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Project leader:	Dr Jill England, ADAS Boxworth
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The results and conclusions in this report are based on an investigation conducted over a one-year period. The conditions under which the experiments were carried out and the results have been reported in detail and with accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results, especially if they are used as the basis for commercial product recommendations.

AUTHENTICATION

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

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GROWER SUMMARY

Headline

- Omex SW7, Serenade ASO* and Signum* applied as pre-sticking dip treatments improved rooting of Geranium cuttings (* no label approval); Rhizopon was effective as a quick dip on younger cuttings, but not as a long dip or on older cuttings.
- Fifteen glass coating products tested on new glass reduced light transmission and altered light quality.
- Response of autumn flowering ornamentals to polythene films varied with species and type of film; beneficial effects occurred in compactness, flowering period and overall plant quality.
- None of the nine herbaceous perennials grown over winter with minimal heat input were marketable by week 13/14; however five were at or just beginning to flower.

Background

The Bedding and Pot Plant Centre (BPPC) has been established to address the needs of the industry via a programme of work to trial and demonstrate new product opportunities and practical solutions to problems encountered on nurseries. Knowledge transfer events including trial open days and study tours were also included in the programme.

The work programme is guided by a grower-led Management Group that includes members of the BPOA Technical Committee and representatives from Baginton Nurseries, Coventry the host nursery for the BPPC. The agreed objectives for the second year of the Bedding and Pot Plant Centre were:

1. To improve cutting success
2. To reduce occurrence of leaf spotting and chlorosis in *Verbena*
3. To characterise environmental effects, ease of use and durability of glass coatings
4. To identify spectral films that improve plant production
5. To develop cold store treatments to induce flowering in hellebore before Christmas
6. To advance the marketing window of perennials by overwintering under glass and polythene

Summary

Objective 1: Improving cutting success

The 2015 AHDB/BPOA US study tour provided the inspiration for this trial, where Dr John Dole (Floriculture Professor, NCSU, North Carolina State University) presented a summary of trials carried out to resolve cutting quality problems that develop during delays in transit or as a result of incorrect storage, including loss of condition, dehydration and disease. In the UK, growers are increasingly taking advantage of the widening range of plant varieties available as un-rooted cuttings from an international market. This trial builds on the US work and incorporates treatments based on grower feedback and products available in the UK.

This trial was carried out between March and May 2016. Cuttings of Geranium Green Leaf Series 'Bianca' were sourced from Young Plants, and dispatched from the mother stock in Addis Ababa, Ethiopia, on 19 March (week 11). On receipt (24 March, week 12), the packaging was opened to release any ethylene that had built up, and then refrigerated. The cuttings were treated with Omex SW7, Signum, Fructose, Rhizopon AA tablets and Serenade ASO; Signum and Serenade ASO were applied under an experimental permit. Each was applied as a quick dip (prior to sticking - QD, 5 second, cut end of cuttings only), a long dip (prior to sticking - LD, 30 minute full submersion) and as a spray (after sticking), with relevant water controls. Once stuck, the cuttings were watered in and rooted under glass (15°C, vented at 21°C, 90% RH) on a heated bench (21°C). It had been planned that the cuttings would be stuck three (sticking 1) and six (sticking 2) days after dispatch from the mother stock.

Due to a delay in transit, cuttings were stuck in two batches; the first within 24 hours and the second 5 days after arrival (six and 10 days after dispatch from Ethiopia). The delay resulted in ethylene damage within transit resulting in chlorosis and premature senescence on the lower leaves which were removed, particularly for the second sticking.

Cuttings treated with Omex SW7 (LD, long dip) had greener, brighter foliage immediately after treatment compared with the other treatments and the untreated control. Serenade ASO left a white residue on the foliage when the cuttings were removed from the dip treatments (**Figure 1**).

Cuttings were assessed for quality and the number with visible roots at 11 days after treatment (DAT). Treatments had little effect on plant quality. The exception was the Rhizopon long dip, a treatment not recommended by the manufacturer, which reduced quality in both batches (**Table 1**). Rooting was significantly improved by Omex SW7 quick dip (sticking 1) and long dip (sticking 2), by Signum quick dip (sticking 2 only), by Rhizopon AA

quick dip (sticking 1 only) and Serenade ASO long dip (sticking 1 and 2). With both batches there was a trend for the long dip water treatment to improve rooting compared with untreated cuttings, and a number of other treatments in both sticking 1 (Omex SW7, Signum, fructose and Rhizopon AA spray treatments) and sticking 2 (Signum spray treatment; all fructose and Rhizopon AA treatments; and Serenade ASO quick dip treatment) although none of these differences were statistically significant.

The purpose of this trial was to improve root and cutting quality whilst reducing rooting time, compared with the untreated control. The results indicate Omex SW7, Serenade ASO and Signum dip treatments can improve rooting. Rhizopon used as a quick dip significantly improved rooting of 6-day old cuttings, but not the older cuttings. Further work is planned for 2016 which will look at replicating the most promising treatments and treatment combinations.

Table 1. The effect on plant quality and rooting of pre-sticking treatments applied to 6-day old and 11-day old cuttings of Geranium 'Bianca'

Treatment		**Mean cutting quality (of 15 cuttings)**		**Mean no. rooted (of 15 cuttings)**	
Product	**Method**	**6 day old cuttings†**	**11 day old cuttings††**	**6 day old cuttings†**	**11 day old cuttings††**
Untreated	-	3.0	2.9	0.5	1.5
Water	Spray	2.8	3.0	0.5	1.75
	Quick dip	3.0	3.0	1.5	2.5
	Long dip	2.7	3.0	1.0	3.0
Omex SW7	Spray	2.9	2.9	0.8	3.0
	Quick dip	3.0	2.3	2.0	**3.75**
	Long dip	2.8	2.7	**3.8**	3.25
Signum	Spray	2.7	3.0	0.5	2.0
	Quick dip*	2.9	3.0	2.0	**4.0**
	Long dip*	2.4	3.0	1.5	2.75
Fructose	Spray	2.8	2.8	0.8	1.75
	Quick dip	2.9	2.9	1.0	2.0
	Long dip	3.0	3.0	1.0	2.25
Rhizopon AA	Spray	2.9	3.0	0.6	1.5
	Quick dip	2.1	**1.0**	**4.5**	0.75
	Long dip	0.5	**0.4**	2.0	0.5
Serenade ASO	Spray	2.7	3.0	1.0	3.0
	Quick dip*	2.9	3.0	1.0	2.75
	Long dip*	2.9	3.0	**2.5**	**3.5**

Cutting quality: Cutting quality was assessed on a scale of 0-5 (0 = dead; 1 = very poor, yellow; 2 = green but no new growth, small; 3 = green with new leaves developing; 4 = green with new growth and 5 = good quality, marketable. Rooting success: values in bold are significantly better than untreated. *No label recommendations. †Assessed 11 days after treatment. †† Assessed 13 days after treatment

Figure 1. Sticking 1: untreated (left), Omex SW7, LD (centre) and Serenade ASO, LD (right) treatments <1 hr after application. LD = long dip

Objective 2: *Verbena* leaf spot and chlorosis

Leaf problems have been encountered with *Verbena* at various nurseries, including chlorotic leaf margins and necrotic spots. The cause is unknown. No pathogen has been associated with symptoms. Trials were devised to investigate the influence of irrigation regime, growing medium pH and trace element delivery on symptom occurrence.

Two trials were carried out between March and May 2016 (spring trial) and from May to July 2016 (summer trial). Treatments were irrigation management (dry, standard and wet), pH (4.5, 5.8 and 6.5) and trace element delivery (fritted and un-fritted trace elements). *Verbena* varieties were *V*. 'Quartz Blue' (spring and summer trials); and *V*. 'Obsession Scarlet' and *V*. 'Temari Blue' (summer trial only).

The few symptoms observed occurred in the summer trial *V*. 'Quartz blue' dry treatment. These results were not statistically significant. The observed symptoms were low levels of marginal chlorosis (**Figure 2**). Further work is planned for 2017 that will focus on water quality to try to determine if this induces the symptom.

Figure 2. Leaf chlorosis in *Verbena* 'Quartz Blue', dry treatment, 12 July, 8 WAT (left) and on a commercial nursery (right)

Objective 3: Environmental effects and ease of use of some spectral filters (glass coatings)

Glasshouses are designed to maximise light transmission while minimising the effects of solar heating (taller glasshouses reduce the rate of solar heating). However, the large differences in light that occur through the seasons means that crops can receive too much light and heat in the summer and not enough light in the winter. Removable glass coatings provide a flexible method for managing light transmission and altering the spectral properties of glasshouses through the seasons. A range of glass coatings were trialled for durability and ease of use.

New panes of 3 mm horticultural glass (single batch, 610 mm^2) were mounted onto an array of wooden A-frames, coated with a range of coating products and exposed to the elements between April and November 2016 (**Figure 3**). Light transmission and spectra measurements were recorded for a variety of glass coating products from Mardenkro (ReduFuse, ReduFuse IR, ReduHeat and ReduSol), Hermadix (D-Fuse Floriculture, D-Fuse, Vegetable, DeGree, Q Heat, Q3, Q4) and Sudlac (Optifuse, Optifuse IR, Optimix RB, TransPAR and Eclipse LD) and compared with untreated standard glass and untreated diffuse glass.

Figure 3. Arrangement of glass panes on A-frame structures at Baginton Nurseries, 2016

For this trial, glass coating products were applied by hand pressure sprayers as opposed to spray guns or mechanical application, and they were applied to individual glass panes, rather than a large expanse of glass.

The silicon coating applied to new glass to make it easier to separate panes prevented the spectral coatings from adequately adhering to the glass. The first application and silicon were removed using a release agent (Removit) and the treatments re-applied, achieving even coverage.

Light diffusing products (e.g. ReduFuse and TransPar) had a greater tendency to run at the dose rates used in this trial, however most products generally spread as they dried to produce a fairly even coat. No difficulties were experienced with blocked nozzles.

Coatings designed to diffuse light (ReduFuse, D-fuse, Optifuse) or to provide shading (Eclipse, ReduSol, Q3 and Q4) had little influence on the spectrum of transmitted light but changed the total amount of light that was transmitted (**Figure 4**). All products were observed to diffuse light to some extent, although the diffusion (haze factors) was not determined. Products designed to reduce solar heating caused by sunlight (Q Heat, TransPAR, ReduHeat) reduced transmission of light with wavelengths greater than 650 nm (i.e. in the red region of the PAR spectrum) and of UV light (315 – 400 nm, predominantly UV-A). The reduction of UV transmission may have little impact of crop performance when used on glass structures as glass also removes UV light from the spectrum but may have greater effect if used on structures constructed from UV transmitting plastics. The corresponding products produced by the different manufacturers were observed to have similar light transmitting qualities. The measured transmittance values were found to be similar to those reported by the manufacturers.

Durability was determined as the change in light transmission between the first and final light transmission measurements. The greatest difference occurred in the shade products (Redusol, Q4, Q4 and Eclipse LD), where transmission increased by 16%, 16% and 5% respectively over the time period. However, growers do not always require a long period of time for shading or spectral amendment, preferring products to weather as the season progresses and light levels reduce. Duration can be adjusted by changing the concentration of the solution applied; duration is longer with a higher concentration solution. Growers should determine their needs prior to application.

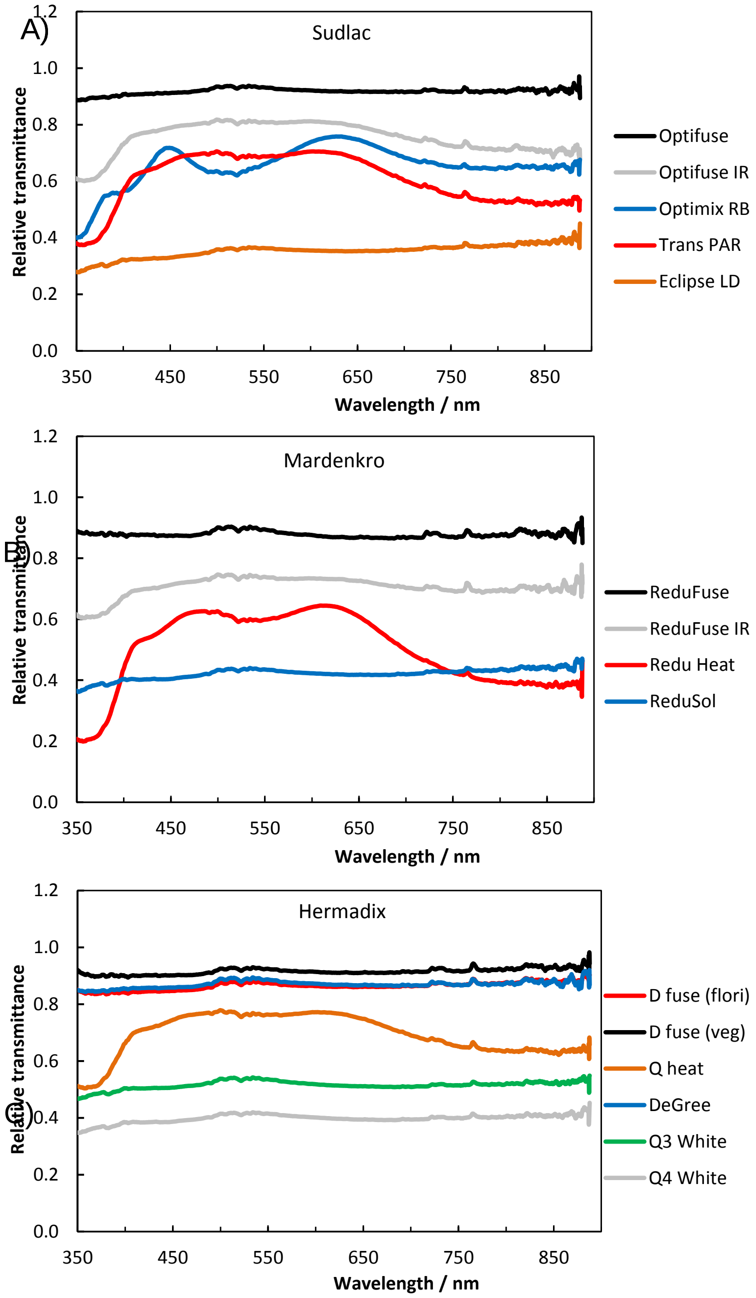


Figure 4. The relative mean transmission spectra of the different glass coatings. Spectra are grouped based on the manufacturer that produced the products **A)** Sudlac, **B)** Mardenkro and **C)** Hermadix. Transmission spectra were calculated relative to the transmission of glass and so exclude the influence of glass. Data provided by Dr Phil Davis, STC

Objective 4: Spectral filters (films) that improve plant production

Growers are keen to reduce their reliance on chemical inputs through adoption of cultural and non-chemical methods, and this can include the use of spectral filters (films). A range of spectral filters are available capable of manipulating the light spectra afforded to the crop beneath, influencing plant growth and quality, and the incidence of some pests and diseases. A demonstration trial was established to investigate the effect of a range of spectral filter films on plant growth and quality.

Work was carried out between June and November 2016, under four separate polythene tunnels covered with SunSmart Blue (new and old), Lumisol and Luminance, and a glasshouse. Potential degradation of film over time was investigated using a tunnel that had been covered with SunSmart Blue film in 2009, compared with one re-covered with this film in February 2015. Plug plants of eight species (*Bellis* 'Medicis' Mixed, *Cheiranthus* 'Sugar Rush' Mixed, *Cineraria* 'Silver Dust', *Cyclamen* 'Metis Decora' Mixed, Pansy 'Matrix' Autumn Select Mixed, Polyanthus 'Piano' Mixed, Primrose 'Bonneli' Mixed and *Viola* 'Sorbet XP' Autumn Select Mixed) were transplanted into 6-packs using a peat (60%) / woodfibre (40%) growing medium. The *Cyclamen* were transplanted in week 22, and the remaining species in week 34. Plants were set down in the five treatment areas and grown as a commercial crop. Plants were monitored for pests and diseases, with pesticide treatments applied as necessary; no PGRs were applied to avoid confounding the effects of the treatments.

The response of plants to spectral films varied with species and film. Plant quality was generally good (score >7, commercially acceptable), with lower scores due to uneven plant height and spent flowers; this was most evident in *Cyclamen* as their production cycle was earlier than the other species examined. Lower quality was recorded in the two light diffusing treatments (Luminance and Lumisol) relative to the other treatments for the *Cyclamen*, but this trend was not evident across all species. SunSmart Blue improved quality in five of the eight species tested, Luminance in four and Lumisol in two.

Many of the flowering differences seen in this trial were varietal, i.e. were due to differences in the natural flowering periods. Compared with the untreated glass, Luminance appeared to advance flowering in *Bellis, Cheiranthus,* pansy and primrose; Lumisol in *Cyclamen,* pansy and primrose; and SunSmart Blue in *Cyclamen,* pansy and primrose.

There was no single treatment where plants of all varieties were more compact than the other treatments (**Table 2**). Compared with untreated glass, Lumisol resulted in more compact plants than the other treatments for four species (*Cheiranthus, Cineraria, Cyclamen* and *Viola)*, and SunSmart Blue in one species (*Cheiranthus*). None of the films improved the compactness or quality of the *Bellis*. Growth was generally more compact under the new SunSmart Blue tunnel than the old SunSmart Blue tunnel, except for the *Cheiranthus* and Primrose.

The variable response of the different species to the treatments is demonstrated by these results, for example growth of *Bellis* 'Medici' was more compact under the untreated glass than the new SunSmart Blue treatment, whilst the converse was true for the *Cheiranthus*.

Table 2. Observed effect of four polythene films on plant height (H) and quality (Q) of some autumn flowering ornamentals, compared with growth under glass – 17 November 2016

Variety	**Film and assessment**							
	Luminance		**Lumisol**		**SunSmart Blue – New**		**SunSmart Blue - Old**	
	H	Q	H	Q	H	Q	H	Q
Bellis ‘Medici’	↑	↔	↔	↔	↑	↔	↑	↔
Cheiranthus ‘Sugar Rush’	↔	↑	↓	↔	↓	↑	↓	↑
Cineraria ‘Silver Dust’	↔	↑	↓	↔	↔	↑	↔	↑
Cyclamen ‘Metis’	↔	↓	↓	↓	↔	↔	↔	↔
Pansy ‘Matrix’	↑	↔	↔	↔	↑	↑	↑	↑
Polyanthus ‘Piano’	↑	↑	↔	↑	↑	↔	↑	↔
Primrose ‘Bonneli’	↑	↑	↔	↑	↑	↑	↑	↔
Viola ‘Sorbet’	↔	↔	↓	↔	↔	↑	↔	↑

Key: ↑ - increased; ↓ - decreased; ↔ - no change. Treatments which increased plant quality and improved compactness are highlighted in red.

Objective 5: Pre-Christmas production of hellebore

The market for hellebore as pot plants has increased over the last five years as new seed and micro propagated varieties have become available. Although white varieties are marketed in flower before Christmas, this trial was established to determine if cold treatments can be used to manipulate the new coloured varieties to flower in time for Christmas marketing.

The work was carried out between March and December 2016. Six micro-propagated hellebore varieties (‘Anna’s Red’, ‘Molly’s White’ ‘Penny’s Pink’ - Exceptio bv; ‘HGC Madame Lemonnier’ and ‘Paradenia’ – Heuger; and ‘Royal Emma’ - Beekenkamp Plants bv) were grown outdoors under shade (1.5 L pots). They were subjected to six weeks cold store treatment (2°C, 12 hour day / night, 100 watt incandescent light) in two batches from 24 August (CS1) and 21 September (CS2). A cold store malfunction occurred on two occasions when the temperature fell below 0°C for 16.5 hours and 8 hours respectively, reaching -12°C and -14°C. ‘Anna’s Red’ ‘Molly’s White’ and ‘Penny’s Pink’ were the most cold sensitive varieties, with fewest surviving plants. ‘Royal Emma’ was least sensitive to the cold, and was the only variety with flowers opening (three plants, treatment CS1) by week 46; flowers on

‘Paradenia’ were open in week 49 (CS2b). Due to the cold store malfunction this trial will be repeated in 2017.

Objective 6: To advance the marketing period of perennials by overwintering under glass and polythene

There is an increasing trend, and interest among growers, to extend the herbaceous perennial season and product range so as to provide more flowering plants by late March ready for impulse sales. In previous work (PC 247 and PC 267), a range of seed and cutting raised perennials were grown under protection with the use of heat and light to force them for early spring marketing. The objective in this trial was to identify perennials that may be produced successfully under protection with minimal energy inputs, aiming to advance the natural marketing window. Nine species chosen by the project steering group were examined under both glass and polythene tunnel protected environments.

Seeds of nine perennial species (*Campanula glomerata* ‘Acaulis’, *Campanula persicifolia* ‘Takion Blue’, *Coreopsis grandiflora* ‘Presto’, *Echinacea* ‘Cheyenne Spirit’, *Gaura lindheimeri* ‘Sparkle White’, *Prunella grandiflora* ‘Freelander Blue’, *Scabiosa japonica* var. *alpina* ‘Ritz Blue’, *Silene alpestris* ‘Starry Dreams’ and *Verbena rigida* (syn. *V. venosa*) were sown into 104-cell trays in two batches (weeks 27 and 29), transplanted into jumbo 6-packs and 1 L pots (week 40) and set down under glass and within a polythene tunnel. Young plants from the second sowing (week 29) were transplanted for all species except *Campanula persicifolia* ‘Takion Blue’, for which plants from the first sowing (week 27) were used. *Gaura lindheimeri* ‘Sparkle White’ was trimmed prior to transplant. The glasshouse trial was heated from 24 March 2017 (week 12).

Plants were monitored throughout the winter and assessed for number in flower, quality and height in week 13/14, the target marketing date.

None of the species examined reached the target marketing criterion (90% of plants with fully open flowers) by late March in either the glasshouse or polythene tunnel environment. Five species (*Campanula glomerata* 'Acaulis, *Campanula persicifolia* 'Takion Blue', *Prunella grandiflora* 'Freelander Blue', *Scabiosa japonica* var. *alpina* 'Ritz Blue' and *Silene alpestris* 'Starry Dreams') had buds and / or were just beginning to flower. *Gaura lindheimeri* ‘Sparkle White’ and *Verbena rigida* in particular suffered cold damage in the glasshouse and polythene tunnel environments following sub-zero temperatures (-4.4˚C and -3.7˚C respectively); the cold damage was first observed in March 2017. Plant quality in late March was good for glasshouse grown *Campanula persicifolia* 'Takion Blue' and Silene *alpestris* ‘Starry Dreams’, and for the latter species grown in the polythene tunnel. The mean plant quality for the other species was poor. There was greater than 50% plant death of *Echinacea* 'Cheyenne Spirit' (packs) and *Gaura lindheimeri* 'Sparkle White' (pots) in the polythene tunnel. Survival was generally greater in packs than pots in the polythene tunnel, with the converse in the glasshouse. It was concluded that for the nine species examined production of flowering plants by late March will generally require more than two weeks of heat at 15˚C in March as used in this work.

Financial benefits

Objective 1: Improving cutting success

The benefits of this work are directly linked to reduced waste and quicker throughput of product. The farmgate value to growers of geraniums produced from cuttings in 10.5 cm or 1 L pots or jumbo 6-packs is estimated at 80-90p, £1.40 - £1.50 or £2.80 – £2.90 per unit respectively. Treatments costs are provided in **Table 3**.

Cuttings that are unusable due to a delay in transit may be replaced by the supplier, which would delay the finished product, or the supplier may not be able to provide replacements. In either case it may be necessary to purchase replacement plants from an alternative supplier. The cost of plants sourced from surplus lists is likely to be 10-20% higher than the grower's sale price to his client, excluding labour, labelling, input or transport costs.

Any gaps in supply can jeopardise client relationships with the potential for penalties to be applied under some contracts. Sourcing plants from an alternative supplier's surplus list increases the risk of supplying inferior quality plants, the plants may be a different variety or quantity and there may be insufficient to fill the gap in the production programme.

Table 3. Improving cutting success: costing

Item	**£/unit + VAT**	**Rate**	****Cost / treatment (1000 cuttings) SPRAY & QUICK DIP**	****Cost / treatment (1000 cuttings) LONG DIP**
Geranium 'Bianca'*	0.08-0.1p each plus 0.036p royalty			
Serenade ASO	£124.74 / 10L	10 L/ha	24.95 ml = £0.31	1000 ml = £12.47
Signum	£161.70 / 2.5 kg	1.35 kg/ha	3.37 g = £0.22	135 g = £8.73
Fructose	£4.70 / 100 g	2 L/ha	5 g = £0.24	200 g = £9.40
Rhizopon	£21.00 / 20 tablets	0.06 kg/ha	3 tablets = £3.15	120 tablets = £126
Omex SW7	£54.76 / L	0.5 L / ha	1.25 ml = £0.07	50 ml = £2.74

*unrooted cuttings. ** excluding labour costs

Potential financial benefits will be achieved through energy savings due to faster root development and reduced crop throughput time. The energy cost to increase glasshouse temperature by 1˚C compared with the outside temperature will vary depending on a number of factors, including the heating system, glasshouse size, infrastructure (screened or unscreened), and fuel used.

As an example (**Table 4**), the energy cost to heat a glasshouse (one acre) to 18 ˚C (outside temperature 5˚C) using an air heater fuelled by gas oil is estimated at £327.25/day. The energy cost is calculated in two stages: 1) the energy requirement to increase the glasshouse temperature by 13˚C, and 2) the cost to provide the required energy.

Note that this example assumes an air heater that is 100% efficient in energy delivery is used. Cabinet heaters and boiler systems are estimated at 95% and 85% efficient in energy delivery. For an 80% efficient boiler, adjust the calculation: energy requirement in glasshouse / 0.8 kWh (i.e. 10098/0.8 = 12,623 kWh).

Table 4. Parameters for example energy cost calculation

Example	**Temperature (˚C)**			**Heat loss from a screened or unscreened glasshouse due to the difference between the glasshouse and outside temperatures ($W/m^2/˚C$)**
	Glasshouse set	**Outside**	**Difference**	
Unscreened glasshouse	18	5	13	8
Screened glasshouse	18	5	13	6

1. The energy requirement to increase glasshouse temperature by 13 ˚C

$$Energy\ requirement\ (\text{kWh})\ to\ heat\ the\ glasshouse\ by\ 13\ ^{\circ}\text{C}$$
$$= \text{heat loss x acre x temperature difference x 24hrs/1000}$$

For this example, the calculation is as follows:

$$Energy\ requirement\ (\text{kWh})\ to\ heat\ the\ glasshouse\ by\ 13\ ^{\circ}\text{C}\ = 8\ x\ 4046\ x\ 13\ x\ \frac{24}{1000}$$
$$= \mathbf{10,098}\ \boldsymbol{kWh}$$

Where: heat loss = heat lost from a screened or unscreened glasshouse due to the temperature difference between the glasshouse and outside; acre is the conversion factor from m^2 to acres (1 acre = 4046 m^2); temperature difference = the difference between the glasshouse temperature and outside temperature (˚C); 24 hrs converts the calculation from hours to days; and 1000 converts from Wh to kWh.

2. The cost to increase the glasshouse temperature by 13˚C

The cost to heat the glasshouse by 13˚C = volume of fuel [heat requirement / energy content of fuel (kWh/L)] x fuel cost.

$$Cost\ to\ heat\ a\ glasshouse\ by\ 13^{\circ}\text{C}\ = \frac{energy\ requirement}{fuel\ energy\ content}\ x\ fuel\ cost$$

For this example:

$$Cost\ to\ heat\ a\ glasshouse\ by\ 13^{\circ}\text{C}\ = \frac{10{,}098}{10.8}\ x\ 0.35 = \pounds\mathbf{327.25}\ \boldsymbol{per\ acre\ per\ day}$$

Where: energy content of gas oil = 10.8 kWh/L; fuel cost = 35p/L (45p minus horticultural fuel duty rebate).

Objective 2: Verbena leaf spot and chlorosis

The incidence of marginal leaf chlorosis and necrotic spotting symptoms vary from year to year, ranging from one or two varieties up to 60% of varieties in some years; the problem can affect 100% of the crop. While the value of *Verbena* to the horticulture sector is not known, grower feedback suggests that 5-6% of spring bedding sales can be affected. To put this into context, many nurseries consider 3% waste as the upper acceptable limit and above this would stop producing a particular crop or variety. Symptoms have been reported on many nurseries across the sector.

As an example, the turnover associated with a batch of 100,000 *Verbena* (double 6-pack, 12 plants) is estimated at £22,000 to the grower. Where 60% of the crop is affected, the value of this wastage is estimated at £13,200.

Objective 3: Spectral filters (glass coatings)

These measurements will aid growers to make informed decisions when they choose which glass coating to use on their glasshouse through understanding the effects of the products on the growing environment, plant quality and worker comfort. The data will help growers not only to select a coating that meets their needs but to also compare the products produced by different manufacturers (**Table 5**). Application rates will be dependent on the product used and the effect required and will depend on the nursery location, and growers should follow manufacturers' guidelines. For shade loving ornamental plants the need for spectral filters or shade coatings is vital to prevent leaf and flower scorch (and loss of quality) on bright, hot days. For non-shade loving ornamental plants the direct financial benefits are less defined and include improvements in plant habit, size and quality and working environment.

Table 5. Glass coatings: costing*

Manufacturer	Product	Cost (£ + VAT)	Unit (kg)	Manufacturers' application guidelines. Cans/ha	Cost / ha (£ + VAT)
	Horticultural glass	6.00	m^2	-	-
	Diffused glass	12.00	m^2	-	-
Hermadix	D-Fuse Floriculture	90.00	15	13	1170
	D-Fuse Vegetable	90.00	15	13	1170
	DeGree	120.00	15	13	1560
	Q-Heat	120.00	15	22-44	2640 - 5280
	Q3	45.00	20	13-34	585 - 1530
	Q4	54.00	20	10-34	540 - 1836
Mardenkro	Redusol	62.70	20	10-33	627 - 2069
	Redufuse	125.70	15	12-20	1508 - 2514
	Redufuse IR	131.10	15	18-22	2378 - 2884
	Reduheat	155.90	15	21-30	3274 - 4677
Sudlac	Optifuse	117.40	15	13	1526
	Optifuse IR	120.40	15	17-22	2047 - 2649
	Optimix RB	126.02	15	17	
	Transpar	120.30	15	20-30	2406 - 3609
	Eclipse LD	59.26	20	10-30	590-1778

*Costs provided are undiscounted for trade or quantity and do not include application or removal costs

Objective 4: Spectral filters (films)

Spectral filters can help to reduce inputs e.g. plant growth regulators, and reduce waste.

A polythene tunnel clad with SunSmart Blue polythene can provide growers with additional production flexibility when used to hold plants back to meet marketing deadlines. This helps to ensure that orders are filled without loss of quality and avoids or reduces the waste usually associated with delayed marketing or plants that reach marketing stage ahead of schedule. As an example, the value associated with a standard single span polythene tunnel (4 m x 20 m) of mixed bedding in standard double 6-packs (dimensions 0.082 m^2) that would otherwise be wasted is estimated at £2,341, assuming all plants are sold.

