Project title: A practical evaluation of the potential technical and economic benefits of modifed plastic crop covers for horticultural crops

Project number: CP 19

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The results and conclusions in this report are based on a series of crop scale observations, crop trials and more detailed field- and laboratory-based experiments conducted over a two year period. The conditions under which the studies were carried out and the results have been reported with detail and accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with the interpretation of the results especially if they are used as the basis for commercial product recommendations.

Authentication

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

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

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Grower Summary

Headlines

- The overall aim has been to evaluate the potential technical and commercial benefits effects of five spectral filters on a wide range of commercially important crops.
- The 2003 and 2004 seasons were very different, providing comparisons under contrasting weather conditions. Results were generally consistent across the seasons although many of the effects were more pronounced in brighter weather.
- There have been marked effects of filters on plant growth regulation, canopy development, time to flowering, colour intensity and oil production. These have varied between plant species / cultivars.
- More detailed scientific studies, using young lettuce plants as a model, have provided an insight into some of the underlying physiological changes.
- Young lettuce plants partly raised under UV transparent films were consistently shorter and stockier than those produced by the commercial standard, making them less vulnerable to physical damage during mechanised planting.
- A filter which modified the ratio of red:far red light reaching the crop has shown potential to regulate plant growth, which could provide an alternative to chemical growth regulators in some ornamental crops.
- Foliar pigmentation was more intense in lollo rosso when grown under the UV-transparent filter. Switching plants from UV-opaque to UV-transparent mid way through production provided benefits in terms of both yield and pigmentation.
- The wet summer in 2004 demonstrated the benefits of protecting cut flowers from the vagaries of British weather. More subtle effects on these crops resulting from the choice of filters are being evaluated.
- The UV-transparent filter has produced flowers with more intense colouration in red and blue asters, and red and blue pansies, particularly under brighter conditions.
- Plant canopy development was altered in a number of crops grown under various filters. For example, an increase in vegetative cover was observed in asters under a red / far red (Solatrol) modifying film.
- Growth modifications resulting in increased biomass were recorded in perennial herbs. This gave greater oil yield under all filters relative to open plot plants (*eg.* plus 500% and 541% under UV-opaque for rosemary and sage respectively).

Project background and expected deliverables

The cultivation of crops under simple plastic covered structures is now commonplace in UK horticulture because of its potential to extend growing seasons, control harvests and improve the quality of produce. In recent years advances in technology have allowed the manufacture of novel materials that ‘fine-tune’ the growing environment still further, by manipulating the quantity and wavelength of light reaching the crop. Much of the international research on modified plastics has been carried out in warm climates and has concentrated on the absorption of UV light to reduce the scorching effects of the sun, to manipulate pest behaviour, and to reduce establishment of certain pathogens. However, in the UK there may be greater benefits from improving transmission of UV light, which could harden the plant cuticle, reduce the trauma of planting out, improve resistance to pests and disease, reduce the need for artificial growth regulators, increase oil content of aromatic plants and improve colour intensity of flowers and foliage. More specifically, the manipulation of the red : far red light ratio can provide predictable modification of plant growth, while the manipulation of infra red wavelengths can have a cooling effect in summer, which could improve the quality of certain cut flowers.

Although a limited number of small-scale studies have investigated the potential impacts of this technology on UK crop production, the majority of large-scale work has been carried out on crops common to arid regions. In contrast, the aim of this long-term, large-scale project is to investigate the costs and benefits to the UK horticultural industry of adopting modern plastic technology, by concentrating on crops that are of specific importance to the UK market. This project will clarify the situation by evaluating plastic covers with a broad range of light manipulating properties, determine their benefits to key UK horticultural crops and rapidly transfer that technology to UK growers. In addition, the proposed research will provide direction for more fundamental scientific studies to determine the underlying mechanisms, with a view to further enhancing the beneficial effects of such filters, and aiding in the development of new spectral filters.

Summary of the project and main conclusions.

The project, driven by a consortium of growers (*i.e.* Grower Steering Group or GSG) from a wide range of commodity sectors, began in March 2003 with the overall aim of "developing, evaluating and implementing technologies to exploit the benefits of modified plastic crop covers in UK horticulture".

The current project is designed and managed by a partnership of scientists, agronomists, product suppliers and potential end-users (GSG) and will run for four years until March 2007. The core activities measure agronomic and physiological changes in a range of plants selected in two groups. The first group consists of container-grown crops propagated under plastics, and subsequently transplanted to the field, while the second group consists of annual and perennial crops grown to harvest in field soil under the plastics. The measurements, which vary between crops, focus on the findings from the first year's work, and include "tactical deployment" of the plastic filters (*i.e.* switching plants between plastics at particular stages of production).

The following tasks were completed in accordance with the second year's (2004) objectives:

- Continued collation of information produced elsewhere about the effects of modified plastics on crop plants, their associated pests and pathogens, and other agronomically significant factors.
- Continued refinement of facilities.
- Selection of key plant species / cultivars in liaison with the GSG.
- Continued evaluation of the degradation of the five types of plastic covers.
- Continued evaluation of the potential agronomic and economic benefits of the filters on the selected crops.

- Further “growing-on” trials with brassicas, iceberg lettuce and bedding plants raised under the various filters.
- Preliminary assessment of the benefits of “tactical deployment” of plastic filters.
- Preliminary shelf life and taste test trials.

The facility

The facility at STC was established in 2003 with the assistance of Haygrove Tunnels and bpi.Agri. The following five modified plastics were selected because they represented the range of properties exhibited by materials currently available:

- Standard clear horticultural film
- Diffusing standard film (Luminance)
- Red / far red modified film (designed to increase R:FR ratio) (Solatrol)
- UV-B transparent film (designed to transmit the full solar UV spectrum)
- UV opaque film

Each was used to cover a 740m^2 ‘Haygrove’ tunnel and they were compared to an open field plot.

The agronomic studies

The overall objective in 2003 was to detect clear differences in growth and quality of the selected indicator plants and to provide direction for further R&D. The initial results showed marked effects on plant growth regulation, canopy development, time to flowering, colour intensity and yield of essential oils. However, these effects varied between plant species and cultivars. All the data were provided in the first Annual Project Report (Project CP19, HDC, March 2004).

The studies carried out in 2004 replicated much of the work done in the first year and thus began to take into account the influence of different growing seasons. There were some modifications based on the experience gained; *eg.* strawberry, HONS and some leafy salads (corn salad, chard, pak choi) were removed from the project, while additional bedding plants and asparagus were included. The GSG selected the following plants:

- Vegetable propagation (lettuce, cauliflower, cabbage).
- Bedding plants (antirrhinum, impatiens, pansy, petunia [2 cvs], salvia, argyranthemum [2 cvs], fuchsia [2 cvs]).
- Leafy salads (lolla rosso, endive)
- Cut flowers (asters, stocks, larkspur, lilies)
- Herbs (rosemary, sage, lavender, thyme, black peppermint)
- Asparagus [2 cvs].

Meteorological data

Observations were made at STC in accordance with UK Meteorological Centre protocols for the measurement of sunlight, precipitation and temperature. The seasons were very different, which provided the opportunity to compare the effects of the plastic covers under contrasting conditions. Between April and August (inclusive) there were 14% more hours of sunshine in 2003 than 2004, with the greatest difference in the early season (*i.e.* 72% greater in April). The reverse was seen with rainfall, with 42% more in 2004 over the same period. However, the most dramatic difference was seen in August, with 6mm and 140mm of precipitation in 2003 and 2004 respectively. The differences in effects on the plants were particularly evident on the propagation material grown at the beginning of each season and on the cut flowers which reached maturity during the summer. The conditions in August in 2004 were such that very few unprotected cut flowers were of marketable quality in these trials.

Degradation of plastics

During the first year of use, light transmission changed significantly for only one type of plastic; *i.e* the standard horticultural plastic. However, all plastics were replaced in 2004 to allow fair comparisons between seasons. To monitor longer term degradation of the plastics, samples of all the removed materials were attached to frames where they will be exposed to natural sunlight for the remainder of the project. The light transmission through each will be tested at the end of each year.

Agronomic results

Over the two years, the trials have shown marked effects of spectral modification on plant growth regulation, canopy development, time to flowering and colour intensity. The results have been consistent but more pronounced in brighter conditions. The following summaries highlight the observations and results that could have the most commercial relevance to each group of crops.

<u>Lettuce in propagation</u>

Studies in 2003 and 2004, using iceberg lettuce as the “model plant”, showed that propagating under UV-transparent filter produced plants that were comparable to those propagated by common commercial practice (*i.e.* started under glass and hardened off outside) but without the need for the hardening off phase. The plants were “short and stocky”, which made them less vulnerable to damage during mechanised planting. More detailed studies showed this to be a function of reduced epidermal cell expansion and increased leaf thickness rather than reduced carbon fixation. Broadly similar effects were seen with cos lettuce and lolla rosso. These changes can have long term effects on plant development that persist after the plant has been removed from the altered light regime. Subjecting plants to altered light regimes for short periods could therefore provide a tool by which growers can manipulate crop development through to harvest using minimal inputs at the propagation stage.

<u>Brassicas in propagation</u>

Results from 2003 suggested that Solatrol provided the shortest, stockiest cabbage plants with a relatively well developed root system. While these features aid mechanised planting, they did not lead to increased fresh weight at harvest. With regards to cauliflower, the standard filter produced the shortest, stockiest plant

although at the expense of root development. We also observed a tendency for UV-opaque to produce short, stocky plants with increased leaf thickness, and this treatment outperformed all others post-planting in the field. Trials in 2004 were extended to include two timings for moving plants from the glasshouse to the tunnels; *i.e.* 2 and 4 weeks after emergence. Both were compared to "commercial controls", which were entirely propagated under glass (*i.e.* 6 weeks). The trials were repeated three times, with early, mid and late season sowings. All were planted out in the field and monitored through to harvest.
The results with cabbage reinforced the preliminary results from 2003. Again, Solatrol produced short, stocky plants, particularly those transferred from the glasshouse at the earlier stage. These plants had reduced shoot fresh weights and reduced leaf area at the time of planting-out, but root fresh weight was increased. Some trends were observed after planting in the field but the yield results at harvest were not conclusive. In contrast to 2003, the cabbage plants did not exhibit visual changes in leaf colour under Solatrol, which was thought to be linked to changes in alkane production. This was probably due to the different weather conditions during the 2004 growing season.

Results with cauliflower in 2004 largely mirrored findings from 2003. The standard filter produced the shortest, stockiest plants when transferred from the glasshouse at the later stage. These plants had reduced shoot fresh weight, leaf area and plant height, and increased root fresh weight at the time of planting-out compared to the other filter treatments. However, these changes did not lead to increases in fresh weights at harvest.

In conclusion, results over two years suggest that spectral filters can affect brassica development in potentially beneficial ways. However, cabbage and cauliflower respond differently to the various filter treatments. Future work will seek to clarify these responses by quantifying yield benefits and qualifying changes in crop quality and taste.

Bedding plants

Results from the first year's study provided preliminary evidence of the effects of the five filters on both vegetative growth and flower development in bedding. More intense flower colouration was observed in blue and red pansy grown under the UV-transparent filter, suggesting that certain cultivars responded to high levels of UV light by increasing the synthesis of anthocyanonins. There was evidence of changes in time to flowering, total number of flowers produced and flower diameter, but these effects were not uniform across varieties.

The 2004 season's results, using an increased range of plants, highlight the complexity of responses induced by the five filters. For instance, while in impatiens "expo select", salvia "vista red", petunia "frenzy blue", argyranthemum "sultans dream", and fuchsia "Helen Fahey" there was a tendency for Solatrol to reduce plant height, in antirhinnum and fuchsia "brutus" plant height was increased. With regards to shoot biomass, both Luminance and UV-opaque filters produced consistent increases in total fresh and dry weights. In a limited number of varieties, most notably antirrhinum, impatien "expo select", petunia "frenzy blue", salvia "vista red" and fuchsia "Helen Fahey", there was also a tendency for either Luminance or UV-opaque to produce increases in inflorescence length and diameter, and/or the number of ancillary flowers. We did not observe the increased flower pigmentation under the UV-transparent filter that was so apparent in 2003 but this could be linked to the very different weather conditions.

"Carry over" effects were observed when fuchsia "Helen Fahey" and argyranthemum "butterfly" were planted out in the field after just three weeks under filters. The fuchsia plants raised under Solatrol were significantly taller eight weeks after being removed from that treatment. In argyranthemum "butterfly", plant height was increased in UV-transparent treated plants and the total number of inflorescences was increased in Luminance when compared to UV-transparent and Solatrol, and in UV-opaque relative to Solatrol. Results from this relatively small scale planting-out trial produced sufficient evidence to warrant more extensive growing-on trials in the coming season.

<u>Soil grown leafy salads</u>

Previous studies had shown that both the standard and UV-transparent filters produced visually increased levels of red pigmentation in lolla rosso compared to the other treatments. The standard filter also produced plants with higher fresh and dry weights compared to UV-transparent.

Despite very different weather conditions, the three sequential trials with lolla rosso in 2004 followed the same trends as 2003. Standard and the UV-transparent increased crop fresh, dry weights and colour pigmentation. Results of tests by Snaith Salads showed that shelf life was extended in UV-opaque and UV-transparent plants but considerably reduced under standard. Preliminary results from a taste test panel indicated that 'bitterness' was increased in UV-transparent compared to Luminance and UV-opaque.

A further investigation into the tactical deployment of spectral filters was done in 2004. This built on previous results, which had shown that yield was increased under both Luminance and UV-opaque filters but at the expense of the red pigmentation. These trials confirmed that switching plants from UV-opaque to UV-transparent mid way through production provided benefits in terms of both yield and pigmentation. The results also indicated that switching plants from Luminance and UV-opaque to UV-transparent extended shelf life by up to two days. Furthermore, taste tests suggested that the plants switched from Luminance to UV-transparent were comparable to plants grown permanently under UV-transparent. The commercial viability of tactical deployment of filters will be evaluated by members of the GSG.

Endive is also primarily used in leafy salad packs and visual properties (*eg.* leaf habit, natural blanch) as well as crop weight at harvest are very important. Crop productivity was observed to vary greatly under the filters. Both standard and UV-transparent produced increases in total leaf areas, leaf thickness and plant fresh weights, especially when compared to Solatrol and conventionally produced plants

Cut flowers

Cut flower producers are coming under increasing pressure from large retailers to increase their product range, schedule supplies more accurately and reduce production costs. The latter is largely dependant upon reducing losses resulting from poor quality during adverse weather conditions. The 2004 season demonstrated that most of these factors could be improved by growing under simple forms of protection. However, if growers are to invest in tunnels, then it is important to know which types of plastic covers are most appropriate for their crops.

Results in 2003 suggested productivity and quality of cut flowers could be manipulated by switching to production under spectral filters. For example, stocks had increased number of individual inflorescences and increased length of the terminal inflorescence under Solatrol, larkspur appeared to have increased terminal inflorescence and ancillary flower numbers under Luminance, and asters clearly showed more dense canopy development under Solatrol. However, asters showed less colour intensity under Solatrol compared to those grown in the open and under UV-transparent.

These effects were largely confirmed by results in the 2004 trials, although the number of comparisons was reduced because the wet conditions rendered most of the unprotected crops unmarketable. For asters, standard and UV-transparent produced plants with increased number of ancillary inflorescences and ancillary stems, while UV-transparent gave increased pigmentation in both inflorescences and foliage. Lilies clearly showed the benefit of production under any protection compared to the open field. Among the filter treatments, Solatrol produced plants with significantly increased plant height, stem thickness, total leaf area and total plant fresh weight, which together provided a more "substantial" product. The increase in vegetative biomass was at the cost of inflorescence fresh weight, although this was not visually apparent at the time of harvest. For stocks, Luminance and UV-opaque plants produced plants with increased length of terminal inflorescence and increased number of individual inflorescences. Evidence from the first two seasons suggested that larkspur did not respond to the various filters to the same degree as other plant types.

