	10
	600	8.9	1.4	0.3	12.4	7
	Green	8.8	1.4	0.5	11.3	8
***Elaeagnus pungens* 'Maculata'**	**400**	14.2	2.1	0.2	68.4	2
	SteriLite	12.5	1.9	0.2	55.3	3
	Blue	12.0	1.6	0.1	72.7	2
	600	19.8	2.6	0.3	70.3	2
	Green	17.3	1.9	0.1	69.9	1
***Escallonia illinita* 'Iveyi'**	**400**	16.7	3.3	0.6	30.6	2
	SteriLite	16.4	3.1	0.5	33.4	3
	Blue	14.0	2.9	0.3	29.3	3
	600	12.1	2.9	0.4	25.4	3
	Green	14.5	3.0	0.8	31.6	2
***Forsythia giraldiana* 'Golden Times'**	**400**	18.3	1.7	1.1	44.2	5
	SteriLite	26.8	2.3	1.2	45.3	5
	Blue	15.6	1.5	0.7	38.2	6
	600	15.6	1.5	0.7	35.1	6
	Green	20.2	1.6	1.1	37.7	5

Table 1 (cont'd)

	Cover	Mean Internode length (mm)	Stem thickness (mm)	Root density over pot-ball Score 1-5, 5 = most	Leaf size (mm)	No. breaks
***Hebe pinguifolia* 'Pagei'**	**400**	7.3	1.6	0.2	11.8	7
	SteriLite	6.9	1.6	0	11.0	6
	Blue	6.2	1.5	0	11.0	7
	600	6.4	1.6	0.1	11.8	4
	Green	5.7	1.4	0	10.8	4
***Helianthemum umbellatum* 'Wisley Pink'**	**400**	14.9	1.9	1.5	32.8	10
	SteriLite	12.8	1.8	0.8	33.3	9
	Blue	19.0	1.6	1.5	31.1	7
	600	14.9	1.9	2.1	30.1	6
	Green	17.4	1.6	2.3	28.9	6
***Hydrangea macrophylla* 'Madame Emile Mouillére'**	**400**	19.3	2.6	0	44.2	5
	SteriLite	20.9	3.1	0	45.3	5
	Blue	21.1	2.8	0	48.3	5
	600	18.6	2.6	0	36.5	4
	Green	19.3	2.7	0	35.1	5
***Hypericum henryi* 'Hidcote'**	**400**	20.0	1.9	0.6	35.4	7
	SteriLite	20.5	1.6	0.3	34.0	6
	Blue	20.9	1.5	0.1	30.2	6
	600	19.0	1.5	0.3	30.6	7
	Green	20.4	1.5	0.3	29.6	7

Table 1 (cont'd)

	Cover	**Mean Internode length** (mm)	**Stem thickness** (mm)	**Root density over pot-ball** Score 1-5, 5 = most	**Leaf size** (mm)	**No. breaks**
Ilex aquifolium **'Argentea Marginata'**	**400**	13.0	2.3	0	31.7	3
	SteriLite	11.8	2.2	0	32.9	3
	Blue	8.1	2.3	0	30.8	3
	600	11.4	2.5	0	36.2	2
	Green	10.7	2.3	0	35.3	3
Philadelphus tomentosus **'Virginal'**	**400**	30.9	2.4	1.7	55.8	3
	SteriLite	34.3	2.3	1.4	56.2	4
	Blue	27.3	2.1	0.8	53.2	2
	600	28.8	2.0	1.5	58.6	4
	Green	31.7	2.0	0.8	51.3	4
Physocarpus opulifolius **'Diabolo'**	**400**	49.1	3.5	2.2	68.5	4
	SteriLite	43.3	3.1	1.7	58.3	4
	Blue	35.3	2.7	0.6	56.6	4
	600	35.0	2.7	1.8	55.8	4
	Green	33.3	2.6	1.3	51.8	4
Potentilla fruticosa **'Red Ace'**	**400**	16.6	1.3	0.8	13.8	11
	SteriLite	16.1	1.1	0.6	12.8	10
	Blue	14.9	1.0	0.2	12.2	11
	600	12.8	1.1	0.4	12.5	8
	Green	12.3	0.9	0.3	10.5	7

Table 1 (cont'd)

	Cover	Mean Internode length (mm)	Stem thickness (mm)	Root density over pot-ball Score 1-5, 5 = most	Leaf size (mm)	No. breaks
Pyracantha gibbsii **'Orange Glow'**	**400**	14.4	2.2	1.4	25.8	4
	SteriLite	13.0	2.1	1.3	27.8	6
	Blue	11.8	1.8	0.8	26.3	3
	600	14.2	1.9	2.3	27.7	5
	Green	12.3	2.1	1.8	28.4	6
Spiraea japonica **'Shirobana'**	**400**	13.0	1.6	1.8	40.5	15
	SteriLite	14.2	1.7	1.4	42.3	14
	Blue	10.5	1.4	0.5	33.0	18
	600	11.3	1.6	0.8	31.4	14
	Green	10.2	1.5	0.4	33.3	9
Viburnum tinus **'Eve Price'**	**400**	22.2	1.8	0.8	42.9	5
	SteriLite	18.3	2.1	0.5	47.6	4
	Blue	16.3	1.9	0	43.3	3
	600	18.8	1.9	0.7	42.6	3
	Green	32.9	2.5	0.5	41.7	5
Weigela florida **'Variegata'**	**400**	35.9	2.0	0.5	49.8	5
	SteriLite	34.8	2.2	0.8	58.4	5
	Blue	36.8	1.9	0.3	52.9	3
	600	29.8	2.1	0.9	51.6	4
	Green	27.7	2.1	1.0	50.7	4

Table 1 (cont'd)

	Cover	**Mean Internode length** (mm)	**Stem thickness** (mm)	**Root density over pot-ball** Score 1-5, 5 = most	**Leaf size** (mm)	**No. breaks**
HEATHERS						
***Calluna vulgaris* 'Tib'**	**400**	4.2	0.9	5.0	1.8	>50
	SteriLite	4.3	0.8	5.0	1.7	>50
	Blue	3.2	0.7	5.0	1.7	>50
	600	5.1	0.9	5.0	1.3	>50
	Green	5.1	0.7	5.0	1.8	>50
Erica carnea	**400**	3.4	0.9	5.0	4.8	>50
	SteriLite	4.2	0.8	5.0	5.3	>50
	Blue	3.3	0.8	5.0	4.7	>50
	600	3.8	0.8	5.0	5.3	>50
	Green	3.8	1.0	4.8	6.2	>50
***Erica carnea* 'Vivellii'**	**400**	2.8	0.8	5.0	3.8	>50
	SteriLite	3.2	1.0	5.0	4.2	>50
	Blue	3.0	1.0	4.5	5.2	>50
	600	3.5	0.9	5.0	5.2	>50
	Green	3.3	0.9	4.7	5.2	>50
Erica x darleyensis	**400**	3.6	0.9	5.0	4.9	>50
	SteriLite	3.2	0.8	5.0	5.2	>50
	Blue	3.3	0.8	5.0	5.2	>50
	600	3.2	0.8	5.0	5.6	>50
	Green	4.3	1.5	5.0	6.2	>50