The cost to cover a polythene tunnel (4 m x 20 m) skinned with Lumisol or SunSmart Blue covers is provided in **Table 6**. Luminance has been superseded by Lumisol and is no longer produced by BPI Visqueen.

Table 6. Polythene cost (material only)

Product*	Cost / m^2 + VAT (£)	Tunnel cover cost + VAT (£)***
Lumisol	1.11*	265
SunSmart Blue	0.88**	209

*LBS, **XL horticulture. *** Cost to cover a 4 m x 20 m tunnel, with the polythene trenched into the ground; excluding labour and fittings

Although plant growth regulators were not used in this trial, the treatment costs for a single application of Bonzi (at 1.25 ml/L) to hold plants back at dispatch in a 4 m x 20 m tunnel (requiring 20 ml of Bonzi) equates to £1.90 (per application) plus the cost of the labour and equipment to apply it.

Objective 5: Pre-Christmas production of hellebore

This work with hellebores will potentially broaden the range of plants in flower for the pre-Christmas marketing window to compliment poinsettia, given appropriate variety selection for key house plant attributes (such as flowers facing upwards and attractive foliage as well as flowers). Consumers have the option to purchase hellebore during this period, display them as a house plant and then subsequently plant them in the garden rather than disposing of them at the end of the season (as they would for poinsettia).

Sold as pot plants in flower, some hellebore varieties can demand high retail prices with a 10% premium over green plants. Current retail prices for some of the varieties used in this trial include: *Helleborus* 'Emma' and *H*. 'Penny's Pink', £13.50 (1.5 L); *H.* 'Anna's Red' £12.49 – £19.99 (1.5 L); *H*. 'Madame Lemonnier', £14.44 (2 L), from various outlets.

Based on the retail price range for *H*. 'Anna's Red' in a 1.5 L pot, the grower could receive in the region of £5.20 to £8.33 per plant in the natural flowering season. By marketing this product in flower before Christmas it is considered that a premium of 10% may be achievable. This would be a new product line, and a hypothetical market value of 50,000 plants would be estimated at £286,000 to £458,150.

Hellebore growers would need to set the projected extra income against the associated costs of operating their own cold room at 2˚C for two weeks at today's energy costs, and would need to include associated costs such as the labour cost to transfer plants to and from the cold store.

To help put this into context, we can use data from the AHDB publication 'HNS Cold Storage – a Grower Guide' as guidance. It was calculated that for nursery stock plants in 3 L pots, stacked on Danish trolleys with 4 to 5 shelves per trolley, the break even yield would be 9.66 to 7.72%; i.e. the benefit exceeds the cost when 9.66% to 7.72% more product is sold (**Table 7**). The break even yield would be reduced to 5.52% for plants in 9 cm pots, therefore the 1.5 L pots used in this trial falls between the two. This is based on a nursery output of £55.28 /m^2 and a cold store cost of £21.35 /m^2 (the cold store cost is the average annual cost to build and run a cold store when spread over a ten year pay-back period and excludes costs associated with any building the store may be situated within). Assumptions were made for this 2009 industry-wide cost:benefit analysis, and it was calculated as the average cost for facilities ranging from relatively low cost refrigerated lorry backs to large, purpose built cold stores.

Table 7. Break even yields for cold storage use

Pot size	Number of layers on Danish trolley	Cost of cold storage/m^2 (£)	Nursery output* (£)	Break even yield (%)
3 L	4	21.35	221.12	9.66
3 L	5	21.35	276.40	7.22
9 cm	7	21.35	386.96	5.52
*Nursery output assumed to be £55.28/m^2				

Objective 6: Overwintered perennials

The objective of this trial was to advance flowering in a range of perennials for impulse purchases in early spring. This has the potential to increase sales opportunities during a marketing window traditionally filled with species such as *Primula* and *Viola*, and more recently with Senetti. First marketed in Europe in 2001, Senetti is a prime example of a new crop that has been brought to market that flowers at a time of year when there are fewer products available in flower and that now commands strong consumer demand each year.

It is estimated that for sales of perennials in flower in early spring, the trade price would be in the region of £1.00 to £1.25 (1 L pot), for comparison, perennials sold without flower may command £0.85 each, but demand would be lower as they would not have the visual impact of plants in flower.

Action points

1. *Improving cutting success*

- Consider using Omex SW7 and Rhizopon as pre-sticking quick dip treatments to improve success of geranium rooting, particularly when cuttings have been delayed in transit.

2. *Verbena leaf spot and chlorosis*

- Conditions that cause these symptoms have not yet been identified. As a general measure, it is recommended that growers ensure healthy root development in *Verbena* through careful application of water; over application of water so that growing media is continually very wet will limit root development and impair nutrient uptake.

3*. Spectral filters (glass coatings)*

- Consider use of appropriate glass coatings (Redufuse, D-fuse and Optifuse) to improve crop quality and working environment (to diffuse light, reduce light intensity and reduce solar heating), adjusting application rates to achieve the required effect and duration.
- To reduce the effect of solar heating and maintain a cooler environment consider using products such as DeGree, Q Heat, Redufuse IR and ReduHeat, Optifuse IR or TransPAR.
- Closely monitor crop performance under treated glass. Account for associated application and removal costs in budget projections.

4. Spectral filters (films)

- Consider the use of SunSmart Blue film to hold batches of plants back.
- Light diffusing films such as Lumisol can be used to improve plant habit and quality and can be particularly useful for shade loving crops to prevent scorch.

5. Overwintered perennials

- There appears to be potential to force certain herbaceous species into flower with additional heat only. To determine such responsive species, trials should be carried out using different species (which ideally should be short-day or day neutral in their flowering response) and temperature regimes on growers' own holdings prior to any large scale production.

SCIENCE SECTION

Introduction

The total value of the UK commercial horticulture sector in 2013 was estimated at £3,007 million, 12% of total agricultural output. The production of ornamentals equated to 7% (11,891ha) of the total horticultural area in 2013, but generated 37% of the output from horticulture, with a value of £1,097 million (a 4% increase on 2012) (Crane et al., 2015). However, for this sector the increasing cost of inputs, and particularly labour costs following the recent introduction of the new National Living Wage, have made it increasingly difficult to maintain profitability levels. Whilst introducing efficiencies may go some way to achieving this, seeking new market opportunities during the autumn and winter seasons for pot and bedding plant growers will help to maximise year round production.

Each production business will have its own unique relationship with its customer base, but in general terms potential methods of increasing production and profitability include: 1) season extension via new crops or varieties, production of niche crops for specific markets, development of value added products (e.g. hanging baskets and planted arrangements in pots) and taking advantage of the new, innovative and exciting breeding lines that become available to provide consumers with increased choice, 2) utilisation of breeding techniques to solve production (e.g. pest and disease) issues, and 3) a reduction in inputs and associated costs (e.g. pesticide, plant growth regulator, fertiliser, water, energy use and labour).

The Bedding and Pot Plant Centre (BPPC), located at Baginton Nurseries, near Coventry, has been established to address the needs of the industry via a programme of work, initially over two years, to trial and demonstrate new product opportunities and practical solutions to problems encountered on nurseries, particularly those associated with the above three points. Knowledge transfer events, including trial open days and study tours, also form an essential element of the programme of work.

The work programme is guided by a grower-led Management Group that includes grower members of the BPOA Technical Committee along with representatives from the host nursery.

The agreed work programme for the second year of the Bedding and Pot Plant Centre had the following objectives:

Objective 1. To improve cutting success

The 2015 AHDB/BPOA US study tour provided the inspiration for this trial, where Dr John Dole (Floriculture Professor, NCSU, North Carolina State University) presented a summary of a project carried out at the North Carolina State University Extension Cooperative. The US work was developed to resolve cutting quality problems that sometimes develop when material is delayed in transit or stored incorrectly, resulting in a loss of cutting turgidity and quality.

Loss of turgidity and quality in cuttings is governed by numerous factors including:

- Water, which has a dual role in terms of cutting quality. Cuttings rapidly lose water post-harvest, resulting in desiccation and defoliation. However, although dry when dispatched, temperature fluctuations and cutting transpiration during transport can cause condensation, providing favourable conditions for fungal and bacterial disease development.
- Ethylene. This can be used during stock plant production to promote branching and root development, it is also produced by cutting material in response to stress when it can cause chlorosis, defoliation and epinasty, resulting in leaf senescence and abscission. The adverse effects of ethylene can be prevented by the use of ethylene absorbent labels or pads, or counteracted by the application of gibberellin.

  There is an interaction between ethylene and carbohydrate levels, as stored geranium cuttings (with depleted carbohydrate levels) are sensitive to exogenous ethylene, while freshly harvested cuttings do not appear to be similarly affected.
- Carbohydrate levels. The carbohydrate content of geranium cuttings can be affected by nitrogen levels during stock plant production, with increased nitrogen supply resulting in reduced carbohydrate levels in cuttings.

In addition to this, cuttings continue to respire once harvested. To maintain cutting quality, respiration should be reduced as soon as possible after harvest, and this is achieved by reducing the storage temperature (avoiding chilling / freezing injury). Geranium cuttings can be stored for up to five days at 4˚C without any detrimental effect compared with unstored cuttings.

Various products were tested in the US work (**Table 8**) that were expected to improve cutting recovery through a number of different processes. The most promising treatments for geranium were the 30 minute dip in K-IBA (400 ppm) plus either fructose or Pageant. For most treatments, water plus CapSil dipping solution had a positive effect on rooting even when applied to unstored cuttings.

Table 8. Products tested by NCSU, USA and their expected effects

US product	Active ingredient(s)	Expected effect
CapSil (Aquatrols) -	Blend of polyether-polymethylsiloxanecopolymer and non-ionic surfactant	Wetting agent, improves uptake of water
Pageant (BASF)	boscalid and pyraclostrobin	Fungicide, provides disease control
Daconil (Syngenta) -	chlorothalonil	Fungicide, provides disease control
Plant hormones	K-IBA	Growth hormone, IBA products promote rooting
Fascination (Valent)	Gibberellin	Growth hormone, counteracts the effect of exogenous ethylene
Configure (Fine)	Benxyladenine (cytokinin)	Growth regulator, promotes cell division and axillary bud development.
Sucrose, glucose, fructose	Carbohydrates	Restores depleted carbohydrates. Low carbohydrates limit rooting in Geranium
Urea solution	Nitrogen	Increased nitrogen in feed results in reduced carbohydrate levels in cuttings for Geranium
Distilled water	Water	Restores turgidity

Results of BASF and Aquatrols funded work using their products (Pageant Intrinsic and CapSil, respectively) is available on their websites.

UK growers are increasingly taking advantage of the widening range of plant varieties available as un-rooted cuttings from an international market. However, plant material can suffer from loss of condition, dehydration and potentially disease as experienced with material in the USA as a result of the long transit journeys involved.

The treatments used in this trial incorporated the most promising outcomes of the NCSU work, and suggestions from growers. Signum and Serenade ASO were included for disease prevention; Signum is the UK equivalent to Pageant although as a different formulation. Fructose was included as a carbohydrate source. Rhizopon is equivalent to K-IBA rooting hormone and Omex as a wetting agent in place of CapSil.

Objective 2. To reduce leaf spot and chlorosis in Verbena

Problems have been encountered with *Verbena* plant quality at various nurseries. Symptoms are reported to appear in propagation prior to transplant when a minimal amount of liquid feed has been applied, and also as plants proceed to flowering. Both seed and cutting raised plants may be affected. Symptoms include:

1. Necrotic margins on older leaves and leaf yellowing which can work upwards to younger foliage. Necrotic spots have also been seen on leaves, from which it has not been possible to isolate any pathogens. These symptoms are generally worse in blue varieties from both seed and cutting raised material.

2. Chlorosis starting from the top of the plant and moving down; starting towards the middle of the leaf and spreading out.

Interpretation of growing media and water analyses provided by nurseries where *Verbena* have been affected by these issues suggests that the variable quality of irrigation water (in terms of conductivity, particularly as influenced by the level of chloride, sulphates etc., and alkalinity) may influence the development of symptoms (mains water suppliers routinely change the water source at various times of year depending on water table levels). In addition to this, problems have variously been attributed to transient iron deficiency and manganese toxicity; manganese is more available, potentially at toxic levels, at pH <5 whilst iron can become deficient in high pH depending on the plant sensitivity.

Fritted trace elements are less soluble than inorganic trace elements, therefore available to plants more slowly and over a longer period of time, providing less potential for toxicity problems (plants have to work harder to access nutrients). Bulrush Horticulture has reported success in using fritted trace elements to ameliorate manganese deficiency in brassicas and so their use was examined in the trial. Growing conditions were also investigated via three irrigation regimes (standard, wet and dry). Spring and summer trials were undertaken to identify any effect of light/temperature on symptom expression.

Objective 3. To identify spectral filters (glass coatings) for ease of use and durability and to characterise effects on the glasshouse environment

There is interest among growers in the use of glass coatings to provide specific environmental conditions within glasshouses to optimise plant growth and quality. However, new products have recently come onto the market with limited independent data available on their effect on light quality and transmission, and product durability; short or longer durability may be desirable depending on the application they are used for. This trial combined both data collection from a trial of a range of products, and knowledge exchange. Data was also collected on manufacturer-coated samples.

Objective 4. To identify spectral filters (films) that improve plant production

Growers are keen to reduce their reliance on chemical inputs through adoption of cultural and non-chemical means, and this can include the use of spectral filters (films) to control growth and aid scheduling. A range of films are available to growers, capable of manipulating the light spectra afforded to the crop beneath, influencing plant growth and quality, and the incidence of some pests and diseases. Plant architecture, for example, can be influenced by light quality, with stem elongation limited by an increased red:far red light ratio; plant height is also influenced by temperature as the growth rate of plants grown in the cooler environment under films that reflect infrared light is lower than under glass. Previous work using spectral filters indicated that both Solatrol and UV-T (UV transparent) filters can successfully control growth in bedding plants, although not all plant species are responsive. Light diffusing filters, such as Luminance or Lumisol, can influence plant quality through deeper penetration of light into the crop and reducing 'hot spots' at plant level. SunSmart Blue is promoted as reducing plant height and is used by growers to hold plants back until marketing. The back catalogue of research and knowledge has not been widely adopted by the industry to date, but demonstration of the potential benefits and drawbacks would help to inform grower decision making.

Objective 5. To develop cold store treatments that induce flowering of hellebore pre-Christmas

The market for hellebores as pot plants has increased over the last five years as new seed and micro propagated cultivars have become available. Previously, only white varierties have been marketed prior to the New Year, but new English bred pink and red varieties are now available that may be manipulated to flower before Christmas by subjecting plants to cold treatments. This work has been developed from an idea based on the work of Christaens *et al* (2012) and Richardson *et al* (1974).

Objective 6. To advance the marketing period of perennials by overwintering under glass and polythene

There is an increasing trend and interest among growers to extend the growing season and product range using a range of seed/cutting raised perennials, grown under protection for marketing as early flowering spring plants for impulse sales in late March. Previous work in this area has included use of heat and light to control flowering to force perennials for early spring marketing (Lambourne and Brough, 2009). Preliminary trials had identified that week 14 was too early to sow seed for transplanting in week 40, and that seeds sown in week 29 produced plug plants at the correct development stage for transplanting. This trial included selected perennial subjects that may be produced under protection, either glass or polythene tunnels, but with minimal energy inputs, aiming to advance the natural marketing window of products grown without protection.

Project objectives

Specific objectives in Year 2 were:

Objective 1. To investigate the use of a range of products to increase the success rate and decrease rooting time when striking un-rooted cuttings. **(Improving cutting success)**.

Objective 2. To investigate the effect of growing medium pH, irrigation regime and trace element form on the occurrence of necrotic leaf spots on both seed and cutting raised *Verbena*. **(*Verbena* leaf spot and chlorosis)**.

Objective 3. To characterise the ease of application, durability and environment effects (light spectrum and transmission, and temperature) of a range of glass coating and shading products. **(Spectral filters - glass coatings)**.

Objective 4. To determine the quality of eight bedding and pot plant species grown under four spectral plastic films compared with growth under untreated glass. **(Spectral filters - films)**.

Objective 5. To investigate the effect of two cold store treatments on the flowering time of five coloured hellebore. **(Pre-Christmas production of hellebore)**.

Objective 6. To determine the potential of nine herbaceous perennial species for production as flowering plants in early spring (weeks 13-14, 2017). **(Overwintered perennials)**.

Materials and methods

Objective 1: Improving cutting success

The trial was carried out between March and May 2016. Cuttings of Geranium Green Leaf Series 'Bianca' were sourced from Young Plants (2400 in total), and dispatched from the mother stock location in Addis Ababa, Ethiopia, on 19 March (week 11). The cuttings arrived at Baginton Nurseries in small polythene bags (100 cuttings per bag) within a cardboard box on 24 March (week 12). The packaging was opened and cuttings agitated to release any ethylene that had built up during transit, and were immediately refrigerated. On 25 March (week 12), 1200 cuttings were removed from the fridge and mixed together. A sub-sample of 20 cuttings were assessed for quality and stem thickness before the treatments (

Table 9) were applied and cuttings stuck (Sticking 1). Note that Signum and Serenade ASO were applied under an experimental permit, as there are no label or EAMU approvals that permit dip treatments with these products.

Table 9. Treatment list used for cuttings, 2016

Treatment No.	Product	Application	Rate of use - Kg/ha or L/ha
1	Untreated control	N/A	N/A
2	Water only	Spray	N/A
3	Water only	Quick dip	N/A
4	Water only	Long dip	N/A
5	Omex SW7	Spray	0.5 L/ha
6	Omex SW7	Quick dip	0.5 L/ha
7	Omex SW7	Long dip	0.5 L/ha
8	Signum*	Spray	1.35 kg/ha
9	Signum*	Quick dip	1.35 kg/ha
10	Signum*	Long dip	1.35 kg/ha
11	Fructose	Spray	1%
12	Fructose	Quick dip	1%
13	Fructose	Long dip	1%
14	Rhizopon AA tablets	Spray	6 tablets/L
15	Rhizopon AA tablets	Quick dip	6 tablets/L
16	Rhizopon AA tablets	Long dip	6 tablets/L
17	Serenade ASO*	Spray	10 L/ha
18	Serenade ASO**	Quick dip	10 L/ha
19	Serenade ASO*	Long dip	10 L/ha

* Note that Signum and Serenade ASO were applied under an experimental permit.

Each plot consisted of half of a 72-cell plug tray (Pöpplemann, Cell – 3.6 x 3.4 cm, 41 ml cell volume). 15 cuttings were stuck into each tray; 15 cells were filled with growing medium, with the remaining cells left empty. Cells were filled with a peat based growing medium (Peat + 20% perlite propagation medium (Tref), pH 5.8-6.2) and watered in before the cuttings were stuck. Trays were evaluated in a randomised block design with four replications (total 76 trays).

Each product was applied as an overhead spray, a 5-second quick dip (QD) and a 30 minute long dip (LD). For the spray treatments, cuttings were stuck into the trays, and the treatments were sprayed overhead using a knapsack sprayer and single nozzle lance with an 02f110 nozzle, at a rate of 200 L/ha. For the dip treatments, two 1 L solutions were made up, one for the QD and one for the LD. For the QD, the bases of the cuttings only were agitated in the solution for 5 seconds (five cuttings were treated at a time) before being stuck into the growing medium. For the LD, cuttings for all replicate trays (60 cuttings in total) were fully submerged in the 1 L solution for 30 minutes, before being removed and stuck into the growing medium. The trays were arranged in a randomised block design on a heated bench (21°C) within the propagation house (heated to 15°C, vented at 21°C, 90% RH) and once the cuttings had dried, they were watered in. Temperature and humidity was monitored (Tinytag data loggers) and the trial was covered with fleece.

On 29 March (week 13), the remaining 1200 cuttings were removed from the fridge, and treated following the same assessment and treatment process (Sticking 2). Prior to sticking, any large or yellowing leaves on the cuttings were removed. The trays were placed on the same heated bench with the Sticking 1 trays.

A frame was constructed around the trial (1 April) and covered with white propagation film. The trial was lightly watered to maintain humidity.

The trial was monitored for root development and growth of foliage. The first full assessment for Sticking 1 was carried out on 5 April (11 days after treatment – DAT) and for Sticking 2, on 11 April (13 DAT). The trial was assessed (non-destructive) for quality and the number of cuttings with visible roots from a sub-sample of five. Assessments were carried out weekly until the end of the trial (4 May, week 18) (**Table 10**), using a scoring system summarised in **Table** ,

Table 4 and **Table 5**.

Table 10. Summary of cutting success trial inspections and assessments, 2016

Date	Action	Assessment
19 Mar (wk 11)	Cuttings dispatched	-
24 Mar (wk 12)	Cuttings arrived	-
25 Mar (wk 12)	Sticking 1 set up	-
29 Mar (wk 13)	Sticking 2 set up	-
05 Apr (wk 14)	1st assessment – Sticking 1 (11 DAT*)	No. of cuttings with visible roots and plant quality for 5 cuttings per plot
11 Apr (wk 15)	1st assessment – Sticking 2 (13 DAT)	No. of cuttings rooting per tray, no. of cuttings with visible roots and plant quality for 5 cuttings per plot
20 Apr (wk 16)	2nd assessment – Sticking 1 (26 DAT) and Sticking 2 (22 DAT)	No. of cuttings rooting per tray, no. of dead cuttings per tray and quality for 5 cuttings per plot
27 Apr (wk 17)	3rd assessment – Sticking 1 (33 DAT) and Sticking 2 (29 DAT)	No. of cuttings rooting per tray, no. of dead cuttings per tray and quality for 5 cuttings per plot
04 May (wk 18)	Final assessment – Sticking 1 (40 DAT) and Sticking 2 (36 DAT)	No. of cuttings rooting per tray, no. of dead cuttings per tray and root quality for 5 cuttings per plot

*DAT = days after treatment

Table 11. Pre-sticking quality assessment scores

Score	**Definition**
0	Dead
1	Very poor quality
2	Poor quality
3	Good quality, some damage visible
4	Very good quality, very little damage
5	Excellent quality, no damage visible

Table 4. Cutting quality assessment scores

Score	Definition
0	Dead
1	Very poor, yellow
2	Green but no new growth, small
3	Green with new leaves developing
4	Green with new growth
5	Good quality, marketable

Table 53. Root assessment scores

Score	Definition
0	No change / dead
1	Callous formed
2	Finely rooted in up to 25% of cell
3	Rooting in 25 - 50% of cell
4	Rooting in 51 - 85% of cell
5	Fully rooted and ready for transplanting

Objective 2: Verbena leaf spot and chlorosis

Two trials were carried out to investigate the influence of nutrition and irrigation management on the development of marginal chlorosis and necrotic spots in *Verbena*, between March and May 2016 (spring trial) and from May to July 2016 (summer trial). Treatments were the same in both trials. Prior to transplant, plugs were assessed for plant quality (0-9), root quality (0-5) and height.

Spring trial

Plug plants of *Verbena* 'Quartz Blue' (PanAmerican, seed raised), were delivered to Baginton Nurseries in week 10 and transplanted into 6-packs (black plastic). Treatments consisted of three factors; watering regime, growing medium pH and trace element form (**Table 6**). Each treatment was replicated four times, and plots consisted of two 6-packs. pH adjusted growing medium was supplied by Bulrush Horticulture Ltd (**Appendix 2**). The plants were grown on under glass in the propagation house, and temperature and humidity were recorded every 30 minutes using three Watchdog 1000 series microstation data loggers. In addition, light and growing medium moisture were also monitored for each of the irrigation treatments using a LightScout Quantum Light 3 Sensor PAR probe and a WaterScout SM100 soil moisture sensor (one for each of the three irrigation treatments).

Table 6. Treatments used in the *Verbena* nutrition trials, 2016

Treatment No.	Irrigation*	pH	Trace elements
1	Dry (standard - 30%)	Low (4.5)	Fritted
2	Dry (standard - 30%)	Low (4.5)	Unfritted
3	Dry (standard - 30%)	Standard (5.8)	Fritted
4	Dry (standard - 30%)	Standard (5.8)	Unfritted
5	Dry (standard - 30%)	High (6.5)	Fritted
6	Dry (standard - 30%)	High (6.5)	Unfritted
7	Standard	Low (4.5)	Fritted
8	Standard	Low (4.5)	Unfritted
9	Standard	Standard (5.8)	Fritted
10	Standard	Standard (5.8)	Unfritted
11	Standard	High (6.5)	Fritted
12	Standard	High (6.5)	Unfritted
13	Wet (standard + 30%)	Low (4.5)	Fritted
14	Wet (standard + 30%)	Low (4.5)	Unfritted
15	Wet (standard + 30%)	Standard (5.8)	Fritted
16	Wet (standard + 30%)	Standard (5.8)	Unfritted
17	Wet (standard + 30%)	High (6.5)	Fritted
18	Wet (standard + 30%)	High (6.5)	Unfritted

* Commercial irrigation based on grower knowledge.

To achieve different irrigation regimes, the dry treatment plants were watered as necessary to prevent the plants from wilting. The wet treatment plants were watered at the same time as the standard irrigation treatment, but with approximately 30% extra water, determined by grower knowledge; the dry treatments were watered less than the standard.

Plants were monitored for the development of symptoms attributed to nutritional disorders and a full assessment was carried out in week 19 (**Table 7**). Samples of growing media and foliage were taken at the beginning and the end of the trial, and analysed by Natural Resource

Management (NRM). A sample of the irrigation water was also taken at the start of the trial **(Appendix 2**).

Table 7. Summary of trial inspections and assessments, spring trial, 2016

Date	Week No.	Trial stage (WAT*) / action	Assessment
10 Mar	10	Pre-transplant	Plant quality, root quality, plant height (20 plants). Plant and growing medium samples taken.
27 Apr	17	10 WAT	pH assessment.
11 May	19	9 WAT	Plant quality, root quality (3 plants/plot), plant height (5 plants/plot) and no. of plants in flower. Plant and growing medium samples taken.

*WAT = weeks after treatment.

Summer trial

Plug plants of *Verbena* 'Quartz Blue' (PanAmerican, seed raised), *V.* 'Obsession Scarlet' (Syngenta Flowers, seed raised) and *V.* 'Temari Blue' (Suntory Flowers Ltd, cutting raised) were delivered to Baginton Nurseries in week 20 and transplanted into 6-packs (black plastic). Treatments were the same as in the spring trial (**Table 65**), except this time plots consisted of one 6-pack and each treatment was replicated three times. Plants were grown on in a polytunnel, and environmental conditions were monitored using Watchdog 1000 series microstation data loggers, a LightScout Quantum Light 3 Sensor PAR probe and a WaterScout SM100 soil moisture sensor (one for each of the three irrigation treatments). Plants were monitored for the development of symptoms and a full assessment was carried out in week 27 (

Table 86). An additional assessment was completed on the *V.* 'Quartz Blue' dry treatment plants only in week 28 due to the development of chlorosis on the foliage. Samples of growing medium and plant foliage were taken at the beginning and the end of the trial, and analysed by Natural Resource Management (NRM) (**Appendix 2**).

Table 86. Summary of trial inspections and assessments, summer trial, 2016

Date	Week No.	Trial stage (WAT) / action	Assessment
20 May	20	Pre-transplant	Plant quality, root quality, plant height (10 plants). Plant and growing medium samples taken.
24 June	25	5 WAT	pH assessment.
07 July	27	7 WAT	Plant quality, root quality (3 plants/plot), plant height (3 plants/plot) and no. of plants in flower. Plant and growing medium samples taken.
12 July	28	8 WAT	Extra assessment on *V.* 'Quartz Blue' dry treatment only for chlorosis on foliage.

Soil moisture sensor calibration

The SM100 Soil Moisture Sensor needed to be calibrated to the growing medium used in the trial. Soilless media tend to be hydrophobic, and shrink when dry, therefore the moisture content of the growing medium was established by adding water to a known quantity of growing medium. This was done on a mass wetness (MW) basis where mass wetness is defined as:

$$MW = 100 \times \frac{M_{water}}{2 \times M_{material}}$$

MW = target mass wetness (%)
M_{water} = mass of water needed
$M_{material}$ = total air-dry mass of sample

For the calibration, 18 containers (1 L) were used, providing three replicates at six different water contents. Each empty pot weighed 21 g.

Approximately 3.5 L of growing medium was placed into a polythene bag and weighed, there were six bags in total, one for each mass wetness. Target mass wetnesses of 0, 40, 80, 120, 160 and 200% were used. Water was added to each bag to bring the material to the desired mass wetness using the following equation:

$$M_{water} = 2 * \frac{MW}{100} * M_{material}$$

Once the water had been incorporated, the sealed bags were left for 24 hours to allow the water and material to come to equilibrium. The material was then added to the 1 L containers and weighed. For each container, three readings were taken using the SM100. Readings were taken perpendicular to the sides of the container. The growing medium was then removed from the containers, completely air-dried and re-weighed. The volumetric water content (VMC) for each container was calculated using the following equation:

$$VWC = \frac{M_{wet} - (M_{dry-only} + M_{cont})}{P_w \times V_{cont}}$$

$$VWC = \frac{M_{wet\text{-}total} - (M_{dry\text{-}only} + M_{cont})}{P_w * V_{cont}}$$

VWC = Volumetric water content (%)

$M_{wet-total}$ = Total mass of container and wet material

$M_{dry-only}$ = Mass of air-dry material

M_{cont} = Mass of container

P_w = Density of water (1 g/ml)

V_{cont} = Volume of container

Objective 3: Spectral filters (glass coatings)

Work on glass coatings was carried out between April and November 2016. New panes of horticultural glass (single batch) measuring 610 mm x 610 mm, 3 mm thick, were mounted onto an array of wooden A-frames which had been constructed at ADAS Boxworth and transported to Baginton Nurseries prior to the trial commencing. The frames were situated on a standing out area at the nursery, away from any glasshouses or polytunnels. The glass panes were arranged on the sloping side of the frame (21˚ angle at the base), all facing the same direction and at the same height above the ground (similar to an array of ground level solar panels) (**Figure 5**). A variety of glass coating products (**Table 9**) were sourced from three manufacturers, and compared against untreated glass and untreated diffuse glass. There were three replicate panes of glass for each treatment. Each A-frame structure represented one replicate. The products were pre-mixed with water in a ratio determined in consultation with the manufacturers and agitated using a mixing tool to ensure the coating was fully mixed. The products were applied to the glass by hand using a hand pressure sprayer (Verve Hand Sprayers, 1.5 L), one for each product, on 6 April (week 14). The Verve hand sprayer had been selected from a range that were tested for ease of use and even application of products. Glass either side of each pane to be treated was covered with a spray-shield to prevent overspray onto the adjoining panes.

Figure 5. Arrangement of glass panes on A-frame structures at Baginton Nurseries, 2016

An extra pane of glass was treated with each product, and stored at ADAS Boxworth, so that comparisons could be made between weathered and un-weathered glass. Factory coated glass was also supplied by each of the manufacturers, and these were also stored at ADAS Boxworth.

When the products were applied on 6 April, it was noted that the glass appeared to repel some of the products, and it was not possible to achieve an even coating across the pane and the coatings soon began to erode. It was discovered that new horticultural glass is supplied with a very thin layer of silicon to prevent the panes from sticking together when they are stacked and transported. Commercially, this silicon is removed by general weathering, or when glass is cleaned, and so would not create a problem when trying to apply glass coatings. The decision was taken to remove the original coatings, as this would also remove the silicon, and then re-apply. All glass panes were washed with Removit (Hermadix) on 14 July (week 28), double-rinsed and dried, before the treatments were re-applied using the same method as previously. Improved adherence and more even coverage were achieved (Appendix **3**).