Soil grown herbs

The 2003 and 2004 trials both showed that clear gains could be made by growing under UV opaque compared to outdoors or under standard polythene. UV-opaque generally increased both fresh weight and the amount of essential oil per gram of lavender, rosemary, black peppermint, sage and thyme. The result was boosts in yields of oil of up to 500% in rosemary and 540% in sage. Oil composition was unaffected. This work has now been terminated and the resource will be switched to container-grown herbs from 2005.

Asparagus

The purpose of the work in 2004 was to establish the crop and begin to monitor the development of biomass, paying particular attention to the impact of filters on speed of plant establishment and susceptibility to pests and disease. Interim results and visual observations made during the first year suggested that both varieties (Jersey

Giant and Gymly) responded very quickly to filter treatments. Solatrol significantly increased plant height in both varieties and the UV opaque filter appeared to increase total biomass. Unfortunately, the latter cannot the confirmed without destructive harvests.

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Financial benefits to growers

Potential benefits:

The potential benefits will vary between different combinations of plant species and modified plastics, but they are likely to include:

- Reduction in use of chemical growth regulators.
- Reduction in pesticide use.
- Improved quality of crops.
- Reduction in wastage due to failure to meet QC standards.
- Improved crop scheduling and extension of the growing season.
- Reduction of hardening off periods and plant losses during that critical phase.
- Import substitution.
- Improved pigmentation of foliage (e.g. in coloured-leaved lettuce) and flowers (e.g. Pansy and Asters).
- Increased yields of essential oils from herb crops due to increases in plant biomass.

One of the tasks in the third year of the project (2005) is to liase with the grower steering group to calculate the potential financial benefits of the factors listed above and to determine the economic viability of adopting the new growing systems.

Action points for growers:

The Project Management Team and GSG believe that it would be premature to make firm recommendations on the basis of the trials completed so far.

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CP19: Horticultural crops:
Further demonstration of the potential benefits of modified plastic crop covers

Science section

SCIENCE SECTION

SECTION A. GENERAL INTRODUCTION

Project background

The cultivation of crops under simple plastic covered structures is now commonplace in UK horticulture because of its potential to extend growing seasons, control harvests and improve the quality of produce. In recent years advances in technology have allowed the manufacture of novel materials that 'fine-tune' the growing environment still further, by manipulating the intensity and wavelength of light reaching the crop.

Much of the international research on spectrally modified plastics has been carried out in warm climates and has concentrated on reducing the transmission of UV light (280-400nm in sunlight) compared with standard films, to reduce the scorching effects of the sun, to manipulate pest behaviour, and to reduce sporulation of certain pathogens. However, in the UK there may be benefits from improving transmission of UV light compared with standard plastics. Increasing UV can harden the plant cuticle, reduce the trauma of planting out, improve resistance to pests and disease, reduce the need for artificial growth regulators, increase oil content of aromatic plants and improve colour intensity of flowers and foliage. Spectral modification at wavelengths longer than UV are also exploited. The manipulation of blue wavelengths (broadly 400-500nm) has been reported to control a number of economically relevant diseases. The manipulation of the red : far red ratio (centred on 650 and 730nm respectively) can provide predictable modification of plant growth. Finally, increasing the light scattering ("diffusing") properties of films, can reduce solar heat load due to reductions in infra red wavelengths and so a cooling effect in summer, which could improve the quality of certain cut flowers, improve fruit yield in strawberry etc.

Although a limited number of small-scale studies have investigated the potential impacts of spectrally modified plastics on UK crop production, the majority of published research studies come from regions with hotter, sunnier climates which may be hard to extrapolate to UK conditions. Therefore, to date, UK growers have been presented with little objective information about the effects modified plastic covers under UK conditions and using structures approaching the commercial scales.

In contrast, the aim of this long-term, large-scale project is to investigate the costs and benefits to the UK horticultural industry of adopting modern plastic technology, by concentrating on crops that are of specific importance to the UK market. This project will clarify the situation by evaluating plastic covers with a broad range of light manipulating properties, determine their benefits to key UK horticultural crops and rapidly transfer that technology to UK growers. In addition, the proposed research will provide direction for more fundamental scientific studies to determine the underlying mechanisms, with a view to further enhancing the beneficial effects of such filters, and aiding in the development of new spectral filters.

Commercial objectives

The project has been driven by a consortium of growers from a wide range of commodity sectors (led by horticultural consultant, Mr Stuart Coutts) who formed the project's Grower Steering Group. The project also has the support of the leading tunnel and plastic manufacturers. The partnership of applied scientists, agronomists, product suppliers and potential end-users will ensure that the materials are properly evaluated under conditions relevant to commercial crop production and that the results become available to growers as quickly as possible.

Figure 1. Large scale spectral filter trial (Stockbridge Technology Centre, Summer 2003).

SECTION B. MATERIALS AND METHODS

Plant material.

Plants were grown, following grower instructions, under five spectral filters (Standard, UV-transparent, Solatrol, Luminance and UV-opaque) provided by Bpi. Agri (Stockton-on-Tees, UK). Each plastic altered the spectrum of light under the canopy in the way detailed on the following pages. A Mypex covered open field plot was also used.

Determination of root / shoot fresh and dry weights.

Plants were harvested at the time of first flower (unless otherwise stated) and shoot / root fresh weights were determined. Shoot / root dry weights were obtained by weighing the plant material after drying at 75 °C until a constant mass was reached.

Leaf expansion measurements.

Daily expansion was measured from the time of leaf emergence. Both length and width measurements were taken at the widest point using electronic digital callipers and area calculated accordingly (Screwfix Direct, Yeovil, UK).

Daily area growth increments, which correlate highly with absolute leaf area (r^2 = 0.97 - 0.99, depending on species), were calculated from lengths and widths, measured using a LI-3100 area meter (LI-COR Inc, Lincoln, Nebraska, USA) at destructive harvests throughout development.

In instances where destructive harvests were made determination of leaf area was quantified using an automatic Leaf Area Meter LI-3000 (Li-Cor, Inc., Lincoln, NE, USA).

Epidermal cell size and cell numbers.
At 20 d after emergence, leaf two of lettuce was removed following the cessation of growth, in order to measure epidermal cell size using the dental rubber impression technique (Weyers & Johansen 1985; Poole *et al*. 1996). Measurements were made at the central region of the lamina. The procedure involved first covering the leaf surface with dental impression material (Xantopren, Dental Linkline, UK) to make an imprint of the epidermal surface area. Once the material had set (30-60 s) the leaf was peeled away. Acrylic-based nail varnish was used to produce a translucent positive replica from the negative rubber impression. Cell size was measured at 400X magnification using a Leitz 'Labovert' (Leica, UK) microscope fitted with a ½ inch CCD digital video camera (JVC, Japan). Final leaf area of leaf two was also determined before harvest using the method described in a previous section.

Leaf thickness.
Leaf thickness was measured at the central region of the lamina, adjacent to the mid-vein, using a 0-25mm micrometer (RS Components, Corby, UK).

Light microscopy.
Samples were dissected into small pieces approximately 5mm square ready for processing. Samples were fixed in 4% glutaraldehyde in PBS (Sigma, UK) for 2 hours and washed three times in PBS for 15 minutes at each wash before being passed through a graded alcohol series (50%, 70%, 80%, 90%, 95% and 100%). Samples were transferred to LR White resin (TAAB Laboratories, UK) and agitated for one hour. This process was repeated with subsequent washes under agitation in fresh resin for one hour and overnight. The samples were then embedded in moulds containing fresh resin and polymerised at 50°C for 24 hours. Semi-thin sections were cut on a Reichert Ultracut E microtome (UK) and collected on cleaned glass slides prior to examination at 400X magnification on a Leitz 'Labovert' (Leica, UK) microscope fitted with a high resolution digital camera (JVC, Japan).

Field trials.
Preliminary field trials of Lettuce and Brassica were carried out beginning on the 29 August 2003. Plants were removed from their respective spectral filters and planted out in a random block design.

Shelf life trials.
Shelf life trials were undertaken by Snaith Salads (Snaith, North Yorks) for Lollo rosso and Premier Plants assessed shelf life in cut flowers (Spalding, Lincolnshire).

Statistical analysis.

Multiple Student t-tests were used in all analysis except when calculating daily leaf expansion in lettuce. Because the same leaves were measured throughout the lettuce growth experiment, leaf area data were analysed using two way, repeated measures ANOVA with *post hoc* multiple pairwise comparison using Tukey tests to investigate the effect of treatments on leaf area during development. All analyses were performed using Sigmastat V 2.03 (SPSS Inc.).

SECTION C. RESULTS SECTION

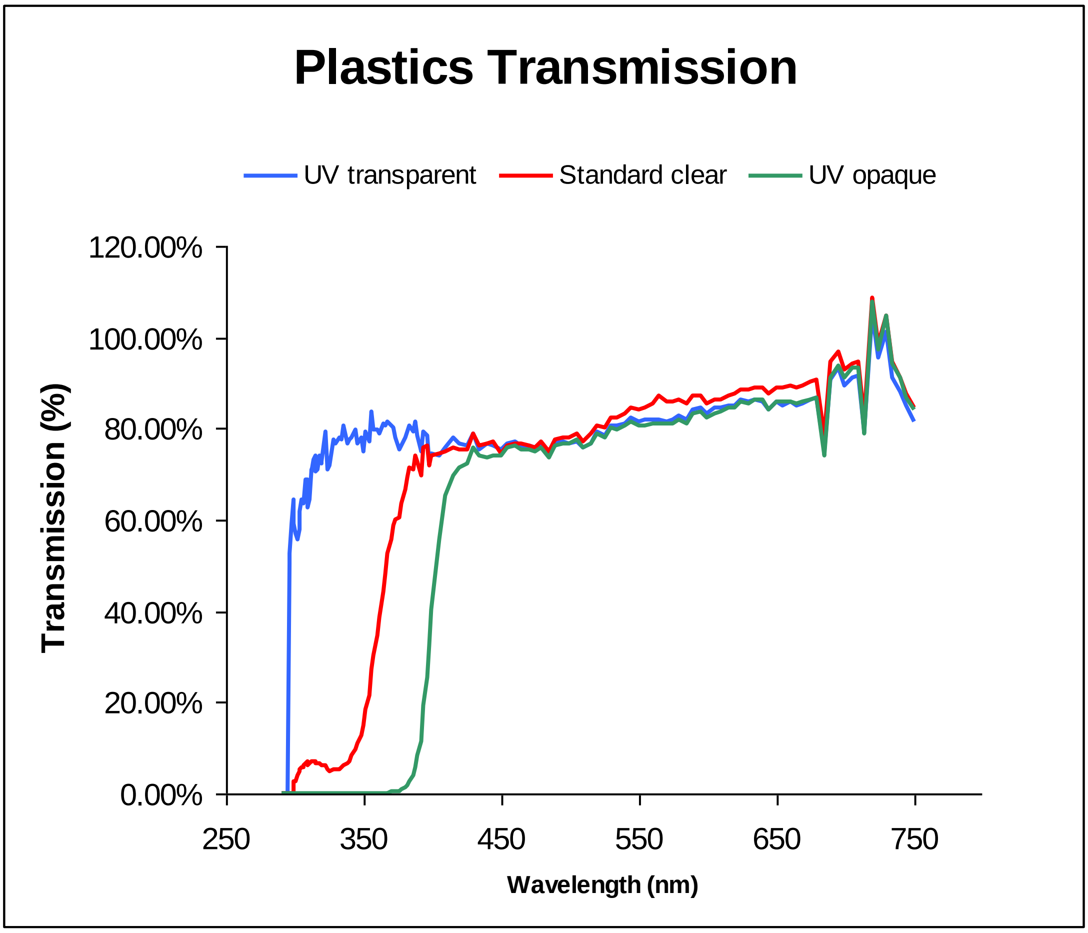
Part 1. The performance of the spectral filters over a 2 year period and meteorological observations.

Measurement of irradiance

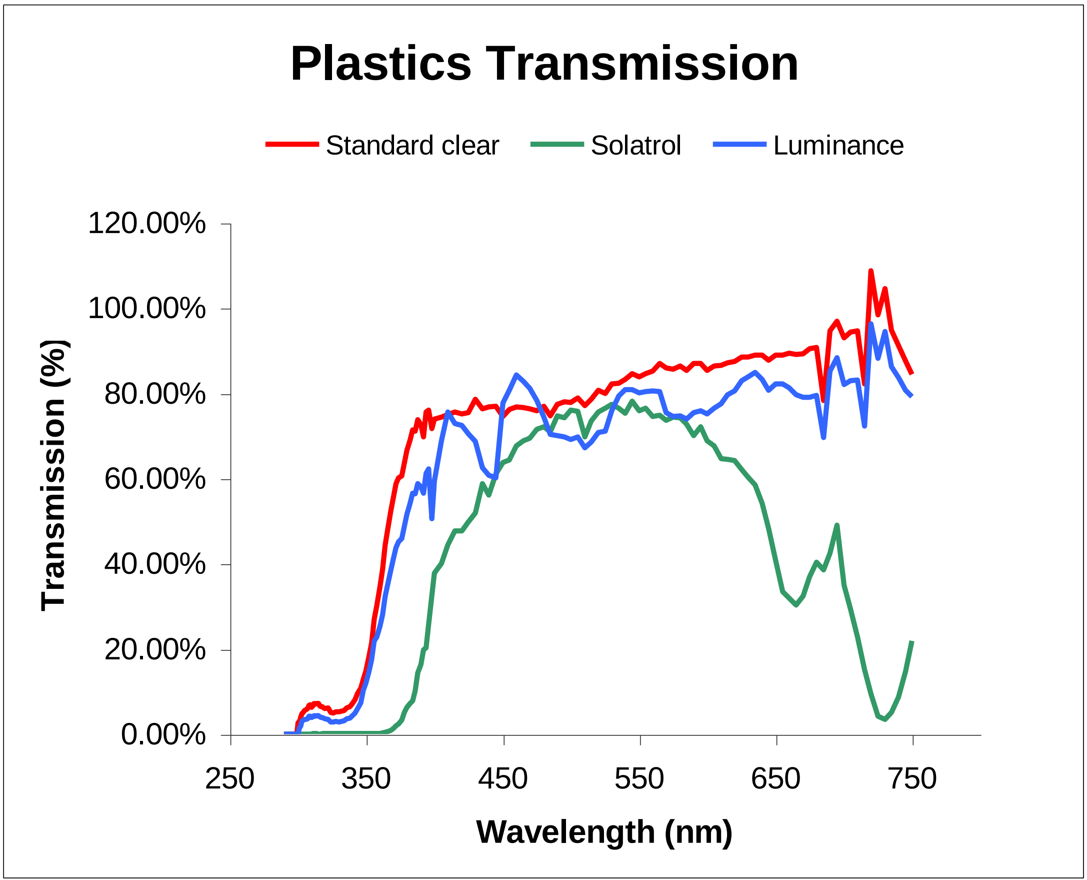
Spectral irradiances within the polytunnels were measured relative to ambient spectral irradiances using two double monochromator spectoradiometers (S9910-PC and SR9910-V7, Macam Photometrics, Livingston, UK). The spectroradiometers were calibrated for wavelength using spectral lines from a mercury arc lamp (LOT Oriel, Leatherhead, UK) and for spectral irradiance against tungsten and deuterium sources (Macam SR903) based on National Physics Laboratory Standards.

Transmissions at the end of the 2003 season.