Table 1 (cont'd)

	Cover	**Mean Internode length** (mm)	**Stem thickness** (mm)	**Root density over pot-ball** Score 1-5, 5 = most	**Leaf size** (mm)	**No. breaks**
Erica erigena	**400**	3.4	0.9	5.0	5.1	>50
	SteriLite	3.3	0.9	5.0	4.8	>50
	Blue	3.6	0.7	5.0	5.2	>50
	600	3.4	0.7	5.0	4.9	>50
	Green	3.7	1.1	4.9	5.1	>50
HERBACEOUS						
***Euphorbia amygdaloides* 'Purpurea'**	**400**	8.2	4.2	1.3	58.4	9
	SteriLite	8.4	3.6	0.6	54.6	6
	Blue	9.3	3.5	0.3	51.1	4
	600	10.0	3.4	0.5	44.5	6
	Green	9.8	3.2	0.4	48.0	5
***Sedum atuntsuense* 'Autumn Joy'**	**400**	24.5	4.8	0.8	65.3	6
	SteriLite	23.8	4.0	0.4	55.3	4
	Blue	19.4	3.6	0.3	49.8	3
	600	18.3	3.7	0.4	42.9	3
	Green	15.7	3.0	0	37.3	2
***Veronica gentianoides* 'Variegata'**	**400**	8.3	1.1	1.1	17.8	35
	SteriLite	8.2	1.1	0.3	19.8	35
	Blue	7.9	1.1	0.3	19.7	28
	600	9.3	1.3	0.3	18.6	25
	Green	9.7	1.4	0.7	20.1	21

Table 1 (cont'd)

	Cover	Mean Internode length (mm)	Stem thickness (mm)	Root density over pot-ball Score 1-5, 5 = most	Leaf size (mm)	No. breaks
ALPINES						
***Ajuga reptans* 'Burgundy Glow'**	**400**	30.5	3.2	3.2	42.1	6
	SteriLite	33.7	3.3	3.3	43.3	6
	Blue	31.7	3.3	3.1	39.7	5
	600	39.4	3.5	3.7	42.0	6
	Green	15.9	2.0	3.0	41.4	2
***Aubretia albomarginata* 'Astolat'**	**400**	5.4	1.2	0.9	14.5	8
	SteriLite	5.3	1.6	0.4	14.4	6
	Blue	5.3	1.4	0.7	18.6	22
	600	4.2	1.5	0.5	12.3	5
	Green	4.3	1.0	2.0	14.3	8
***Geranium cinereum* 'Splendens'**	**400**	-	0.9	0.6	13.9	29
	SteriLite	-	0.9	0.5	13.1	22
	Blue	-	0.9	0.3	13.1	19
	600	-	0.9	0.5	12.6	22
	Green	-	1.0	1.2	12.1	21
***Lithospermum diffusum* 'Heavenly Blue'**	**400**	3.4	1.8	0	15.3	6
	SteriLite	4.1	2.1	0.1	17.3	6
	Blue	3.5	1.9	0.3	16.1	8
	600	3.9	2.3	0.1	13.6	9
	Green	3.9	1.9	0.4	15.1	5

Table 1 (cont'd)

	Cover	Mean Internode length (mm)	Stem thickness (mm)	Root density over pot-ball Score 1-5, 5 = most	Leaf size (mm)	No. breaks
***Phlox subulata* 'McDaniel's Cushion'**	**400**	7.6	1.4	0.2	11.5	13
	SteriLite	7.4	1.5	0.5	12.0	9
	Blue	6.3	1.6	0	10.8	7
	600	5.3	1.5	0	9.3	7
	Green	7.4	1.2	0.3	8.6	7
***Saxifraga deorum* 'Stansfieldii'**	**400**	4.3	1.1	0.3	8.8	17
	SteriLite	3.3	1.2	0.1	9.1	15
	Blue	2.4	1.1	0	7.9	8
	600	3.3	0.8	0	6.9	18
	Green	3.7	1.1	0	10.3	20
***Thymus x citriodorus* 'Aurens'**	**400**	7.4	0.9	1.6	7.8	>50
	SteriLite	8.3	0.9	0.8	7.5	>50
	Blue	8.1	0.8	1.3	8.3	>50
	600	8.2	1.0	0.8	8.0	>50
	Green	7.1	0.9	1.5	7.2	>50

APPENDIX: 5

Table 2

Plant growth records - Spring 2002 - CONIFERS

(Figures are a mean of 6 plants in each treatment block)

	Plant Height (cm)					**Root Density** (1-5, 5 = most)				
Species	**400**	**SteriLite**	**Blue**	**600**	**Green**	**400**	**SteriLite**	**Blue**	**600**	**Green**
***Chamaecyparis lawsoniana* 'Broomhill Gold'**	36.0	32.3	30.5	32.2	33.7	5.0	4.3	3.7	4.0	4.5
***Chamaecyparis lawsoniana* 'Ellwoodii'**	29.3	26.3	32.4	33.4	33.9	4.8	4.7	4.8	4.8	4.8
***Chamaecyparis lawsoniana* 'Little Spire'**	39.5	30.6	34.2	33.7	35.7	5.0	5.0	4.8	5.0	4.8
X Cupressocyparis leylandii	54.7	56.6	44.5	48.4	56.9	4.8	4.8	4.3	5.0	4.7
***X Cupressocyparis leylandii* 'Castlewellan Gold'**	52.9	52.6	41.5	50.0	54.9	5.0	5.0	3.7	4.8	5.0
***Juniperus horizontalis* 'Blue chip'**	22.2	22.3	19.4	24.0	23.9	4.7	4.3	3.7	4.7	4.3
***Juniperus x media* 'Sulphur Spray'**	26.9	21.7	25.6	27.3	26.8	2.0	2.2	2.0	2.3	2.0
***Picea glauca albertiana* 'Conica'**	16.6	17.2	16.0	19.6	17.9	4.5	4.5	3.3	4.5	4.0
***Thuja plicata* 'Rogersii'**	23.6	19.5	19.6	20.3	25.8	2.8	3.3	3.3	3.3	3.7

APPENDIX: 6

Table 3

Plant growth records - Summer 2002

(Figures are a mean of 6 plants)