Table 97. Glass coating products trialled at Baginton Nurseries, 2016

Treatment	Product	Manufacturer	Light diffusion	Shading agent	Effect on light quality	Lower glasshouse (G) / plant (P) temperature	Ratio	Product (ml)	Water (ml)
1	Untreated diffused glass	N/A	✓				N/A	N/A	N/A
2	Untreated glass	N/A					N/A	N/A	N/A
3	D-Fuse Floriculture	Hermadix	✓			P	1:5	150	750
4	D-Fuse Vegetable	Hermadix	✓			P	1:5	150	750
5	DeGree	Hermadix	✓		NIR*** reflected	PG	1:4	175	700
6	Q Heat	Hermadix		✓	NIR*** reflected	G	1:3	200	600
7	Q3	Hermadix		✓		G	1:5	150	750
8	Q4	Hermadix		✓		G	1:5	150	750
9	ReduFuse	Mardenkro	✓			PG	1:5	150	750
10	ReduFuse IR	Mardenkro	✓		IR** reflected	PG	1:4	175	700
11	ReduHeat	Mardenkro			NIR*** reflected	G	1:3	200	600
12	ReduSol	Mardenkro		✓		G	1:5	150	750
13	Optifuse	Sudlac	✓			P	1:5	150	750
14	Optifuse IR	Sudlac	✓		NIR ***reflected	PG	1:4	175	700
15	Optimix RB	Sudlac	✓		Green* partially reflected	P	1:4	175	700
16	TransPAR	Sudlac			NIR***partially reflected	PG	1:3	200	600
17	Eclipse LD	Sudlac		✓		G	1:5	150	750

*Green = 500-600 nm **IR = infrared (800 – 4000 nm). ***NIR = near infrared (700-2500 nm)

Light transmission measurements (ADAS)

Fortnightly light transmission measurements were taken under the glass, using a Watchdog 1000 Series data logger and two external Light Scout Quantum Light 3 Sensor PAR probes. This allowed for simultaneous measurement of ambient light and light transmission beneath the treated glass. Six measurements were taken at different points underneath each glass pane. Measurements were taken under varying weather conditions (i.e. full sun, full cloud etc.) and were taken between 11:00 and 14:00. Additional measurements (light transmission and spectra) were also taken on 26 August (week 34) by Philip Davis (Stockbridge Technology Centre) during full sun. The glass panes were removed on 13 December 2016 (week 50) and returned to ADAS Boxworth where they were stored before being sent to Reading University for measurements to be carried out under laboratory conditions.

Light measurements (STC)

Light measurements were made on the 26th August between 11am and 2pm using a hand held portable Jaz spectroradiometer (Ocean optics). To ensure the light measurements only recorded light that passed through the glass the sensor was placed inside a black plant pot that was placed against the under surface of the glass. For measurements of unfiltered sunlight the sensor and plant pot were mounted at the same angle and direction as for the glass transmittance measurements. During the measurement period few clouds obscured the sun allowing rapid measurement progress. To avoid noise in the data, measurements were only made under full sun conditions (measurements were suspended even if cloud partially obscured the sun). For each pane of glass five measurements were made, one at the centre and one near each corner of the pane. Two light transmittance spectra were calculated for each treatment: 1) The mean light transmittance relative to unfiltered sunlight (calculated as the measured light transmittance of the three replicated samples divided by the mean solar radiation) and 2) the light transmittance relative to the light transmission of untreated glass (calculated as the measured light transmittance of the three replicated samples divided by the three replicated plain glass samples).

Objective 4: Spectral filters (films)

The spectral filters trial was carried out between June and November 2016, under four separate polytunnels covered with SunSmart Blue (new and old), Lumisol and Luminance coverings, and a glasshouse (**Table 10**). The potential degradation of film over time was investigated through use of a tunnel that had been covered with SunSmart Blue film in 2009, and a further tunnel that was re-covered with new SunSmart Blue polythene in February 2015.

Table 108. Details of spectral filter treatments examined in 2016

	Treatment	Effect on light	Expected effect on plants	Manufacturer's product description
1	Untreated glass	UVA / B (<400 nm) absorbed by glass	Expect taller plants	
2	Luminance (tunnel)	Light diffusion, reduced infrared transmission	Scatters light, enabling greater light penetration into the crop. Fewer 'hot spots' at plant level. Improved plant quality	Total solar heat load can be reduced by over 20% under Luminance without any significant decrease in PAR light (although greenhouse temperatures depend on a number of factors, including ventilation levels). PAR light transmission 87%, light diffusion >90%. Reduced infrared radiation. Cooler tunnel
3	Lumisol (tunnel)	Diffusion, UV open	Scatters light, enabling greater light penetration into the crop. Fewer 'hot spots' at plant level. Improved plant quality	Helps growers to create an optimum growing environment by actively managing light transmission, diffusion and temperature. Light diffusion >90%. PAR light transmission ≥88%. UV transmission >70% (290-400 nm). Reduced temperature within the tunnel
4 & 5	SunSmart Blue* (tunnels)	Diffusion, UV open	Greater light penetration into crop, reduced shading of lower leaves. Improved crop quality. Delayed flowering.	Delay flowering by around two weeks. Produce plants with shorter internode length (in spring), increased basal branching and enhanced leaf colour. The environment within the tunnel is cooler. There is also an anti-drip additive. PAR light transmission >65%, PAR light diffusion 30%. UV open (300-399 m,)
		Blue (400- -500 nm) and green (500-600 nm) partially blocked	100% blue light causes plants to stretch, but a mixture of blue and red will result in more compact plants.	
		Far red partially blocked.	More compact plants	
		Red/far red partially blocked	Cooler environment.	

*Two SunSmart Blue tunnels, covered in 2009 and 2015.

Table 11. Plant species used in the spectral filters trial (films), 2016

Plant Species	
Bellis 'Medici' Mixed	Pansy 'Matrix' Autumn Select Mixed
Cheiranthus 'Sugar Rush' Mixed	Polyanthus 'Piano' Mixed
Cineraria 'Silver Dust'	Primrose 'Bonneli' Mixed
Cyclamen 'Metis Decora' Mixed	*Viola* 'Sorbet XP' Autumn Select Mixed

Plug plants of eight species (**Table 11**) were transplanted into 6-packs (2 packs/plot, with four replications) using a peat (60%) / woodfibre (40%) growing medium. The *Cyclamen* were transplanted in week 22, and the remaining species in week 34. Plants were set down in the five treatment areas and grown as a commercial crop, with overhead irrigation. Plants were monitored for pests and diseases, with pesticide treatments applied as necessary. However, no PGRs were applied to avoid confounding the effects of the treatments.

Table 20. Summary of spectral filters (films) trial inspections and assessments, 2016

Date	Week No.	Trial stage (WAT) / action	Assessment
03 June	22	Pre-transplant (*Cyclamen* only)	Plant quality, root development (5 plants/tray) and plant height (5 plants/tray)
26 Aug	34	Pre-transplant (Remaining varieties)	Plant quality, root development (5 plants/tray) and plant height (5 plants/tray)
26 Aug	34	12 WAT (*Cyclamen*)	Number of plants in flower
26 Aug	34	12 WAT (*Cyclamen*)	Light transmission and spectra
23 Sept	38	16 WAT (*Cyclamen*), 4 WAT (all other spp.)	Number of plants in flower
11 Oct	41	19 WAT (*Cyclamen*), 7 WAT (all other spp.)	Number of plants in flower
19 Oct	42	20 WAT (*Cyclamen*), 8 WAT (all other spp.)	Number of plants in flower, plant height
17 Nov	46	24 WAT (*Cyclamen*), 12 WAT (all other spp.)	Plant quality, plant height and number of plants in flower
13 Dec		N/A	Light transmission and spectra

The plants were evaluated in a randomised block design within each treatment. It was not possible to replicate treatment areas, as the treatment structures used were diverse in terms of size, air volume etc., therefore statistical analysis of the results between treatments was not appropriate.

The plants were monitored for date of first flowering, and the number of plants per plot in flower were recorded on three occasions during the trial. At the final assessment (week 46), plants were assessed for height and the number of plants in flower (**Table 20**). Temperature and humidity were recorded in each of the five treatment areas (30 minute intervals), using TinyTag data loggers.

Light spectra and transmission measurements

Light measurements were taken by Dr Phillip Davis (STC), between 11am and 3pm on 26 August and 13 December using a hand held portable Jaz spectroradiometer. During the measurement period patchy cloud cover caused large variations in light intensity. To avoid noise in the data, measurements were only made when the sun was not obscured by clouds. Several measurements of direct sunlight outside were made before and after measurements were made within each of the trial areas to ensure changes in light intensity were accounted for in the measurements. Within each of the trial areas several measurements were made along the length of the polytunnels or bays of the glasshouse.

Measurements were performed in the five trial areas including four polytunnels and one glasshouse. Within the glasshouse, measurements were made when the screens were open and when the screens were closed.

The spectra presented are the mean of at least five measurements. Data were discarded if there was evidence of reduced light levels caused by cloud cover. Transmittance was determined as the mean spectrum within the trial area divided by the mean spectrum measured outside.

Objective 5: Pre-Christmas production of hellebore

The hellebore trial was carried out between March and December 2016. 40 plug plants of six micro-propagated hellebore varieties (**Table 21**) were delivered to Baginton Nurseries in week 10, transplanted into 1.5 L terracotta coloured pots (week 11), and placed outdoors in a randomised block design (10 plants / plot, four replications). The plants were provided with overhead irrigation, and shaded (green shade netting) from week 19. Temperature and humidity was recorded every 30 minutes using an Easylog USB data logger.

Table 21. Hellebore varieties used in the pre-Christmas production trial, 2016

Variety No.	Variety	Supplier	Breeder
1	'Anna's Red'	Exceptio bv	Rodney Davey
2	'HGC Madame Lemonnier'	Heuger	Heuger
3	'Molly's White'	Exceptio bv	Rodney Davey
4	'Paradenia'	Heuger	Heuger
5	'Penny's Pink'	Exceptio bv	Rodney Davey
6	'Royal Emma'	Beekenkamp Plants bv	Thierry van Paemel

All plants were transported to ADAS Boxworth in week 33, where they were set down on a shaded (green shade netting) standing out area. Fifteen plants of each variety were subjected to six-week cold store treatment (2°C, 12 hour day / night, 100 watt incandescent light) from 24 August (week 24, CS1). Plants were set down on the floor in a randomised block design with five plants per plot (**Figure 6**). They were watered overhead the day prior to entering the cold treatment to allow the foliage to dry, and transferred at 7 am whilst still cool. Temperature and humidity within the cold store was recorded every 30 minutes using a Tinytag data logger.

Figure 6. Hellebore plants placed into the cold store at ADAS Boxworth in week 34, 2016

On 21 September (week 38) a further 15 plants of each variety were subjected to cold treatment for six-weeks (CS2). For the second batch, 'Madame Lemonnier' was not put into cold store, as the outdoor plants had already started producing buds. The remaining 10 plants of each variety remained outdoors on the standing out area as a control.

Overnight on 4-5 October (week 40) the cold store temperature fell steadily and below 0°C for 16.5 hours. The plants from treatment CS1 were returned to the outdoor standing down area (as planned). The cold store temperature returned to normal following repair and treatment CS2 was allowed to continue until a similar episode on 10 October week 41, when the cold store temperature fell below 0°C for 8 hours (**Appendix 6**). Although temperatures then returned to normal, half of the plants were removed from the cold store and placed on the outside standing down area (CS2a), leaving the remaining plants in the store to complete the treatment (CS2b).

In week 42, the plants from CS1 and CS2a were moved into a heated glasshouse (18°C), along with six plants of each variety from the outdoor control, to provide an indoor control. Four plants of each variety remained outdoors for the duration of the trial (outdoor control). The plants in the glasshouse were allowed to settle for six days before any brown / dying leaves were removed and the plants treated with Signum (1.35 kg/ha, 600 L/ha) using a knapsack sprayer and single nozzle lance with an 02f110 nozzle, to protect against *Botrytis*. Temperature and humidity within the glasshouse were recorded every 30 minutes using a Tinytag data logger.

The plants from treatment CS2b were removed from the cold store on 2 November (week 44) and placed on the standing out area, where they remained for five days before being transferred to the glasshouse with the rest of the trial. Leaves were removed and the plants were treated with Signum on 10 November. Plant movements were as summarised in **Table 12**.

Table 122. Hellebore early flowering trial – plant movements during 2016

Date	Action
Week 10	Delivery to Baginton Nurseries. Plants placed in prop house
Week 11 (18/03/16)	Plants potted and placed outside
Week 19 (11/05/16)	Shade netting placed over trial
Week 33 (16/08/16)	Plants moved to Boxworth. Shade netting placed over trial
Week 34 (24/08/16)	CS1 treatment plants placed in cold store (CS)
Week 38 (21/09/16)	CS2 treatment plants placed in CS
Week 40 (4-5/10/16)	Cold store issue (temps below 0° for 16.5hrs)
Week 40 (05/10/16)	CS1 plants moved to standing out area
Week 41 (10/10/16)	Cold store issue (temps below 0° for 8hrs)
Week 41 (13/10/16)	CS2a plants moved to standing out area
Week 42 (20/10/16)	CS1, CS2a and indoor control plants moved to glasshouse
Week 44 (02/11/16)	CS2b plants moved to standing out area
Week 45 (07/11/16)	CS2b plants moved to glasshouse

During and after the cold store treatments, the plants were monitored for date of bud production and flowering for each variety. Plants were assessed for quality prior to cold store treatment, and detailed assessments were carried out in week 44, 46 and week 1, 2017 (**Table 13**).

Table 13. Summary of Hellebore trial inspections and assessments March 2016 – Jan 2017

Date	**Week No.**	**Trial stage**	**Assessment**
18 March	11	Pre-potting	Plant quality, root quality, plant height (5 plants/tray), no. of true leaves
23 Aug	34	Pre-cool treatment 1	Plant quality
21 Sept	38	Pre-cool treatment 2	Plant quality
02 Nov	44	Post-cool treatments	No. of closed buds, no. of open flower buds and no. of new open leaf buds
18 Nov	46	Post-cool treatments	No. of alive and dead plants
04 Jan (2017)	1	Post-cool treatments	No. of alive and dead plants, no. with buds or flowers

Due to the unforeseen circumstances with the cold store, this trial will be repeated in 2017.

Objective 6: Overwintered perennials

This trial began in July 2016 and was completed in April 2017. A crop diary of key events is summarised in Table 27. Seeds of nine perennial species obtained from Moles Seeds UK Ltd and Jelitto Staudensamen GmbH (Error! Reference source not found.) were sown into 04-cell trays (two trays per species) in week 27, and allowed to germinate in the propagation house at Baginton Nurseries (minimum temperature 15˚C). In week 29, a second batch of seeds was sown, to ensure sufficient germination for each species. Plants were then transplanted into black jumbo 6-packs and 1 L pots, and set down under glass within the unheated propagation area, and within a polythene tunnel covered with Luminance film. On 10 February 2017 (week 6) plants from the unheated propagation glasshouse were moved to the modern Venlo glasshouse.

Table 24. Plant species used in the overwintered perennials trial, 2016/17

Treatment	Plant species	Photoperiod response*
1	*Campanula persicifolia* 'Takion Blue'	Day neutral
2	*Campanula glomerata* 'Acaulis'	Facultative long day
3	*Coreopsis grandiflora* 'Presto'	Long day
4	*Echinacea* 'Cheyenne Spirit'	Short day/long day
5	*Gaura lindheimeri* 'Sparkle White'	Long day
6	*Prunella grandiflora* 'Freelander Blue'	Long day
7	*Scabiosa japonica* var. *alpina* 'Ritz Blue'	Long day
8	*Silene alpestris* 'Starry Dreams'	Long day
9	*Verbena rigida* (syn. *V. venosa*)	Information not available, flowers naturally from late spring

*Day neutral plants flower under any day length. Long day plants flower in days >12 hours, with a critical day length for the species. Facultative long day plants flower under any day length, but faster under long days. Short day/long day plants flowering occurs earliest if plants have been exposed to a period of short days followed by a period of long days.

Young plants from the second sowing (week 29) were transplanted for all species except *Campanula persicifolia* 'Takion Blue', for which plants from the first sowing (week 27) were used. *Gaura lindheimeri 'Sparkle* White' was trimmed prior to transplant, all other plugs were of a suitable size for transplanting.

Temperature and humidity were recorded every 30 minutes throughout the trial using TinyTag data loggers, which were placed at plant height within the trial area (

Appendix 7). The trial under glass was heated to 15˚C from 24 March 2017 (week 12).

Plants were monitored for pests and disease throughout. The following fungicide and plant growth regulator (PGR) treatments were applied:

- Amistar (as azozystrobin) at 1.0 ml/L water, one application, was applied to all varieties.
- Bonzi (as paclobutrazol) at 5.0 ml/L water, one application, was applied to the *Campanula persicifolia* 'Takion Blue', *Campanula glomerata* 'Acaulis', *Gaura lindheimeri* 'Sparkle White', *Prunella grandiflora* 'Freelander Blue', *Silene alpestris* 'Starry Dreams', *Verbena rigida* to prevent them becoming too soft.

The trial used a randomised block design with nine treatments (species), with four replicate blocks. For both trials, plots consisted of two 6-packs and 12 1 L pots, except where germination was poor and plot size was reduced to one 6-pack and six pots. This resulted in 96 plants per species within each growing area, or 48 where germination was poor.

Results were examined by ANOVA with use of Duncan's multiple range test to separate treatments.

Inspections and assessments are summarised in (**Table 275**) and following:

In week 40, seedlings that were to be used for transplanting were assessed for percentage germination, quality, and height of three plants per tray. Quality was assessed on a scale of 0-9, whereby 0 = plant death 7 = commercially acceptable and 9 = perfectly healthy vigour.

The trial was monitored throughout the winter and observations were made on the quality of the plants. The target marketing date for this trial was week 13/14 2017; final marketing assessments carried out on 28 March 2017 (polythene tunnel treatments) and 4 April 2017 (glass treatments) included the number of plants in flower, plant quality and plant height (Error! Reference source not found.**6** and

Table 26). A more detailed scoring assessment was used for the final assessments for the plants under glass as they were more advanced than those under polythene.

Table 145. Plant quality scores for the overwintered perennials marketing assessment 28 March 2017 (polythene tunnels)

Score	Definition
0	Dead
1	Very poor quality
2	Poor quality
3	Good quality, no flower
4	Good quality saleable some flower / close to flower / buds
5	Excellent quality, 90% in flower

Table 26. Plant quality scores for the overwintered perennials marketing assessment 4 April 2017 (glasshouse)

Score	Definition
0	Dead
1	Poor, dying, cold damage
2	Plants very small
3	75% pot/pack cover
4	100% pot/pack cover
5	Flower spikes developing
6	Flower spikes beginning to extend
7	Flower spikes, no bud break
8	Flower spike extended, bud break
9	Fully open flowers on some plants in plot
10	Excellent quality, 90% in flower

Table 27. Summary of overwintered perennials trial inspections and assessments, 2016/17

Date	Week no.	Action	Assessment
06/07/2016	27	First sowing	-
20/07/2016	29	Second sowing	-
26/08/2016	34	Inspection	Plants inspected for germination, pest and disease
03/10/2016	40	Pre-transplant	Plant quality (three plants / tray), plant height (three plants / tray), % germination (of 208 cells) and root development
10/10/2016	41	Inspection	General inspection including for pests and diseases
26/10/2016	43	Inspection	General inspection including for pests and diseases
07/11/2016	45	Inspection	General inspection including for pests and diseases
13/12/2016	50	Inspection	General inspection including for pests and diseases
24/01/2017	4	Inspection	General inspection including for pests and diseases
16/02/2017	7	Inspection	General inspection including for pests and diseases
28/03/2017	13	Interim assessment (glasshouse), final assessment (polythene tunnels)	Plant quality and plant height (8 plants / plot - 4 pots and 4 packs). Number of dead plants
04/04/2017	14	Final assessment (glasshouse)	Plant quality and plant height (8 plants / plot - 4 pots and 4 packs). Number of dead plants

Results

Objective 1: Improving cutting success

Pre-sticking

On arrival at Baginton Nurseries, the cuttings had been in transit for five days and were showing signs of wilting. Cutting size was variable, therefore a sub-sample of 20 cuttings were assessed for quality and stem thickness prior to sticking on 25 March. The average quality score for the first batch of cuttings (Sticking 1) was 3.1 – good quality with some damage visible. Damage was generally related to dehydration causing slight browning on the edges of some cuttings. The average stem thickness was 2.7 mm.

The second batch of cuttings (Sticking 2) was assessed just prior to sticking on 29 March, after a further five days cool storage. These cuttings were very wilted (**Figure 7**), and some of the leaves were showing signs of ethylene damage, with yellowing to the edges of the leaves. The average quality score for the second batch of cuttings was 2.8, with some visible signs of damage. The average stem thickness was 5.5 mm.

Figure 7. Geranium cuttings showing signs of wilting on 29 March, 2016

Post-sticking - sticking 1

It was observed that the cuttings treated with Omex SW7 (LD, long dip) had greener, brighter foliage immediately after treatment compared with the other treatments and the untreated control. Serenade ASO left a white residue on the foliage when the cuttings were removed from the LD (**Figure 8**). Although the cuttings were assessed weekly from week 14 until week 18, the first assessment proved to be the most informative. Any differences seen between treatments at the first assessment generally remained throughout the trial.

The cuttings were assessed for quality and the number of cuttings per plot with visible roots on the cutting 11 days after treatment (DAT). Considering cutting quality scores, there was little difference between the treatments with the majority of scores similar to the untreated control (**Figure 9**); the exception was the quality score for the Rhizopon AA (LD) treatment, which scored significantly lower than the untreated control and the water only LD treatment ($p<0.001$). Many of these cuttings were failing, with a number developing basal stem rot due to bacterial soft rot. It should be noted that the manufacturer of Rhizopon does not recommend a full submersion for Geranium, but was included as a treatment for completeness (i.e. all products were subjected to the same treatments). In terms of application method, overall cutting quality was significantly better in the quick dips and spray application than the long dip (P<0.001).

Figure 8. Sticking 1: untreated (left), Omex SW7, LD (centre) and Serenade ASO, LD (right) treatments directly after application. LD = long dip

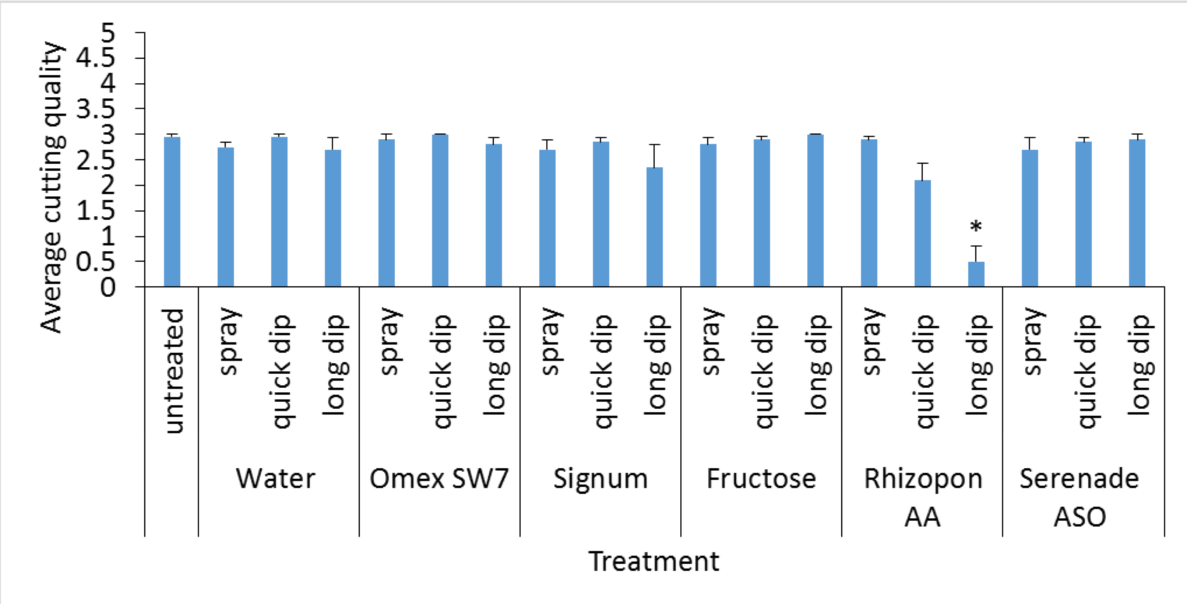


Figure 9. Sticking 1: average Geranium cutting quality, 11 DAT. Scale of 0-5 (0 = dead, 1 = very poor, yellow, 2 = green but no new growth, small, 3 = green with new leaves developing, 4 = green with new growth and 5 = good quality, marketable. * = significantly different to the untreated control

The number of cuttings with visible roots on the outside of the plug tray varied between treatments at 11 DAT, with significantly more visible roots present in the Omex SW7 (LD) and Rhizopon AA (QD) than all other treatments (p<0.001). Cuttings treated with Omex SW7 (LD) and Rhizopon AA (QD) and Serenade ASO (LD) all produced significantly more visible roots than the untreated control and water only treatments (p<0.001) (**Figure 10**). In terms of application method, the overall visible root score was significantly better in the quick and long dips than spray application (P<0.001).

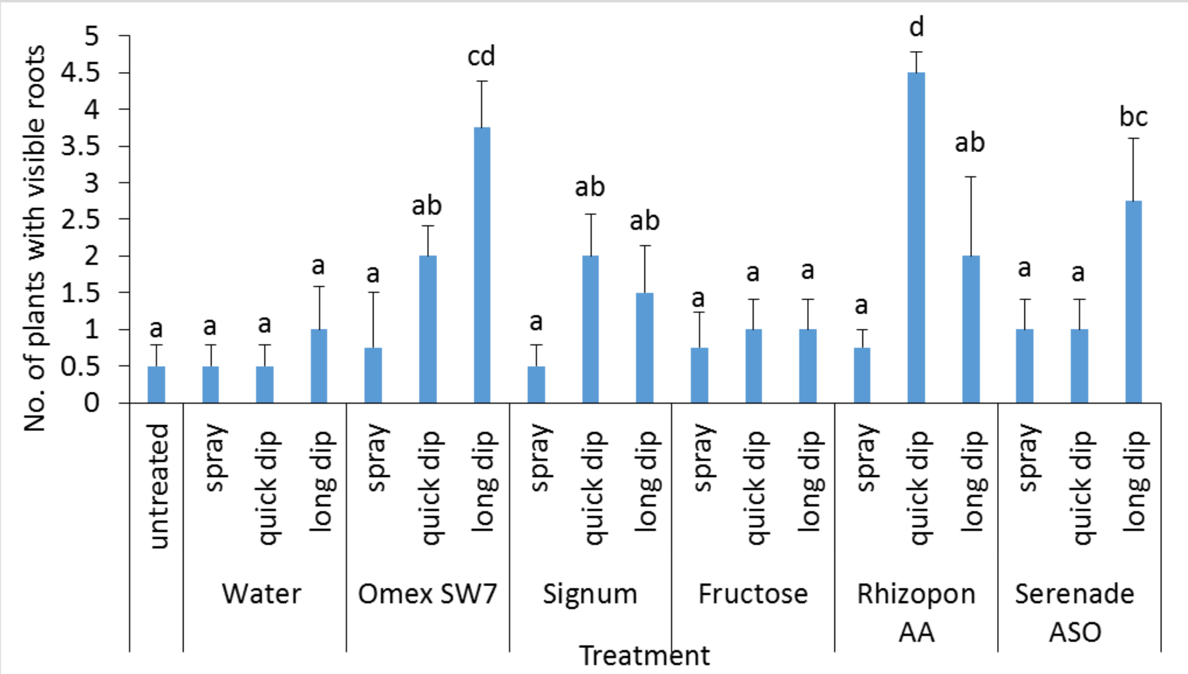


Figure 10. Sticking 1: number of Geranium cuttings with visible roots, 11 DAT. Treatments that do not share a common letter are significantly different (p=5%)

The quality of the cuttings treated with Rhizopon AA (QD and LD) deteriorated throughout the trial and by 20 April (26 DAT) the majority of those from the LD had died and been removed from the trial. The cuttings subjected to the other treatments remained unchanged. A root quality assessment completed at the end of the trial (4 May, 40 DAT) revealed that significantly less root development was recorded in the Rhizopon AA (LD) treatment (p<0.001, **Figure 11**). Rooting quality in the untreated control and water only treatments was not significantly worse relative to the other treatments except for the Rhizopon AA (LD).

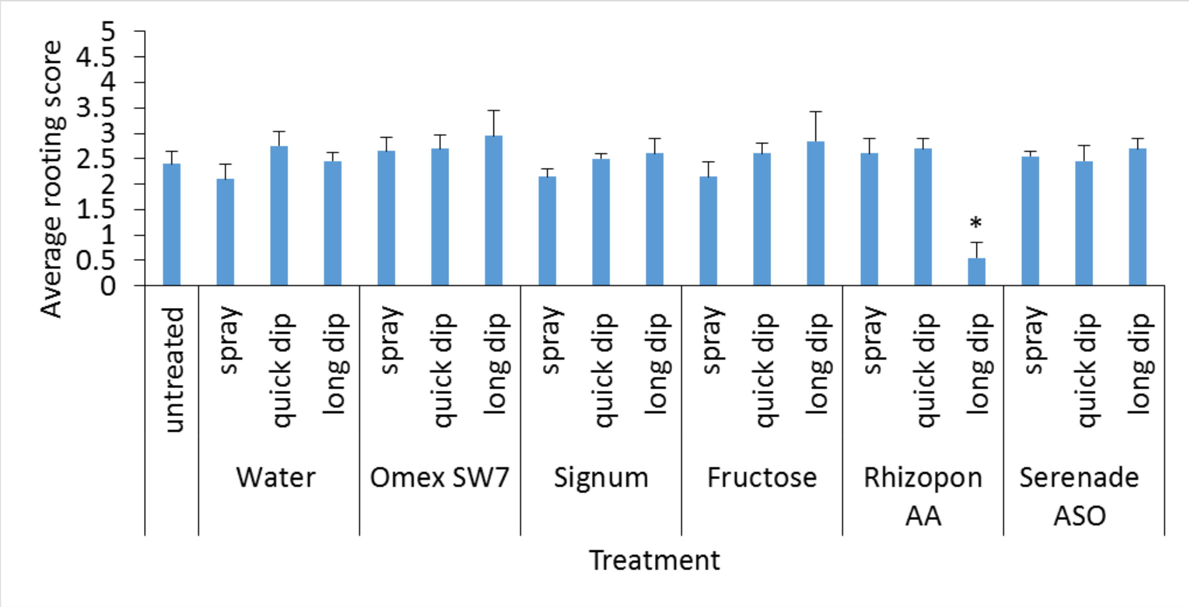


Figure 11. Sticking 1: average root quality, 40 DAT. Scale of 0-5 (0 = no change / dead, 1 = callous formed, 2 = finely rooted in up to 25% of cell, 3 = rooting in 25 - 50% of cell, 4 = Rooting in 51 - 85% of cell and 5 = fully rooted and ready for transplanting). * = significantly different to the untreated control

Post-sticking - sticking 2

As for Sticking 1, the cuttings treated with Omex SW7 (LD, long dip) had greener, brighter foliage immediately after treatment compared with the other treatments and the untreated control, and the Serenade ASO left a white residue on the foliage when the cuttings were removed from the LD (**Figure 8**). The cuttings were assessed for quality the number per plot with visible roots at 13 DAT. As with the Sticking 1 cuttings, there was little difference between the treatments for cutting quality, with the majority of the treatments similar to the untreated control. However, the quality of the cuttings treated with Rhizopon AA as both a 5-second QD and a 30 min LD was significantly worse than the untreated control ($p<.001$) (**Figure 12**). The majority of the cuttings from the Rhizopon LD treatment had died, and over half of the QD treatment had died. These cuttings were removed from the trial.