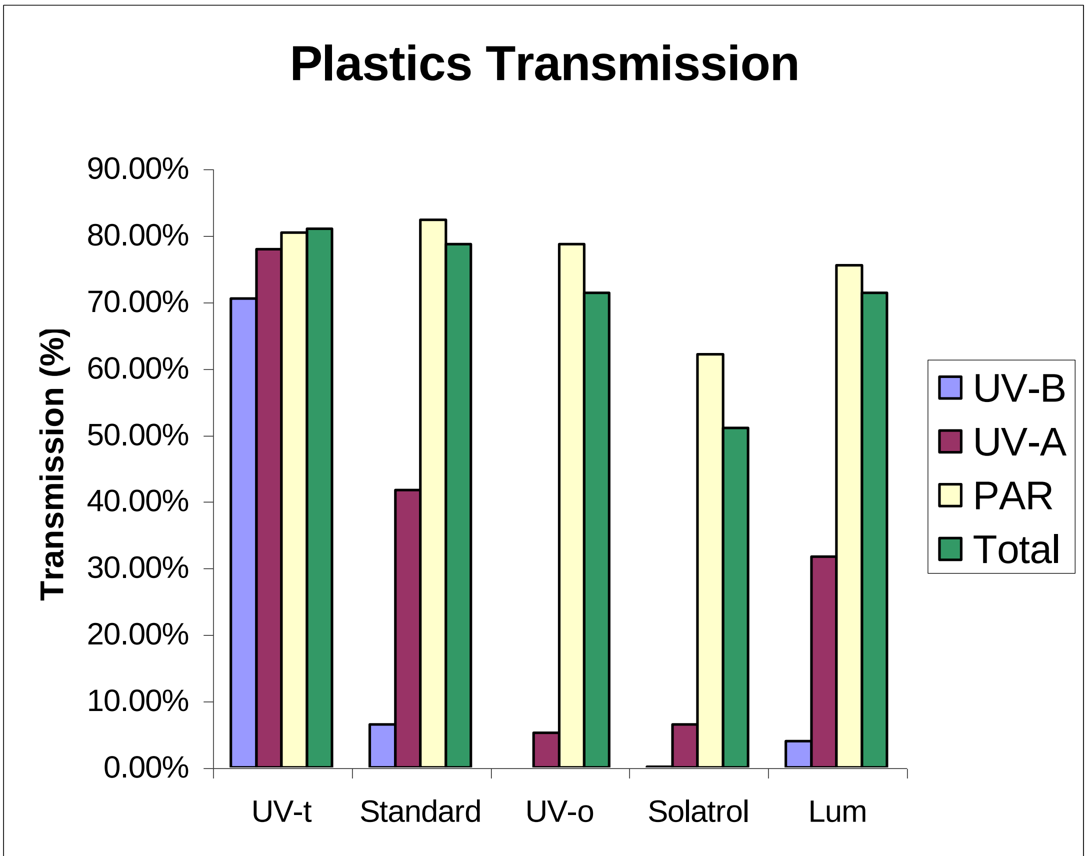
a)



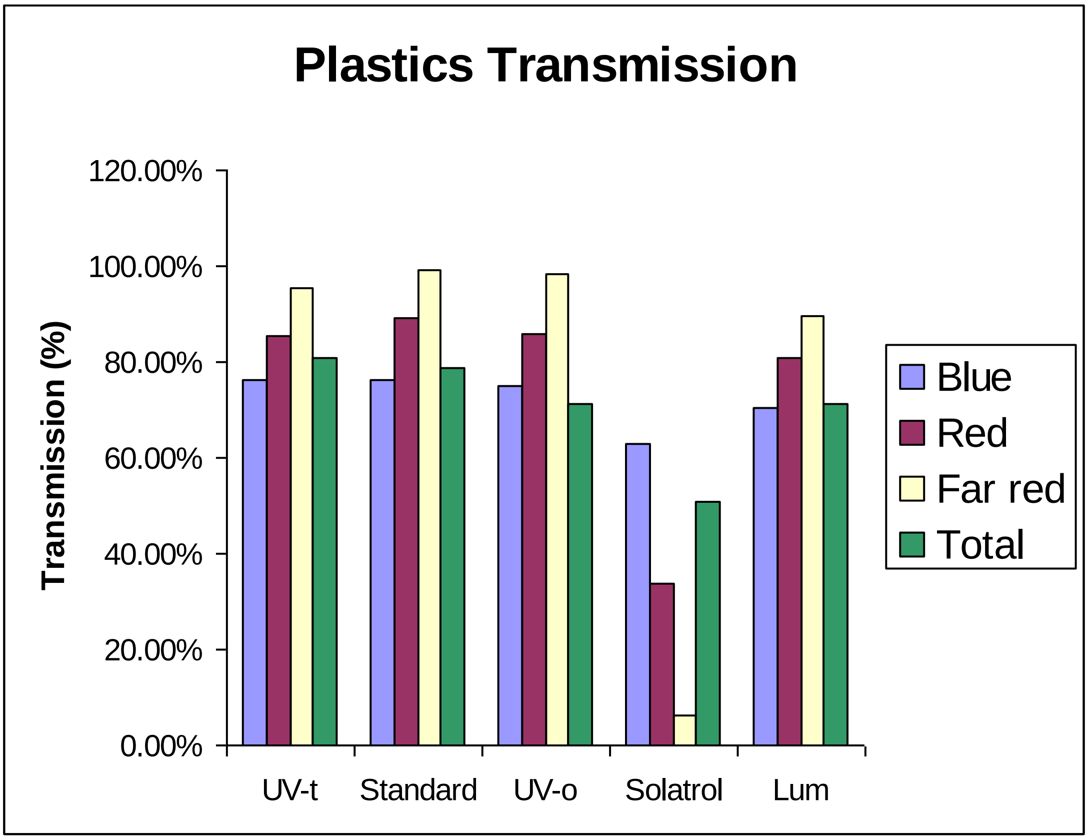
b)


Plastics Transmission
Standard clear
Solatrol
Luminance
Transmission (%)
120.00%
100.00%
80.00%
60.00%
40.00%
20.00%
0.00%
250
350
450
550
650
750
Wavelength (nm)

c)


Plastics Transmission
Transmission (%)
90.00%
80.00%
70.00%
60.00%
50.00%
40.00%
30.00%
20.00%
10.00%
0.00%
UV-t
Standard
UV-o
Solatrol
Lum
UV-B
UV-A
PAR
Total

d)



e)

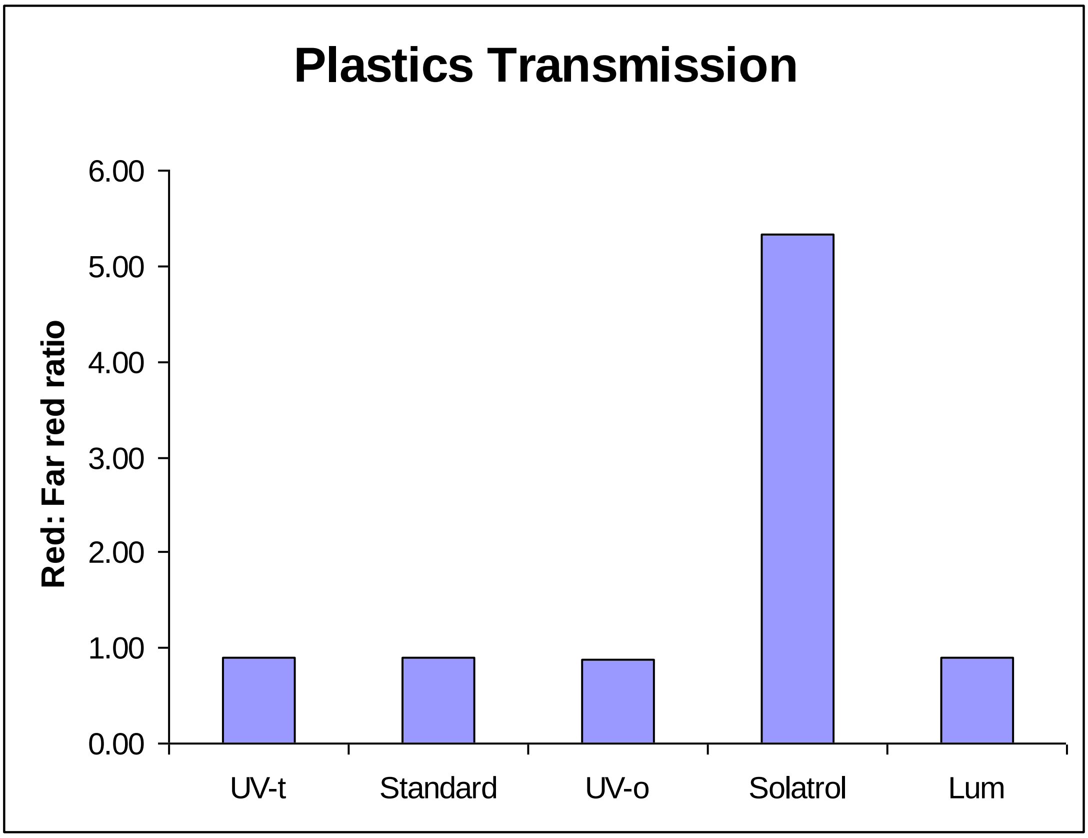


Figure 1. Spectral measurements made at Lancaster University on samples taken from the 5 tunnels at Stockbridge Technology Centre in August 2003.

Conclusions from 2003 / 2004 season.

In 2003 transmission properties of all the spectrally modified plastics had been stable, despite the high light intensity and temperature of that summer. The one plastic to show substantial changes was the standard clear film, which was stable in the visible (= photosynthetically active = 400-700nm) part of the spectrum, but showed marked increases in transmission in the UV (290-400nm, but changes were especially marked at the shorter wavelengths). For this reason, the standard clear film was replaced for the 2004 growing season. Conditions during 2004 were much cooler and less sunny than in 2003. Such conditions would not be expected to cause substantial degradation of films, and this is what was observed. There were no changes in the transmission spectra of any film that were beyond the usual sample-to-sample variation (approx 3%).

This year highlighted the importance of variation in ageing, especially when measuring changes on complete structures. Differences in location do lead to differences in degradation rate. For example areas which are shaded, facing north or near vertical are likely to age more slowly than those with full exposure, facing south or near horizontal. Our experience is that such spatial variation may be substantial relative to changes over time, with the result that taking only limited samples of films may lead to misleading results. In principle, we would recommend that analyses of changes in spectral properties of films during use be based on replicate samples taken from contrasting locations. However, this needs to be balanced with the practical limits on removing plastic from structures. We do not see this as a major issue in quantifying broad changes in very different film types, as in CP19, but sample to sample variation does mean that interpretation of changes based on limited samples must be made with caution. For the longer-term analysis of the ageing of the films used in CP19, we will place samples of films removed at the end of 2004 on simple rectangular frames orientated south and at a fixed angle, so that exposure to incident radiation is standardised.

Meteorological comparison for 2003 / 2004 season.

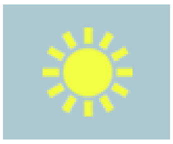
					°C	
	2003	2004	2003	2004	2003	2004
March	78	81	12	25	12	10
April	164	95	34	74	14	13
May	177	199	59	21	17	17
June	182	151	89	51	21	20
July	165	160	47	47	23	21
August	173	152	6	140	23	22

Figure 3. Observations were made at Stockbridge Technology Centre in accordance with UK's Meteorological Centres procedures and protocols in measuring a) hours of sunlight, b) precipitation in mm and, c) average temperature in °C.

CP19: Horticultural crops:
Further demonstration of the potential benefits of modified plastic crop covers

Propagated lettuces

Part 2. Propagated lettuces (Iceberg, Little gem and Lollo rosso)

Introduction

A UK based plant propagator has been conducting trials with lettuce grown experimentally under a Luminance-type plastic for a number of years, but with less than satisfactory results. Plants have exhibited abnormally elongated leaves, either due to increased cell division or cell expansion, or both. Lamina tissue also possessed reduced mechanical strength when compared to glasshouse grown plants, which is likely due to changes in the architecture, and hence the mechanical properties, of the cell wall.

Results from both the 2002/ 2003 seasons showed that propagating lettuce under UV-transparent filter produced plants that were comparable to those propagated under glass. They were “short and stocky”, a function of reduced epidermal cell expansion, not cell division, and increased leaf thickness, which preliminary results seemed to indicate was a function of an increase in both the number (and size) of the photosynthesising palisade mesophyll cell layer. Furthermore, these morphological changes may have aided in the plants early adaptation to ambient conditions in field trials, since those plants propagated under UV-transparent produced a 24% increase in fresh weight at time of harvest when compared to plants propagated under the remaining 4 filter treatments. We hypothesised that this may have been, at least in part, a result of an increase in the mechanical strength of the epidermal cell wall and therefore the leaf as a whole, mediated by an increase in the plants exposure to UV radiation under the UV-transparent filter.

The purpose of this years work was to further characterise the morphological adaptations of lettuce under the 5 filters and compare results to plants propagated under traditional commercial glass. Finally, results from extended field trials using plants propagated under the 5 filters and under commercial glass is presented here.

Objectives

To identify a filter(s) that produces a plant that is “short and stocky”, possesses good mechanical strength and that performs well in the field. This will allow lettuce plant propagators to bypass the ‘hardening-off’ stage of production and reduce production costs.

Results

PROPAGATION ICEBERG LETTUCE – THE "MODEL PLANT"

EARLY SEASON CROP – DAILY MEASUREMENTS

DAILY INCREMENTAL INCREASES IN LEAF 2 AREA - "EARLY SEASON CROP"

At day 6 UV-transparent exibited increased total leaf area when compared to both Luminance and Solatrol only (P<0.05, fig. 1.a.). By day 14 leaf area in UV-transparent was reduced relative to Standard (P<0.001, fig. 1.a), Luminance (P<0.01, fig. 1.a.) and UV-opaque (P<0.001, fig. 1.a.) whereas compared to Solatrol it was significantly increased (P<0.05, fig. 1.a). Solatrol produced significant reductions in leaf area compared to all remaining treatments by 11 (P<0.001, fig. 1.a.) and this remained true for the remainder of the experiment (P<0.001, fig. 1.a.). Both Standard and UV-opaque produced significant increases in final leaf area when compared to all remaining treatments (P<0.001, fig. 1.a) except Luminance (P>0.05, fig.1.a.).

DAILY INCREMENTAL INCREASES IN LEAF 2 THICKNESS - "EARLY SEASON CROP"

By day 6 UV-transparent increased leaf 2 thickness when compared to all treatments (P<0.01, fig. 1.b). Between day 7 and 10 there was no significant difference between leaf thicknesses in Standard and UV-transparent (P>0.05, fig. 1.b), although UV-transparent was still producing significantly thicker leaves than all remaining treatments (P<0.001, fig. 1.b). At day 11 the thickness of leaf 2 in UV-transparent was again significantly increased relative to all treatments (P<0.001, fig. 1.b) and it remained so throughout the experiment (P<0.001, fig. 1.b).

DAILY INCREMENTAL INCREASES IN LEAF 2 FRESH WEIGHT - "EARLY SEASON CROP"

Leaf 2 fresh weight was significantly reduced in Solatrol by day 8 when compared to UV-transparent, Standard and UV-opaque (P<0.01, fig. 2), although there was no significant effect relative to Luminance (P>0.05, fig. 2). By day 9 Solatrol was producing significantly reduced leaf 2 fresh weights when compared to all remaining treatments (and this remained so throughout the experiment ($P\leq0.001$, fig. 2). On days 13 and 14 leaf 2 fresh weight was also reduced in UV-transparent when compared to Standard, Luminance and UV-opaque ($P\leq0.05$, fig. 2). Standard increased leaf 2 fresh weight by day 14, although this was only a significant increase relative to UV-transparent and Solatrol ($P\leq0.01$, fig. 2).

MID SEASON CROP – MEASUREMENTS TAKEN AT DAY 14

LEAF 2 FRESH WEIGHT AT DAY 14 - "MID SEASON CROP"

UV-transparent significantly reduced leaf 2 fresh weight when compared to Luminance (P<0.001), UV-opaque (P<0.001) and Commercial (P<0.05) treatments, although there was no effect relative to Standard and Solatrol (P>0.05, fig. 3.a). Commercial significantly increased fresh weight when compared to UV-transparent (P<0.05) and reduced them relative to UV-opaque only (P<0.05), fig. 3.a).