	Cover				
	400	**SteriLite**	**Blue**	**600**	**Green**
WOODY SHRUBS					
***Aucuba japonica* 'Variegata'** (assessed 12 March 2002)					
Internode length (mm)	7.0	11.7	9.2	3.5	10.2
Stem thickness (mm)	4.2	4.3	4.3	2.5	3.6
Root density over pot-ball (1-5, 5 = most)	4.3	4.5	4.0	3.5	4.8
Number breaks	2.8	3.2	2.5	2.0	3.3
Leaf size (mm)	35.8	37.2	32.5	33.0	37.3
% flowering	6.0	12.0	14.0	12.0	4.0
Ceanothus thyrsiflorus repens (assessed 4 May 2002)					
Mean shoot length (cm)	33.0	43.0	49.6	36.1	48.3
Overall quality (1-5, 5 = best)	4.0	5.0	5.0	3.0	5.0
% flowering	90.0	100.0	74.0	82.0	24.0
% dead	6.0	6.0	8.0	8.0	4.0
***Chaenomeles speciosa* 'Nivalis'** (assessed 4 March 2002)					
Internode length (mm)	8.3	9.0	5.7	5.9	12.8
Stem thickness (mm)	2.3	1.6	1.0	1.4	1.9
Root density over pot-ball (1-5, 5 = most)	4.2	4.7	4.0	4.5	4.2
Leaf size (mm)	34.2	45.0	49.3	33.2	64.3
% flowering	24.0	24.0	12.0	42.0	22.0
***Choisya* 'Aztec Pearl'** (assessed 4 May 2002)					
Plant height (cm)	39.7	46.7	30.9	43.5	43.9
Overall quality (1-5, 5 = best)	4.0	4.3	3.0	5.0	4.0
% flowering	4.0	10.0	6.0	24.0	2.0
% dead	2.0	0	0	0	4.0
***Choisya ternata* 'Sundance'** (assessed 4 May 2002)					
Plant height (cm)	28.8	28.7	31.0	24.2	32.7
Root density over pot-ball (1-5, 5 = most)	5.0	4.3	5.0	4.3	3.5
Leaf size (mm)	49.5	49.0	43.8	46.0	38.7
Overall quality (1-5, 5 = best)	5.0	5.0	4.0	3.0	5.0
***Cistus x pulverulentus* 'Sunset'** (assessed 4 May 2002)					
Plant height (cm)	38.6	38.7	42.4	44.3	41.3
Overall quality (1-5, 5 = best)	5.0	4.0	4.0	5.0	4.0
% flowering	26.0	32.0	0	30.0	6.0
% dead	2.0	2.0	0	4.0	12.0

Table 3 (cont'd)

	Cover				
	400	**SteriLite**	**Blue**	**600**	**Green**
***Forsythia giraldiana* 'Golden Times'** (assessed 4 May 2002)					
Plant height (cm)	58.2	65.3	53.1	53.0	57.4
Leaf size (mm)	18.0	21.7	24.0	31.7	30.8
Overall quality (1-5, 5 = best)	5.0	5.0	4.0	3.0	4.0
***Hydrangea macrophylla* 'Madame Emile Mouilliére'** (assessed 15 April 2002)					
Plant height (cm)	32.5	34.1	38.4	33.8	37.1
Overall quality (1-5. 5 = best)	5.0	4.0	5.0	5.0	5.0
***Hypericum henryi* 'Hidcote'** (assessed 15 April 2002)					
Plant height (cm)	44.0	47.2	48.3	41.5	44.1
Internode length (mm)	29.2	34.7	17.7	29.7	25.0
Overall quality (1-5, 5 = best)	5.0	5.0	4.0	5.0	4.0
***Philadelphus tomentosus* 'Virginal'** (assessed 4 May 2002)					
Plant height (cm)	66.7	72.4	63.1	65.9	78.8
Overall quality (1-5, 5 = best)	5.0	4.8	4.3	5.0	5.0
% dead	0	0	4.0	0	0
***Physocarpus opulifolius* 'Diabolo'** (assessed 19 March 2002)					
Plant height (cm)	48.9	52.9	45.4	48.8	66.9
Overall quality (1-5, 5 = best)	5.0	5.0	4.0	5.0	4.0
% dead	0	0	0	0	2.0
***Potentilla fruticosa* 'Red Ace'** (assessed 4 March 2002)					
Plant height (cm)	13.7	14.2	12.6	37.2	11.4
Overall quality (1-5, 5 = best)	5.0	5.0	3.0	4.0	3.0
% dead	4.0	0	2.0	0	2.0
***Spiraea japonica* 'Shirobana'** (assessed 4 May 2002)					
Plant height (cm)	56.4	59.3	52.2	57.5	43.9
Overall quality (1-5, 5 = best)	5.0	4.0	5.0	5.0	4.0
***Viburnum tinus* 'Eve Price'** (assessed 9 April 2002)					
Plant height (cm)	23.4	24.2	25.9	25.8	27.3
Overall quality (1-5, 5 = best)	4.0	4.0	4.0	3.0	4.0
% flowering	28.0	32.0	42.0	46.0	36.0
***Weigela florida* 'Vareigata'** (assessed 12 March 2002)					
Plant height (cm)	51.1	54.0	50.3	56.9	47.1
Overall quality	5.0	4.0	4.0	5.0	5.0
% flowering	90.0	88.0	46.0	96.0	92.0

Table 3 (cont'd)

			Cover		
	400	**SteriLite**	**Blue**	**600**	**Green**
HEATHERS					
***Calluna vulgaris* 'Tib'** (assessed 17 April 2002)					
Plant height (cm)	13.5	13.3	14.4	14.8	16.9
Overall quality (1-5, 5 = best)	4.0	5.0	4.0	5.0	4.0
% flowering	32.5	43.6	0	61.5	48.7
% dead	0	2.6	5.0	0	0
Erica carnea (assessed 17 April 2002)					
Plant height (cm)	10.7	11.8	14.4	13.2	11.6
Overall quality (1-5, 5 = best)	3.0	4.0	3.0	3.0	3.0
% flowering	55.5	61.7	55.5	50.0	33.3
% dead	11.1	2.1	6.7	18.2	35.6
***Erica carnea* 'Vivellii'** (assessed 17 April 2002)					
Plant height (cm)	11.8	13.3	12.1	12.7	14.0
Overall quality (1-5, 5 = best)	4.0	4.0	3.0	3.0	4.0
% flowering	75.0	81.8	50.0	84.6	58.3
% dead	8.3	9.1	16.7	7.7	0
Erica x darlyensis (assessed 17 April 2002)					
Plant height (cm)	11.8	13.4	13.6	12.8	13.3
Overall quality (1-5, 5 = best)	2.0	3.0	4.0	3.0	3.0
% flowering	33.3	60.4	41.3	73.8	62.2
% dead	27.1	10.4	2.2	9.5	11.1
Erica erigena (assessed 17 April 2002)					
Plant height (cm)	13.4	12.7	15.3	14.7	15.4
Overall quality (1-5, 5 = best)	4.0	4.0	5.0	3.0	4.0
% flowering	87.8	87.0	83.3	71.4	75.6
% dead	14.6	6.5	2.1	17.1	15.6
HERBACEOUS					
***Anemone x hybrida* 'Richard Ahrens'** (assessed 15 Aril 2002)					
Plant height (cm)	28.7	28.1	30.1	21.6	27.0
No. breaks	12.3	13.3	8.3	11.5	13.7
Overall quality (1-5, 5 = best)	4.0	5.0	5.0	4.0	4.0
***Euphorbia amygdaloides* 'Purpurea'** (assessed 19 March 2002)					
Internode length (mm)	8.3	8.8	5.7	10.3	6.3
Stem thickness (mm)	2.8	2.6	2.3	2.1	3.0
No. breaks	6.0	6.2	2.8	5.3	3.2
Leaf size (mm)	30.0	38.5	26.5	32.2	40.3
Density of flowering (1-5, 5 = most)	5.0	4.0	5.0	5.0	4.0