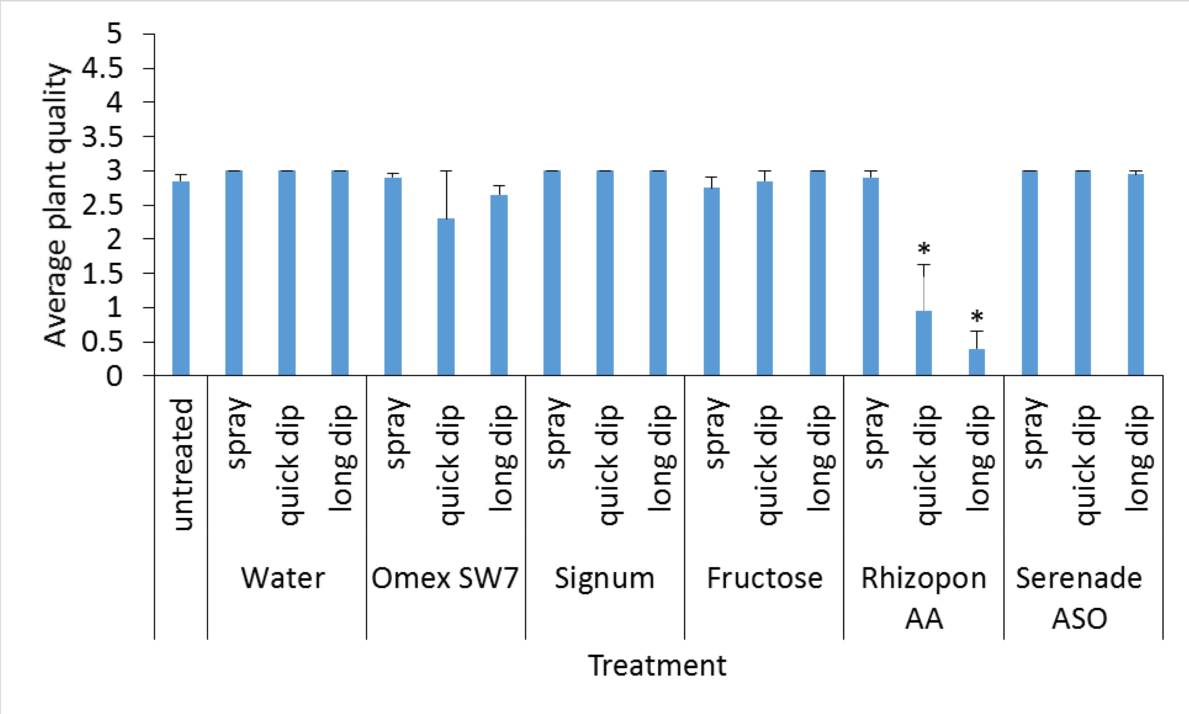


Figure 12. Sticking 2: Geranium cutting quality, 13 DAT. Scale of 0-5 (0 = dead, 1 = very poor, yellow, 2 = green but no new growth, small, 3 = green with new leaves developing, 4 = green with new growth and 5 = good quality, marketable. * = statistically significant compared to the untreated control

The number of cuttings with visible roots varied between treatments at 13 DAT. Although the cuttings treated with Omex SW7 (QD), Signum (QD) and Serenade ASO spray (LD) resulted in significantly more plants with visible roots than the untreated control, the number of visible roots was not significantly different to the water only treatments (**Figure 13**), indicating that for these cuttings, treatment with water only was effective as the other treatments under the conditions of this trial.

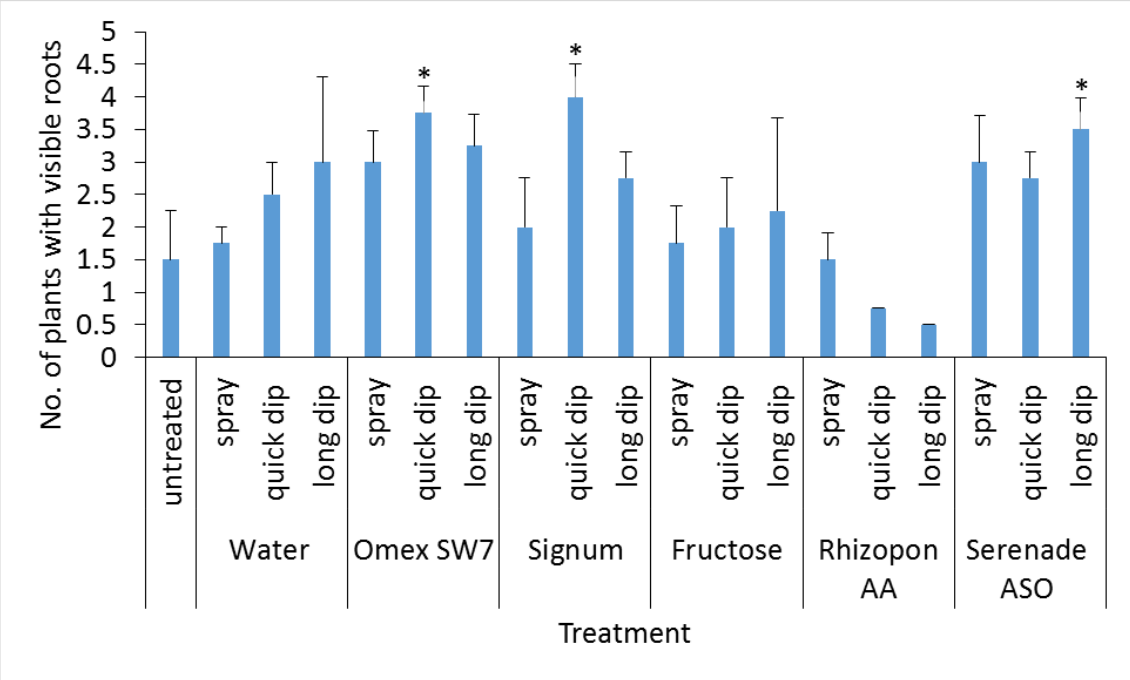


Figure 13. Sticking 2: average number of Geranium cuttings with visible roots, 13 DAT. * = significantly better than the untreated control, but not the water only treatments

Throughout the trial, the quality of the cuttings treated with Rhizopon AA as both a QD and a LD deteriorated, and by 20 April (22 DAT) all of the cuttings from these two treatments, apart from one in the QD, had died and been removed from the trial. An assessment was completed on the root quality at the end of the trial on 4 May (36 DAT), using a sub-sample of five cuttings per plot (**Figure 14**). Cuttings treated with Signum (spray) achieved significantly greater root scores than the untreated control, and all water only treatments. Due to the high level of plant death in the Rhizopon AA dip treatments, with one plant remaining in each of the quick and long dips, the rooting scores were significantly different to all other treatments ($p<.001$).

Full results of assessments are tabulated in **Appendix 1**.

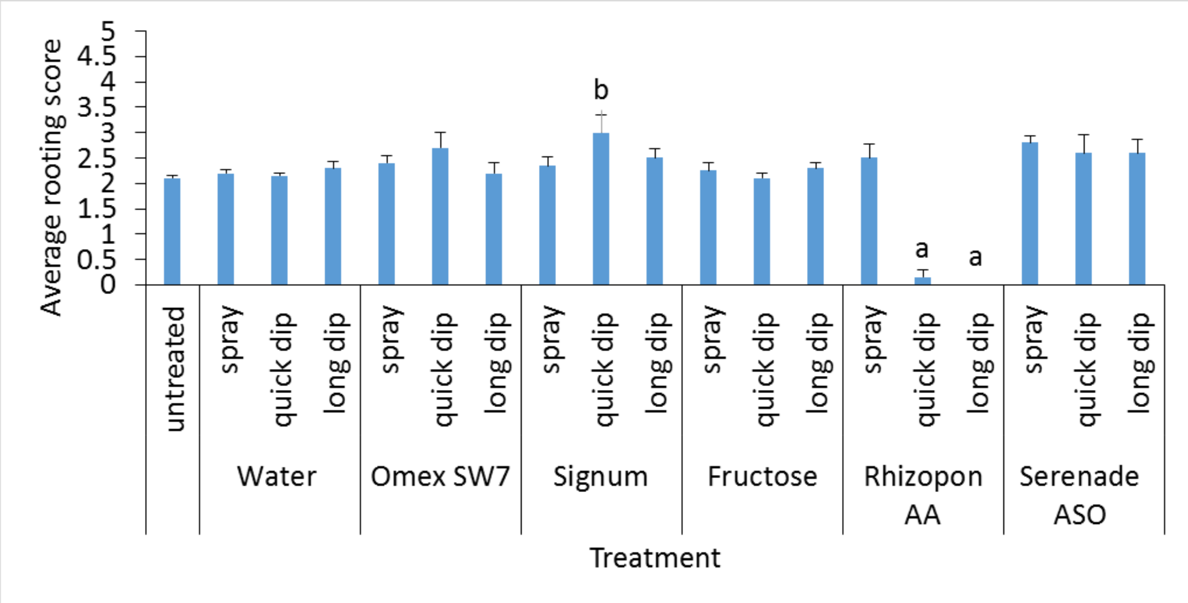


Figure 14. Sticking 2: average root quality, 36 DAT. Scale of 0-5 (0 = no change / dead, 1 = callous formed, 2 = finely rooted in up to 25% of cell, 3 = rooting in 25 - 50% of cell, 4 = Rooting in 51 - 85% of cell and 5 = fully rooted and ready for transplanting). a = significantly different to all other treatments. b = significantly different to untreated control and water only treatments

Objective 2: Verbena leaf spot and chlorosis

Spring trial

Pre-transplanting

Prior to transplant, a sub-sample of *Verbena* 'Quartz Blue' plugs were assessed for plant quality (score 8.0), root quality (score 4.0, with healthy white roots) and height (average 33 mm), and were determined to be healthy and suitable for transplant.

Post-transplanting

No symptoms were expressed in the spring trial, therefore no formal analysis is reported.

All treatments did have an influence on plant height, however, with clear height difference between the dry, standard and wet irrigation treatments (short, medium and taller plants respectively) at the final assessment (7 July, 7 WAT).

Growing medium analysis (7 July, 7 WAT) indicated that nutrients (nitrate-N and ammonium-N, phosphorus and potassium) were depleted in all treatments; nitrogen levels in the tissue was similarly depleted in all treatments (**Appendix 2**).

Summer trial

Pre-transplanting

At the pre-transplant assessment, the *V*. 'Quartz Blue' and *V*. 'Obsession Scarlet' both achieved a plant quality score of 8.0, whereas the 'Temari Blue' scored 6.0. The *V*. 'Temari Blue' were larger than the other varieties with some flowers present, and the foliage showed signs of chlorosis (**Figure 15**, **Table 158**).

Figure 15. *Verbena* summer trial pre-transplant assessment - *Verbena* 'Quartz Blue' (left), *V.* 'Obsession Scarlet' (centre) and *V.* 'Temari Blue' (right), week 20

Table 15. *Verbena* summer 2016 trial: pre-transplant assessment

Variety	Height (mm)	Plug quality (0-9)	Root quality (0-5)
V. 'Quartz Blue'	49	8	5
V. 'Obsession Scarlet'	37	8	4
V. 'Temari Blue'	91	6	4

Post-transplanting

Symptoms did not develop in any of the treatments or varieties other than the *Verbena* 'Quartz Blue', dry treatment, therefore a detailed assessment of these plants were carried out (12 July, 8 WAT), where a low level of marginal chlorosis (but no necrotic spotting) was observed on the foliage of some plants (**Figure 16**).

Within the dry treatment, more plants were affected more severely in the trace element (unfritted) treatment at standard (5.8) and high (6.5) pH, the converse occurred at low pH (4.5) where the greater effect was observed in the fritted trace element treatment (**Figure 17**). However, statistical analysis identified no significant differences due to the treatments.

Growing medium and tissue analyses (7 July, 7 WAT) indicated that nutrients, particularly nitrogen (nitrate-N and ammonium-N) were depleted; nitrogen levels in the tissue was similarly low in the majority of treatments (**Appendix 2**).

Figure 16. Symptomatic plants: *Verbena* 'Quartz Blue', dry treatment, 12 July, 8 WAT (left) and on a commercial nursery (right)

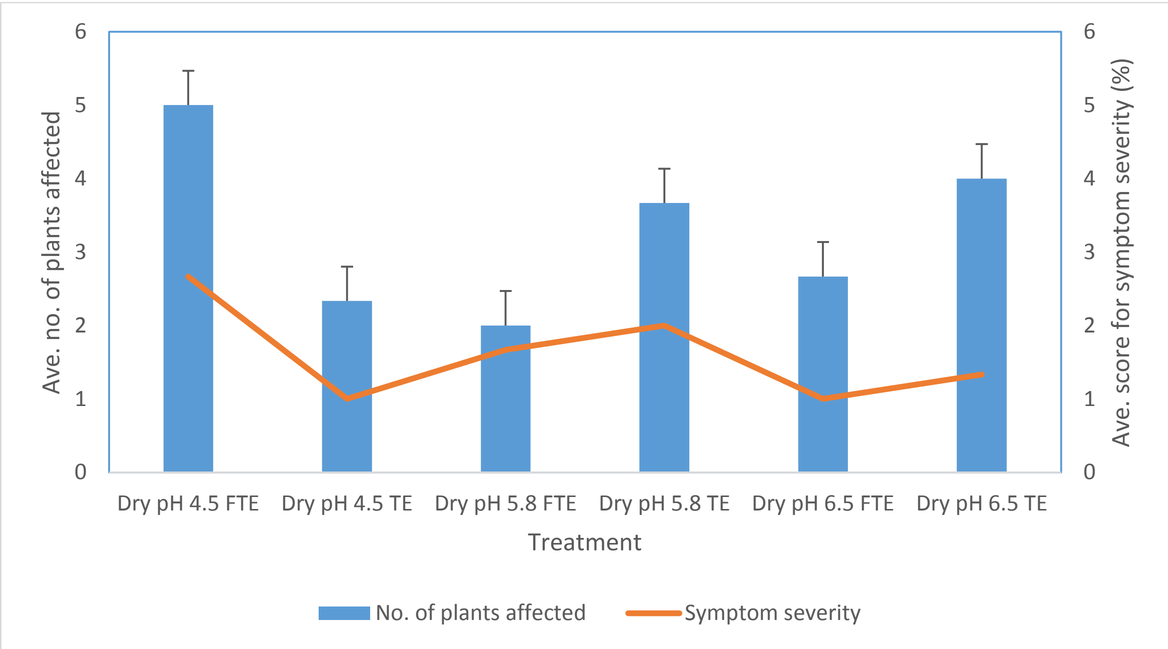


Figure 17. *Verbena* nutrition, summer trial, *V.* 'Quartz Blue', dry treatment only: no. of plants affected and symptom severity. 12 July, 8 WAT. TE = trace elements, FTE = fritted trace elements

Objective 3: Spectral filters (glass coatings)

Application and removal

In the Netherlands, mechanical application is often the preferred method for applying glass coatings as a more even coating is achieved, in the UK it is more usual to use a spray gun. For this trial, hand pressure sprayers were used and the products were applied to individual glass panes, which made it more difficult to achieve an even coating.

Light diffusing products, e.g. ReduFuse and TransPar (Appendix **3**) were translucent and had a tendency to run. Most products generally spread to provide a more even cover once applied. There were no difficulties with blocked nozzles, although care had to be taken to ensure that the products were fully mixed.

The release agent Removit (Hermadix) was used to remove products from all manufacturers prior to the second application, and was equally effective for all products across all manufacturers.

Light measurements (ADAS)

Instantaneous light was measured over the PAR (photosynthetically active radiation, µmol/m^2/s) region of the light spectrum. Measurements were recorded on 10 occasions between 14 July and 7 November 2016 for each glass coating product, uncoated glass and diffuse glass (Appendix **4**). Light transmission data is expressed as a percentage of sunlight; data was recorded simultaneously under the product and as direct sunlight. Although this doesn't take account of the effect of the glass, consistency was sought by obtaining the glass from a single source and batch Data points are an average of three measurements taken either beneath the treatment or under direct sunlight, which were then averaged across the three replications (i.e. from three panes of glass, giving a total of nine measurements for each product on each occasion).

Treated glass panes were also retained from the first application (AP1) of four products which did not appear to adhere adequately; ReduFuse IR, D-Fuse Floriculture, Q4 and Optimix RB, and measurements were also recorded for these treatments. It should be noted that that these were reference treatments with no replication. Whilst every effort was taken to take recordings at the same time of day and under the same weather conditions on clear days, this was not always possible.

The influence of the light diffusing glass and glass coatings on light spectra was measured by Dr Phil Davis (STC) and is reported below.

A comparison of the data for the **untreated glass** and **untreated diffuse glass** indicated that relative light transmission was similar for both materials (**Figure 18**); diffuse glass naturally reflects a proportion of light, due to this the diffuse glass was not treated with an anti-reflectant coating.

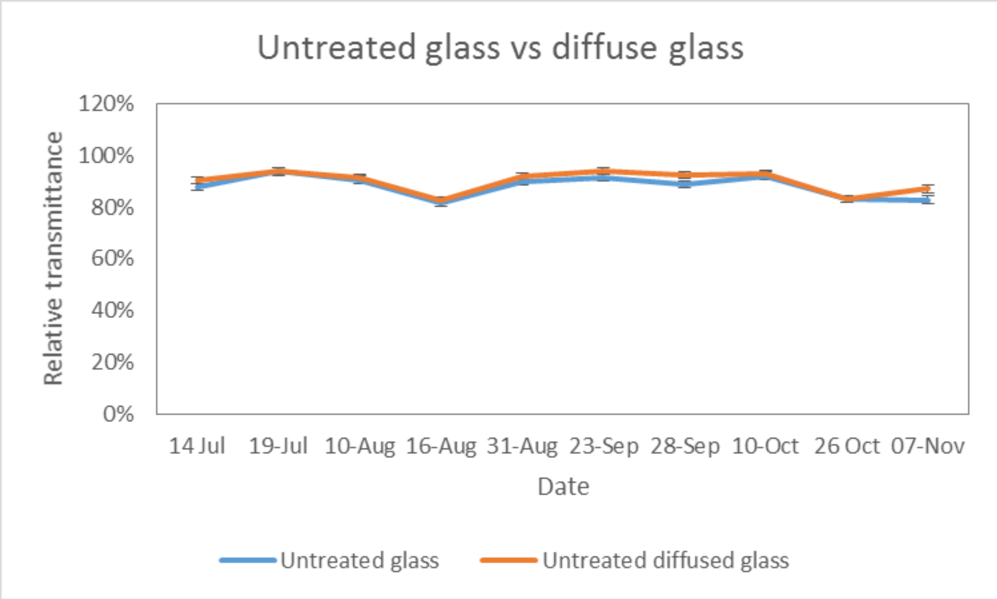


Figure 18. Untreated glass and diffuse glass. The data presented is the light transmission data for untreated standard glass (blue line) and untreated diffused glass (brown line) and expressed as a percentage of sunlight; data was recorded simultaneously under the product and as direct sunlight. Data points are an average of three measurements taken either beneath the treatment or under direct sunlight, which were then averaged across the three replications (i.e. from three panes of glass)

Data for the **Mardenkro** products (**Figure 19**) indicated that, except for Redusol, the influence of the majority of products on relative light transmission did not appear to change greatly by the end of the trial. The data suggests that Redusol degraded sufficiently for the relative light transmission to increase (16%) over the course of the trial. At the concentration used, the ReduHeat and ReduSol had the greatest influence on light transmission, transmitting 27% and 34% less light respectively than the untreated glass.

For the ReduFuse IR, relative light transmission retained from AP1 was greater than for the second application as expected; the difference in relative light transmission increased during the course of the trial, suggesting that AP1 degraded more quickly than the second application.

Figure 19. Mardenkro products: relative light transmission. The data presented is the light transmission data for treated (brown line) and untreated (blue line) glass expressed as a percentage of sunlight; data was recorded simultaneously under the product and as direct sunlight. Data points are an average of three measurements taken either beneath the treatment or under direct sunlight, which were then averaged across the three replications (i.e. from three panes of glass). The grey line represents data recorded from the first application (AP1); this data is an average of three measurements taken either beneath the treatment or under direct sunlight, but was not replicated (i.e. from one pane of glass)

Data for the **Hermadix** products (**Figure 20**) showed that relative light transmission did not increase for D-Fuse Floriculture, D-Fuse Vegetable, Q Heat or DeGree, suggesting little erosion of the product through the season. However, for the shading products, Q3 and Q4, relative light transmission did increase through the course of the trial, with the greatest difference recorded for Q4 (16% difference, second application, **Table 169**). Samples of the D-Fuse Floriculture and Q4 from AP1 indicated that relative light transmission was generally greater than for the second application, as expected. The difference was clearer for the Q4 shading product; light transmission for both products did reduce compared with the untreated glass. However, a comparison of relative light transmission for the two Q4 applications suggests that more weathering occurred with the second application (**Table 16**). It is likely that this was due to more product adhering to the glass at the time of the second application than the first application.

Table 16. Hermadix Q4: Variation in relative light transmission between 14 July and 7 November 2016

Treatment	Relative light transmission		
	14 July	7 November	Difference
Q3 2nd application	59%	67%	8%
Q4 1st application	72%	78%	6%
Q4 2nd application	49%	65%	16%

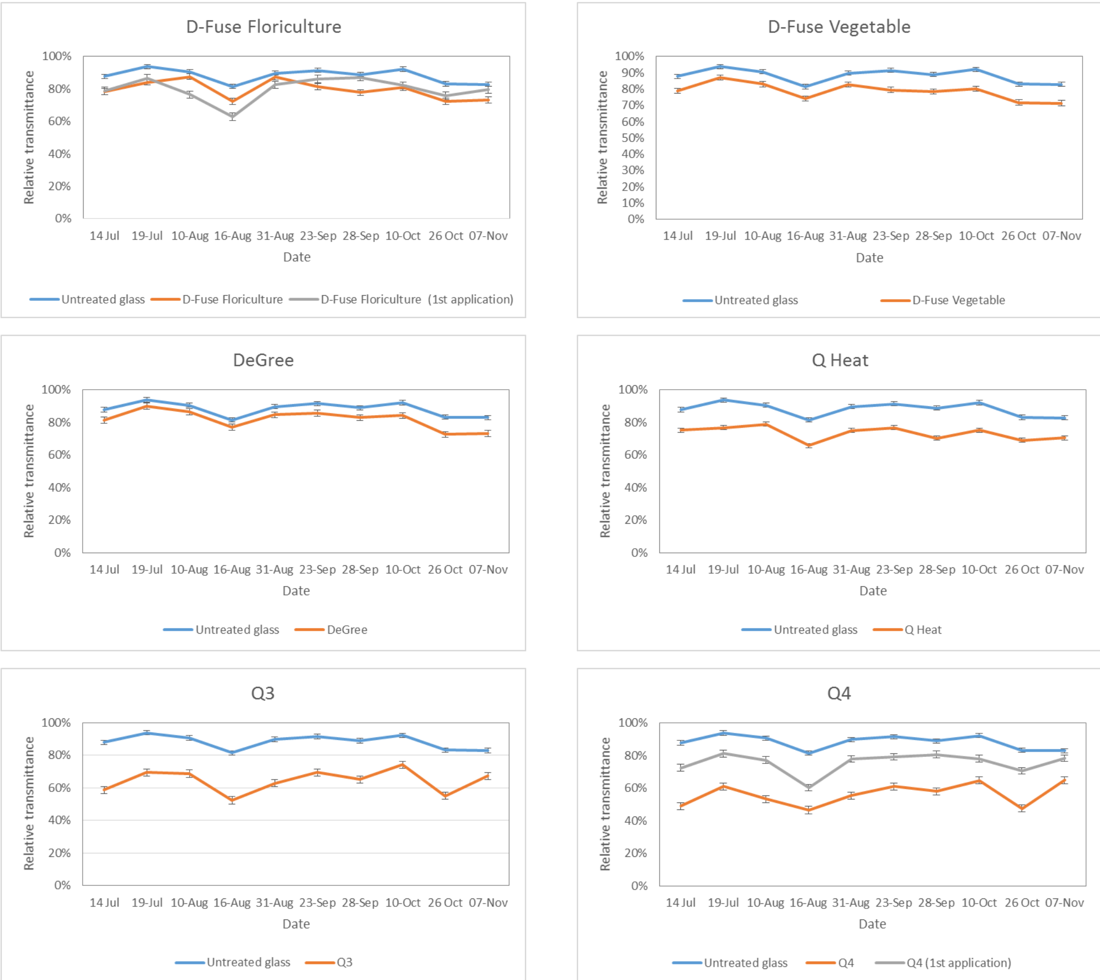


Figure 20. Hermadix products: relative light transmission data. The data presented is the light transmission data for treated (brown line) and untreated (blue line) glass expressed as a percentage of sunlight; data was recorded simultaneously under the product and as direct sunlight. Data points are an average of three measurements taken either beneath the treatment or under direct sunlight, which were then averaged across the three replications (i.e. from three panes of glass). The grey line represents data recorded from the first application (AP1); this data is an average of three measurements taken either beneath the treatment or under direct sunlight, but was not replicated (i.e. from one pane of glass)

For the **Sudlac** products (**Figure 21**), relative light transmission increased for Optimix RB and Eclipse LD over the course of the trial. Optimix RB stood out from other products due to its green hue (green light is reflected by this product). Similar to the measurements for Mardenkro and Hermadix, the greatest difference was recorded for the shading product Eclipse LD (8%). Measurements for the Optimix RB sample retained from AP1 indicated that relative light transmission was generally greater than for the second application, as expected.

Figure 21. Sudlac products: relative light transmission. The data presented is the light transmission data for treated (brown line) and untreated (blue line) glass expressed as a percentage of sunlight; data was recorded simultaneously under the product and as direct sunlight. Data points are an average of three measurements taken either beneath the treatment or under direct sunlight, which were then averaged across the three replications (i.e. from three panes of glass). The grey line represents data recorded from the first application (AP1); this data is an average of three measurements taken either beneath the treatment or under direct sunlight, but was not replicated (i.e. from one pane of glass)

Light measurements (STC)

To estimate the overall influence of glass type and glass coating on plant growth rate we determined the percentage transmission of sunlight over the PAR region of the spectrum (sunlight percentage transmission). For the standard untreated glass the PAR sunlight percentage transmission was 84% (**Table 30**). The diffuse glass was observed to have similar sunlight percentage transmission to the standard untreated glass (83%). For the glass coatings PAR sunlight transmission varied considerably with the greatest values associated with coatings designed to diffuse light (D-fuse Floriculture = 72%, D-fuse Vegetable = 77%, ReduFuse = 74% and Optifuse = 77%) and the lowest associated with products designed to provide shading during the summer months (Q3 = 44%, Q4 = 30%, ReduSol = 35% and Eclipse LD = 30%). Coatings designed to alter the spectrum in some way, for example to remove the heat from the light, had intermediate PAR transmission values (Q heat = 63%, ReduFuse IR = 61%, ReduHeat =50%, Optifuse IR = 67% and TransPAR = 57%).

To understand how the different coating products influenced the light spectrum we also determined the percentage of light transmission relative to that of the control untreated glass (product percentage transmission). This calculation removes the absorbance that was associated with the glass revealing the spectral properties of the coatings. The product percentage transmission spectra, along with the sunlight percentage transmission spectra are presented in **Figure 22**, **Figure 23** and **Figure 24** for the Mardenkro (and the untreated glass panes), Hermadix and Sudlac products respectively.

The diffuse glass was found to have a higher light transmission in the UV end of the spectrum and the far-red region of the spectrum (**Figure 22** and **Table 30**) than the standard untreated glass. This is likely to be caused by different iron contents in the different types of glass used to produce these panes.

Table 30. The light transmission data for the different glass types and glass coating examined. Transmission data were calculated relative to sunlight over the PAR (400-700nm) range (sunlight percentage transmission) and relative to the control untreated glass over several different wavelength ranges (product percentage transmission)

			Sunlight % transmission		Product % transmission					
Product	Manufacturer	Ratio	PAR		PAR	315-400nm (UV-A)	400-500nm	500-600nm	600-700nm	700-800nm (Infrared)
Untreated glass	N/A		84.0		-	-	-	-	-	-
Untreated diffused glass	N/A		82.6		98.4	109.9	97.4	98.1	99.1	104.1
D-Fuse Floriculture	Hermadix	1:5	72.4		86.3	84.3	85.1	87.1	86.2	87.0
D-Fuse Vegetable	Hermadix	1:5	76.7		91.3	90.6	90.5	92.1	91.1	91.9
DeGree	Hermadix	1:4	73.2		87.2	85.0	86.3	88.3	86.8	87.0
Q Heat	Hermadix	1:3	63.1		75.2	55.9	74.5	76.6	74.3	65.9
Q3	Hermadix	1:5	43.6		51.9	48.7	51.2	53.1	51.2	51.6
Q4	Hermadix	1:5	30.3		40.0	36.7	39.2	41.1	39.5	40.0
ReduFuse	Mardenkro	1:5	73.8		87.9	88.2	87.8	89.0	86.9	87.3
ReduFuse IR	Mardenkro	1:4	61.0		72.6	63.0	71.6	73.7	72.3	69.7
ReduHeat	Mardenkro	1:3	50.3		59.9	27.5	58.7	61.0	59.6	43.5
ReduSol	Mardenkro	1:5	35.4		42.1	38.5	41.0	43.1	41.9	42.8
Optifuse	Sudlac	1:5	77.3		92.1	89.6	91.5	92.9	91.7	91.8
Optifuse IR	Sudlac	1:4	67.0		79.8	65.0	79.0	81.0	79.1	73.1
Optimix RB	Sudlac	1:4	58.2		69.3	50.6	66.1	66.9	73.5	65.8
TransPAR	Sudlac	1:3	57.0		67.9	44.0	67.1	69.3	67.1	55.9
Eclipse LD	Sudlac	1:5	29.5		35.2	30.2	33.5	36.0	35.4	36.6

Mardenkro products

The ReduFuse and ReduSol coatings were found to have flat product percentage transmission spectra (**Figure 22**) but with large differences in the magnitude of transmission, 88% and 42% respectively (**Table 30**). The ReduFuse IR and the ReduHeat were both found to reduce the product percentage transmission of UV light, compared to PAR wavelengths. The ReduHeat coating had a more pronounced effect at reducing far-red and NIR than the ReduFuse IR coating. These measurements don't cover the entire NIR range so may be missing the region of the spectrum where the ReduFuse IR coating is most effective.