LEAF 2 DRY WEIGHT AT DAY 14 - “MID SEASON CROP”

Leaf 2 dry weight was increased in both Luminance and UV-opaque when compared to Standard (P<0.05) and Solatrol only (P<0.001) and in Commercial relative to Standard (P<0.05) and Solatrol (P<0.001) (fig. 3.b). Solatrol reduced leaf 2 dry weight relative to all treatments except Standard (P>0.05, fig. 3.b).

LEAF 2 LENGTH AT DAY 14 - “MID SEASON CROP”

The length of leaf 2 at harvest was significantly reduced in Solatrol when compared to Standard (P<0.01), UV-transparent (P<0.05) Luminance (P<0.001) and UV-opaque (P<0.001) only (fig. 3.c). Luminance and UV-opaque increased leaf 2 length relative to all remaining treatments (P≤0.01, fig. 3.c).

LEAF 2 WIDTH AT DAY 14

Leaf width was significantly increased in Luminance and UV-opaque when compared to all remaining treatments (P≤0.01, fig. 4.a). There was no other significant effect of treatments on the width of leaf 2 (P>0.05, fig. 4.a).

LEAF 2 THICKNESS AT DAY 14

The thickness of leaf 2 was significantly increased in Commercial when compared to UV-transparent (P<0.01), Solatrol (P<0.001), Luminance (P<0.001) and UV-opaque (P<0.001), although there was no effect relative to Standard (P>0.05, fig. 4.b). UV-transparent significantly reduced leaf thickness when compared to both Commercial (P<0.01) and Standard treatments (P<0.01), although leaf thickness was increased in UV-transparent when compared to Luminance (P<0.01) and UV-opaque (P<0.01) (fig. 4.b). There was no significant difference between leaf 2 thickness in UV-transparent and Solatrol (P>0.05) (fig. 4.b).

PROPAGATION ICEBERG LETTUCE – EARLY & MID SEASON FIELD TRIALS

In early season field trials, Commercial significantly increased fresh weights at time of harvest when compared to Solatrol (11%, P<0.01) and Luminance (10%, P<0.05) only (fig. 5.a). Although UV-transparent increased mean fresh weights when compared to Standard (2%), Solatrol (4%), Luminance (5%) and UV-opaque (1%) these did not represent significant increases (fig. 5.a). Similarly, Commercial produced a non significant increase in fresh weights relative UV-transparent (5%, fig. 5.a).

In mid-season field trials Commercial significantly increased harvestable fresh weights when compared to Standard (16%, P<0.001), UV-transparent (9%, P<0.001), Solatrol (6%, P<0.05), Luminance (8%, P<0.01) and UV-opaque (8%, P<0.01) (fig. 5.b).

PROPAGATION ICEBERG LETTUCE – SHELF LIFE TEST

When the crop reached the point when it was ready for market lettuces were transported to Snaith Salads Ltd within 6 hours of harvest for shelf life tests. Preliminary results from the first years trial suggest that those plants propagated for 14 days under the Standard filter, prior to planting out, produced a crop which remains at grade 1 for significantly longer ($\geq$3 d) than remaining filter treatments (Table 1). These trials will be extended in year 3 and 4.

a)

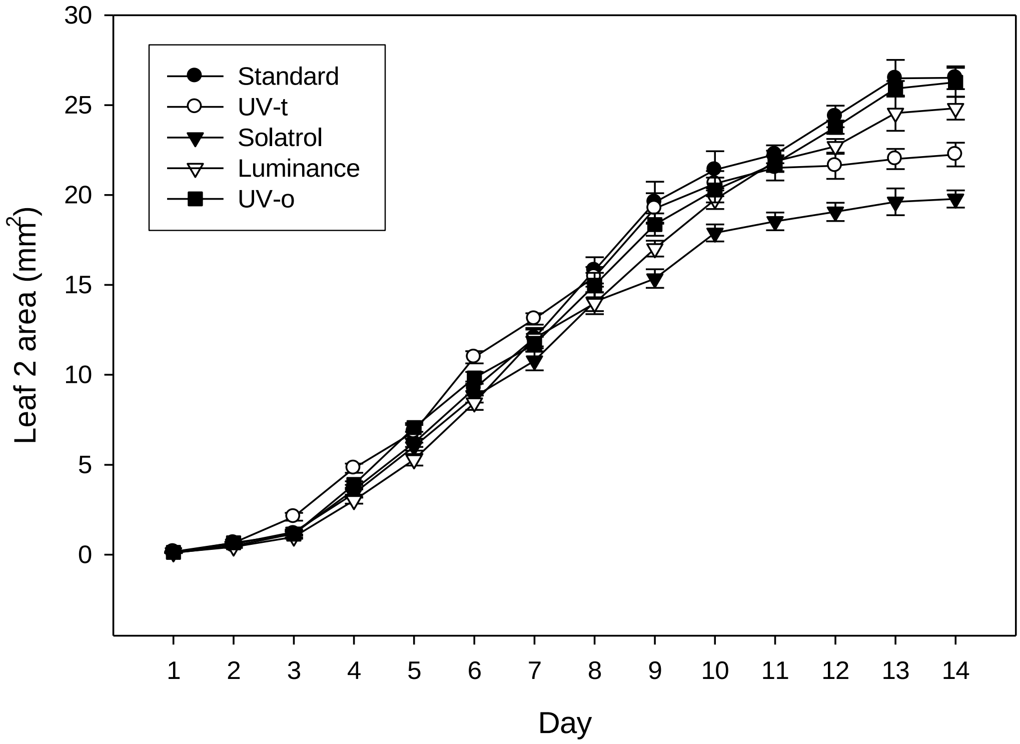
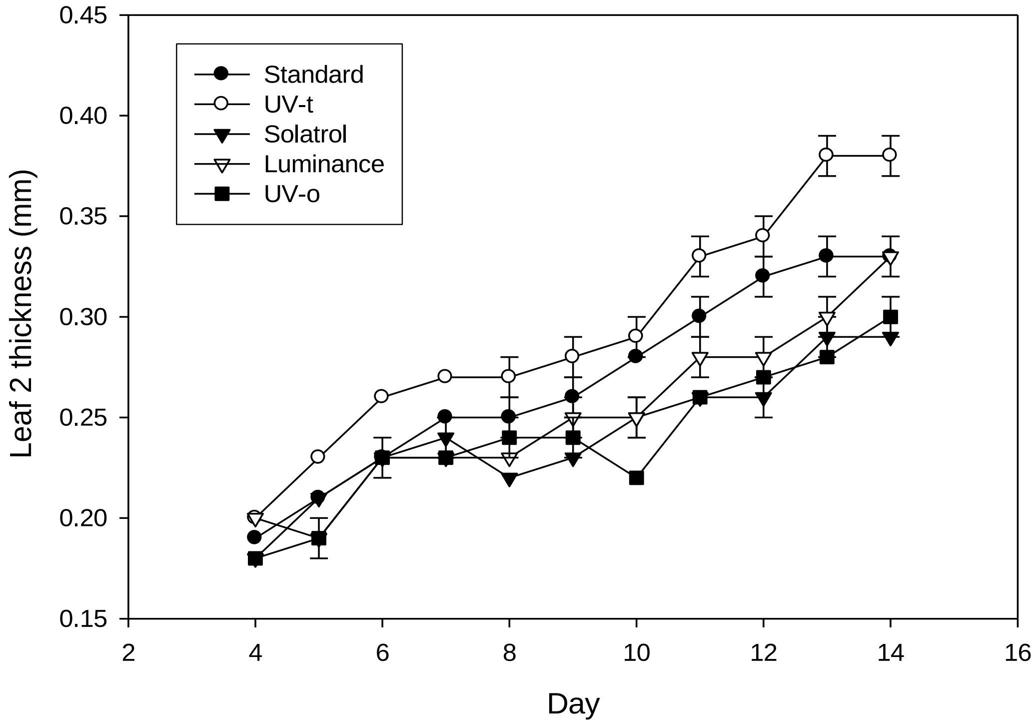


Figure 1.a. Effects of treatment on total leaf area in propagation Iceberg lettuce. Each value is the mean $\pm$ S.E. of 15 replicates.

a)



b)

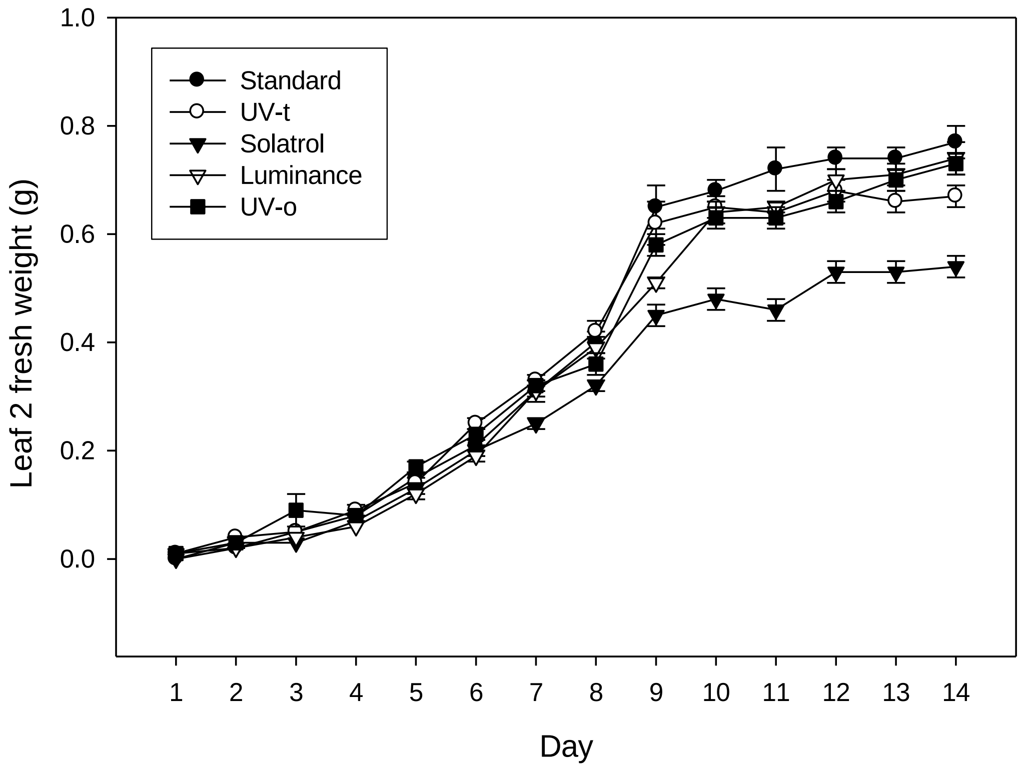
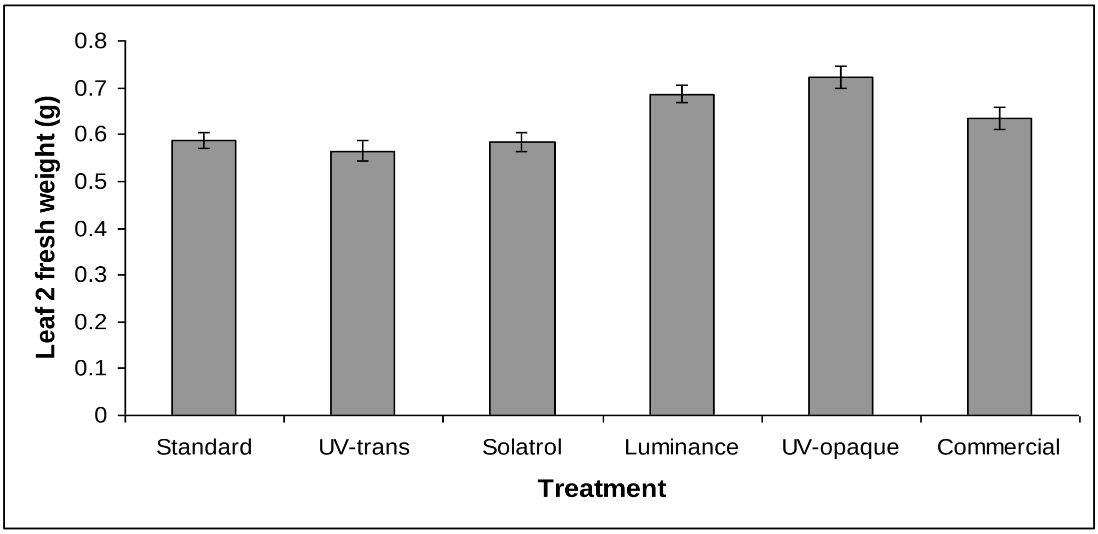
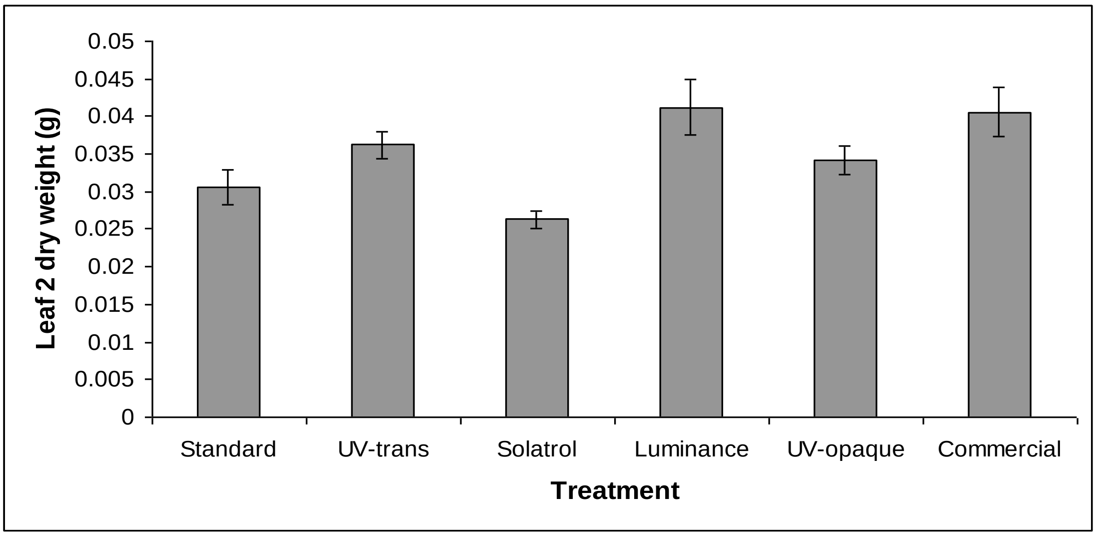


Figure 2. Effects of treatment on a) fresh weight and (b) leaf thickness of leaf 2 in propagation Iceberg lettuce. Each value is the mean ± S.E. of 15 replicates.

a)



b)



c)