Table 3 (cont'd)

			Cover		
	400	**SteriLite**	**Blue**	**600**	**Green**
***Heuchera* hyrids** (assessed 9 April 2002)					
Plant height (cm)	15.5	16.3	16.2	14.8	15.1
Overall quality (1-5, 5 = best)	4.0	5.0	4.0	4.0	3.0
% flowering	46.0	40.0	28.0	28.0	14.0
***Lamium maculatum* 'Chequers'** (assessed 9 April 2002)					
Plant height (cm)	11.7	14.3	12.1	12.4	12.7
Overall quality (1-5, 5 = best)	4.0	4.0	4.0	4.0	3.0
% flowering	12.0	8.0	2.0	2.0	6.0
% dead	4.0	2.0	0	4.0	6.0
***Sedum atuntsuense* 'Autumn Joy'** (assessed 12 March 2002)					
Internode length (mm)	6.4	9.8	6.3	5.6	2.0
Stem thickness (mm)	7.3	8.0	7.0	6.0	3.0
No. breaks	9.7	12.2	7.2	9.2	5.3
Leaf size (mm)	52.5	53.8	47.2	53.7	23.5
***Stokesia laevis* 'Blue Star'** (assessed 9 April 2002)					
Plant height (cm)	17.9	16.9	16.2	15.2	14.1
Overall quality (1-5, 5 = best)	5.0	4.0	4.0	5.0	4.0
ALPINES					
***Ajuga reptans* 'Burgundy Glow'** (assessed 9 April 2002)					
Overall quality (1-5, 5 = best)	5.0	5.0	4.0	4.0	4.0
Density of flowering (1-5, 5 = most)	5.0	5.0	3.0	5.0	2.0
***Aubretia albomarginata* 'Astolat'** (assessed 23 April 2002)					
Plant height (cm)	15.8	25.2	22.8	18.7	31.5
Overall quality (1-5, 5 = best)	4.0	3.0	4.0	3.0	4.0
% flowering	90.0	87.5	95.8	89.6	100.0
Density of flowering (1-5, 5 = most)	5.0	-	3.0	-	-
% dead	6.0	12.5	4.2	10.4	0
***Geranium cinereum* 'Splendens'** (assessed 23 April 2002)					
Plant height (cm)	25.9	29.2	27.0	29.5	38.4
Overall quality (1-5, 5 = best)	4.0	3.0	5.0	3.0	4.0
Leaf size (mm)	33.7	28.2	31.3	31.5	56.8
% flowering	87.0	81.8	86.4	95.6	95.6
Density of flowering (1-5, 5 = most)	5.0	-	4.0	-	-

Table 3 (cont'd)

	Cover				
	400	**SteriLite**	**Blue**	**600**	**Green**
***Lithospermum diffusum* 'Heavenly Blue'** (assessed 22 April 2002)					
Plant height (cm)	22.8	17.7	15.8	23.0	23.8
Overall quality (1-5, 5 = best)	4.0	5.0	3.0	4.0	3.0
% flowering	95.8	96.0	90.0	93.6	85.7
Density of flower (1-5, 5 = most)	4.0	5.0	4.0	3.0	-
% dead	4.2	4.0	10.0	6.4	14.3
***Phlox subulata* 'McDaniel's Cushion'** (assessed 17 April 2002)					
Plant height (cm)	14.2	13.3	-	9.9	14.2
Overall quality (1-5, 5 = best)	2.0	3.0	1.0	2.0	1.3
% dead	66.0	48.0	80.0	68.0	80.0
***Thymus x citriodorus* 'Aureus'** (assessed 22 April 2002)					
Plant height (cm)	13.8	14.7	21.8	15.2	20.0
Overall quality (1-5, 5 = best)	4.0	3.0	4.0	5.0	5.0

APPENDIX: 7

Table 4

Detailed growth records of selected species - May 2002

(figures are a mean of 6 plants)

	400	SteriLite	Blue	600	Green
Aucuba japonica **'Variegata'**					
Selected stem length (cm)	14.3	16.1	13.4	9.4	14.4
No. expanded nodes on stem	2.7	3.2	2.5	2.5	3.0
Average node length (cm)	5.4	5.1	5.4	3.8	4.8
Berberis darwinii					
Selected stem length (cm)	7.7	10.9	17.8	23.3	26.6
No. expanded nodes on stem	4.0	4.8	11.8	14.7	13.5
Average node length (cm)	1.9	2.2	1.5	1.6	2.0
Ceanothus thyrsiflorus repens					
Selected stem length (cm)	13.3	8.8	18.5	17.1	24.0
No. expanded nodes on stem	10.0	4.8	11.3	12.3	14.5
Average node length (cm)	1.3	1.8	1.6	1.4	1.7
Choisya **'Aztec Pearl'**					
Selected stem length (cm)	7.9	9.6	5.7	7.6	5.6
No. expanded nodes on stem	2.6	3.5	2.8	2.5	2.3
Average node length (cm)	3.0	2.8	2.0	3.0	2.4
Choisya ternata **'Sundance'**					
Selected stem length (cm)	10.4	10.1	9.5	6.0	14.1
No. expanded nodes on stem	3.0	3.0	3.3	2.8	6.2
Average node length (cm)	3.5	3.4	2.9	2.1	2.3
Cotoneaster **'Coral Beauty'**					
Selected stem length (cm)	13.5	13.3	20.2	18.8	23.5
No. expanded nodes on stem	8.8	13.8	17.5	16.0	19.5
Average node length (cm)	1.5	1.0	1.2	1.2	1.2
Forsythia giraldiana **'Golden Times'**					
Selected stem length (cm)	15.5	13.3	14.9	15.9	16.4
No. expanded nodes on stem	6.7	5.8	7.2	7.0	2.3
Average node length (cm)	2.3	2.3	2.1	2.3	7.0
Hydrangea macrophylla **'Madame Emile Mouilliére'**					
Selected stem length (cm)	20.2	24.6	23.5	29.7	31.7
No. expanded nodes on stem	3.3	3.8	4.2	3.8	4.7
Average node length (cm)	6.1	6.4	5.6	7.8	6.8

Table 4 (cont'd)