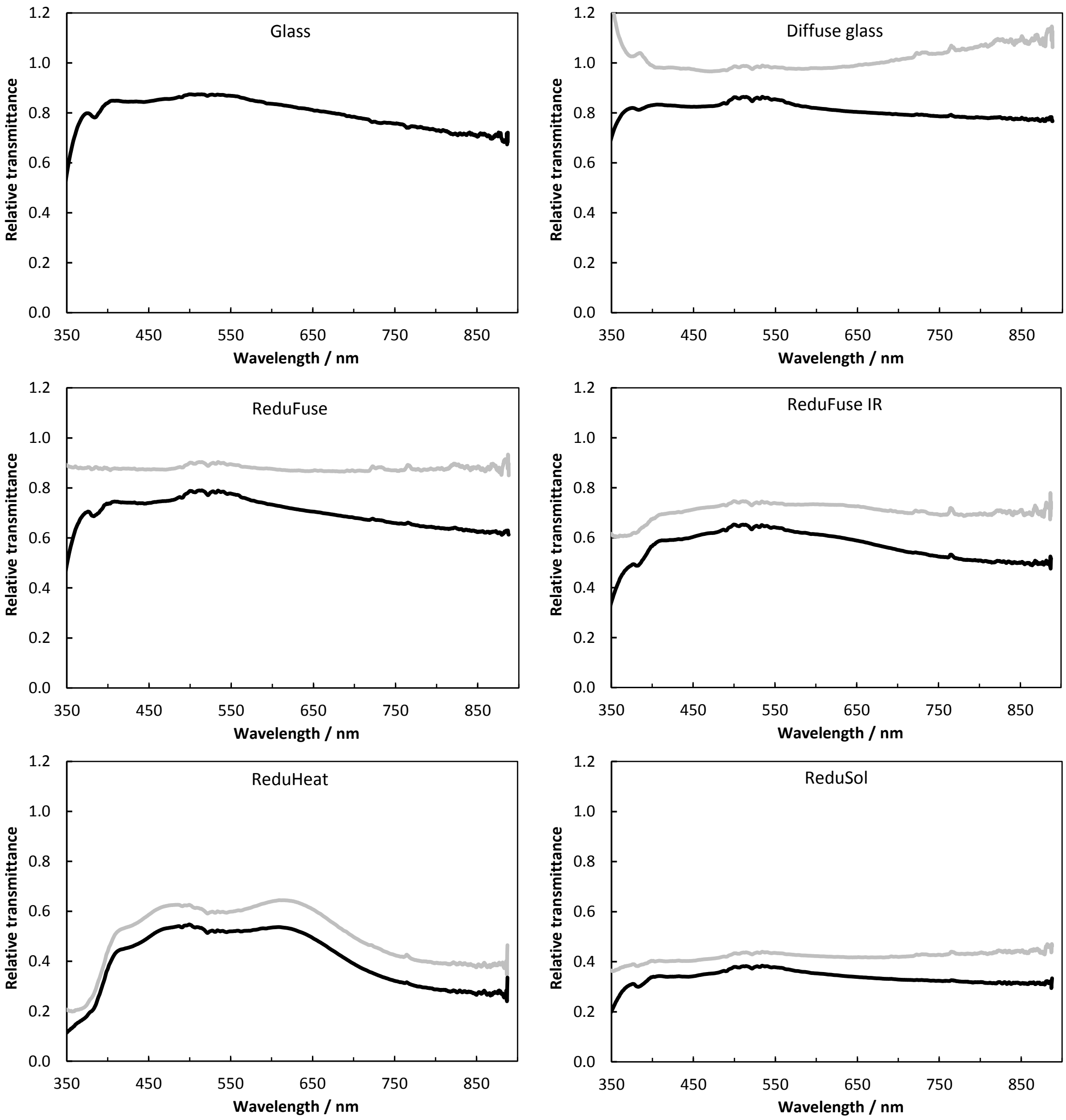


Figure 22. The light transmission spectra of the two untreated glass types (standard glass and diffuse glass) and the glass panes treated with the Mardenkro products from the Redu range. Black lines indicate the transmittance calculated relative to direct solar radiation (sunlight percentage transmission) and grey lines indicate the transmittance calculated relative to the transmittance of standard glass (product percentage transmission)

Hermadix products

The D-fuse Floriculture, D-fuse Vegetable and the DeGree product percentage transmission spectra (**Figure 23** and **Table 30**) were very similar in magnitude and shape (all flat spectra). The Q3 and Q4 coatings also had flat spectra but transmitted considerably less light (52% and 40% respectively). No evidence of enhanced NIR reflection by the DeGree coating (compared to the D-fuse products) was apparent in these measurements. However, these measurements do not cover the entire NIR range so may be missing the region of the spectrum where this coating is effective. The Q Heat coating reduced the relative percentage transmission of UV light and far-red and NIR light compared to PAR wavelengths, the reflection was greater in the UV region than the far-red and NIR regions examined with these measurements.

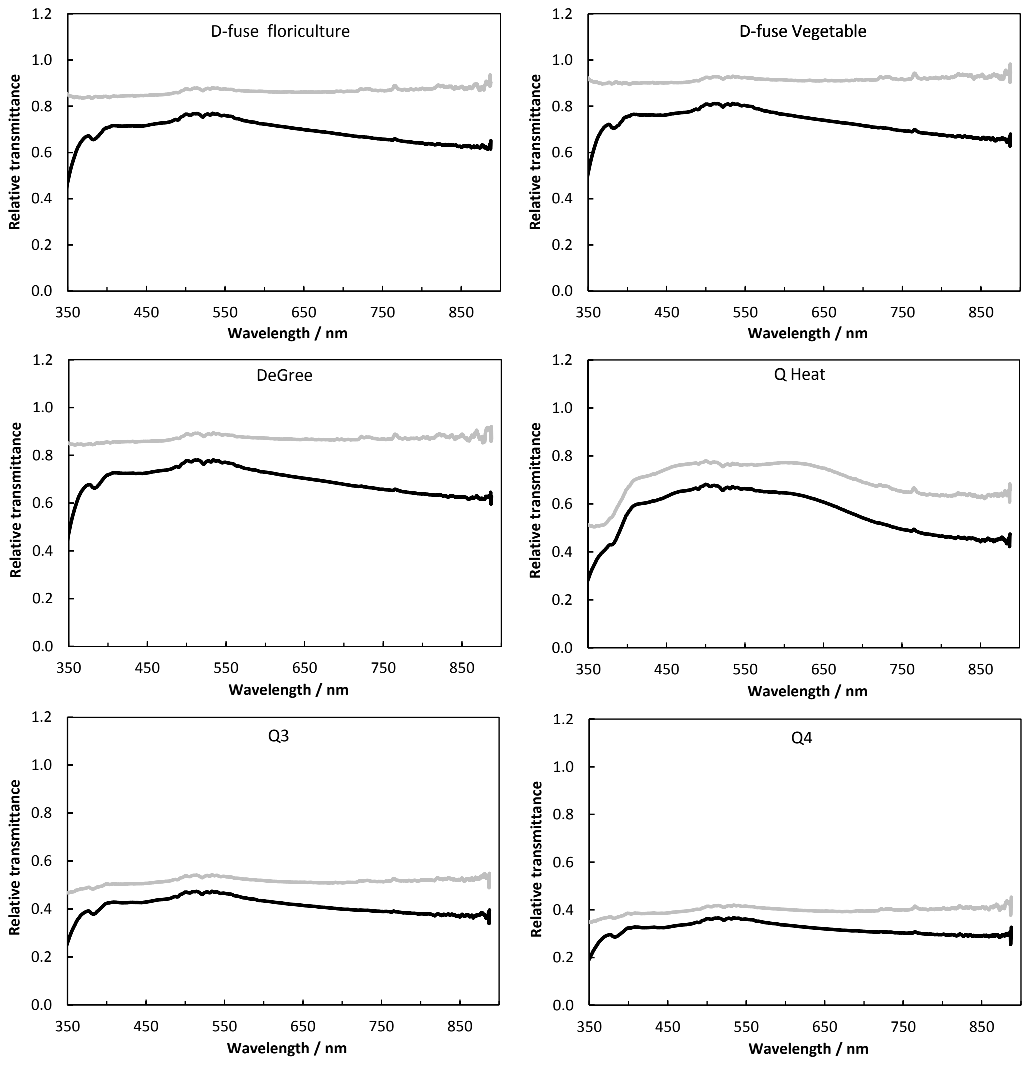


Figure 23. The light transmission spectra of glass panes treated with the Hermadix products. Black lines indicate the transmittance calculated relative to direct solar radiation (sunlight percentage transmission) and the grey lines indicate the transmittance calculated relative to the transmittance of standard glass (product percentage transmission)

Sudlac products

The Optifuse and the Eclipse LD coatings were both found to have flat product percentage transmission but large differences in transmission, 92% and 35% respectively (**Figure 24** and **Table 30**). The Optifuse IR coating was observed to reduce the transmission of UV, far-red and NIR radiation. TransPAR had a lower PAR transmittance than the Optifuse IR but also had a stronger influence on the UV, Far-red and NIR transmittance. Optimix RB was the only product tested that is designed to alter the colour balance of visible light and reflection of green light that can be seen from certain angles when the material is viewed from above. There were noticeable peaks in the transmission spectra at about 450nm (blue) and 630nm (red). Transmission in the green region (500-550nm) was approximately 10% lower than the red and blue region of the spectrum.

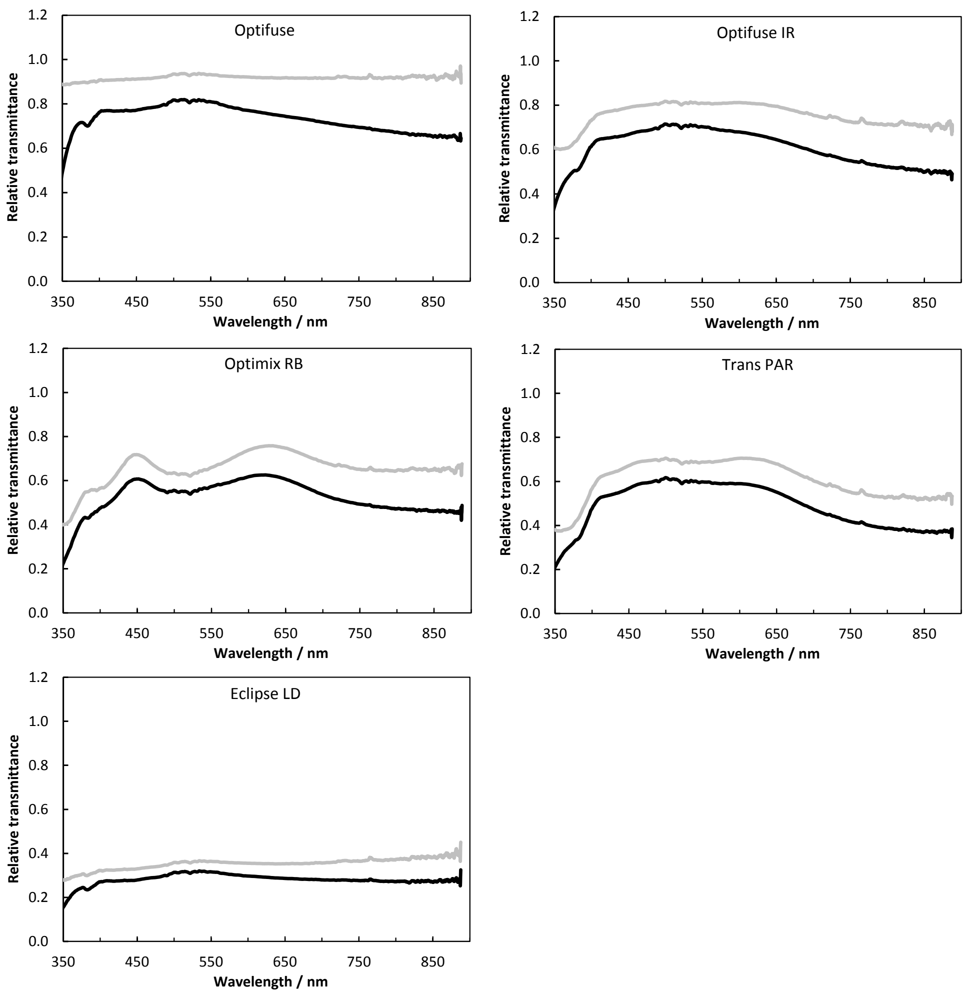


Figure 24. The light transmission spectra of glass panes treated with the Sudlac products. Black lines indicate the transmittance calculated relative to direct solar radiation (sunlight percentage transmission) and the grey lines indicate the transmittance calculated relative to the transmittance of standard glass (product percentage transmission)

Objective 4: Spectral filters (films)

Plants were monitored throughout the trial for pests and diseases and the following treatments applied:

- Fubol Gold (mancozeb and metalaxyl-M, rate 1.9 g/L water, one application) was applied to the *Cheiranthus* to control downy mildew
- A protective treatment of Amistar (azoxystrobin, rate 1.0 g/L water, one application) was applied to all varieties
- Dynamec (abamectin, rate 0.5 g/L water, two applications) was applied to *Viola* and pansy to control red spider mite.

It was not possible to replicate treatment areas and the treatment structures used were diverse (size, air volume etc.), therefore statistical analysis of the results between treatments was not appropriate. Analysis within each treatment compared the effect of the environment (temperature, humidity, light quality and light transmission) provided by each spectral filter on a range of plant species.

Temperature and humidity

Temperature and humidity were monitored throughout the trial (**Appendix 5**). It was generally warmest under the untreated glass and Luminance tunnels, and coolest under the SunSmart Blue (old) and Lumisol treatments. Humidity levels appeared to be less affected by the spectral filters early in the season, although they were generally lower under the untreated glass, and in October lower under the Lumisol treatment.

Plant quality

The quality of the plugs supplied was good, with all plants having healthy roots evenly distributed throughout the plug, and even plant height within species.

Plant quality was generally good (score >7, commercially acceptable) (**Figure 25,** 17 November). Where lower scores were recorded, this was generally due to uneven plant height and spent flowers within treatment plots. This was most evident in the *Cyclamen* ‘Metis’, where quality scores were below 7. Lower quality was recorded in the two light diffusing treatments (Luminance and Lumisol) than other treatments for the *Cyclamen* ‘Metis’, but this was not a trend across all varieties.

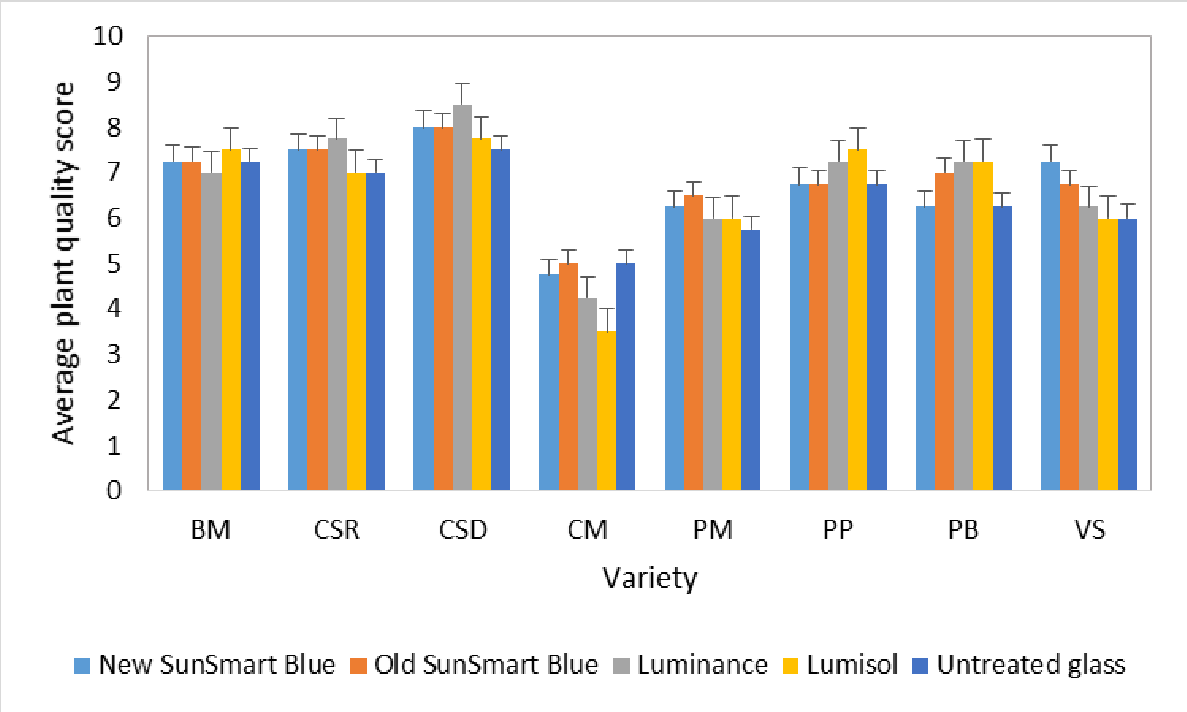


Figure 25. Plant quality under glass and four polythene films. 17 November 2016, 24 WAT (*Cyclamen*), 12 WAT all other varieties. Varieties: BM-*Bellis* 'Medici', CSR-*Cheiranthus* 'Sugar Rush', CSD-*Cineraria* 'Silver Dust', CMD-*Cyclamen* 'Metis Decora', PM-Pansy 'Matrix autumn select', PP-Polyanthus 'Piano', PB-Primrose 'Bonneli', VS-*Viola* 'Sorbet XP autumn select'. Quality: 1 = poor, 7 = commercially acceptable, 9 = exceptional

Flower development

Many of the differences in flowering seen in this trial were varietal, i.e. difference in the periods that the species naturally flower. The number of flowers were assessed on four occasions, (**Figure 26**) and there were clear differences in flower pattern for the various species, for example the *Viola* flowering was similar throughout the assessment period, whilst the *Bellis* 'Medici', primrose and *Polyanthus* were later flowering under all treatments. The *Cyclamen* 'Metis' came into flower earlier than other species, and were coming to the end of their flowering period when others were in full flower.

The films influenced the flowering period, with consistent differences in flowering under the different films (**Table 3**, **Figure 26**). The data also indicated variability within each variety. Of the varieties in flower on the 23 September, the majority had produced more flowers under the Lumisol than the Luminance treatments, the exception being *Cheiranthus* 'Sugar Rush'. By the 17 November assessment, more or an equal number of plants were in flower under the Luminance than the Lumisol treatment, (except for *Cyclamen* 'Metis'), indicating a slight delay in flowering in plants produced under Luminance film compared with Lumisol.

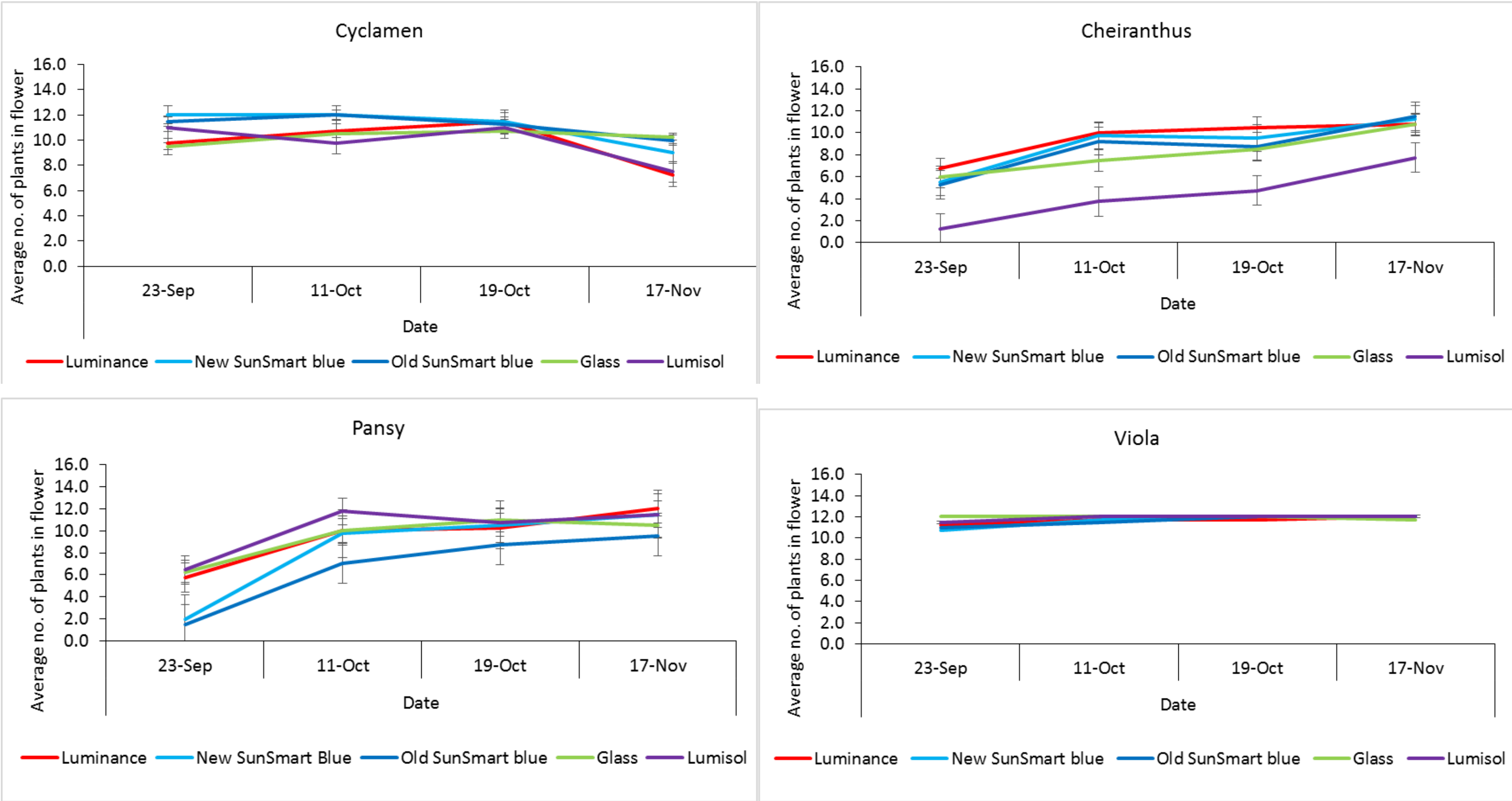
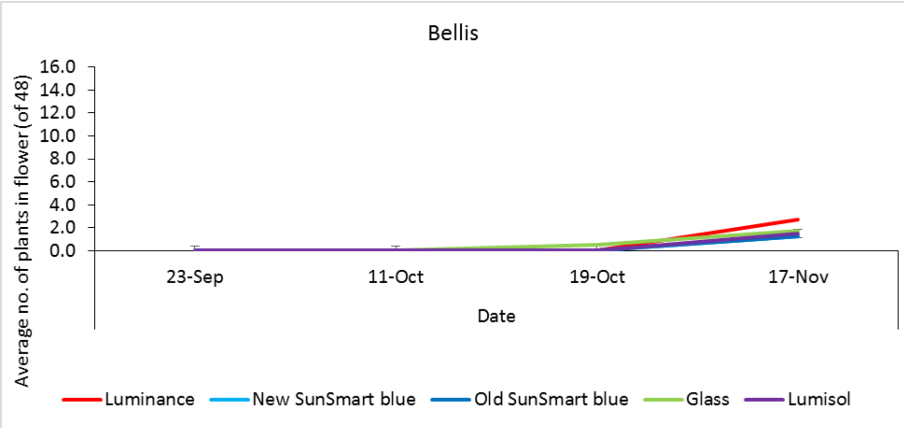
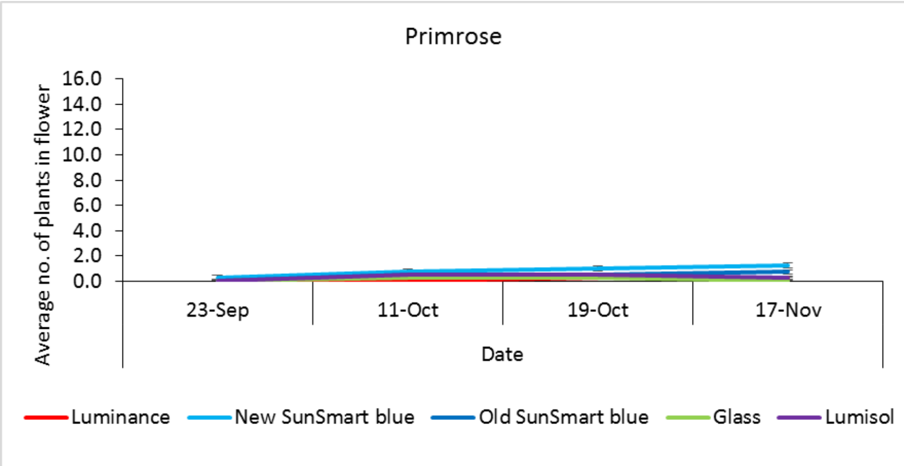


Figure 26. Number of plants with flowers under glass and four polythene films. Assessed on 23 September 2016, 11 October 2016, 19 October 2016 and 17 November 2016; 24 WAT (*Cyclamen*), 12 WAT all other varieties. Varieties: *Bellis* 'Medici', *Cheiranthus* 'Sugar Rush', *Cineraria* 'Silver Dust', *Cyclamen* 'Metis Decora', Pansy 'Matrix autumn select', Polyanthus 'Piano', Primrose' Bonneli', *Viola* 'Sorbet XP autumn select'. Contd…





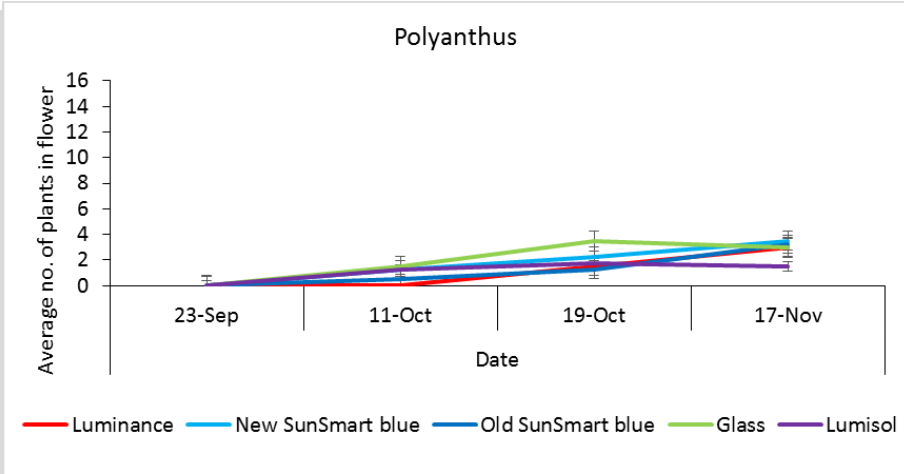


Figure 26 continued. Number of plants with flowers under glass and four polythene films. Assessed on 23 September 2016, 11 October 2016, 19 October 2016 and 17 November 2016; 24 WAT (*Cyclamen*), 12 WAT all other varieties. Varieties: *Bellis* 'Medici', *Cheiranthus* 'Sugar Rush', *Cineraria* 'Silver Dust', *Cyclamen* 'Metis Decora', Pansy 'Matrix autumn select', Polyanthus 'Piano', Primrose 'Bonneli', *Viola* 'Sorbet XP autumn select'

Table 31. Observed effect of four polythene films on flowering (number in flower) of some autumn ornamentals on 23 September and 17 November compared with flowering under untreated glass – 2016

Variety	Film and assessment							
	Luminance		Lumisol		SunSmart Blue – New		SunSmart Blue - Old	
	Sep	Nov	Sep	Nov	Sep	Nov	Sep	Nov
Bellis 'Medici'	O	↑	O	↔	O	↔	O	↔
Cheiranthus 'Sugar Rush'	↑	↔	↓	↓	↔	↔	↔	↔
Cineraria 'Silver Dust'	O	O	O	O	O	O	O	O
Cyclamen 'Metis'	↔	↓	↑	↓	↑	↓	↑	↔
Pansy 'Matrix'	↔	↑	↔	↑	↓	↑	↓	↓
Polyanthus 'Piano'	O	↔	O	↓	O	↔	O	↔
Primrose 'Bonneli'	O	↑	O	↑	O	↑	↑	↑
Viola 'Sorbet'	↓	↔	↓	↔	↓	↔	↓	↔

Key: ↑ = increased flowering; ↓ = reduced flowering; ↔ = same as glass; O = No flowers

Treatments which increased flowering are highlighted in red.

Plant height

Whilst statistical analysis has not been used to compare differences between treatments, the Lumisol cover resulted in more compact plants than other treatments for all varieties except the *Bellis* 'Medici' which was more compact when grown under the untreated glass (**Figure 27**). There was no single treatment where plant height was greater across all varieties. However, plants were more compact, if marginally, in all varieties under the Lumisol than all other treatments, except for the *Bellis* 'Medici' under untreated glass. Similarly, plants were generally more compact under the new SunSmart Blue tunnel than the old SunSmart Blue tunnel, except for the *Cheiranthus* 'Sugar Rush' and Primrose 'Bonneli' (difference < 1 mm). The variable response of the different varieties to the various treatments is demonstrated by these results, for example for *Bellis* 'Medici', plants were more compact under the untreated glass than the new SunSmart Blue treatment, whilst the converse was true for the *Cheiranthus* 'Sugar Rush' (**Table 32**). There was variability in the temperature patterns under the various treatments; temperature was generally greater under the glass and Lumisol, and cooler under the two SunSmart blue and Luminance tunnels (**Appendix 5**). For all treatments, the temperature became cooler from mid-September, and this will have resulted in more compact plants of all varieties.