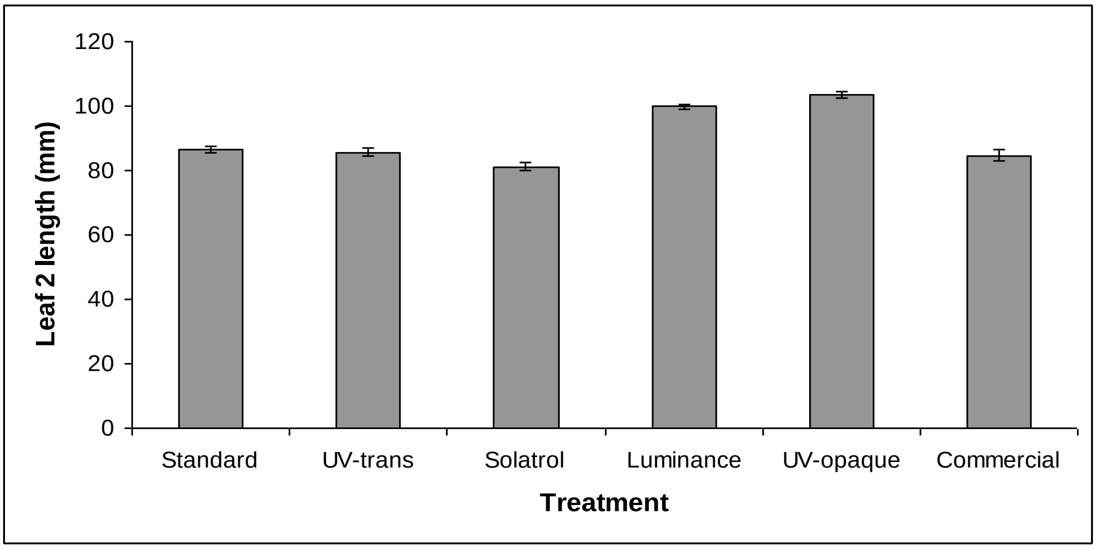
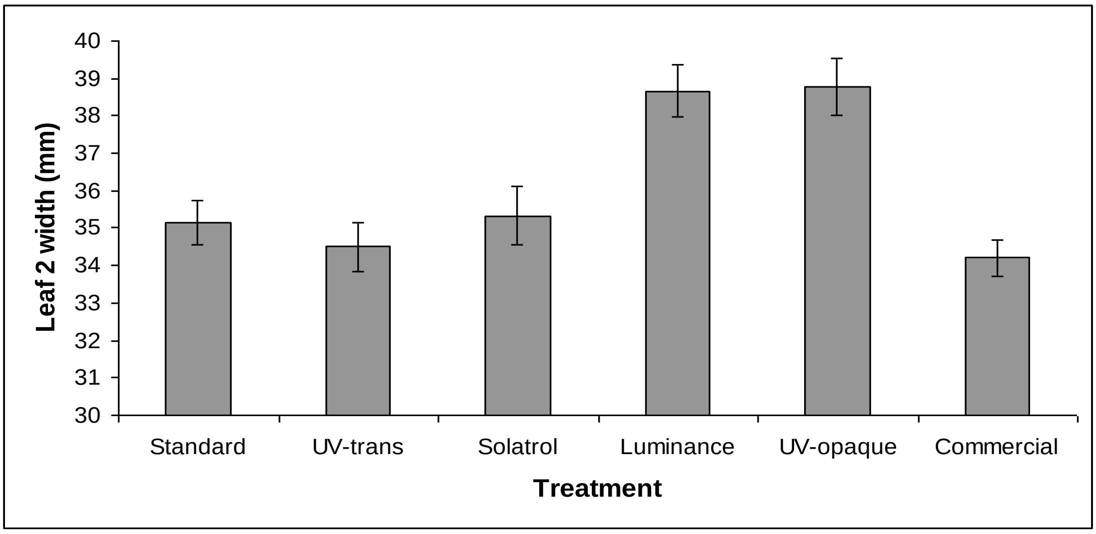


Figure 3. Effect of treatments on (a) leaf fresh weight (b) leaf dry weight and (c) leaf length in leaf 2 in propagation iceberg lettuce at 14d. Each value is the mean ± S.E. of 20 replicates.

a)



b)

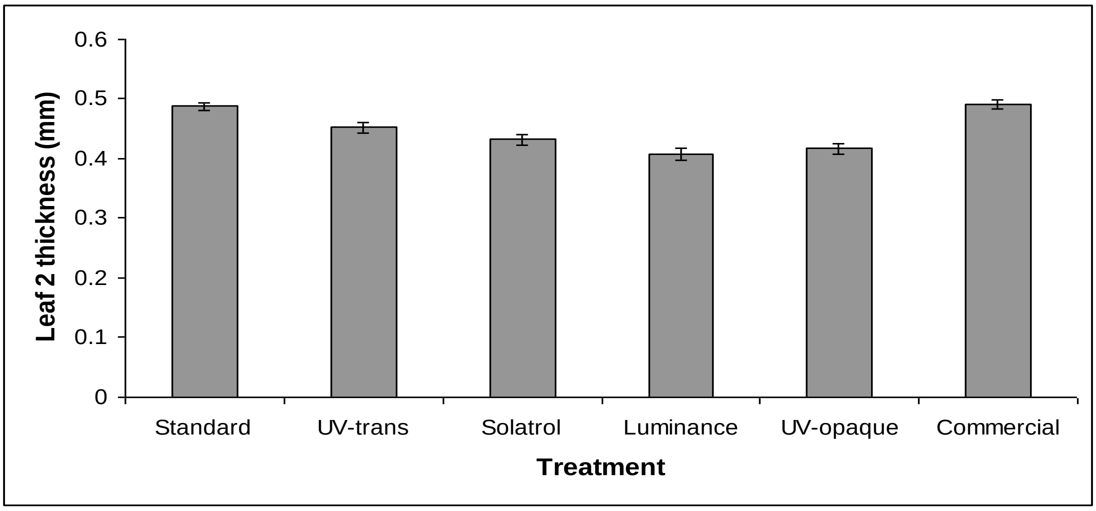
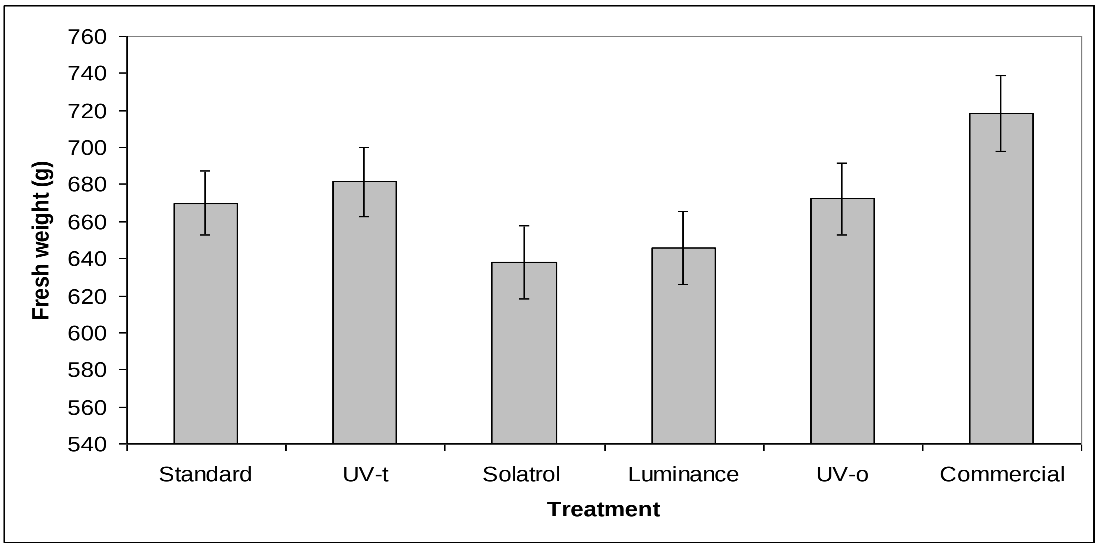


Figure 4. Effect of treatments on (a) leaf width and (b) leaf thickness in Iceberg propagation lettuce at 14d. Each value is the mean ± S.E. of 20 replicates.

a)



b)

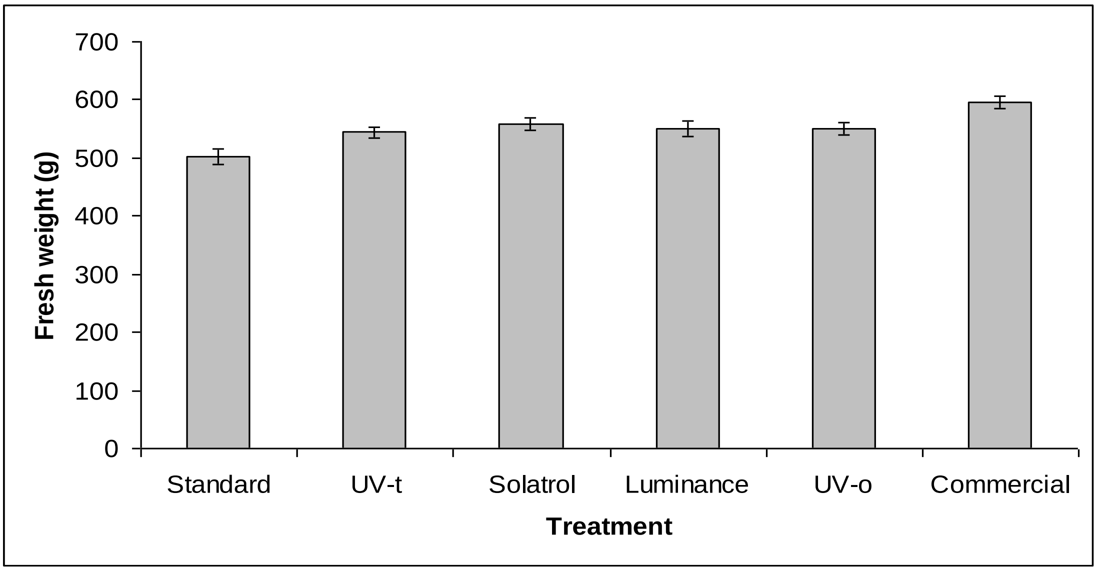


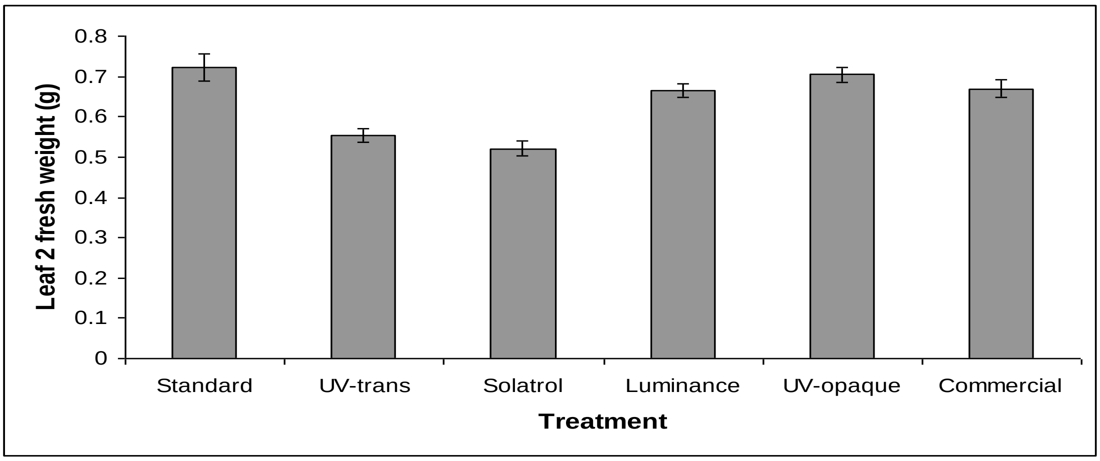
Figure 5. Effect of treatments on head fresh weight Iceberg lettuce in field trials at time of harvest in (a) early and (b) mid season plantings. Each value is the mean $\pm$ S.E. of $\geq$ 45 replicates.

Table 1. Results from shelf life tests carried out on behalf of the project by Snaith Salads, West Yorkshire. Grade 1 represents a perfect marketable specimen and increasing values are indicative of crop deterioration.

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Standard	1	1	1	1	1	1	1
UV-t	1	1	1	2	2	2	2 or 3
Solatrol	1	1	1	1	2	2	2 or 3
Luminance	1	1	1	1	2	2	2
UV-o	1	1	2	2	2 or 3	2 or 3	3
Commercial	1	1	1	2	2	2	2

Solatrol significantly reduced leaf 2 fresh weight when compared to all treatments except UV-transparent (fig. 6.a). There was no effect on leaf 2 fresh weight of Commercial treatment when compared to Standard, UV-transparent, Luminance and UV-opaque, although Commercial fresh weight was significantly increased relative to Solatrol (fig. 6.a). Solatrol significantly reduced leaf 2 dry weight when compared to all treatments except UV-transparent (fig. 6.b). Dry weights were significantly increased in Commercial when compared to both UV-transparent and Solatrol, although there was no effect relative Standard, Luminance and UV-opaque (fig. 6.b). The length of leaf 2 was significantly increased in UV-opaque when compared to all treatments except Luminance (fig. 7.a). Both Solatrol and Commercial treatments produced significant reductions in leaf 2 length when compared to all remaining treatments but not between the two treatments (fig.7.a). Leaf 2 width was significantly increased in Luminance and UV-opaque when compared to UV-transparent, Solatrol and Commercial, although there was no effect relative to Standard (fig. 7.b). The thickness of leaf 2 was significantly increased in Luminance when compared to Solatrol, UV-opaque and Commercial treatments only (fig. 7.c).

a)



b)

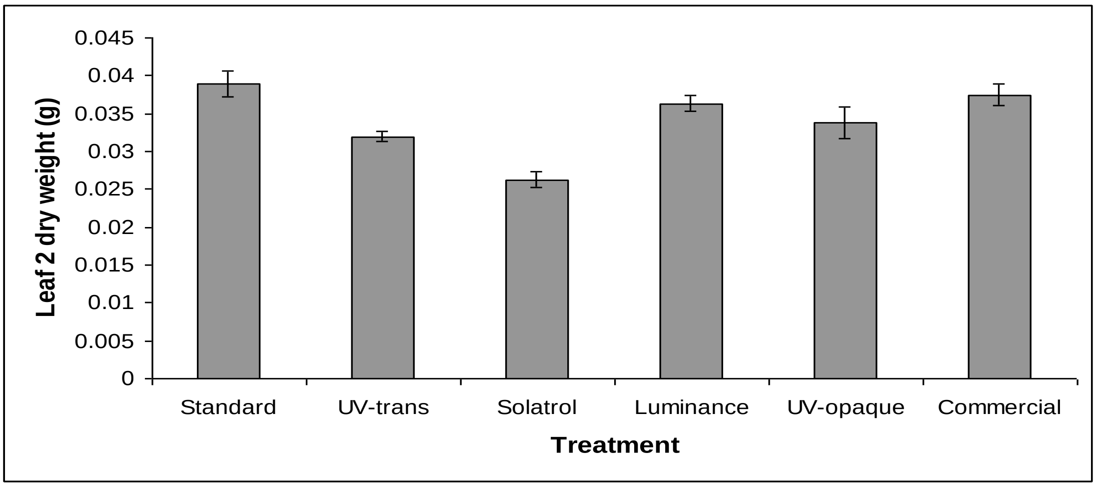
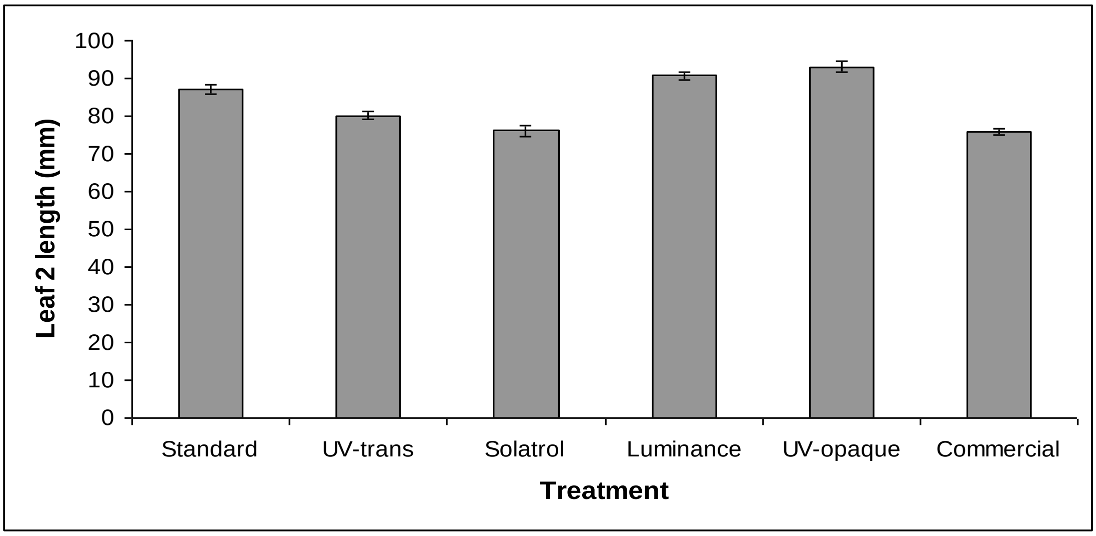
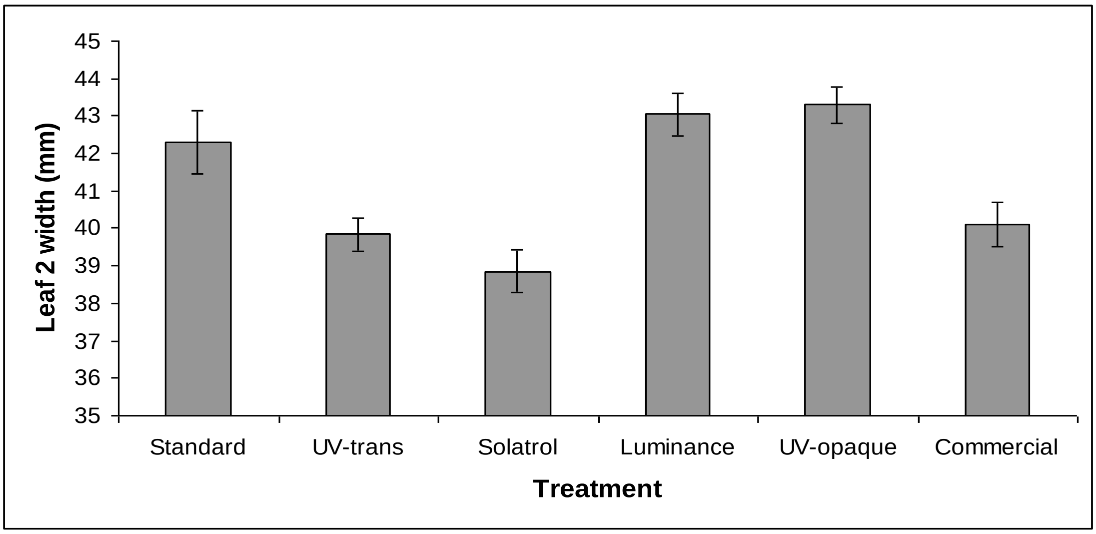