	400	SteriLite	Blue	600	Green
Hypericum henryi **'Hidcote'**					
Selected stem length (cm)	28.8	37.7	35.3	31.0	28.5
No. expanded nodes on stem	9.0	12.7	10.8	10.7	8.8
Average node length (cm)	3.2	3.0	3.3	2.9	3.2
Philadelphus tomentosus **'Virginal'**					
Selected stem length (cm)	26.1	29.1	31.1	32.2	29.6
No. expanded nodes on stem	5.0	5.7	6.5	7.0	7.0
Average node length (cm)	5.2	5.1	4.8	4.6	4.2
Physocarpus opulifolius **'Diabolo'**					
Selected stem length (cm)	26.4	27.5	17.6	17.2	20.1
No. expanded nodes on stem	6.3	6.0	5.2	5.3	5.3
Average node length (cm)	4.2	4.6	3.4	3.2	3.8
Spiraea japonica **'Shirobana'**					
Selected stem length (cm)	27.2	30.8	27.2	36.4	28.4
No. expanded nodes on stem	28.7	24.5	20.8	24.8	21.5
Average node length (cm)	0.9	1.3	1.3	1.5	1.3
Viburnum tinus **'Eve Price'**					
Selected stem length (cm)	4.2	4.3	6.6	6.0	6.6
No. expanded nodes on stem	2.8	2.5	3.3	4.0	2.8
Average node length (cm)	1.5	1.7	2.0	1.5	2.3
Weigela florida **'Variegata'**					
Selected stem length (cm)	9.5	9.7	9.7	15.0	12.6
No. expanded nodes on stem	2.2	1.8	2.7	2.7	2.5
Average node length (cm)	4.4	5.3	3.6	5.6	5.1

Appendix 8: Counts of *Myzus persicae* on *Pyracantha gibbsii* 'Orange Glow' in three tunnels covered with different spectral filters at the HDC trials at Weggs Farm. 16th May 2002. Showing total numbers of alatae, apterae and infested shoots, for all the 148 plants examined.

	Superstrength 400 HDF			Sterilite HDF			Superstrength 600 HDF		
Plant	Alatae	Apterae	Infested Shoots	Alatae	Apterae	Infested Shoots	Alatae	Apterae	Infested Shoots
1	-	-	-	-	-	-	-	-	-
2	-	-	-	-	1	1	-	1	1
3	-	-	-	-	-	-	-	-	-
4	-	-	-	1	-	1	-	-	-
5	-	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-
7	-	-	-	-	4	1	-	-	-
8	-	-	-	-	-	-	-	-	-
9	-	-	-	-	2	2	-	1	1
10	-	-	-	-	5	3	-	-	-
11	-	-	-	-	1	1	-	-	-
12	-	1	1	-	2	2	-	2	1
13	-	-	-	-	1	1	-	-	-
14	-	5	1	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-	-
16	-	4	1	-	2	1	-	-	-
17	-	-	-	-	-	-	-	-	-
18	-	2	1	-	1	1	-	1	1
19	-	2	1	-	4	1	-	2	1
20	-	3	1	-	1	1	-	-	-
21	1	2	1	-	-	-	-	-	-
22	-	1	1	-	4	1	-	-	-
23	-	-	-	-	1	1	-	-	-
24	-	-	-	-	-	-	-	-	-
25	-	2	1	-	3	2	-	-	-
26	-	-	-	-	4	2	-	-	-
27	-	-	-	1	6	2	-	-	-
28	-	-	-	-	-	-	-	-	-
29	-	-	-	-	3	1	-	-	-
30	-	-	-	-	1	1	-	-	-
31	-	2	1	-	-	-	-	1	1
32	-	13	2	-	2	2	-	-	-
33	-	1	1	-	-	-	-	-	-
34	-	2	2	-	4	2	-	1	1
35	-	2	2	-	5	4	-	-	-
36	-	-	-	-	-	-	-	2	1
37	-	1	1	-	2	2	-	-	-
38	-	-	-	-	3	2	-	-	-
39	-	-	-	-	-	-	-	-	-
40	-	-	-	-	5	2	-	-	-
41	-	-	-	-	1	1	-	-	-
42	-	1	1	-	1	1	1	-	1
43	-	-	-	-	6	2	-	-	-
44	-	-	-	-	1	1	-	1	1
45	-	9	2	-	42	3	-	-	-
46	-	-	-	-	14	5	-	2	1
47	-	1	1	-	18	3	-	-	-
48	-	-	-	-	40	4	-	-	-
49	-	-	-	1	19	5	-	-	-
50	-	-	-						
	Superstrength 400 HDF			Sterilite HDF			Superstrength 600 HDF		
	Alatae	Apterae	Shoots	Alatae	Apterae	Shoots	Alatae	Apterae	Shoots
TOTAL	1	54	22	3	209	65	1	14	11
Average	0.02	1.08	0.44	0.06	4.26	1.33	0.02	0.29	0.22

Appendix 8: Counts of *Myzus persicae* on *Philadelphus tomentosus* 'Virginal' in three tunnels covered with different spectral filters at the HDC trials at Weggs Farm. 16th May 2002. Showing total numbers of alatae, apterae and infested shoots, for each of the 144 plants examined.

	Superstrength 400 HDF			Sterilite HDF			Superstrength 600 HDF		
Plant	Alatae	Apterae	Infested Shoots	Alatae	Apterae	Infested Shoots	Alatae	Apterae	Infested Shoots
1	2	5	2	1	23	3	-	-	-
2	2	17	2	-	21	3	-	-	-
3	-	13	4	1	29	3	-	-	-
4	2	36	5	1	5	2	-	10	1
5	-	23	2	-	20	1	-	1	1
6	-	1	1	-	6	1	-	-	-
7	-	57	2	-	33	3	-	-	-
8	1	1	2	-	16	2	-	-	-
9	-	32	3	-	1	1	-	2	1
10	-	28	3	-	4	2	-	-	-
11	-	6	1	1	3	1	-	-	-
12	-	1	1	-	-	-	-	1	1
13	-	1	1	-	8	1	-	1	1
14	-	1	1	1	8	1	-	-	-
15	-	5	1	-	-	-	-	-	-
16	1	26	3	-	1	1	1	3	1
17	-	4	2	1	13	2	-	-	-
18	-	13	4	-	-	-	-	-	-
19	-	13	5	-	3	2	-	9	1
20	1	27	2	-	3	1	1	-	1
21	1	16	2	-	-	-	-	-	-
22	-	8	2	-	5	3	-	-	-
23	-	2	2	-	8	2	-	-	-
24	-	5	1	-	4	2	-	-	-
25	1	12	4	-	-	-	-	-	-
26	1	14	3	-	-	-	-	-	-
27	-	-	-	-	-	-	-	22	1
28	-	1	1	-	4	3	-	-	-
29	-	2	1	-	-	-	-	-	-
30	-	7	2	-	-	-	-	-	-
31	1	31	4	-	9	1	-	3	1
32	-	16	1	-	5	2	-	1	1
33	4	31	4	-	3	1	-	-	-
34	1	29	4	-	2	2	-	-	-
35	-	23	3	1	-	1	-	-	-
36	2	15	2	1	10	1	-	1	1
37	1	32	2	-	1	1	-	1	1
38	1	2	2	-	-	-	-	2	2
39	1	3	3	-	24	2	-	4	2
40	-	-	-	-	13	1	-	-	-
41	1	26	3	-	3	2	-	6	1
42	2	33	3	-	9	2	-	3	2
43	-	2	1	-	21	2	-	8	2
44	1	4	3	-	1	1	-	5	2
45	-	2	2	-	4	2	-	7	3
46	1	17	4	2	36	3	-	1	1
47	6	120	6	1	34	3			
48	-	7	2	-	2	2			
49	5	86	3	-	54	8			
	Superstrength 400 HDF			Sterilite HDF			Superstrength 600 HDF		
	Alatae	Apterae	Shoots	Alatae	Apterae	Shoots	Alatae	Apterae	Shoots
TOTAL	39	856	117	11	449	77	2	91	28
Average	0.8	17.47	2.39	0.22	9.16	1.57	0.04	1.98	0.61

APPENDIX 8

Review of photoselective covers and their effects on plant growth

Light is required by plants to accumulate carbohydrates (photosynthesis) and to regulate plant development (photomorphogenisis). The region between 400-700 nm (photosynthetically active radiation - PAR) provides the energy which plants use to combine carbon dioxide and water to produce oxygen and carbohydrates. The most efficient wavelengths to drive photosynthesis are blue and red (nm).