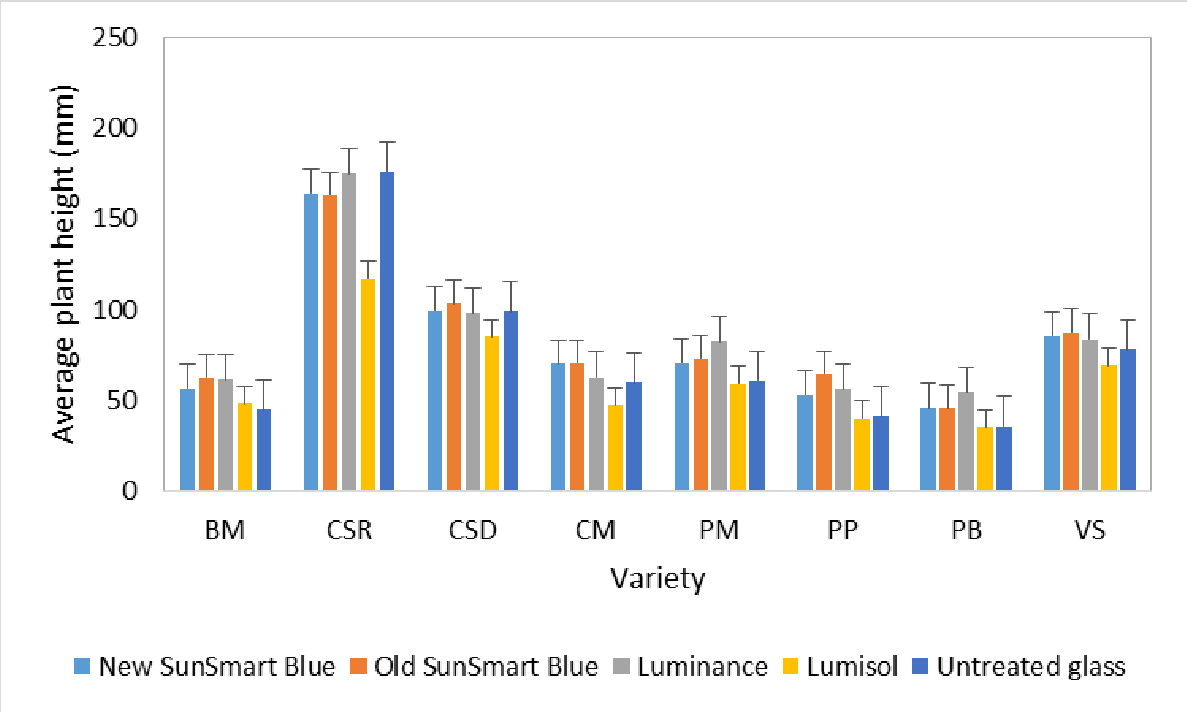


Figure 27. Average plant height under glass and four polythene films. 17 November 2016, 24 WAT (*Cyclamen*), 12 WAT all other varieties. Varieties: BM-*Bellis* 'Medici', CSR-*Cheiranthus* 'Sugar Rush', CSD-*Cineraria* 'Silver Dust', CMD-*Cyclamen* 'Metis Decora', PM-Pansy 'Matrix autumn select', PP-Polyanthus 'Piano', PB-Primrose 'Bonneli', VS-*Viola* 'Sorbet XP autumn select'

Light transmission and spectra

The proportion of light transmitted within each treatment remained unchanged from that collected in 2015. The glass reduced the PAR light intensity by 21% and the UVA light intensity by 38%. The spectrum within the glasshouse (**Figure 28**, green line) was similar in shape to that of full sun but when the light transmittance of the glasshouse was determined (**Figure 29**) it was clear that UV light with wavelengths less than 350nm are absorbed by the glass. Within the PAR region of the spectrum slightly more green light (81%) was transmitted than red (80%) or blue (76%) light (**Table 17** and **Figure 29**). With the screens in the glasshouse closed, the total light inside the glasshouse was greatly reduced with only 15% of the available sunlight reaching the plants (**Table 17**).

Table 32. Observed effect of four polythene films on plant height (H) and quality (Q) of some autumn flowering ornamentals, compared with growth under glass – 17 November 2016

Variety	Film and assessment							
	Luminance		Lumisol		SunSmart Blue – New		SunSmart Blue - Old	
	H	Q	H	Q	H	Q	H	Q
Bellis 'Medici'	↑	↔	↔	↔	↑	↔	↑	↔
Cheiranthus 'Sugar Rush'	↔	↑	↓	↔	↓	↑	↓	↑
Cineraria 'Silver Dust'	↔	↑	↓	↔	↔	↑	↔	↑
Cyclamen 'Metis'	↔	↓	↓	↓	↔	↔	↔	↔
Pansy 'Matrix'	↑	↔	↔	↔	↑	↑	↑	↑
Polyanthus 'Piano'	↑	↑	↔	↑	↑	↔	↑	↔
Primrose 'Bonneli'	↑	↑	↔	↑	↑	↑	↑	↔
Viola 'Sorbet'	↔	↔	↓	↔	↔	↑	↔	↑

Key: ↑ - increased; ↓ - decreased; ↔ - no change. Treatments which increased plant quality and improved compactness are highlighted in red.

Light diffusing plastics

Light spectra were assessed in two polytunnels with light diffusing plastic. One was clad with Lumisol and one was clad with Luminance. The light spectrum under the two plastics was similar (

Figure 30) though some differences, especially at shorter wavelengths, were observed. In the far-red region of the spectrum both plastics transmitted a similar amount of light (76%, **Table 17**). As wavelength decreased, absolute transmittance decreased and the differences in transmittance between the two plastics increased (**Figure 31**). In the red and green regions of the spectrum, Luminance transmitted 3% more light than Lumisol. In the blue region of the spectrum Luminance transmitted 4% more light than Lumisol and in the UVA region of the spectrum Luminance transmitted 9% more light than Lumisol.

SunSmart Blue plastic

Light measurements were performed in two polytunnels clad with SunSmart Blue plastic. One tunnel was clad with new plastic and one was clad with older plastic. These plastics transmitted approximately 40% of the available PAR light. The light spectra within the two tunnels was largely similar (**Figure 32**) with proportionally greater transmission in blue (~65%) than green (51%), red (21%) or UVA (21%) region of the spectrum (**Table 17** and **Figure 33**).

The older blue plastic transmitted slightly more red and UVA light than the new plastic which is consistent with slight sun damage of the plastic and/or pigments within the plastic.

Table 17. The mean light intensity measured outside and within each trial area under conditions of full sun.

Colour	PAR	UVA	Blue	Green	Red	Far red
Wave band / nm	400-700	320-400	400-500	500-600	600-700	700-800
	% transmission					
Glass	79	62	76	81	80	78
Glass + Screen	15	10	14	16	16	16
Lumisol	70	57	66	71	72	76
Luminance	73	66	70	74	75	76
New SunSmart blue	43	21	65	51	21	40
Old SunSmart blue	44	22	62	52	25	39

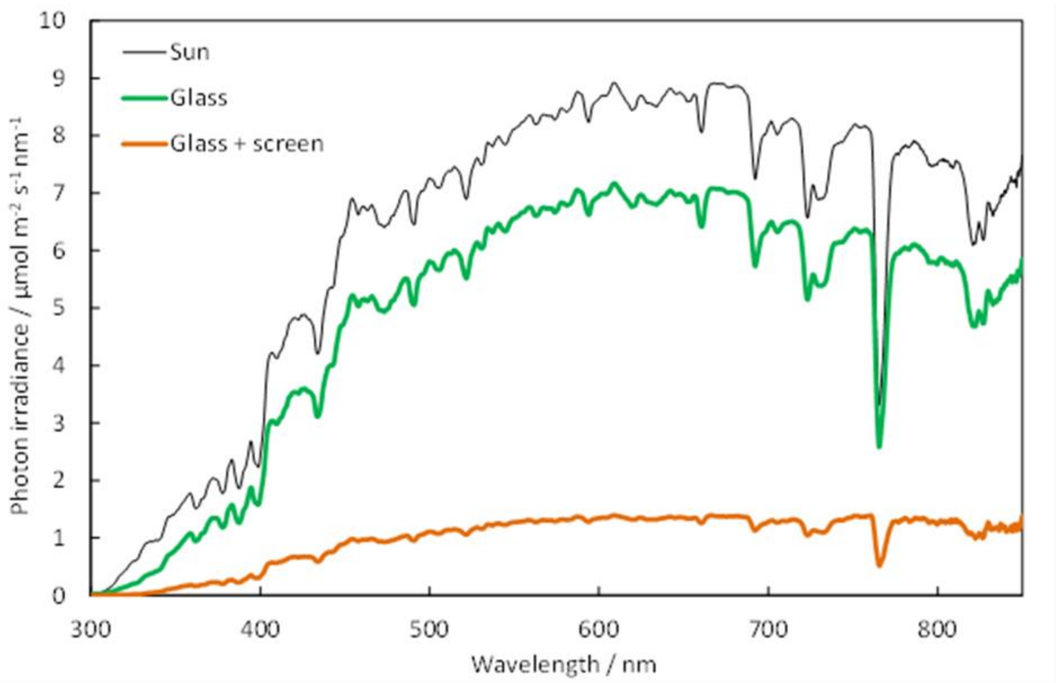


Figure 28. Light spectra measured outside in full sun (Sun) inside the glasshouse when the screens were open (Glass) and when the screens were closed (Glass + screen).

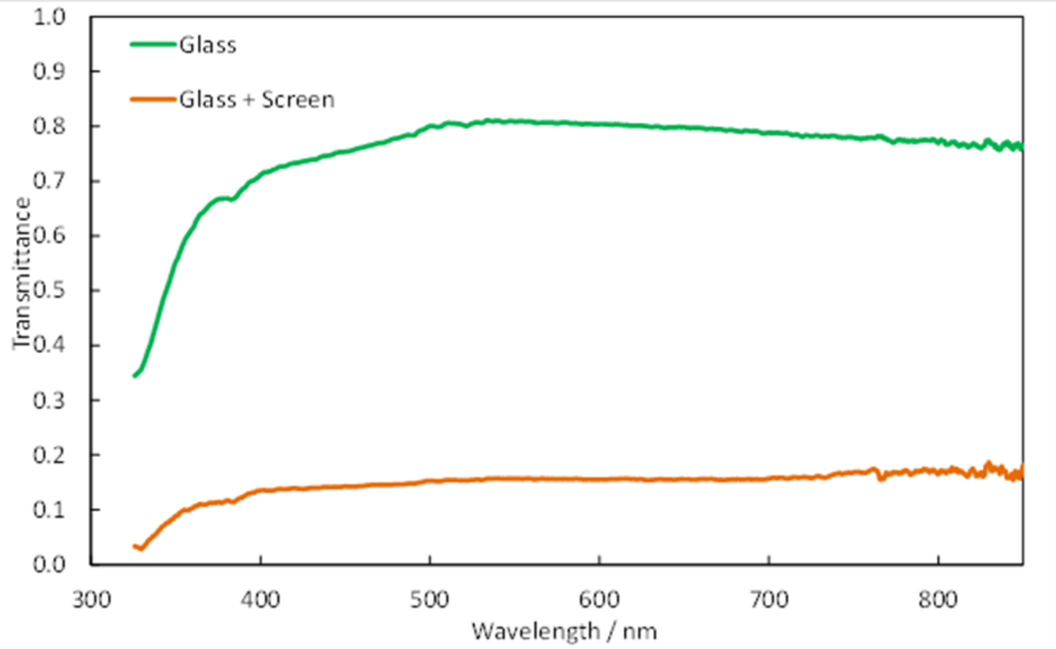


Figure 29. Transmittance spectra of the glasshouse with the screens open (glass) and the closed (glass + screen)

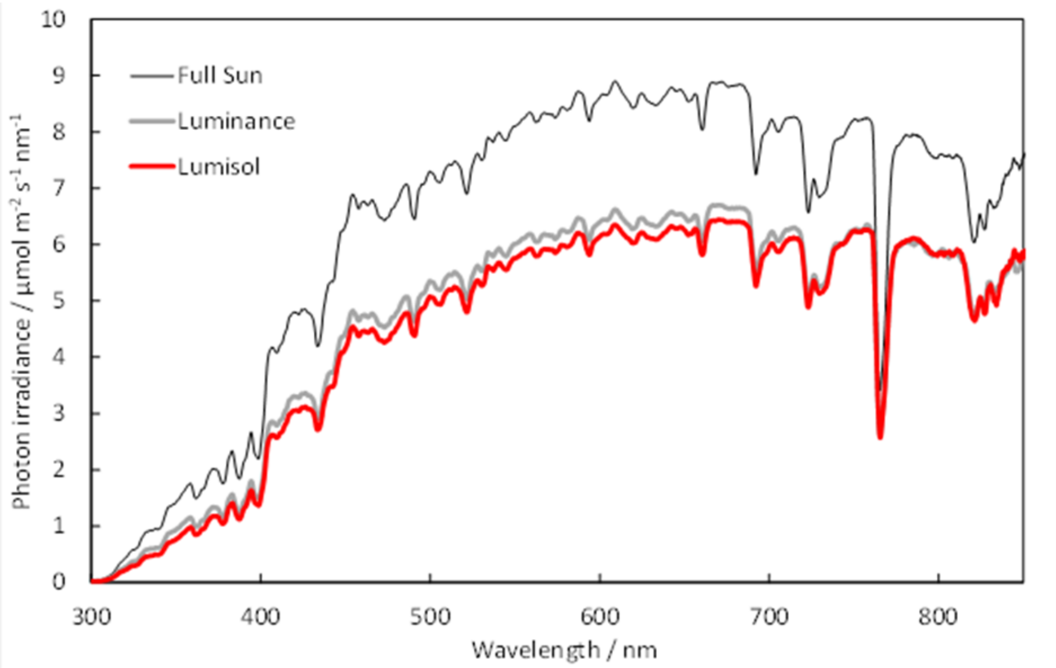


Figure 30. The measured spectra with in a polytunnel covered with Luminance or Lumisol diffusing plastics. The spectrum of full sun is shown for comparison

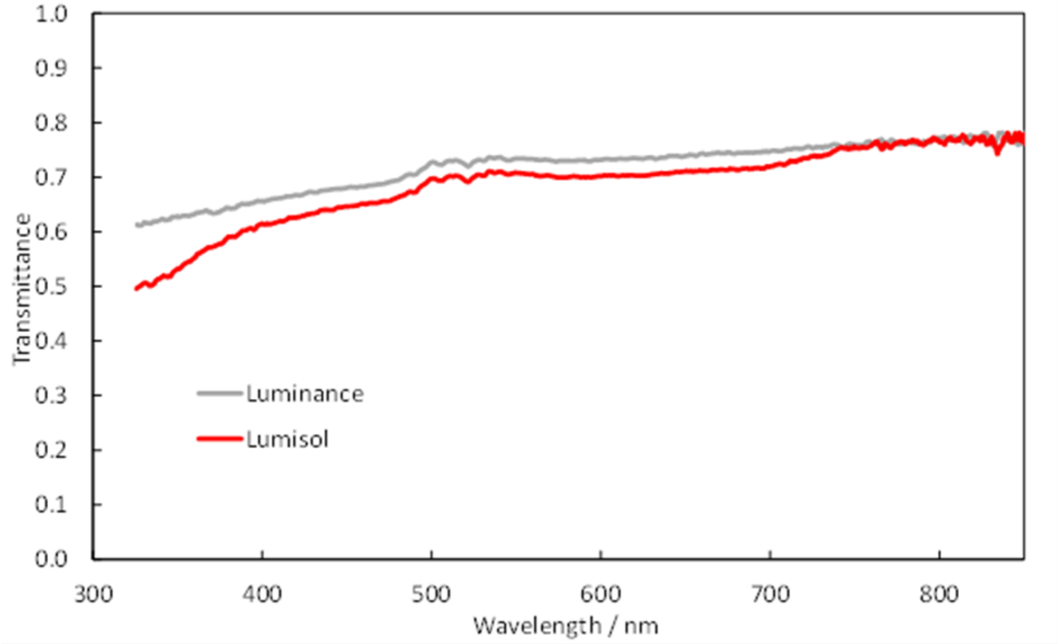


Figure 31. Transmittance spectra of Luminance and Lumisol clad polytunnels

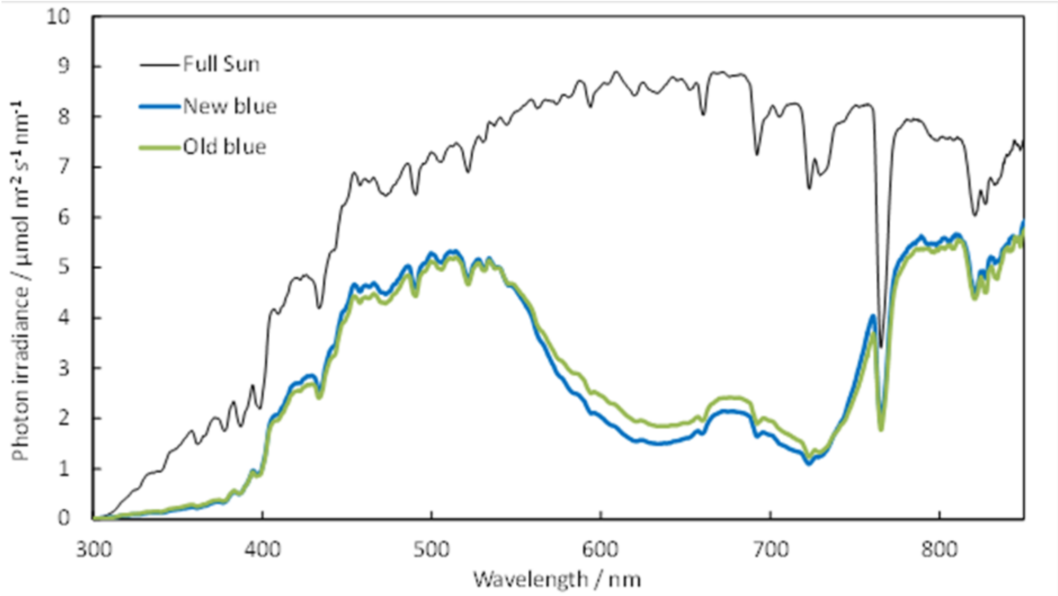


Figure 32. The measured spectra in the polytunnels covered with new and old SunSmart blue plastics. The spectrum of full sun is shown for comparison

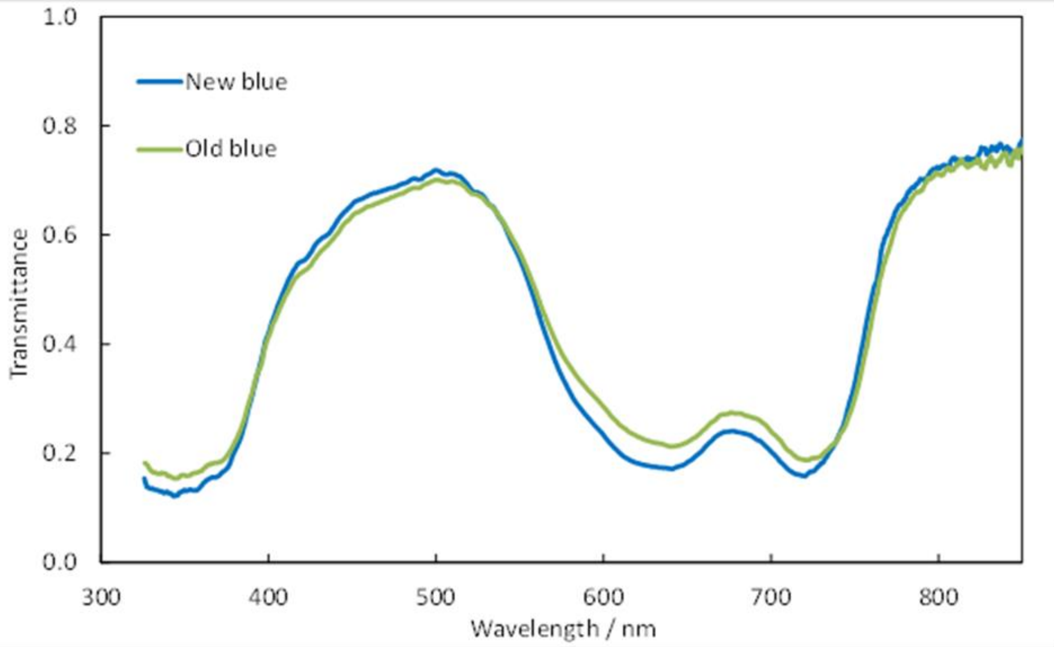


Figure 33. Transmittance spectra of new and old SunSmart blue clad polytunnels

Objective 5: Pre-Christmas production of hellebore

Pre-potting

The pre-potting assessment (week 11, 18 March 2016) revealed that although there was some variation in size, for all varieties the plants received were good quality, with numerous healthy white roots throughout the plug (**Table 18**).

Table 18. Pre-potting assessment of Hellebore, week 11, 2016

Variety	Quality (0-9)	Height (mm)
'Anna's Red'	8	79
'Madame Lemonnier'	8	126
'Molly's White'	8	87
'Paradenia'	8	140
'Penny's Pink'	8	84
'Royal Emma'	8	130

Post-potting

The plants were monitored for pest and disease, and any bud or flower development between weeks 11 and 34, when the first cold store treatment began. There were no issues with pest and disease and no signs of bud development prior to week 34.

Pre-cool treatments

Plants that were selected for the first cold store treatment were assessed for quality (0-9 scale) just before treatment. All of the varieties scored between 7.0 and 8.0, meaning they were all of a high quality.

In week 37, a number of the ‘Madame Lemonnier’ that were on the standing-out area were starting to produce flower buds early, and as a result this variety was not put into cold store for the second cool treatment. Plants selected for the second treatment were assessed for quality prior to cool treatment and again all varieties scored between 7.0 and 8.0.

Post-cool treatments

The technical issue with the cold store, which subjected plants to temperatures below 0°C for 16.5 hrs and below -5°C for 13.5 hrs resulted in some plant death. Any assessments completed post-cool treatment should be treated with caution, as it is not possible to tell whether the effects on the plants were caused by the cold store issue, or if they would have occurred regardless.

When the plants were removed from the cold store, the majority of the leaves turned grey within 2-3 days, although the roots appeared relatively healthy; affected leaves were removed once the plants had been placed in the glasshouse and allowed to acclimatise.

By 26 October (week 43), the majority of the ‘Penny’s Pink’ from CS1 and CS2a had died. By 2 November (week 44) flower buds were present and beginning to open in the ‘Royal Emma’ and ‘Madame Lemonier’, treatment CS1 only. For all varieties except for ‘Paradenia’ fewer leaf buds were present or opening in the cold treated plants than the outdoor control (**Table 19**).

A second assessment (18 November, week 46) indicated that ‘Molly’s White’, ‘Penny’s Pink’ and ‘Anna’s Red’ were the most cold sensitive varieties with fewest surviving plants (**Table 206**); ‘Royal Emma’ was least sensitive to the cold. Observations at this time indicated that of the remaining plants, ‘Royal Emma’ was the only variety with flowers opening (three plants, treatment CS1) by week 46; one ‘Paradenia’ plant had fully open flowers in week 49 (treatment CS2b). ‘Royal Emma’ and Paradenia were the only varieties from any of the cold treatments that produced fully open flowers prior to Christmas.

Table 19. Average number of hellebore flower and leaf buds present on live plants, assessed 2 November 2016 (week 44). CS = cold store

Treatment	Outdoor control (4 plants)			Indoor control (6 plants)			CS1 (15 plants)			CS2a (6 plants)			CS2b (9 plants)		
Variety	Open flower buds	Open leaf buds	Closed buds	Open flower buds	Open leaf buds	Closed buds	Open flower buds	Open leaf buds	Closed buds	Open flower buds	Open leaf buds	Closed buds	Open flower buds	Open leaf buds	Closed buds
'Anna's Red'	-	-	0.8 (20)	-	0.2 (3)	-	-	-	0.1 (0.5)	-	-	-	-	-	0.2 (2)
'Madame Lemonnier'	-	0.8 (20)	-	-	0.2 (3)	-	0.5 (3)	-	0.3 (2)	X	X	X	X	X	X
'Molly's White'	-	0.8 (20)	2 (50)	-	-	0.5 (8)	-	-	-	-	-	-	-	-	-
'Paradenia'	-	0.5 (13)	0.5 (13)	-	-	-	-	-	0.6 (9)		0.3 (5)	0.3 (5)	-	-	1.2 (13)
'Penny's Pink'	-	2.3 (58)	-	-	0.5 (8)	-	-	-	-	-	-	0.2 (3)	-	-	-
'Royal Emma'	-	-	0.8 (20)	-	0.2 (3)	-	0.1 (0.5)	0.8 (5)	-	-	-	0.5 (8)	-	0.3 (3)	-

X = 'Madame Lemonnier' was not included in the second cold store treatment. – No flowers or leaf buds present. Figures in brackets indicate the percentage of plants at the given stage.

Table 20. The number of dead hellebore plants from each cold store treatment, 18 November 2016 (week 46)

Variety	CS1 (from 15 plants)	CS2a (from 6 plants)	CS2b (from 9 plants)	Total
'Anna's Red'	9	5	5	19
'Madame Lemonnier'	3	X	X	3
'Molly's White'	10	6	6	22
'Paradenia'	6	2	1	9
'Penny's Pink'	13	4	5	22
'Royal Emma'	3	0	0	3

X = 'Madame Lemonnier' was not included in the second cold store treatment. CS = cold store

Objective 6: Overwintered perennials

Results for the plants grown in the glasshouse and polythene tunnel are presented separately. As it was not possible to replicate the treatment areas, statistical analysis to compare the two structures was not possible. It was generally cooler under the polythene (mean 7.2˚C, range of -4.4˚C to 24.5˚C) than the glass (mean 8.5˚C, range of -3.7˚C to 36.5 ˚C).

Plant quality

Pre-transplanting

Plants were assessed on 3 October 2016 (week 40), prior to transplanting. Germination was generally good, but uneven in the *Campanula persicifolia* 'Takion Blue' (**Table**) in particular. Plant quality was generally good (score > 7, commercially acceptable), except for the *Campanula persicifolia* 'Takion Blue' (score of 5) due to the uneven germination, and the seedlings were small. Height was slightly variable in the *Campanula glomerata* 'Acaulis' and *Prunella grandiflora* 'Freelander Blue', and there was leaf purpling (minimal) in some seedlings of *Scabiosa japonica* var. *alpina* 'Ritz Blue', *Gaura lindheimeri* 'Sparkle White' and *Verbena rigida.*

Table 37. Germination assessment, 3 October 2016 (week 40)

Treatment	Variety	Germination within plug tray (%)
1	*Campanula persicifolia* 'Taikon Blue'	56
2	*Campanula glomerata* 'Acaulis'	95
3	*Coreopsis grandiflora* 'Presto'	92
4	*Echinacea* 'Cheyenne Spirit'	92
5	*Gaura lindheimeri* 'Sparkle White'	84
6	*Prunella grandiflora* 'Freelander Blue'	79
7	*Scabiosa japonica* var. *alpina* 'Ritz Blue'	76
8	*Silene alpestris* 'Starry Dreams'	73
9	*Verbena rigida*	100

Post-transplanting growth in the polythene tunnel environment

The final plant quality assessment was carried out on 28 March 2017 (week 13). Average quality scores were 3.0 (good quality, but no flower) and below for all species, none of which produced flowers under the conditions experienced in this trial (**Figure 34**). The quality score for *Silene alpestris* 'Starry Dreams' (pots and packs) was significantly greater than for all other species (p=0.05) (**Table 38**). During cold spells the temperature in the polythene tunnel fell below 0˚C on several occasions (extreme of -4.4˚C**,**

Appendix), resulting in cold damage to a number of species. Scorch and purpling was present on the foliage of *Gaura lindheimeri* 'Sparkle White' in particular and also *Verbena rigida*. All plants of *Silene alpestris* 'Starry dreams' survived, as did the majority of plants across all varieties (**Table 399**). Survival was generally greater in packs than pots, likely due to the insulation properties of the polystyrene packs and smaller growing medium volume (and water).

At the final assessment on 28 March 2017 there were no flowers present on the plants grown under polythene.

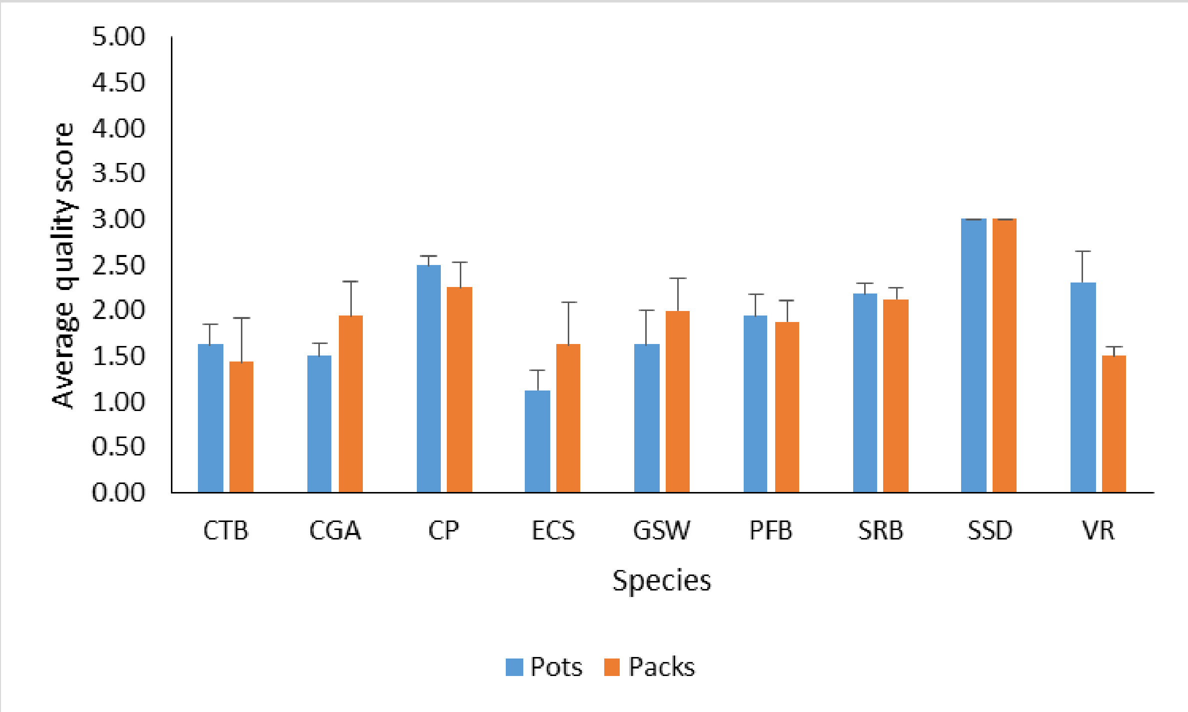


Figure 34. Average plant quality (polythene tunnel), pots and packs, assessed 28 March 2017 (week 14)

Scale of 0-5: 0 = dead; 1 = very poor quality; 2 = poor quality; 3 = good quality, no flower; 4 = good quality, some flower / close to flower / buds; 5 = excellent quality, 90% in flower. Species: CTB - *Campanula persicifolia* 'Takion Blue'; CGA - *Campanula glomerata* 'Acaulis'; CP - *Coreopsis grandiflora* 'Presto', ECS - *Echinacea* 'Cheyenne Spirit'; GSW - *Gaura lindheimeri* 'Sparkle White; PFB - *Prunella grandiflora* 'Freelander Blue'; SRB - *Scabiosa japonica* var. *alpina* 'Ritz Blue'; SSD - *Silene alpestris* 'Starry Dreams'; VR - *Verbena rigida*.