Figure 6. Effect of treatments on (a) leaf fresh weight and (b) leaf dry weight in leaf 2 of propagation Little gem lettuce at 14d. Each value is the mean ± S.E. of 20 replicates.

a)



b)



c)

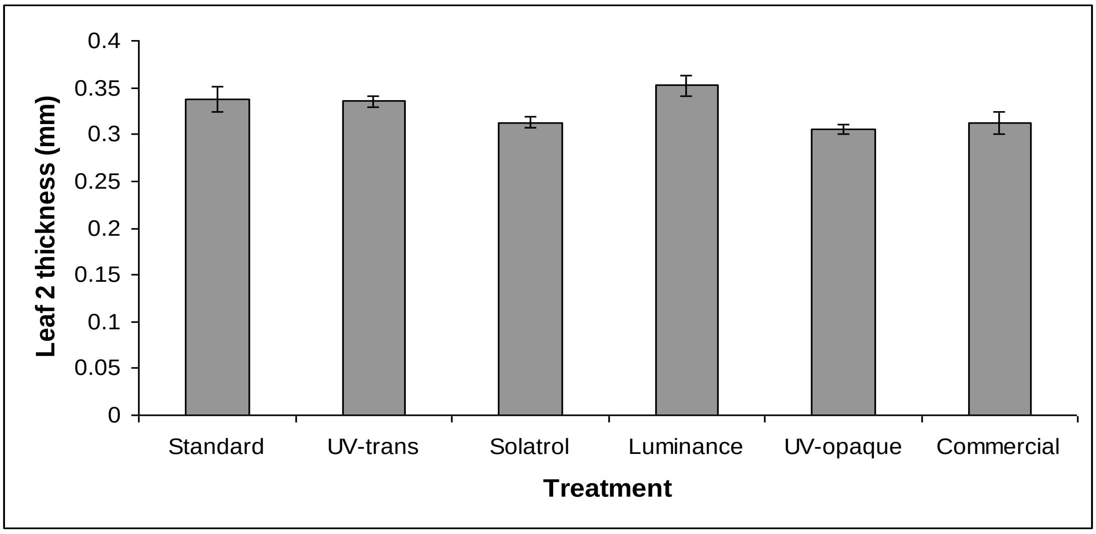
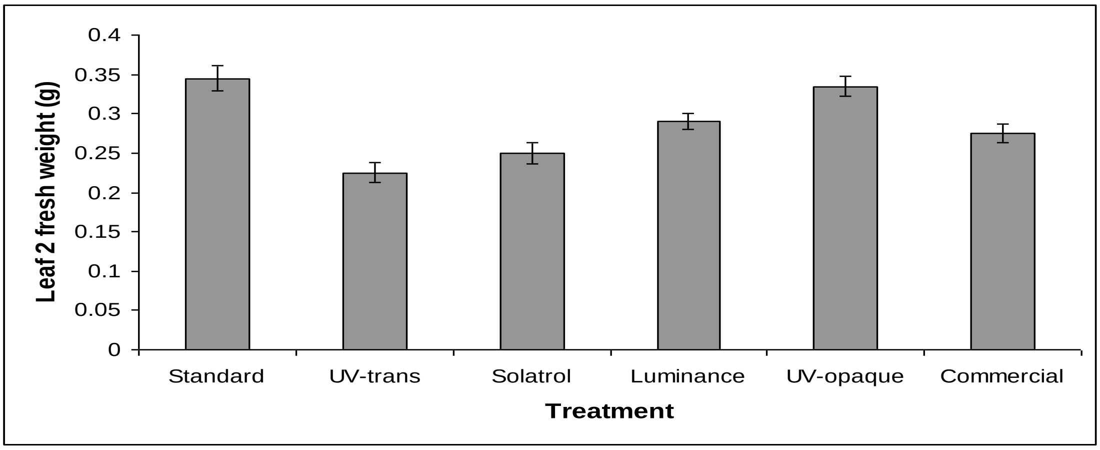


Figure 7. Effect of treatments on (a) leaf length (b) leaf 2 width and (c) leaf thickness in leaf 2 of propagation Little gem lettuce at 14d. Each value is the mean ± S.E. of 20 replicates.

Standard significantly increased leaf 2 fresh weight when compared to all treatments except UV-opaque and was reduced in UV-transparent relative to all treatments except Solatrol (fig. 8.a). Leaf 2 dry weight was significantly increased in Standard when compared to all treatments except UV-opaque (fig. 8.b). Commercial reduced leaf 2 dry weights when compared to Standard, Solatrol, Luminance and UV-opaque, although there was no effect relative to UV-transparent (fig. 8.b). The length of leaf 2 was significantly increased in UV-opaque when compared to all treatments except Standard (fig. 9.a). UV-transparent produced a significant reduction in leaf 2 length when compared to all remaining treatments (fig. 9.a). Commercial produced a reduction in leaf length when compared to Standard, Luminance and UV-opaque only (fig. 9.a). The width of leaf 2 was similarly reduced in UV-transparent when compared to all treatments except Commercial and in Commercial relative to Standard, Luminance and UV-opaque, but not UV-transparent and Solatrol (fig. 9.b). The Commercial treatment significantly increased leaf thickness in leaf 2 when compared to Solatrol, Luminance and UV-opaque only (fig. 9.c). There was no significant difference in the thickness of leaf 2 between the five filter treatments (fig. 9.c).

a)



b)

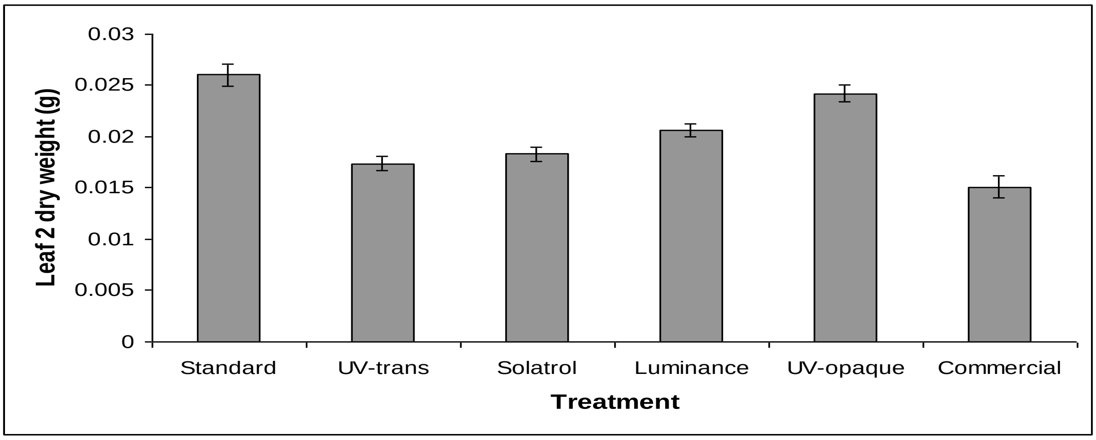
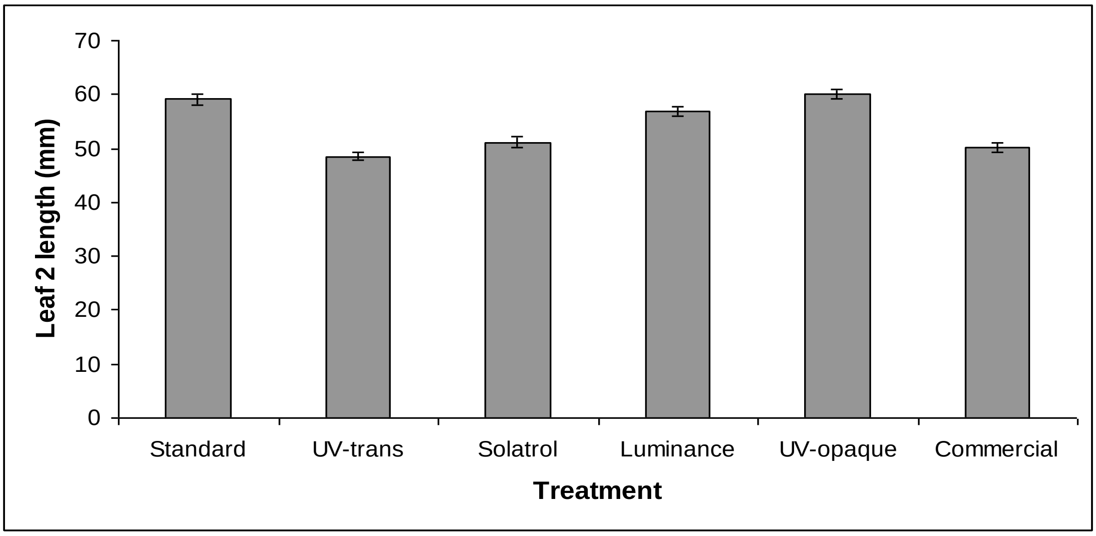


Figure 8. Effect of treatments on (a) leaf fresh weight and (b) leaf dry weight in leaf 2 of propagation Lollo rosso lettuce at 14d. Each value is the mean ± S.E. of 20 replicates.

a)



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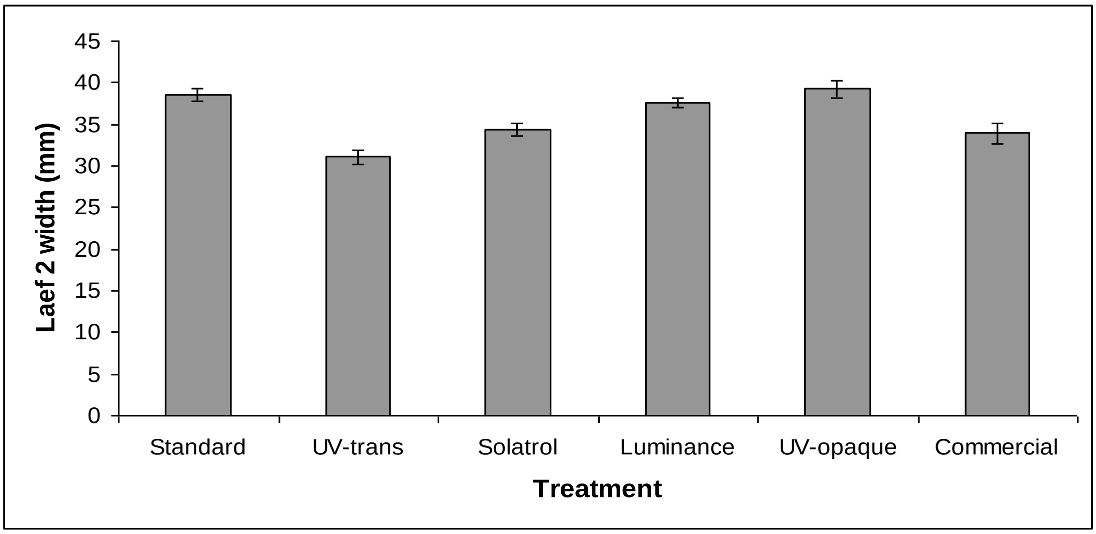


c)

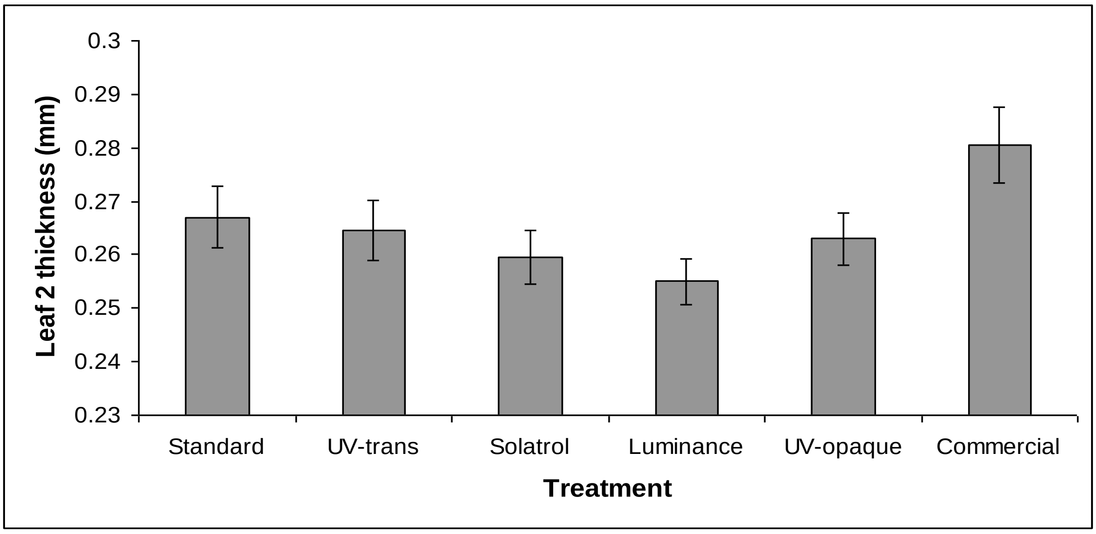


Figure 9. Effect of treatments on (a) leaf length (b) leaf width and (c) leaf thickness in leaf 2 of propagation Lollo rosso lettuceat 14d. Each value is the mean + S.E. of 20 replicates.