Within plant cells, pigments, known as phytochromes and cryptochrome, use certain wavelengths of light to trigger physiological and morphological responses. This process, known as photomorphogenisis, is independent of photosynthesis. Plant responses to changes in light quality are thought to be partly due to changes in gibberellin synthesis.

Not all wavelengths are equally efficient in triggering these responses. Cryptochrome is thought to be the sensor for UV-B and blue light. Phytochrome detects wavelengths from 300-800 nm, with maximum sensitivity in red (660 nm) and far-red (730 nm). This pigment exists in two interconvertible forms: the Pf form which absorbs red light, and the Pfr form which absorbs far-red light. Pfr form is thought to be the active form controlling plant responses. Plant development can be manipulated by altering the amount of red and far-red light plants receive. Under natural conditions, the red: far-red ratio of sunlight is relatively constant through a day. However, shortly before sunrise or sunset, the red:far-red ratio is reduced due to an increase in far-red wavelength.

High levels of far-red stimulate stem elongation, whereas high levels of red light produce short and compact plants, and prevent dark-induced leaf abscission. In long-day plants, such as *Viola x wittrockiana*, *Campanula carpatica* and *Coreopsis x grandiflora*, high levels of far-red promote extension growth and flowering, whereas high red:far-red ratios delay flower initiation in *Campanula* and *C. x grandiflora* and flower development in *Viola* (Runkle and Heins, 2001). Rose plants (cultivar ‘Mercedes’) that received end-of-day red light treatments produced more flowering shoots compared to those plants grown under end-of-day far-red light (Maas and Bakx, 1995).

Ultraviolet radiation of 285 nm or shorter caused stomatal closure in *Eragrostis tef,* and increasing UV intensity increased stomatal conductance (Negash and Bjorn, 1986). In Chrysanthemum, blue light-supplemented long days (400-500 nm) did not adversely affect flower initiation and development, but permitted the use of biological control of thrips (Stack, Drummond and Stack, 1998).

Orientation of the greenhouse and type of material used for cladding have an effect on the quantity and quality of sunlight transmission (Critten, 1988 a.), b.); Critten, 1989; Skov, 1989; McMahon, Kelly and Decoteau, 1990; Giacomelli, Ting and Fang, 1991; Buriol, *et.al.* 1995; Pearson, Wheldon and Hadley, 1995). In the greenhouse, light quality, e.g. the red and far-red balance of the sunlight, can be altered by using either supplementary electric lighting or photoselective cladding (Schultz, 1997; Angus and Morrison, 1998; Kittas and Baille, 1998; Kittas, Baille and Giaglaras, 1999; Papadakis, *et.al.* 2000). An effective increase of the red:far-red ratio can be achieved by absorption of far-red radiation using photoselective greenhouse covers.

Spectral filters

In the 1970's, channeled, doubled-walled greenhouse cladding (acrylic and polycarbonate plastic) containing liquid dyes were used as filtering materials. These 'liquid filters' were mainly assessed for cutting out infrared radiation from sunlight in order to reduce the need for forced ventilation. The ability of aqueous dye filters to remove far-red wavelength from the greenhouse light environment was investigated in the 1990's (Pollock, *et.al.* 1990; Cerney, Rajapakse and Oi, 1999; Rajapakse, 1999). Liquid copper sulfate ($CuSO_4$) filters were most effective in removing far-red light from the natural light spectrum.

$CuSO_4$ spectral filters

Experiments using polycarbonate panels filled with $CuSO_4$ solutions have shown that these filters reduced plant height and internode length of chrysanthemum (Rajapakse and Kelly, 1992; Rajapakse and Kelly, 1995; Hoffmann, 1999), miniature roses (McMahon and Kelly, 1990; Rajapakse and Kelly, 1994), Easter lilies (Kambalapally and Rajapakse, 1998), poinsettia, tomato and lettuce plants. However, *Azalea* and some ornamental bulbs (tulip, hyacinth and daffodil) showed no response to these filters (Rajapakse, Young and Oi, 1998). The height reduction was mainly caused by the reduced length of internodes and to a much lesser extent by a reduction in the number of nodes. In Chrysanthemum, these filters also stimulated growth of lateral buds and plants grown under $CuSO_4$ filters had darker green leaves due to an increase in leaf chlorophyll (McMahon and Kelly, 1995). Varying the concentration of $CuSO_4$ (4 %, 8%, and 16 % solution of $CuSO_4$) in the filter had very little effect on the control of plant growth. Concentrations as low as 4% were as efficient as 47 % in controlling plant height (Rajapakse and Kelly, 1992).

Day length had an effect on the response of Chrysanthemum and miniature roses grown under $CuSO_4$ filters in that height reduction was less pronounced in long day environments (Rajapakse and Kelly, 1994; Rajapakse and Kelly, 1995).

Experiments with Chrysanthemum plants showed that plants grown under $CuSO_4$ filters had 37 % less cumulative water use compared to control plants (Rajapakse and Kelly, 1993). Water loss rate per unit leaf area and size of individual stomata were similar to control plants. However, in plants grown under $CuSO_4$ filters total number of stomata and total stomatal area per plant were about 50% less than control plants. It was thought that this was due to plants produced under $CuSO_4$ filters being smaller plants and with less leaf area.

The influence of $CuSO_4$ filters on flower development and quality varied with plant species, cultivar and growing season. Spectral filters did not affect flower numbers, but size of flowers was reduced in miniature pot roses and Chrysanthemums (Rajapakse and Kelly, 1994). Flower anthesis was delayed by 7 – 13 days in Chrysanthemum (Bright Golden Ann) grown under filtered light in early autumn (September) and winter (December). In Chrysanthemum cultivar 'Spears', $CuSO_4$ filters encouraged earlier flowering under long day conditions but had no effect on anthesis in short days. $CuSO_4$ filters had no effect on anthesis or size and number of flowers in Easter lilies (Kambalapally and Rajapakse, 1998).