Table 38. Average plant quality (polythene tunnel) assessed 28 March 2017 (week 14)

	Variety	Mean quality score	Duncan's multiple range test*	Standard error

1	*Campanula persicifolia* 'Taikon Blue'	1.8	abc	0.13
2	*Campanula glomerata* 'Acaulis'	1.7	ab	0.20
3	*Coreopsis grandiflora* 'Presto'	2.4	c	0.14
4	*Echinacea* 'Cheyenne Spirit'	1.4	a	0.26
5	*Gaura lindheimeri* 'Sparkle White'	1.8	abc	0.25
6	*Prunella grandiflora* 'Freelander Blue'	1.9	abc	0.16
7	*Scabiosa japonica* var. *alpina* 'Ritz Blue'	2.2	bc	0.08
8	*Silene alpestris* 'Starry Dreams'	3.0	d	0.00
9	*Verbena rigida*	1.9	abc	0.22
P = 0.05; Treatment Fprob. <0.001; s.e.d.0.2597; l.s.d. 0.5361				

Scale of 0-5: 0 = dead; 1 = very poor quality; 2 = poor quality; 3 = good quality, no flower; 4 = good quality, some flower / close to flower / buds; 5 = excellent quality, 90% in flower.

Table 39. Plant survival (polythene tunnel and glasshouse): percentage of plants surviving cool conditions under polythene and glass on 28.03.17 and 04.04.17 respectively

	Species	**Polythene tunnel (%)**		**Glasshouse (%)**	
		Pots	**Packs**	**Pots**	**Packs**
1	*Campanula persicifolia* 'Taikon Blue'	78	95	100	100
2	*Campanula glomerata* 'Acaulis'	92	96	100	100
3	*Coreopsis grandiflora* 'Presto'	62	83	100	97
4	*Echinacea* 'Cheyenne Spirit'	58	33	93	58
5	*Gaura lindheimeri* 'Sparkle White'	14	75	97	100
6	*Prunella grandiflora* 'Freelander Blue'	72	87	96	100
7	*Scabiosa japonica* var. *alpina* 'Ritz Blue'	85	87	100	62
8	*Silene alpestris* 'Starry Dreams'	100	100	100	100
9	*Verbena rigida*	97	77	97	97

	Mean	73	81	98	90

Post-transplanting growth in the glasshouse environment

The final plant quality assessment was carried out on 4 April 2017 (week 14) (**Figure 35,**

Appendix). None of the plants species were marketable, i.e. with 90% of the plants per plot with fully open flowers. However, by the 4 April 2017, fully open flowers were present in the *Scabiosa japonica* var. *alpina* 'Ritz Blue' (two plants) and *Silene alpestris* 'Starry Dreams' (three plants) under glass (**Figure 346**), although the peduncle was short on the *S.* 'Ritz Blue', so the flowers were not held above the foliage; this variety is expected to reach 18 cm. Buds were present on other species, with the *Campanula glomerata* 'Acaulis', *Campanula persicifolia* 'Takion Blue' and *Prunella grandiflora* 'Freelander Blue' in particular close to flowering. There were quality differences between pot and packs, with paler foliage in the Campanula glomerata 'Acaulis', *Campanula persicifolia* 'Takion Blue', *Coreopsis grandiflora* 'Presto', *Prunella grandiflora* 'Freelander Blue' and *Silene alpestris* 'Starry Dreams' in packs than pots.

Some cold damage was evident, particularly in the *Gaura lindheimeri* 'Sparkle White' and *Verbena rigida* where foliage scorch and purpling was present. Plant survival was better under glass than polythene, with 100% survival of *Campanula glomerata* 'Acaulis', *Campanula persicifolia* 'Taikon Blue' and *Silene alpestris* 'Starry Dreams' (**Table 39**) in both pots and packs. Converse to the results obtained for the polythene tunnel treatments, more plants in pots than packs survived.

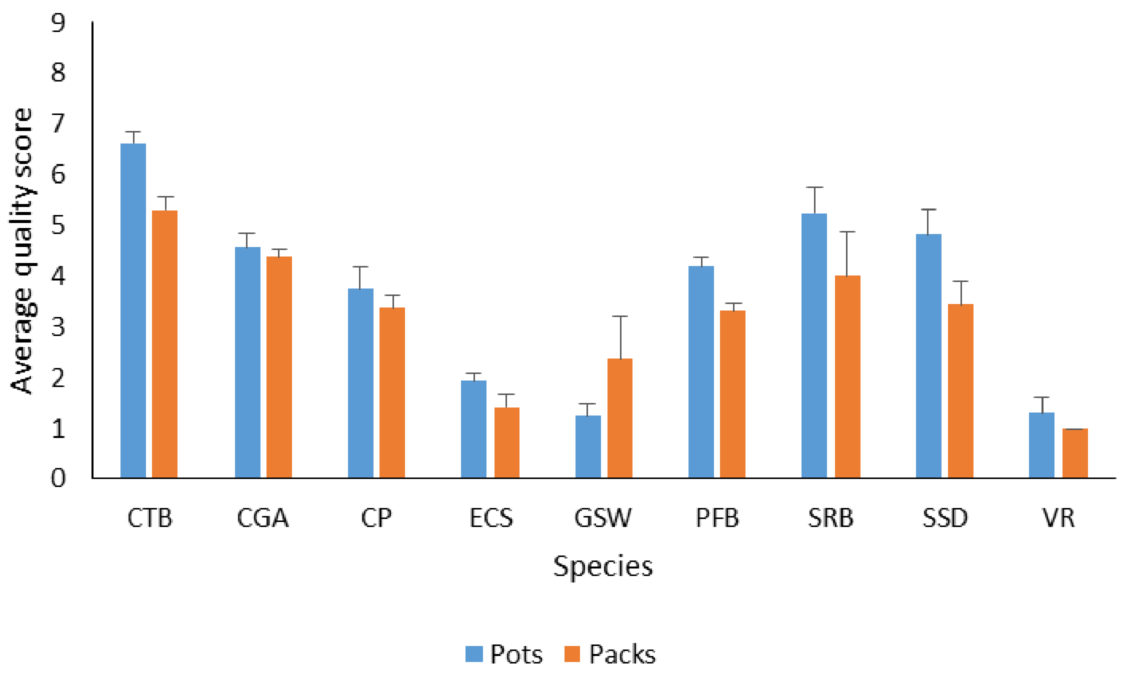


Figure 35. Average plant quality (glasshouse), pots and packs assessed 4 April 2017 (week 14)

Scale of 0-10: 0 = dead; 1 = poor, dying, cold damage; 2 = plants very small; 3 = 75% pot/pack cover; 4 = 100% pot/pack cover; 5 = flower spikes developing; 6 = flower spikes beginning to extend; 7 = flower spikes, no bud break; 8 = flower spike extended, bud break; 9 = fully open flowers on some plants; 10 = excellent quality, 90% in flower. Species: CTB - *Campanula persicifolia* 'Takion Blue', CGA - *Campanula glomerata* 'Acaulis', CP - *Coreopsis grandiflora* 'Presto', ECS - *Echinacea* 'Cheyenne Spirit', GSW - *Gaura lindheimeri* 'Sparkle White', PFB - *Prunella grandiflora* 'Freelander Blue', SRB - *Scabiosa japonica* var. *alpina* 'Ritz Blue', SSD - *Silene alpestris* 'Starry Dreams', VR - *Verbena rigida*.

Table 40. Glasshouse treatments: average plant quality, 4 April 2017 (week 14)

Variety	**Mean quality score**	**Duncan's multiple range test***	**Standard error**
Campanula persicifolia 'Taikon Blue'	3.4	f	0.29
Campanula glomerata 'Acaulis'	2.8	de	0.15
Coreopsis grandiflora 'Presto'	2.6	cd	0.24
Echinacea 'Cheyenne Spirit'	1.3	a	0.16
Gaura lindheimeri 'Sparkle White'	2.3	c	0.46
Prunella grandiflora 'Freelander Blue'	2.5	c	0.20
Scabiosa japonica var. *alpina* 'Ritz Blue'	2.3	c	0.52
Silene alpestris 'Starry Dreams'	3.0	e	0.41
Verbena rigida	1.9	b	0.16
P = 0.05; treatment Fprob. <0.001; s.e.d. 0.1426; l.s.d 0.2942			

Quality scores: scale of 0-10: 0 = dead; 1 = poor, dying, cold damage; 2 = plants very small; 3 = 75% pot/pack cover; 4 = 100 % pot/pack cover; 5 = flower spikes developing; 6 = flower spikes beginning to extend; 7 = flower spikes, no bud break; 8 = flower spike extended, bud break; 9 = fully open flowers on some plants; 10 = excellent quality, 90% in flower. *Mean scores with the same letter are not significantly different to each other.

Figure 346. Glasshouse: *Scabiosa japonica* var. *alpina* 'Ritz Blue' (above left) and *Silene alpestris* 'Starry Dreams' (above right), showing a low level of flower. 4 April 2017 (week 14)

Plant height

Differences in plant height (under glass) between the species are a reflection of the natural differences in height and habit (**Figure 37)**. Plants in pots were consistently larger than the corresponding plants in packs, largely due to container size and growing medium volume, and therefore fertiliser availability. Similar effects were observed with plants in the polythene tunnels. Growth with many of the species would require some kind of chemical control programme to improve the visual appearance of the product.

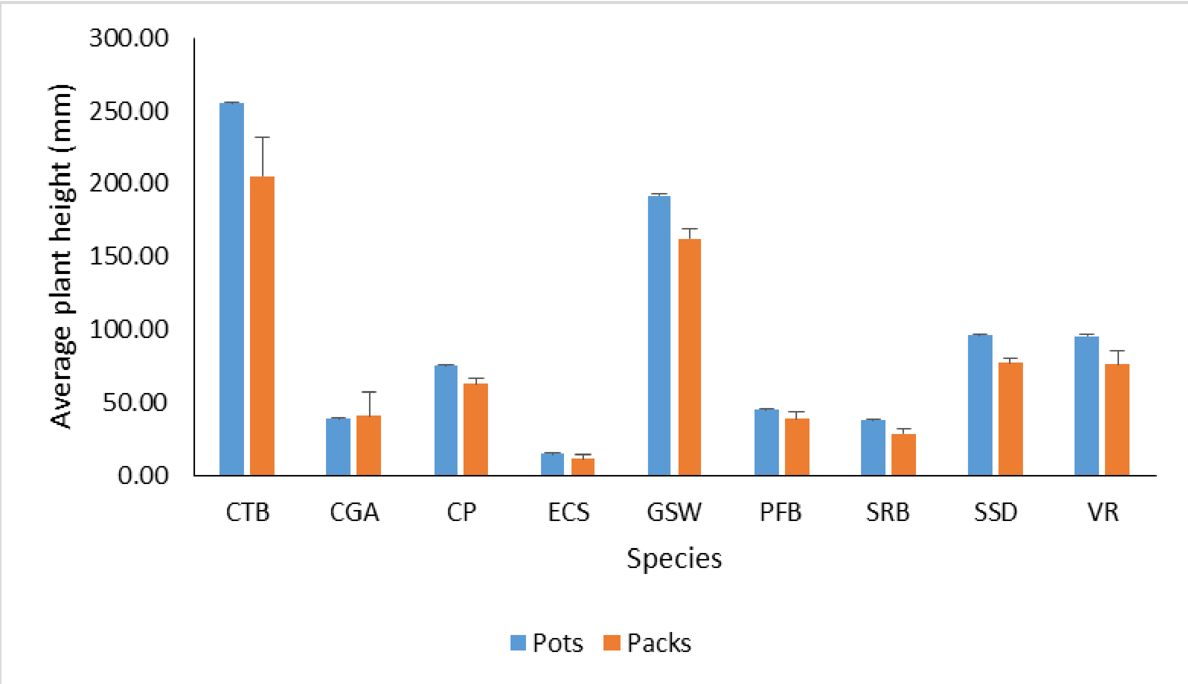


Figure 37. Plant height (glasshouse): assessed 4 April 2017 (week 14). Species: CTB - *Campanula persicifolia* 'Takion Blue', CGA - *Campanula glomerata* 'Acaulis', CP - *Coreopsis grandiflora* 'Presto',

ECS - *Echinacea* 'Cheyenne Spirit', GSW - *Gaura lindheimeri* 'Sparkle White', PFB - *Prunella grandiflora* 'Freelander Blue', SRB - *Scabiosa japonica* var. *alpina* 'Ritz Blue', SSD - *Silene alpestris* 'Starry Dreams', VR - *Verbena rigida*.

Discussion

Objective 1: Improving cutting success

The cuttings used for this trial spent five days in transit and were stuck one (first sticking); and five (second sticking) days after receipt (i.e. six and ten days after they were despatched from the cutting producers in transit, respectively. These transit times resulted in ethylene damage so that foliage became chlorotic and was removed, particularly for the second sticking. In a commercial setting, growers would dispose of the cuttings and the supplier would replace them, however as this trial was carried out late in the season replacement was not possible. However, although cutting condition was extreme, the purpose of this trial was to improve rooting and cutting quality while reducing rooting time.

The Omex SW7, Signum and Serenade ASO all produced promising results within this trial. In sticking 2 simple rehydration, particular applied as a long or quick dip treatment, also provided some increase the number of visible roots, although this was not statistically significant. Although one might expect the importance of disease control (and increased tolerance to stress as seen in strobiluron fungicides (e.g. from Signum) to have a greater influence on cutting success the greater the time difference between the cutting being taken and being stuck, there was no evidence of that in this trial. However, Signum did improve rooting in both the first sticking (six days between dispatch and sticking) and the second (10 days between dispatch and sticking).

Growers should also consider the importance of planning cutting operations to ensure that plant material is kept cool, and minimise the time that they are exposed and vulnerable to desiccation.

A further trial will be carried out in 2017, which will repeat the most promising treatments to see if they can be replicated, and to combine treatments to explore any synergistic effects of the treatments.

Objective 2: Verbena leaf spot and chlorosis

Minimal symptoms were observed in the two *Verbena* leaf spot and chlorosis trials, with symptoms only expressed in the summer trial, *V*. ‘Quartz blue’, dry treatments; these results were not statistically significant. The observed symptoms were low levels of marginal chlorosis, but no necrotic spots. Consideration of these results, the treatments explored and grower feedback suggest that water quality may have more influence on symptom development, particularly from high EC sources. Further work is planned for 2017 that will focus on water quality (high EC, rainwater and a blend), and environment (standard and high humidity) while still including pH (4.2 and 6.5) and irrigation management (wet and dry) treatments.

Objective 3: Spectral filters (glass coatings)

For this trial, application of the glass coating products differed from professional methods as they were applied by hand pressure sprayers as opposed to spray guns or the mechanical application and the products were applied to individual glass panes, rather than a large expanse of glass. Whilst the light diffusing products (e.g. ReduFuse and TransPar) had a greater tendency to run when applied, the products used generally dried to produce a fairly even coat; no other difficulties were encountered during application process such as blocked nozzles. The greatest difficulty encountered was that new glass is coated with silicon to make it easier to separate panes, and which in this instance prevented the coatings from adequately adhering to the glass. This was reflected in the higher relative light transmittance measured for products retained from the first application (the number of panes was determined by space availability on the frames). This difficulty did, however, serve to provide information on the removal of coatings as the release agent Removit (Hermadix) proved equally effective in removing products across all manufacturers. The manufactures do offer their own release agents, and other products are also available which may or may not be effective on all products.

The absolute transmission values presented in this report should only be used as guidance as they are influenced by the location of the sun (which changes with time of day and time of year) and the amount of product applied to each treatment. However, the light transmission of the different coatings varied as expected with shading material reducing light transmission to a greater extent than diffusing materials. The properties of the materials fell within the specification ranges provided by the manufactures and so achieving the desired amount of shading or light diffusion should be possible if the manufacturer's instructions are followed.

All the glass coatings resulted in the transmitted light being diffused, however, the measurements performed here were unable to determine how widely each material scattered light; it is likely that each material resulted in a different amount of diffusion. For example D-Fuse Floriculture, D-Fuse Vegetable and DeGree have very similar transmission values and spectra in the data reported here. However, the manufacturer states that these three products result in different haze factors, a measure of how strongly they diffuse the light. More detailed measurements using a hazemeter would be required to examine how these materials influence light structure. Plant growth trials would demonstrate to growers how the characteristics of these glass coatings, including haze factors, actually influence plant growth rate and quality (for more information on this topic see AHDB CP 147 project report).

During these measurements the sensor head of the spectroradiometer was enclosed in a black plant pot to avoid unfiltered light entering the sensor and influencing the transmission spectra. This results in the measurement being directional, only light from an area of 28 cm^2 (the size of the pot) directly in front of the sensor is measured. For non-diffusing materials (in this case only the standard glass) and direct sunlight conditions (as were encountered during the measurement period) the measurements would result in accurate assessments of light transmission. For diffusing materials this measurement method will result in an underestimate of the actual light transmittance. This is because the plant pot would prevent the measurement of low angle light and for materials with higher haze factors (greater light diffusion) the greater the magnitude of the underestimate. To gain more accurate estimates of absolute light transmission either measurements need to be made in coated glasshouses (ideally in association with plant growth trials) or measurements that can account for the spherical distribution of the light are required. While there is some uncertainty associated with the absolute light transmittance the relative differences in transmission between the products are expected to be correct. Furthermore the shapes of measured transmission spectra are also valid.

In general the coatings from the three manufactures had similar spectral properties. Diffusing and shading materials generally had relatively flat transmission spectra. Materials designed to reduce the heating effects of sunlight reduced transmission in the UV, far-red and NIR regions of the spectrum. While these materials reduced the transmission of NIR to a greater extent than PAR light transmission they do still reduce PAR and will therefore reduce the light available for plant growth.

Objective 4: Spectral filters (films)

The response of eight autumn flowering ornamental species grown under four types of polythene film between June and November 2016 varied with plant species and type of film. Compared with growth under untreated glass, Lumisol resulted in more compact plants of *Cheiranthus*, *Cineraria*, *Cyclamen* and *Viola* and appeared to delay flowering in *Cyclamen* and *Viola*. Luminance did not reduce plant height in any of the species tested, and increased it in four (*Bellis,* pansy*, Polyanthus* and primrose). This film advanced flowering in *Bellis*, *Cheiranthus,* pansy and primrose. SunSmart Blue resulted in more compact *Cheiranthus* plants and advanced flowering in primrose. Temperature will also have influenced plant height; with the general drop in temperature experienced in all treatments as autumn progressed more compact plants were generally produced under the cooler conditions.

Overall plant quality on 17 November 2016, compared with production under glass, was most improved by SunSmart Blue (five out of eight species) and least by Lumisol (two out of eight species). Overall, *Bellis, Polyanthus* and *Viola* showed the least improvements in compactness, advanced flowering and overall plant quality under the spectral films; *Cheiranthus* and primrose showed the greatest. These results indicate that the most appropriate spectral films for improved production of autumn flowering ornamentals will vary with the species grown and the desired outcome.

Objective 5: Pre-Christmas production of hellebore

The cold store malfunction adversely affected this trial, and it will be repeated in 2017. Under the conditions experienced by the varieties in this trial, the Exceptio varieties 'Molly's White', 'Anna's Red' and 'Penny's Pink' were more cold sensitive than other varieties; 'Royal Emma' proved more cold hardy. Although three plants of 'Royal Emma' and one 'Paradenia' did produce flowers prior to Christmas, given the very low temperature shock experienced by the plants and the small number of surviving plants it is not possible to determine if these plants would have been in flower under the planned cold temperature treatments had the equipment malfunction not occurred. However, there were no plants of these varieties with fully open flowers in the outdoor or indoor controls prior to Christmas.

Objective 6: Overwintered perennials

Under the conditions of this trial, none of the plants species reached the target marketable criterion (90% of the plants per plot with fully open flowers) by week 13/14. Some of the species, particularly the *Campanula glomerata* 'Acaulis', *Campanula persicifolia* 'Taikon Blue', *Prunella grandiflora* 'Freelander Blue', *Scabiosa japonica* var. *alpina* 'Ritz Blue' and *Silene alpestris* 'Starry Dreams' had buds and had either started to flower or were close to this stage. Had heat been applied to the crop sooner, more flowers may have been open.

Under glass, the plants in packs often did not achieve full canopy cover and were paler than those in pots; the smaller pot size and volume of growing medium are likely to have contributed to these differences.

The premise of this work was to produce plants in flower with minimal energy input such as heat and light. Many plants have critical vernalisation and photoperiod requirements to induce flowering, and such information is available for some but not all perennial species. Long day plants requiring >12 hour days are more likely to require photoperiodic or night break lighting to induce flowering under short day conditions. Of the nine species examined here, it is known that *Campanula persicifolia* 'Takion Blue' is day neutral (will flower under any day length), *Campanula glomerata* 'Acaulis' is a facultative long day plant (flowers faster under long days) and *Echinacea* 'Cheyenne Spirit' is a short day/long day (requiring a period of short days followed by long days; the remainder were long day plants (will flowers >12 hour days). A thorough review and careful selection of the species to be included and their specific requirements would need to be carried out to further enhance the prospects of achieving early spring flowering with minimal energy input.

Further work will also need to look at the effect of applying heat earlier in the production cycle. However, as the plants grown under these conditions would be softer this will need to include determination of plant growth regulator requirements to control or manipulate development. It is also important to put plants in the correct pot size to present them to their best advantage, and it may be that some of these species are more suited to pots than packs.

Conclusions

Objective 1: Improving cutting success

- Rooting of Geranium cuttings was improved by Omex SW7 (long dip), Rhizopon AA (quick dip) and Serenade ASO (long dip) in a batch of six-day old cuttings; and by Omex SW7 (quick dip), Signum (quick dip) and Serenade ASO (long dip) in a batch of 11-day old cuttings.
- Spray treatments of these products were not effective.
- Fructose and water treatments were generally ineffective, although there was a trend for long dip water treatment to improve rooting.

Objectve 2: Verbena leaf spot and chlorosis

- None of three *Verbena* varieties grown under different watering regimes (dry, standard, wet), pH (4.5, 5.8 and 6.5) and trace element delivery (fritted and unfritted) in spring and summer 2016 developed leaf spot symptoms. The cause of spotting and chlorosis remains unknown.

Objective 3: Spectral filters (glass coatings)

- Fifteen glass coating products tested on new horticultural glass reduced sunlight trasmission as expected (as specified by the manufacturers).
- All the glass coatings resulted in light being diffused; the extent of the diffusion was not determined.
- In general the coatings from Hermadix, Mardenkro and Sudlac had similar spectral properties.

- Materials designed to reduce heating (Q Heat, TransPAR and ReduHeat) reduced transmission in UV (315-400 nm), far red and NIR regions of the spectrum.
- The release agent Removit was equally effective on all products.
- New glass is difficult to coat evenly due to the silicon coating applied to make it easier to separate panes.

Objective 4: Spectral filters (films)

- The response of plants to spectral films varied with species and film.
- Compared with untreated glass, Lumisol film resulted in more compact plants of four species (*Cheiranthus, Cineraria, Cyclamen* and *Viola*) and SunSmart Blue in one species (*Cheiranthus*). Luminance increased plant height of four species and reduced it in none.
- SunSmart Blue improved quality in five of eight species tested, Luminance in four and Lumisol only in two.
- None of the films improved compactness or quality of *Bellis*.
- Compared with untreated glass, Luminance appeared to advance flowering in *Bellis, Cheiranthus,* pansy and primrose; Lumisol in *Cyclamen,* pansy and primrose; and SunSmart Blue in *Cyclamen,* pansy and primrose.
- Lumisol appeared to delay flowering in *Cheiranthus, Polyanthus* and *Viola*. Luminance appeared to delay flowering in *Cyclamen* and *Viola*; SunSmart Blue in pansy and *Viola*.

Objective 5: Pre-Christmas production of hellebore

- A cold store malfunction which resulted in potted hellebore plants experiencing temperatures down to -16°C for a few hours resulted in a high incidence of plant death in the varieties 'Anna's Red', 'Molly's White' and 'Penny's Pink'. Nearly all plants of the varieties 'Royal Emma' and 'Madam Lemonnier' survived.
- Of the plants that survived, three 'Royal Emma' and one 'Paradenia' from cold treatments 1 and 2 respectively came into flower earlier than the control.

Objective 6: Overwintered perennials

- Scabiosa japonica var. alpina 'Ritz Blue' and Silene alpestris 'Starry Dreams' sown on 29 July 2016, transplanted on 3 October 2016 and grown on in a cool glasshouse had fully open flowers present by the end of March 2017.
- *Campanula glomerata* 'Acaulis', *Campanula persicifolia* 'Takion Blue' and *Prunella grandiflora* 'Freelander Blue', sown on 29 July 2016 (except for the *Campanula persicifolia*

'Takion Blue', sown on 6 July 2016), transplanted on 3 October 2016 and grown on in a cool glasshouse all had flower buds present by the end of March 2017.

- Two weeks of heat at 15˚C from (24 March 2017 to 4 April 2017) was not enough to advance plants of any of the species tested to flowering by the end of March.
- It is unlikely that *Echinacea* 'Cheyenne Spirit' in particular will achieve flowering prior to week 13 without specific criteria being met, including some photoperiodic lighting.
- Gaura lindheimeri 'Sparkle White' and Verbena rigida in particular suffered cold damage when grown in a glasshouse / polythene tunnel with minimum temperatures of – 3.7˚C and – 4.4˚C respectively.
- Future work should focus on more detailed scheduling regimes of carefully screened species.

Knowledge and Technology Transfer

- Blog (https://ahdbbppcblog.wordpress.com). Nine blogs were issued for each trial carried out, for the summer open evening and two for the South Coast Study Tour.
- Open days at Baginton Nurseries (13 May and 23 June 2015; 12 and 21 April and 21 June 2016)
- South Coast Study Tour (14 -15 September 2016)
- Diffuse light study tour, the Netherlands (21-23 March 2017)
- AHDB Grower articles:

  England, J., Whiteside, C. (2015) HDC News Issue 210, pg. 28 - 30

  England, J., Whiteside, C. (2015) AHDB Grower Issue 219, pg. 15 – 18

  England, J., Whiteside, C. (2016) AHDB Grower Issue 229, pg. 19 - 21
- Presentations at GroSouth (November 2014 and November 2015) and the BPOA Technical Seminar (January 2015, January 2016 and January 2017)
- Presentation at the Softwood Propagation of Ornamentals 'Managing quality through the propagation process' event (7 February 2017)

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Appendix 1

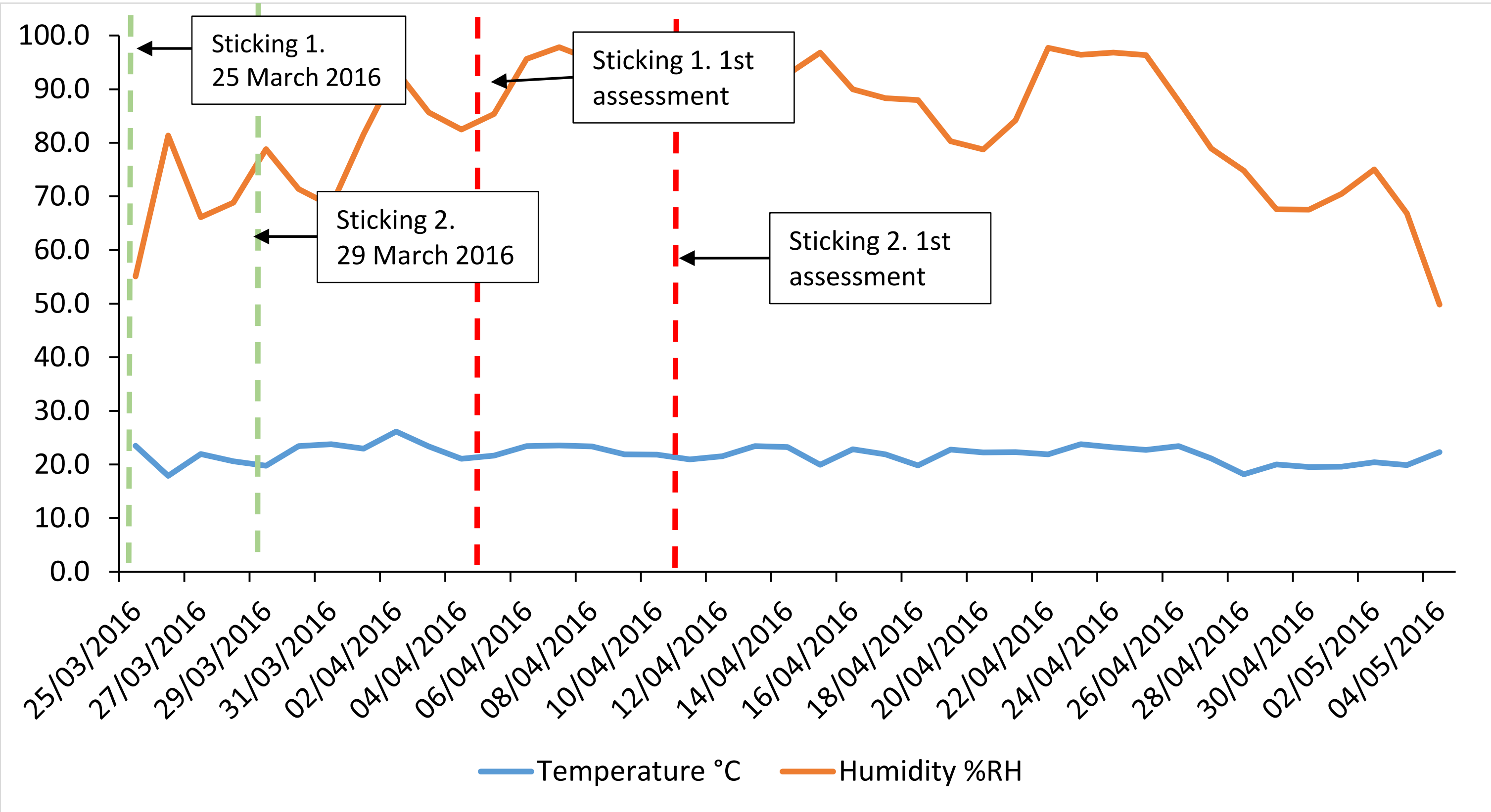
Improving cutting success

Table i. Effect on plant quality and rooting of pre-sticking treatments applied to 6-day old and 11- day old cuttings of Geranium 'Bianca'

Treatment		Cutting quality		Mean no. rooted (of 15)	
Product	Method	6 day old cuttings†	11 day old cuttings††	6 day old cuttings†	11 day old cuttings††
Untreated	-	+	+	0.5	1.5
Water	Spray	+	+	0.5	1.75
	Quick dip	+	+	1.5	2.5
	Long dip	+	+	1.0	3.0
Omex SW7	Spray	+	+	0.8	3.0
	Quick dip	+	(+)	2.0	**3.75**
	Long dip	+	+	**3.8**	3.25
Signum	Spray	+	+	0.5	2.0
	Quick dip*	+	+	2.0	**4.0**
	Long dip*	+	+	1.5	2.75
Fructose	Spray	+	+	0.8	1.75
	Quick dip	+	+	1.0	2.0
	Long dip	+	+	1.0	2.25
Rhizopon AA	Spray	+	+	0.6	1.5
	Quick dip	(+)	-	**4.5**	0.75
	Long dip	-	-	2.0	0.5
Serenade ASO	Spray	+	+	1.0	3.0
	Quick dip*	+	+	1.0	2.75
	Long dip*	+	+	**2.5**	**3.5**

Cutting quality: + average; (+) slightly below average; - poor. Rooting success: values in bold are significantly better than untreated. *No label recommendations. †Assessed 11 days after treatment. †† Assessed 13 days after treatment.