Discussion

It is clear from two seasons of study using propagation Iceberg lettuce as our “model plant” that whole plant morphology (see figs. 10-12 below) and physiology is rapidly altered in the modified light regimes under spectral filters. Morphological changes are observed in Iceberg lettuce within 4 days (leaf area, fig. 1.a) and 5 days (leaf thickness, fig. 1.b). These changes can have long term effects on plant development that persist long after the plant has been removed from the altered light regime (see figs. 5.a. & 5.b). Subjecting plants to altered light regimes for short periods could therefore provide a tool by which growers can manipulate crop development through to harvest using minimal inputs at the propagation stage.

In Iceberg, Little gem and Lollo rosso the immediate effects of the filters was a tendency for increased leaf expansion through the length (figs. 3.c., 7.a. & 9.a), and across the width axis (figs. 4.a., 7.b., & 9.b), in Luminance and UV-opaque plants when compared to the Commercial control within 14 days. The effect on leaf expansion of both the UV-transparent and Solatrol treatments was much less pronounced when compared to Commercial (see figs. 3.c, 7.a & 9.a). However, in Iceberg and Lollo rosso, but not Little gem, the thickness of leaf 2 was increased in Commercial relative to the remaining filter treatments (see figs. 4.b, 7.c, & 9.c). The observed reduction in leaf expansion in UV-transparent and Solatrol produced a “short, stocky plant”, comparable to those plants produced under Commercial glass and required by growers, but without the necessary increase in leaf thickness (see figs. 10-12 photos). In field trials, in both early and mid season plantings, commercially propagated Iceberg lettuce produced increases in harvestable fresh weights when compared to all filter treatments (figs. 5.a. & 5.b).

Results from 2003 showed that this reduction in leaf expansion in UV-transparent and Solatrol is not a function of reduced carbon fixation, but could be attributed to a reduction in epidermal cell area: there was no significant change in epidermal cell number in plants grown under UV-transparent and Solatrol (See CP19, 2003). The effect of the filters on cell expansion was also observable using light microscopy where epidermal cells are clearly elongated in plants grown under both Luminance and UV-opaque filters relative to UV-transparent and Solatrol (See CP19, 2003).

In conclusion, results from 2004, which included trials on a wider range of propogation lettuce varieties, indicate that both the UV-transparent and Solatrol filters produce a crop more that is comaprable to the Commercial glasshouse crop at the end of the propogation stage. While neither UV-transparent nor Soltrol propogated lettuce produced final harvestable yields that were comparable to the commercially produced crop (~6% reduction in yield) we will expand our field trials over the next 2 seasons to determine whether this is the case in a variety of different weather conditions.

Figure 10. Visual effect of treatments on propagation Iceberg lettuce at 14d in 2003.

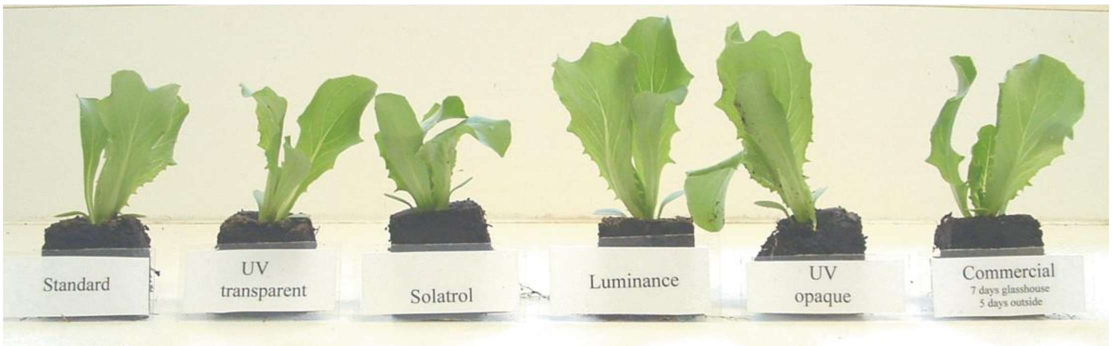


Figure 11. Visual effect of treatments on propagation Iceberg lettuce at 14d in 2004.

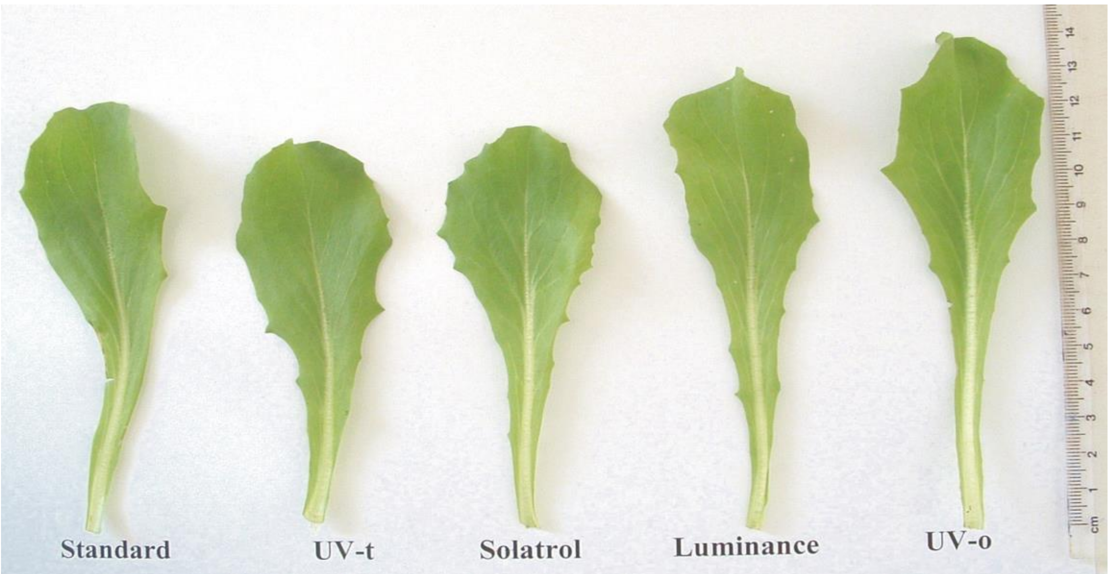


Figure 12. Visual effect of treatments on leaf 2 of propagation Lollo rosso at 14d.

Figure 13. Visual effect of treatments on propagation Little Gem lettuce at 14d.

Figure 14. Visual effect of treatments on propagation Lollo rosso at 14d.

CP19: Horticultural crops:
Further demonstration of the potential benefits of modified plastic crop covers

Direct drilled lollo rosso, endive, rocket and the tactical deployment of spectral filters using lollo rosso

Part 3. Direct drilled Lollo rosso, Endive and the ‘tactical deployment of spectral filters’ using Lollo rosso

Introduction

Lettuce and leafy salad crops are grown for whole head production and for inclusion in mixed leaf pillow packs over as long a season as possible. To maximise quality and prolong shelf life, it is essential that foliage is free from pest and disease contamination. Production under plastic will provide potential benefits including faster growing cycles, ability to reduce pest contamination and better continuity scheduling. Protecting the crop from adverse weather conditions could also help maintain leaf quality.

In this project, red lettuce Lollo rosso and Frisee endive were transplanted following propagation in a glasshouse. The Lollo rosso was included to determine if any of the plastics would either enhance, or have a detrimental affect, on leaf characteristics and coloration. Results from 2003 showed that under UV-opaque, and to a lesser degree Lumiance, Lollo rosso yields were increased relative to the remaining treatments but at the cost of the intense red pigmentation associated with this crop. Therefore, in the 2004 season, we tested a method “the tactical deployment of filters” of transferring Lollo rosso from Luminance and UV-opaque to UV-transparent (to produce the red pigmentation) at various stages throughout development with the aim of maximising both yield and pigmentation. Further studies were also carried out at Snaith Salads, North Yorkshire, to determine if the five filter treatments alter shelf life and the taste of Lollo rosso at harvest. The Endive was included to determine if any of the plastics would affect the development of the flower stalk and subsequent bolting.

Results

LOLLO ROSSO

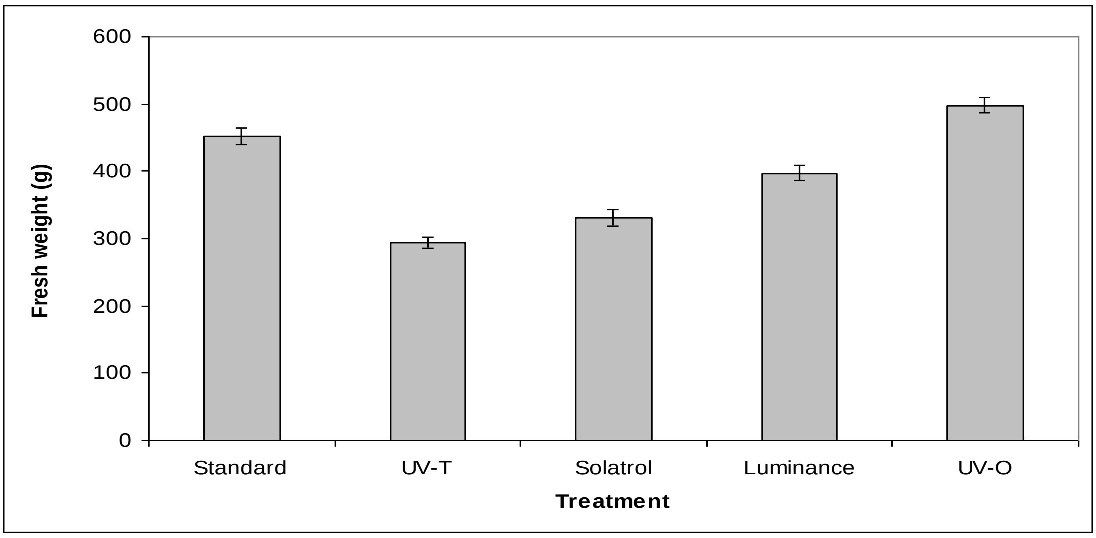
BIOMASS

Head Fresh weight at the time of harvest was significantly increased in UV-opaque when compared to all treatments (fig. 1.a). Final dry weight was also increased in UV-opaque relative to UV-transparent and Solatrol, although there was no effect relative to Standard and Luminance (fig. 1.b).

SHELF LIFE & TASTE TEST

When the crop reached the point when it was ready for market lettuces were transported to Snaith Salads within 6 hours of harvest for shelf life tests. Preliminary results from the first years trial suggest that those plants propagated for 14 days under the UV-transparent or the UV-opaque filter, prior to planting out, produced a crop which remains at grade 1 for significantly longer (≥1 d) than remaining treatments (Table 1). Preliminary results from commercial taste tests show that UV-transparent produced a crop with a ‘bitter’ taste and ‘sweetness’ was increased in order from Standard, Solatrol, Luminance and UV-opaque (Table 2). These trials will be extended in year 3 and 4

a)



b)

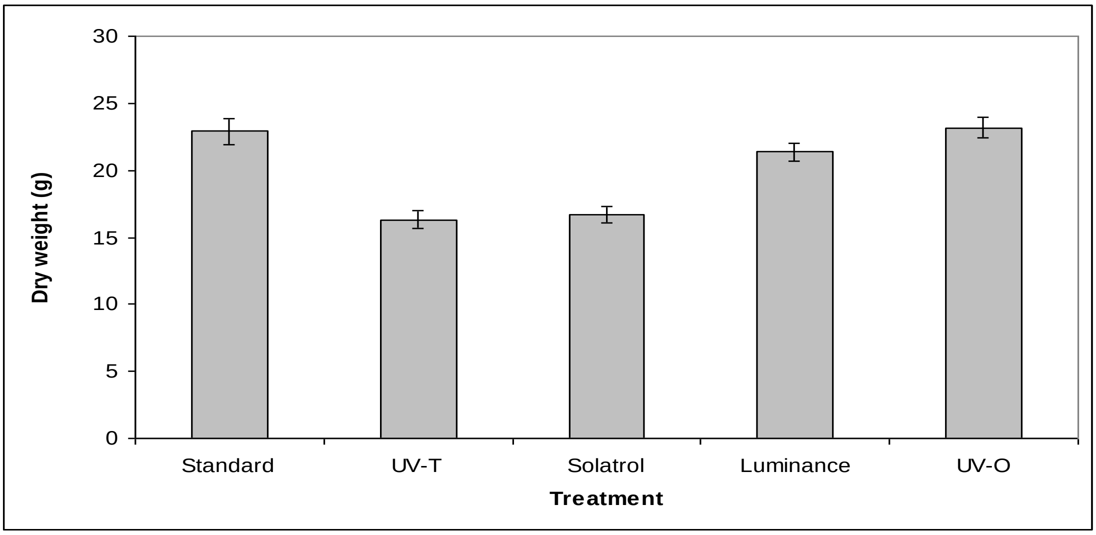


Figure 1. Effect of treatments on a) fresh weight and b) dry in Lollo rosso at time of harvest. Each value is the mean + S.E. of 20 replicates.

LOLLO ROSSO SHELF LIFE & TASTE TEST

Table 1. Results from shelf life tests carried out on behalf of the project by Snaith Salads, West Yorkshire. Grade 1 represents a perfect marketable specimen and increasing values are indicative of crop deterioration.

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Standard	1	1	2	2	2	2	2 or 3
UV-t	1	1	1	1	1	1	2
Solatrol	1	1	1	1	1	1 or 2	1 or 2
Luminance	1	1	1	1 or 2	1 or 2	1 or 2	2
UV-o	1	1	1	1	1	1	1

Table 2. Results from taste tests carried out on behalf of the project by Snaith Salads, West Yorkshire. A value of 1 represents a 'bitter' taste and increasing values are indicative of increasing 'sweetness' in the crop.

	Standard	UV-trans	Solatrol	Luminance	UV-opaque
1	3	2	4	5	4
2	2	1	3	4	5
3	3	3	3	4	3
4	3	2	2	3	5
5	5	2	4	4	5
6	3	1	3	5	4
7	4	2	4	3	4
8	2	2	4	3	5
9	4	2	3	5	3
10	4	3	4	4	5
mean	3.30	2.00	3.40	4.00	4.30
s.e.	0.30	0.21	0.22	0.26	0.26

LOLLO ROSSO PIGMENTATION

Despite the cloudy weather experienced throughout the 2004 growing season the 5 filters produced similar effects as those observed in 2003 on visual pigmentation in Lollo rosso. UV-transparent, in all three batches grown this year, consistently produced increased pigmentation when compared to the remaining 4 filters (see figs. 2-4 below).

a)

b)

Figure 2. Effect of (a) Standard and (b) UV-transparent filters on visual pigmentation in Lollo rosso at time of harvest.

a)

b)

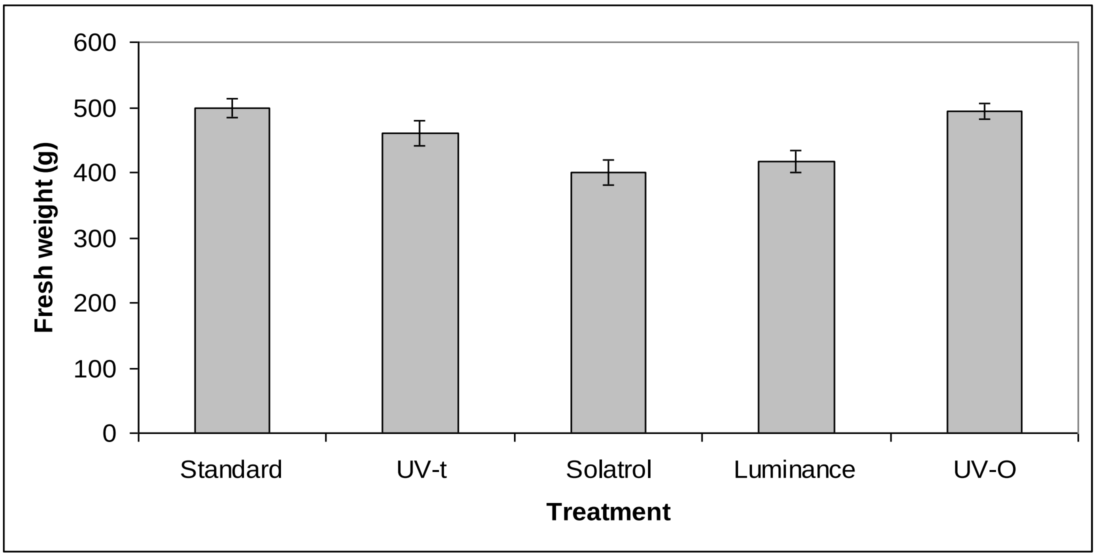
Figure 3. Effect of (a) Solatrol and (b) Luminance filters on visual pigmentation in Lollo rosso at time of harvest.