In Chrysanthemum, $CuSO_4$ filters reduced total shoot dry weight (38%), and translocation of photosynthates was also affected (Rajapakse and Kelly, 1995). Dry matter accumulation was reduced in stems (27 % to 18 %) but increased in leaves (72 % to 82 %). Total soluble sugars in leaves and stem, and starch concentrations, were reduced in Chrysanthemums grown under filtered light. However, the magnitude of reduction varied with growing season in that reductions of leaf soluble sugar concentrations were lower in spring compared to autumn-grown plants.

$CuSO_4$ filters reduced post-harvest quality in potted miniature roses by increasing leaf yellowing during shipment (Rajapakse and Kelly, 1994) and reduced shelf-life of Easter lilies by 3 days (Kambalapally and Rajapakse, 1998).

Exposure of Chrysanthemum plants to end-of -day red reduced plant height and internode length in plants placed under control films, but had no effect on plants grown under $CuSO_4$ filtered light. Plants grown under $CuSO_4$ filters and end-of-day far red showed no reduction of height and internode length and were comparable in growth to plants that had been grown under control conditions with no far-red exposure. The flowering response to spectral filters and end-of-day treatments differed with cultivar (Rajapakse, McMahon, and Kelly, 1993).

Plant responses to changes in light quality are thought to be partly due to changes in gibberellin synthesis, i.e. gibberellin levels in relevant plant cells. Externally applied GA_3 (50mg/l) reversed the height reduction of Chrysanthemums (Bright Golden Anne) grown under $CuSO_4$ filters (Kambalapally, Maki and Rajapakse, 1997).

Liquid spectral filters could potentially be used as an alternative to chemical growth regulators. However, their value to commercial horticulture has been limited because of difficulties in handling materials and initial high construction costs. In addition, $CuSO_4$ is hazardous and requires costly disposal treatments.

Photoselective plastic covers

Pigments that filter out far-red wavelength from sunlight have been added to various plastic greenhouse covers to study their effect on plant development. Increased dye concentration resulted in increased far-red absorption, but also reduced overall light transmission.

Photoselective films were shown to reduce height in bell peppers (Li, Young and Rajapakse, 2000), tomato, *Pachystachys lutea* (Wilson and Rajapakse, 2000), miniature pot-plant roses (McMahon and Kelly, 1990), Chrysanthemum (Tatineni, *et.al*., 2000), selected cut flowers (HDC PC 168, 2000), bedding plants (Cerney and Rajapakse, 1999), and watermelon. However, the magnitude of height reduction varied with species. Number of leaves was not affected, indicating that height reduction was due to decreased internode length. In pot roses, number of flower buds per plant and development of flower buds were not affected by light quality (McMahon and Kelly, 1990). In *Godetia* removing far-red light increased branching, but no effects were noted in stocks (HDC PC 168, 2000).

Various specialist films (XL SuperGreen, Visqueen far-red filter, Luminance THB) were tested for their ability to control growth of bedding plants (HDC PC 150, 1999). In most species, a reduction in plant height and a slight delay in flowering was observed where plants were grown under the Visqueen far-red filter. However, not all species responded to this filter. In marigold and seed raised geraniums height reductions were only slight or even absent. Poorest height control was observed in plants produced under XL SuperGreen filters which absorbs red light. Plants raised under the light diffusing heat-control filter Luminance THB had greatest dry weights whereas bedding plants grown under XL SuperGreen showed lowest dry weight rates.

Oyaert and co-workers assessed three blue polyethylene films (blue:red ratios ranging from 6.2 to 85.5 with increasing pigment concentration; red:far-red ratios 0.43 to 1.45) and one vaporised interference film (blue:red ratio 1.41; red:far-red ratio 2.06) for their ability to alter growth habit of Chrysanthemums (Oyaert,Volckaert and Debergh, 1999). Blue films inhibited stem elongation, reduced the number of axillary shoots, leaf area and total dry weight. Furthermore, dry weight was translocated from stem to leaves. The vaporised film resulted in a small growth reduction and alteration of plant habit due to its low red:far-red ratio and high light transmission percentage. However, if the vaporising technique could be improved to achieve higher red:far-red ratios, this type of film would provide growers with an environmentally friendly tool for growth reduction.

Further experiments on Chrysanthemum showed that overlaying Roscolux coloured acetate films on a $CuSO_4$ filter had an effect on growth and development (Reddy, Rajapakse and Young, 1996). Blue acetate film on its own removed red wavelengths and transmitted blue and far-red wavelengths, while a combination of both filters removed red and far-red wavelengths and transmitted blue. A red acetate film removed blue wavelengths, and transmitted red and far-red while in combination with the $CuSO_4$ filter blue, and far-red wavelengths were absorbed and red wavelengths transmitted. Removal of far-red light reduced plant height by 22 %. The effect of blue light depended on the presence or absence of far-red light. In the presence of far-red light, removal of blue light resulted in 16 % height increase (autumn produced plants) whereas in the absence of far-red the removal of blue light had no effect on growth.

Tests using five different filters (blue and red absorbing; red absorbing, blue absorbing and two partially blue absorbing films) showed that height of Chrysanthemum plants as well as greenhouse temperatures were affected (Khattak and Pearson, 1997). Results suggested that plant height was regulated by phytochrome as well as a ‘blue’ acting photoreceptor. There was no evidence that red or far-red wavelength had an effect on time to flowering, but contrary to other studies (Stack, Drummond and Stack, 1998) increasing levels of blue light reduced time to flowering in Chrysanthemums (‘Snowdon’ and ‘Bright Golden Anne’).

Growth control filters, introduced by XL Horticulture, claim to dwarf growth but increase the amount of basal shoots as well as leaf colour in bedding plants by manipulating the red:far-red ratio in the greenhouse. One photoselective film (XL SuperGreen 720) was recorded to support growth of shade-loving plants.

Phthalocyanine derivatives were added to polymer films and their effect on plant growth investigated (van Haeringen, *et.al.*, 1998). Chrysanthemums grown under the far-red absorbing film showed a growth reduction of 14 %, and leaf number and time to flowering were not affected. In *Antirrinum*, a long-day plant, these filters caused a reduction in height and delay in flowering but a substantial increase in leaf area (70 %).

Yields of *Gypsophila paniculata* increased when grown under plastic sheets to which fluorescent dyes had been incorporated (Novoplansky, *et.al.,* 1990). These dyes increased the red:far-red ratio of the light transmitted through the sheets. The use of spectral filters accelerated growth rate in *Saintpaulia ionantha* and consequently shortened the time interval between potting and flowering (Raviv, 1989).

The interaction of coloured plastic covers with alternating day and night temperatures and its effect on *Petunia* hybrids and *Fuchsia* ‘Beacon’ were assessed by Patil and co-workers (Patil, *et.al.*,2001). It was found that these covers could be used as non-chemical growth regulators in circumstances where thermoperiodic responses meet limitations due to high outdoor temperatures.

Plastic films with low transmittance in the far-red region were used for summer cultivation of *Allium wakegi* Araki since these films inhibit bulb development without impairing leaf colour, leaf length and shoot fresh weight (Yamazaki, *et.al.*, 2000).