Figure i. Temperature and humidity. 24-hour average



Appendix 2

Verbena leaf spot and chlorosis

Table i. *Verbena* nutrition spring trial –unused growing medium analysis (Bulrush Horticulture Ltd.)

Lab Ref	Sample Name	Dens	pH	Cond	$NH^{4-}N$	$NO^{3-}N$	Total N	Cl	K	Mg	Ca	Na	Fe	P	Cu	Mn	Zn	B	SO_4
		g/l		us/cm	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
94106	*Verbena* -T1	383	5.3	374	68.1	135.2	203.3	16.3	170.4	47.0	70.8	33.9	1.38	37.7	0.03	0.5	0.13	0.14	280.4
94107	*Verbena* -T2	378	5.3	346	71.2	115.2	186.4	15.6	134.4	37.0	53.5	31.0	0.27	38.1	0.02	0.33	0.04	0.07	272.3
94108	*Verbena* -T3	373	5.9	339	52.0	121.3	173.4	16.6	136.8	40.8	70.5	31.5	1.01	25.1	0.03	0.26	0.09	0.12	243.6
94109	*Verbena* -T4	369	5.9	351	57.0	118.6	175.6	15.6	140.2	45.7	88.2	30.8	0.25	29.0	0.01	0.21	0.03	<0.05	262.6
94110	*Verbena* -T5	355	6.2	312	43.8	135.0	178.8	16.1	129.7	41.3	82.4	30.6	0.86	22.8	0.02	0.21	0.09	0.10	217.9
94111	*Verbena* -T6	369	6.3	371	62.2	124.7	186.9	16.7	142.6	46.8	91.0	31.5	0.23	30.1	0.01	0.21	0.03	<0.05	284.6

Table ii. Baginton Nurseries water analysis 2016

	pH	EC	Nitrate-N	Cl	SO_4	P	B	K	Cu	Mg	Mn	Ca	Zn	Na	Fe	Carbonate	Alkalinity as HCO3
Units		uS/cm	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Value	7.6	330	2.8	32.5	47.5	1.0	0.03	2.7	<0.01	5.73	<0.01	30.4	0.01	27.3	0.06	<10	80

Table iii. Growing medium analysis – spring and summer trials. FTE = fritted trace elements, TE = unfritted trace elements, Std = standard irrigation treatment, Dry = dry irrigation treatments

Spring trial		pH	EC at 20°C	Density	Dry matter	Dry density	NH_4	NO_3	Total sol. N	Cl	P	K	Mg	Ca	Na	SO_4	B	Cu	Mn	Zn	Fe
Status	Treatment		uS/cm	kg/m3	%	kg/m3	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Unused	pH 4.5 + TE	5.2	306	342	33.8	115.6	67.8	102.9	170.7	13.5	33.3	129.7	29.9	42.8	27.8	219.9	0.07	0.02	0.34	0.05	1.09
	pH 5.8 + TE	5.8	313	359	35.0	125.7	70.7	101.4	172.1	14.7	28.6	122.3	28.1	45.3	29.2	226.0	<0.05	0.02	0.25	0.07	1.01
	pH 6.5 + TE	6.1	292	346	34.8	120.4	292	88.8	149.9	15.6	25.1	109.5	27.8	50.1	27.2	214.2	<0.05	0.02	0.19	0.08	0.96
Used	pH 4.5 Std + TE	5.3	80	312	31.3	97.7	5.8	1.5	7.3	16.0	3.9	10.8	8.2	14.0	42.2	153.8	0.07	0.02	0.07	0.18	1.60
	pH 5.8 Std + TE	5.8	108	280	41.4	115.9	5.4	2.8	8.2	12.8	3.9	9.9	15.1	26.1	48.9	213.8	0.06	0.02	0.08	0.06	1.20
	pH 6.5 Std + TE	6.1	100	244	48.9	119.3	5.1	1.3	6.4	11.1	3.6	8.2	13.3	25.8	44.5	181.6	0.06	0.02	0.06	0.06	0.87
	pH 4.5 Std + FTE	4.9	123	265	42.4	112.4	5.1	<0.6	5.4	24.9	3.6	8.7	16.3	26.0	58.7	239.7	0.05	0.01	0.15	0.05	0.87
	pH 5.8 Std + FTE	5.8	42	348	30.2	105.1	3.9	<0.6	4.3	8.1	3.3	5.0	2.1	3.9	21.5	41.6	<0.05	0.02	0.01	0.05	0.52
	pH 4.5 Std + FTE	6.2	51	325	31.2	101.4	3.8	<0.6	4.2	7.8	2.2	5.4	3.6	6.3	25.3	51.1	<0.05	0.01	0.01	0.04	0.88

Summer trial		pH	EC at 20ºC	Density	Dry matter	Dry density	NH_4	NO_3	Total sol. N	Cl	P	K	Mg	Ca	Na	SO_4	B	Cu	Mn	Zn	Fe
Unused	pH 4.5 +TE	4.7	338	339	36.0	122.0	91.3	113.9	205.3	12.7	43.9	124.3	22.4	35.9	24.1	222.4	<0.05	<0.01	0.31	0.04	0.33
	pH 5.8 +TE	5.4	352	365	36.9	134.7	92.5	132.8	225.3	13	42.7	125.2	23.4	40.6	25.6	227.7	<0.05	0.01	0.23	0.04	0.28
	pH 6.5 +TE	6.0	353	343	37.7	129.3	88.3	112.7	201.0	13.6	37.6	122.5	22.4	48.5	24.4	227.7	<0.05	0.01	0.18	0.03	0.32
Used	pH 4.5 Dry + TE	5.0	136	293	32.2	94.3	15.6	21.1	36.7	35.3	14.1	58.0	8.9	15.9	51.2	167.6	0.06	0.03	0.11	0.04	0.77
	pH 5.8 Dry + TE	6.0	128	335	31.5	105.5	10.3	3.3	13.5	27.9	9.3	37.3	11.4	21.2	54.7	217.1	<0.05	0.03	0.07	0.08	0.73
	pH 6.5 Dry + TE	6.7	146	310	32.9	102.0	9.0	8.7	17.7	29.0	7.8	35.8	14.5	36.5	60.6	189.5	<0.05	0.02	0.05	0.08	0.54
	pH 4.5 Dry + FTE	5.1	113	299	31.9	95.4	12.6	11.9	24.5	34.5	13.7	45.0	6.5	11.7	50.0	152.1	0.06	0.02	0.07	0.06	0.70
	pH 5.8 Dry + FTE	6.0	136	336	35.5	119.3	11.2	7.2	18.3	44.1	11.5	42.6	12.5	23.0	58.7	213.7	<0.05	0.04	0.06	0.08	1.14
	pH 6.5 Dry + FTE	6.6	236	344	34.0	117.0	11.7	17.1	28.8	44.7	11.6	61.5	29.0	68.6	79.1	330.5	<0.05	0.02	0.12	0.09	0.74

Table iv. Leaf tissue analysis – spring and summer trial. FTE = fritted trace elements, TE = unfritted trace elements, Std = standard irrigation treatment, Dry = dry irrigation treatments

		Total nutrients										
		N Dumas	P	K	Ca	Mg	S	Mn	Cu	Zn	Fe	B
SPRING TRIAL		% w/w	% w/w	% w/w	% w/w	% w/w	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Unused	*V*. Quartz Blue	3.74	0.62	4.09	3.19	0.70	4105	118	14.6	60.0	499	25.8
Used	pH 5.8 FTE Std Quartz Blue	2.42	0.47	2.85	2.10	0.80	3571	167	6.3	38.4	352	37.3
Used	pH 5.8 TE Std Quartz Blue	2.34	0.41	2.92	1.85	0.72	3976	167	5.8	33.1	295	39.5
SUMMER TRIAL												
Unused	*V*. Quartz Blue	3.42	0.48	3.56	3.39	0.66	3747	121	11.4	48.3	404	34.5
Unused	*V*. Obsession Scarlet	3.00	0.87	4.87	1.42	0.74	8580	73	10.2	43.0	288	33.2
Unused	*V*. Temari Blue	3.09	0.46	2.89	2.12	0.71	4675	68	8.9	59.0	148	43.7
Used	pH 4.5 TE DRY Quartz Blue	2.23	0.47	3.03	1.23	0.42	3421	155	3.7	27.7	140	29.8
Used	pH 4.5 FTE DRY Quartz Blue	2.40	0.44	3.09	1.30	0.45	4028	159	3.5	27.1	86.2	34.8
Used	pH 5.8 TE DRY Quartz Blue	2.14	0.42	2.92	1.54	0.51	3369	137	4.1	25.7	107	31.8
Used	pH 5.8 FTE DRY Quartz Blue	2.32	0.37	2.94	1.33	0.46	3271	114	3.8	23.2	48.6	27.4
Used	pH 6.5 TE DRY Quartz Blue	2.19	0.39	2.96	1.55	0.46	2975	109	2.9	20.8	102	28.2
Used	pH 6.5 FTE DRY Quartz Blue	2.17	0.40	2.90	1.54	0.47	3042	109	2.7	21.4	71.6	27.7

Appendix 3

Spectral filters (glass coatings)

Figure i. Glass coating products applied by hand held pressure sprayer on 14 July (week 28)

D-Fuse Floriculture - Hermadix

D-Fuse Vegetable – Hermadix

DeGree - Hermadix

Q Heat - Hermadix

Q3 - Hermadix

Q4 - Hermadix

ReduHeat - Mardenkro

ReduSol - Mardenkro

ReduFuse - Mardenkro

ReduFuseIR - Mardenkro

TransPAR - Sudlac

Eclipse LD - Sudlac

Optifuse Sudlac

Optifuse IR - Sudlac

Optimix RB - Sudlac

Appendix 4

Spectral filters (glass coatings)

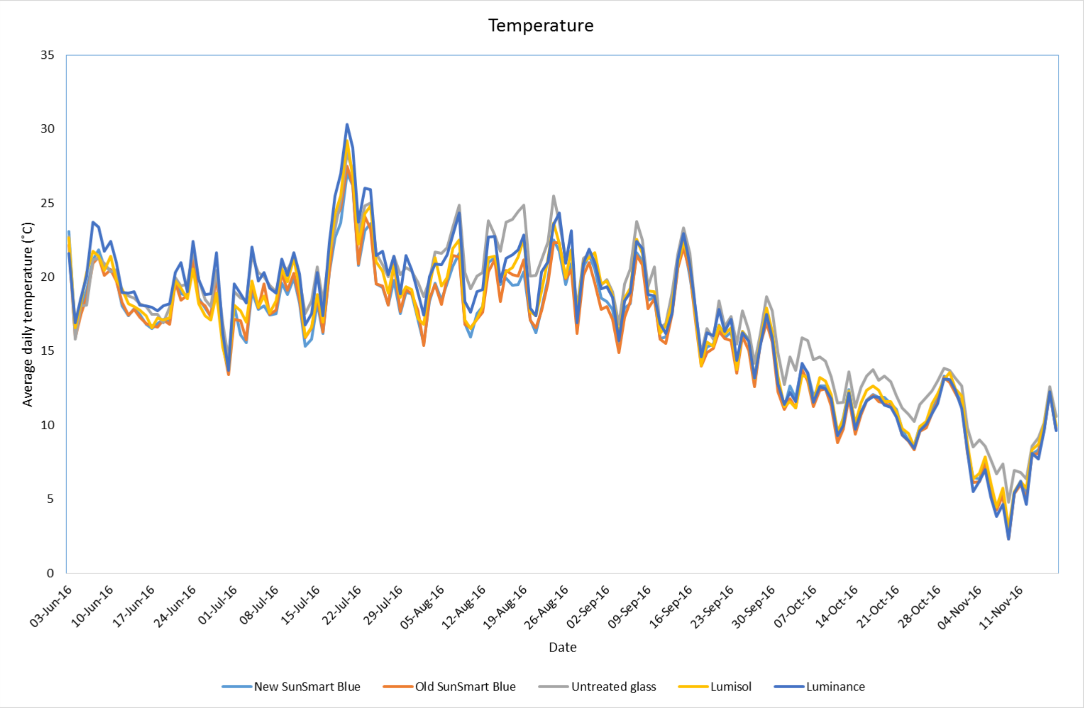
Table i. Light transmission data for treatments and untreated glass and diffused glass. Transmission data are presented as a percentage of ambient sunlight (each is an average of six measurements)

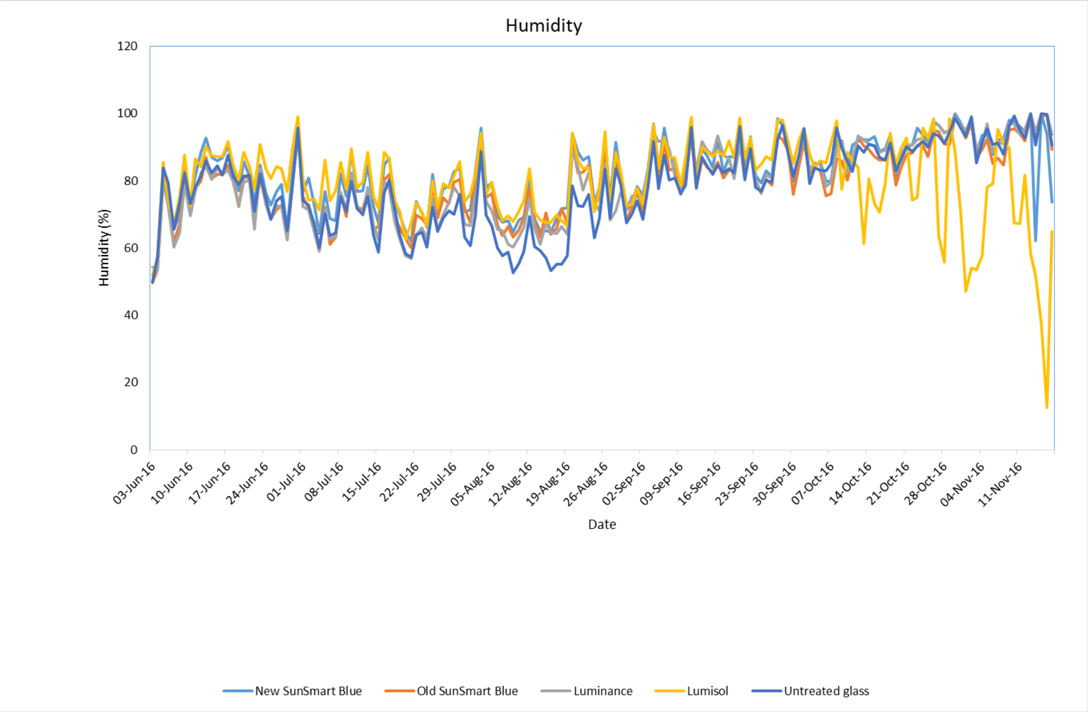
	14 Jul	19-Jul	10-Aug	16-Aug	31-Aug	23-Sep	28-Sep	10-Oct	26 Oct	07-Nov
Product	70% cloud	Clear	100% cloud	60% cloud	90% cloud		Intermittent sun	Clear, becoming cloudy	100% cloud	Clear, becoming cloudy
Untreated glass	88%	94%	91%	81%	90%	91%	89%	92%	83%	83%
Untreated diffused glass	90%	94%	91%	83%	92%	94%	92%	93%	83%	87%
D-Fuse Floriculture	78%	84%	88%	72%	87%	81%	78%	81%	72%	73%
D-Fuse Floriculture (1st application)	79%	86%	77%	63%	83%	86%	87%	82%	76%	79%
D-Fuse Vegetable	79%	87%	83%	74%	83%	80%	78%	80%	72%	71%
DeGree	81%	90%	87%	77%	85%	86%	83%	84%	73%	73%
Q Heat	75%	77%	79%	66%	75%	77%	70%	75%	69%	70%
Q3	59%	69%	69%	52%	63%	69%	65%	74%	55%	67%
Q4	49%	61%	53%	46%	55%	61%	58%	65%	48%	65%
Q4 (1st application)	72%	81%	77%	60%	78%	79%	81%	78%	71%	78%
ReduFuse	81%	89%	85%	74%	87%	81%	81%	82%	79%	73%
ReduFuseIR	75%	80%	78%	64%	74%	74%	71%	74%	71%	69%
ReduFuseIR (1st application)	75%	79%	79%	71%	78%	80%	87%	82%	78%	78%
ReduHeat	61%	70%	68%	55%	62%	64%	63%	67%	58%	60%
ReduSol	54%	66%	59%	49%	60%	70%	64%	67%	50%	66%
Optifuse	80%	91%	84%	73%	81%	84%	82%	81%	77%	74%
Optifuse IR	80%	85%	79%	68%	76%	79%	78%	73%	72%	68%
Optimix RB	75%	81%	74%	64%	74%	76%	81%	74%	70%	75%
Optimix RB (1st application)	76%	87%	80%	67%	77%	78%	84%	80%	73%	78%
TransPAR	71%	77%	70%	62%	68%	69%	68%	65%	66%	65%
Eclipse LD	48%	58%	57%	45%	53%	58%	53%	63%	45%	56%

Appendix 5

Spectral filters (films)

Figure i. Environmental data within each treatment

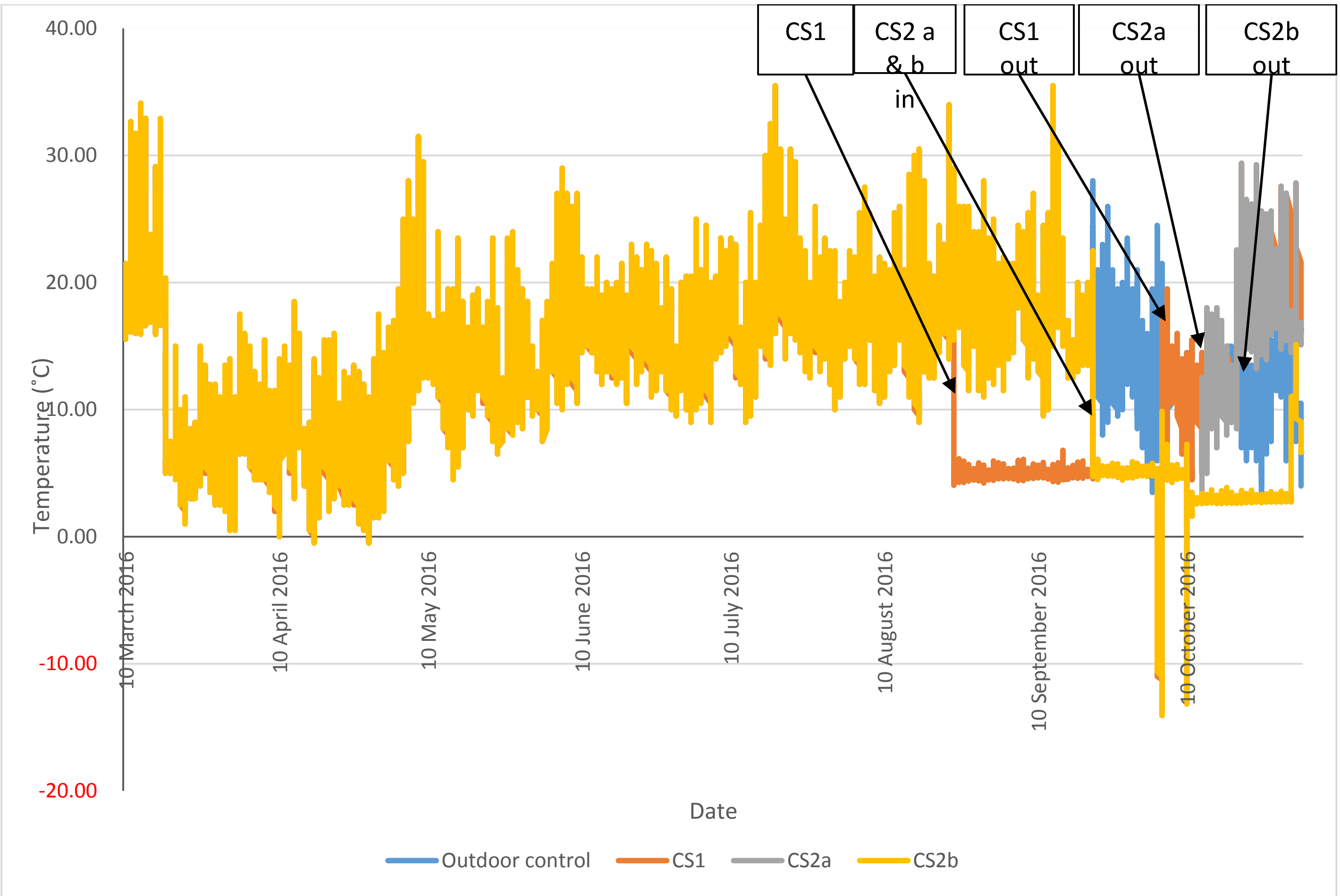




Appendix 6

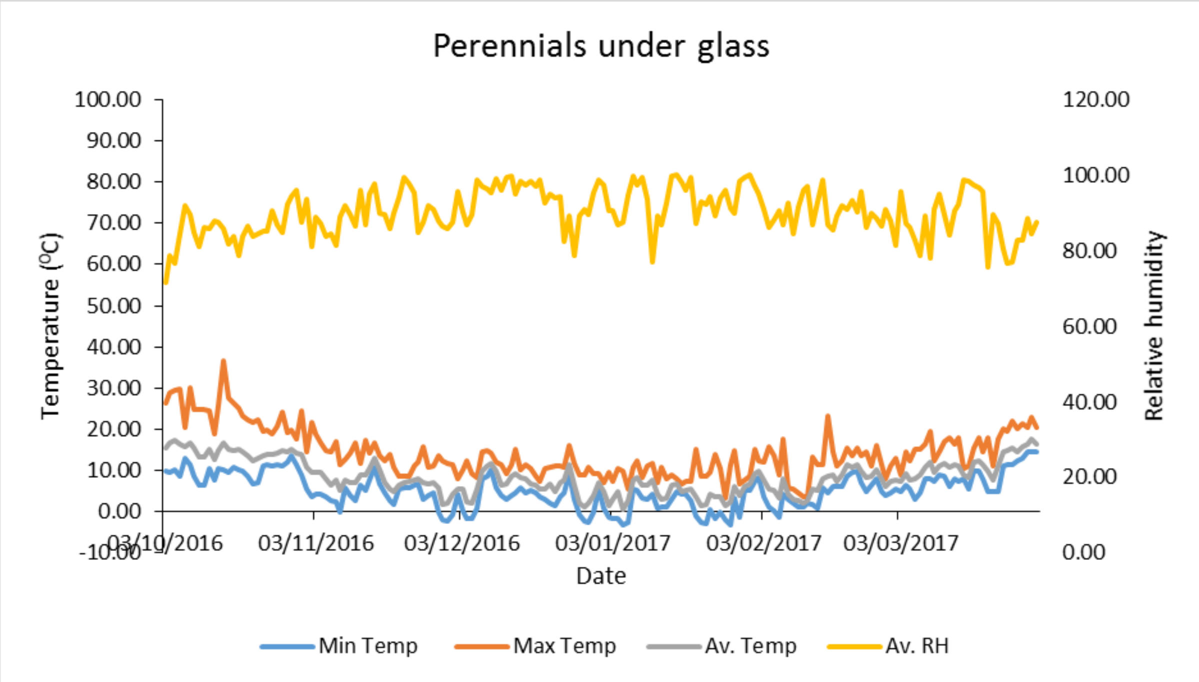
Pre-Christmas production of hellebore

Figure i. Treatment temperatures, identify plant movements in and out of cold store. CS = cold store; outdoor control = plants were outdoors throughout the trial. Treatments CS1, CS2a and CS2b all experienced the low temperature denoted by CS2b (yellow series)



Appendix 7

Figure i. Overwintered perennials: glasshouse and polythene tunnel temperature and humidity



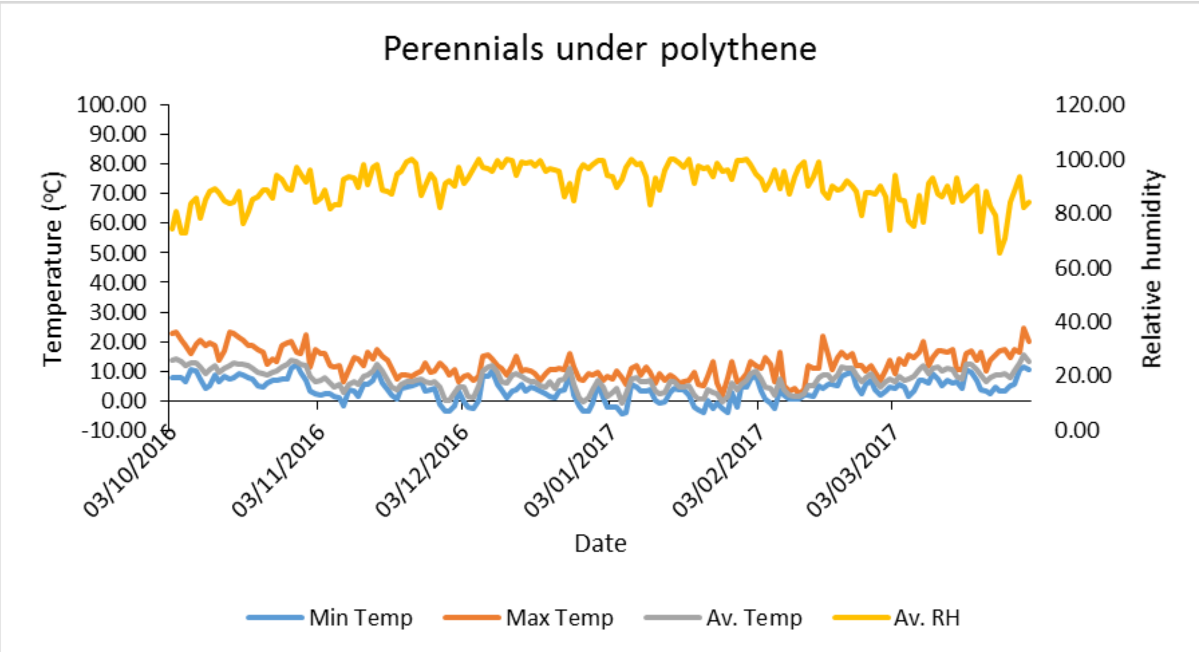


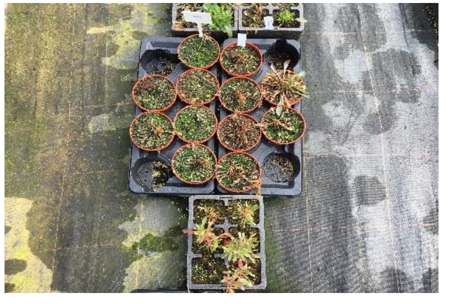
Figure ii. Overwintered perennials. Polythene tunnel 28.03.17 (week 13)

Campanula persicifolia 'Takion Blue'

Campanula glomerata 'Acaulis'

Coreopsis grandiflora 'Presto'

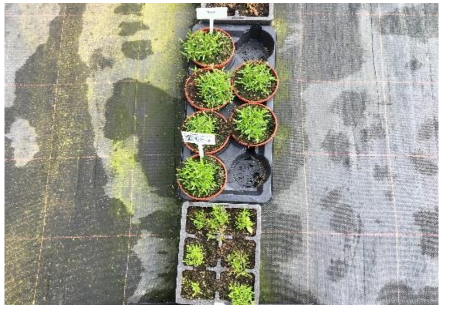
Echinacea 'Cheyenne Spirit'



Gaura lindheimeri 'Sparkle White'

Prunella grandiflora 'Freelander Blue'

Scabiosa japonica var. *alpina* 'Ritz Blue'



Silene alpestris 'Starry Dreams'

Verbena rigida

Figure iii. Overwintered perennials. Glasshouse 05.04.17 (week14)

Campanula persicifolia 'Takion Blue'

Campanula glomerata 'Acaulis'

Coreopsis grandiflora 'Presto'

Echinacea 'Cheyenne Spirit'

Gaura lindheimeri 'Sparkle White'

Prunella grandiflora 'Freelander Blue'

Scabiosa japonica var. *alpina* 'Ritz Blue'

Silene alpestris 'Starry Dreams'

Verbena rigida

Table i. Summary of general observations on the plant species examined

Campanula persicifolia 'Takion Blue'	PGR was applied to the *Campanula persicifolia 'Takion Blue'*, causing them to become firmer with darker green foliage. The plants in packs were smaller, with lighter coloured foliage and would benefit from 'bulking up'. Good pot cover was generally achieved by those in pots (rather than packs). For the plants in this trial, removal of dead basal leaves would be required prior to dispatch. Plant height was variable within plots. These plants would have benefitted from an earlier PGR application. *Campanula persicifolia* is a day-neutral plant.
Campanula glomerata 'Acaulis'	PGR was applied to the *Campanula glomerata* 'Acaulis', firming and darkening the foliage. Good pot cover in both pots and packs was achieved. Plants in packs were paler than in pots. A number of plants were coming up to flower in the glasshouse treatments. This is a facultative long day plant.
Coreopsis grandiflora 'Presto'	The *Coreopsis* plants had good pot cover, with many of the leaves developing their adult form and flower spikes developing. Some basal cleaning would be required for this plant. *Coreopsis grandiflora* varieties are long-day plants.
Echinacea 'Cheyenne Spirit'	These plants were considerably behind the other species, being very small plants with insufficient bulk, although some plants did make better growth by the final assessment on 4 April 2017 under warmer conditions. The photoperiodic response of *Echinacea* appears to be more complex than a simple short-day or long-day response. Echinacea is reported to have a "dual" photoperiodic requirement, and is categorised as a short-day/long-day plant (flowering occurs earliest if plants have been exposed to a period of short days followed by a period of long days).
Prunella grandiflora 'Freelander Blue'	There was some uneven growth within plots, however, good pot cover was achieved, with some plants close to flowering. No or minimal basal leaf cleaning was required with these plants. *Prunella grandiflora* is a long day plant.
Gaura lindheimeri 'Sparkle White'	Although the *Gaura* was showing signs of cold damage, with marks on the leaves, the plants were producing healthy new growth. For these plants there were some dead basal leaves that would require removal prior to despatch. *Gaura lindheimeri* is a long day plant that flowers naturally between June and September.
Scabiosa japonica var. *alpina* 'Ritz Blue'	The *Scabiosa* were close to flowering, with buds on many plants. They did not generally achieve pot cover prior to flowering. The flowering height of this variety is 18 cm, but in this trial the flowers were produced at basal leaf level. There were few dead basal leaves that would require removal prior to dispatch. This *Scabiosa* species is a long day plant.
Silene alpestris 'Starry Dreams'	*Silene alpestris* 'Starry Dreams' has a creeping habit, and was prone to growing over the side of the container as it came up to flower. It appeared to benefit from being grown cooler as more compact plants were produced under polythene than glass, albeit none were in flower by the end of the trial. These plants would have benefited from a PGR application earlier in the production cycle to keep them within the bounds of the pot. *Silene alpestris* 'Starry Dreams' is a long day plant that usually flowers from late spring.
Verbena rigida	Many of the *Verbena* had marginal leaf scorch, but produced healthy new growth. It naturally flowers during the summer and autumn.