Various dyes were added to PMMA (polymethyl methacrylate) sheets (2.7 mm) and PET film (0.1 mm) in order to obtain red and far-red absorbing cladding materials (Murakami, *et.al.*,1996). Far-red intercepting materials decreased elongation growth of sunflowers, cucumbers, tomatoes and cabbages grown in hydroponics. Flowering was delayed in cucumber, tomato and sunflower, and female flower differentiation in cucumber was higher under far-red absorbing covers compared to plants grown under red-intercepting materials.

Stem cuttings of various ornamental plants showed earlier root formation when propagagated under a red-tinged greenhouse cover followed by a blue coloured cover (Sumathy, 1999).

Photoselective films have also been tested for their effects on pest and disease control. The use of UV absorbing (280-320 nm) greenhouse covers can reduce petal blackening in roses and prevent sporolation of *Botrytis cinerea* (Raviv, 1989). Polyethylene films which remove near-ultraviolet up to 405 nm suppressed conidia formation to a higher extent compared to films with UV absorption of up to 384 nm. Infection of *Primula vulgaris* and strawberries with *B. cinerea* was reduced by 50 % and 26 % respectively compared to standard plastic covers (West, *et.al.*, 2000). Initial work using UV-absorbing films showed that these may be of benefit in suppressing pest invasions and reducing pest numbers in protected crops (HDC PC 170, 2000).

Photoselective film curtains drawn shortly before dawn or dusk might exclude far-red light without reducing light transmission during the day. However, in Chrysanthemum changing the daily position of far-red absorbing PMMA film curtains did prevent any height reduction and therefore using film curtains as a substitute for chemical growth retardants cannot be recommended (Hoffmann, 1999).

Photoselective and other films used to cover greenhouses have a short life and pigments in the films degrade within 10-12 months. Their use in northern latitudes under low-light conditions might be limited due to their reduced light transmission properties. Photosynthetic photon flux under 4%, 8% and 16% $CuSO_4$ filters was reduced by 26%, 36% and 47% respectively (Rajapakse and Kelly, 1992).

Photoselective netting

Coloured shade nets have been used to improve yield and quality of *Pittosporum variegatum* (Oren-Shamir, *et.al.* 2001). Red netting stimulated branch elongation, grey nets enhanced branching and blue netting material dwarfed plants.

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APPENDIX: 9

Plate 1 **Light perception under different covers.**

Heathers

SuperStrength 600 (Control)

SuperStrength 400

SteriLite HDF

SuperBlue

SuperGreen

Plate 2 Effects of different covers on plant growth

Convolulus cneorum

SuperStrength 400

SuperBlue

SuperGreen

Plate 3 Effects of different covers on plant growth

X Cupressocyparis leylandii ‘Castlewellan Gold’

SuperStrength 600

Sterilite

SuperStrength 400

SuperBlue

SuperGreen

Plate 4 **Effects of different covers on plant growth**

***Spiraea japonica* ‘Shirobana’**

SuperStrength 600

Sterilite

SuperStrength 400

SuperBlue

SuperGreen

Plate 5 **Effects of different covers on plant growth**

Hydrangea macrophylla **'Madame Emile Mouilliér'**

SuperStrength 600

Sterilite

SuperStrength 400

SuperBlue

SuperGreen

Plate 6 **Effects of different covers on foliage colour during the growing season**

***Cotinus coggygria* 'Royal Purple'**

SS 400 SteriLite SuperBlue SS 600 SuperGreen Outside

Growers inspecting the trials at one of the Open days

Plate 7 **Effects of different covers on autumn foliage colour**

***Cotoneaster* ‘Coral Beauty’**

SuperStrength 600

Sterilite

SuperStrength 400

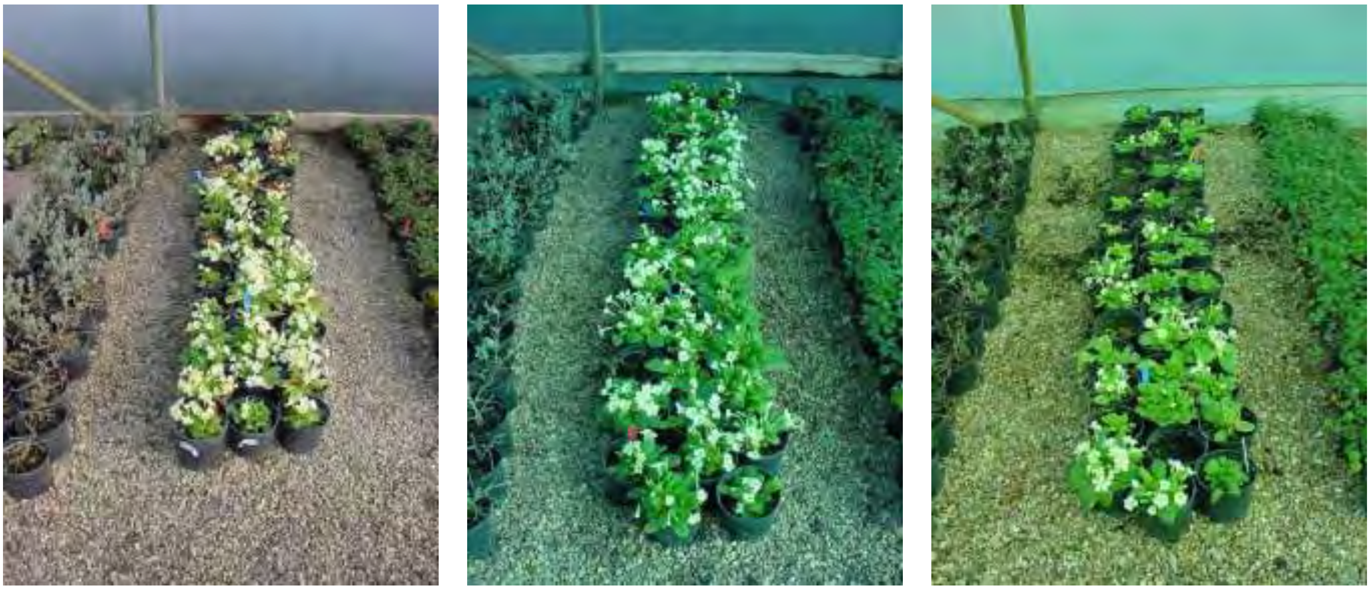
SuperBlue

SuperGreen

Plate 8 **Effects of different covers on flowering**

Primula vulgaris

SuperStrength 600 **Sterilite**



SuperStrength 400 **SuperBlue** **SuperGreen**

Plate 9 **Effects of different covers on flowering**

***Sedum autuntsuense* 'Autumn Joy'**

SuperStrength 600

Sterilite

SuperStrength 400

SuperBlue

SuperGreen

Plate 10 **Aphid attack to *Pyracantha gibbsii* 'Orange Glow'.**

SteriLite **SuperStrength 400**

SuperBlue **SuperGreen**

Also note the better colour on SuperStrength 400 SteriLite compared to softer growth in SuperGreen.