Figure 4. Effect of UV-opaque filter on visual pigmentation in Lollo rosso at time of harvest.

ENDIVE

Standard increased fresh weight when compared to Solatrol and Luminance only (fig.5.a). However, there was no effect of Standard on dry weights when compared to all remaining treatments (fig. 5.b). The only significant effect of treatments was an increase in final dry weights in UV-opaque relative to Solatrol (fig. 5.b).

a)



b)

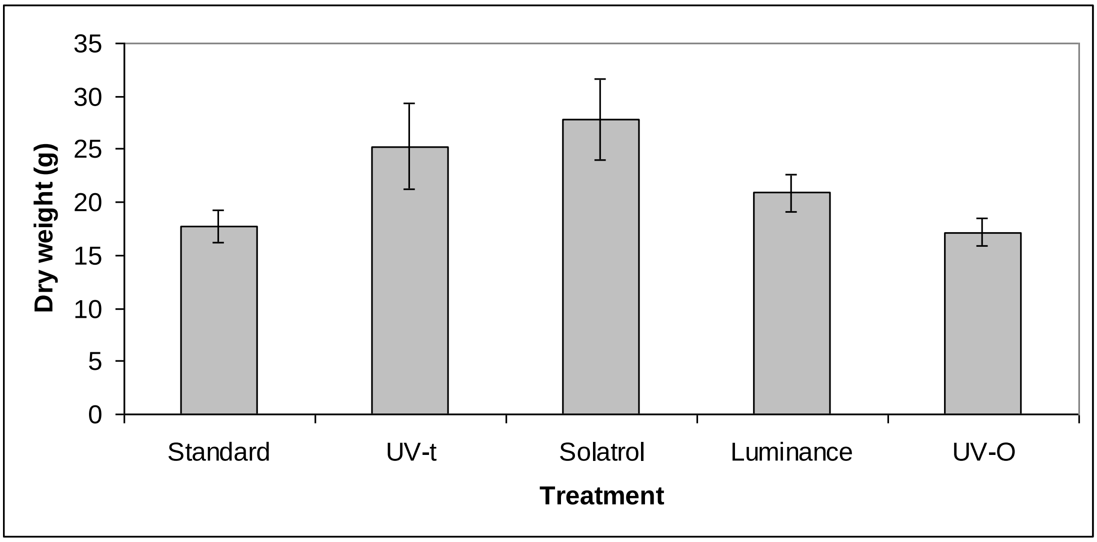


Figure 5. Effect of treatments on (a) fresh weight and (b) dry in Endive at time of harvest. Each value is the mean ± S.E. of 20 replicates.

THE TACTICAL DEPLOYMENT OF SPECTRAL FILTERS IN LOLLO ROSSO

In the above section Lollo rosso are direct drilled under one filter and then taken through to maturity under that filter. Results from the first 2 seasons suggest that while the UV-opaque filter produces increases in harvestable fresh weight by ~25%, this is at the cost of the red colouration associated with Lollo rosso (see fig. 6. below). In an effort to achieve both an increase in head fresh weight and the desired pigmentation it was decided to allow Lollo rosso to develop under both the UV-opaque and Luminance filters and to subsequently transfer plants to UV-transparent at intervals throughout their development up until 42 days, which is 7 days prior to harvest (at 49 days). A batch of Lollo rosso spent the entire duration of the experiment under UV-transparent filter as a control to compare changes in yield and pigmentation.

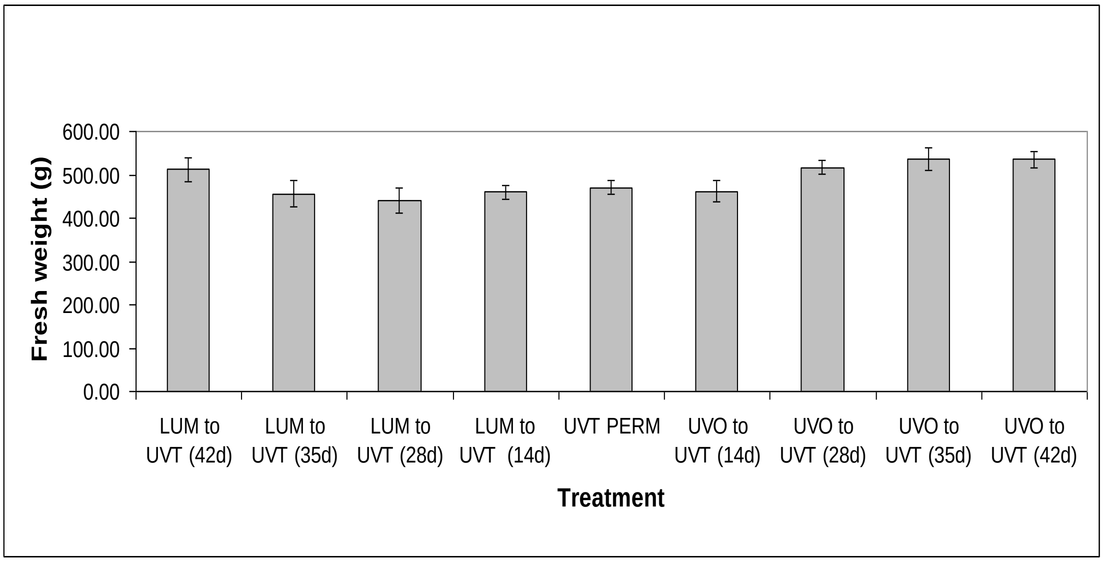
Figure 6. Lollo rosso. Samples were harvested 39 days after beginning of treatment and were typical of all replicates.

BIOMASS RESULTS FROM TACTICAL DEPLOYMENT

There was no significant effect on fresh weight yield at time of harvest of starting Lollo rosso out under the Luminance filter and transferring to UV-transparent at 14, 28, or 35 d (fig. 7.a). Although there was an 8% increase in Lollo rosso fresh weights in those plants that spent 42 days under Luminance before being transferred to UV-transparent (LUM to UVT 42d) this was not a significant increase (fig. 7.a).

Similarly, growing Lollo rosso under UV-opaque and transferring to UV-transparent at 14 days produced no significant effect on final, harvestable fresh weights (UVO to UVT 42d, fig. 7.a). However, transferring Lollo rosso from UV-opaque to UV-transparent at 28d produced a 9% (UVO to UVT 28d) at 35d a 12% (UVO to UVT 35d) and at 42d a 9% (UVO to UVT 24d) increase in fresh weights at time of harvest when compared to UVT-PERM, all of which represented significant increases (fig. 7.a). Final harvestable dry weights in UV-opaque treated plants produced significant increases at 35d (29%) and 42d (32%) only (fig. 7.b) when compared to those plants that remained under UV-transparent throughout the experiment (UVT-PERM).

a)



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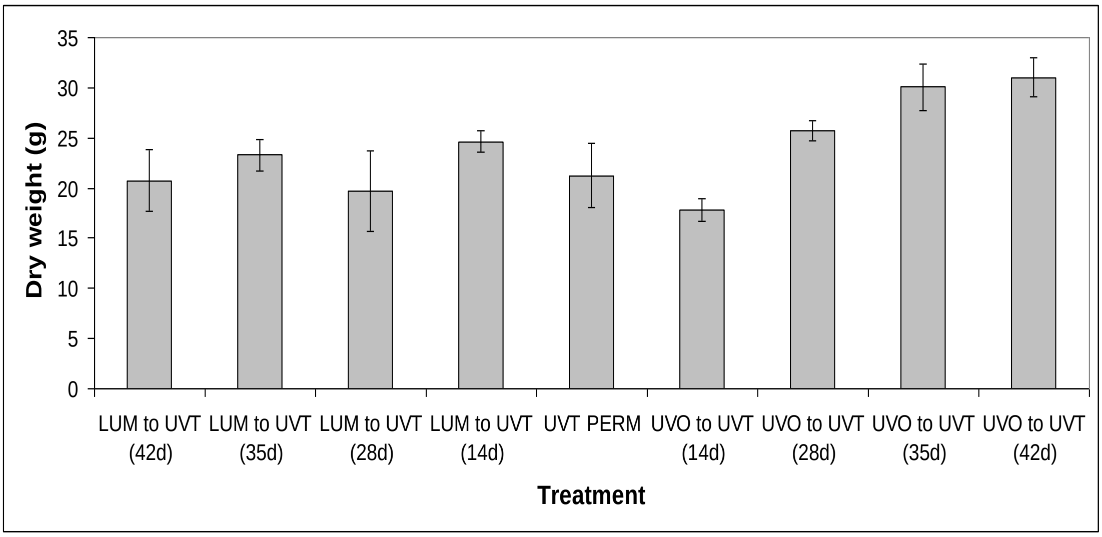


Figure 7. Effect of treatments on (a) fresh weight and (b) dry in Lollo rosso 'tactical deployment' at time of harvest. Each value is the mean $\geq$ S.E. of 10 replicates.

SHELF LIFE AND TASTE TEST RESULTS

Results from this years preliminary trial indicate that those plants that were transferred to the UV-transparent filter from UV-opaque and Luminance at day 14 (LUM to UVT 14d & UVO to UVT 14d) produced a crop with marginally longer shelf lives at grade 1 (Table 3). Both those lettuces transferred from Luminance and UV-opaque to UV-transparent at day 42 (LUM to UVT 42d & UVO to UVT 42d) drop from grade 1 to grade 2 quality 1 day earlier than the remaining transfer treatments, but on the same day as those plants that have remained under the UV-transparent filter for the duration of the experiment (UVT PERM) (Table 3). These are preliminary results and this work will be repeated and extended in the third year of the study.

Taste tests were undertaken on those plants that were transferred from Luminance and UV-opaque to UV-transparent on day 42 (7 days before harvest and taste test). Results show that those plants that remained under the UV-transparent filter for the duration of the experiment (UVT PERM) (Table 4). Preliminary results indicate that crop taste can be manipulated using spectral filters and this work will be extended in 2005.

Table 3. Results from shelf life tests carried out on behalf of the project by Snaith Salads, West Yorkshire. Grade 1 represents a perfect marketable specimen and increasing values are indicative of crop deterioration.

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
LUM to UVT (42d)	1	1	1	1	2	2	2
LUM to UVT (35d)	1	1	1	1	1	2	2
LUM to UVT (28d)	1	1	1	1	2	2	3
LUM to UVT (14d)	1	1	1	1	1	1	2
UVT PERM 21/6	1	1	1	1	2	2	2
UVO to UVT (14d)	1	1	1	1	1	1	2
UVO to UVT (28d)	1	1	1	1	1	2	2
UVO to UVT (35d)	1	1	1	1	1	2	2
UVO to UVT (42d)	1	1	1	1	2	2	2 to 3

Table 4. Results from taste tests carried out on behalf of the project by Snaith Salads, West Yorkshire. A value of 1 represents a 'bitter' taste and increasing values are indicative of increasing 'sweetness' in the crop.

	UV0 to UVT (42d)	UVT perm	LUM to UVT (42d)
1	5	4	3
2	4	3	3
3	3	3	4
4	2	3	1
5	4	3	3
6	4	2	2
7	3	2	3
8	3	3	1
9	4	3	2
10	4	2	3
mean	3.60	2.80	2.50
S.E.	0.27	0.20	0.31

PIGMENTATION

Preliminary results from this years study suggest that after just 7 days under the UV-transparent filter pigmentation in plants switched from the UV-opaque filter is observed to be at a similar level to those plants that had spent either 14, 28 and 35 days, or had been permanently situated, under the UV-transparent filter (see figs.8 & 9)

Figure 8. Lollo rosso under UV-transparent 7 days prior to final harvest. The batch of Lollo rosso in the foreground had just been transferred from the UV-opaque filter where it had been developing for 42d.

Figure 9. Lollo rosso at time of harvest (7 days later) highlighting the speed at which pigmentation occurs.

Discussion

The purpose of the first year's investigation was to determine if the spectral filters could improve crop quality, appearance and/or yield. Given the primary use of Lollo rosso, in mixed leaf pillow packs, both improvements in yield and the visual quality of the crop are of particular importance to growers. A high level of red pigmentation in leaf tissue is desirable as are low levels of visual damage caused by pests and disease. Results from 2003 show both the Standard and UV-transparent filters produced visually increased levels of pigmentation in Lollo rosso when compared to the other treatments (see CP19, 2003). The colouration under Solatrol was almost brown, compared to more vivid colours exhibited by the other treatments (see CP19, 2003). Standard also produced plants with higher fresh and dry weights when compared to UV-transparent which, in conjunction with the relatively high levels of pigmentation, is a highly desirable trait (see CP19, 2003). Endive is also primarily used in leafy salad packs and so the visual properties of the crop including leaf habit, natural blanch and crop weight at the time of harvest are important. Crop productivity was observed to vary greatly under the filters. Both Standard and UV-transparent produced increases in total leaf areas, and leaf thickness and plant fresh weights, especially when compared to Solatrol and conventionally produced field plants (see CP19, 2003).

In this years trials results in Lollo rosso confirmed, across 3 plantings and in very different weather conditions experienced from those of 2003, that both the Standard and the UV-transparent predictably increased crop fresh and dry weights (figs. 1.a & 1.b). Despite the very different climatic conditions experienced during the 2004 growing season, particularly throughout August, visual pigmentation in Lollo rosso was also consistently increased in UV-transparent and Standard, which is in line with observations from 2003 (see figs. 2.a. & 2.b). However, results from the first years shelf life tests, which were carried out under commercial conditions at Snaith Salad Ltd, show that shelf life is extended in UV-opaque and UV-transparent plants and considerably reduced under Standard (Table 1). Preliminary results from a taste test panel indicate that 'bitterness' is increased in UV-transparent and is perceived as being much 'sweeter' in Luminance and UV-opaque (Table 2).

This year we included a brief investigation into the tactical deployment of spectral filters. This investigation was undertaken following results from 2003, which showed that under both Luminance and UV-opaque filters, yield was increased in Lollo rosso but at the expense of the red pigmentation associated with the crop (see fig. 4). The aim of the investigation therefore was to assert whether it is possible to increase yield without the loss of pigmentation by switching plants from Luminance and UV-opaque to the UV-transparent filters at various stages throughout plant development up until 7 days prior to harvest (see figs. 8 & 9). Results from year 1 of this trial show that there are no clear yield gains to be made from switching plants from Luminance to UV-transparent (fig. 7.a). However, switching plants from UV-opaque to UV-transparent at 28 days up to 42 days produced between a 9 and 12 % increase in yield at harvest without visible reductions in pigmentation (fig. 7.a). Preliminary results from shelf life tests do indicate that switching plants from Luminance and UV-opaque to UV-transparent does extend shelf life by approximately one to two days (Table 3). Results from taste tests suggest that plants grown permanently under UV-transparent (and plants switched from Luminance to UV-transparent) are more 'bitter' tasting compared to plants that spent part of their development under UV-opaque (Table 4). Whether the ‘tactical deployment of spectral filters’ approach is commercially viable at this point is not a question that this study set out to answer. What we have demonstrated is that it is possible to manipulate, to a certain degree, both plant growth (yield) and biochemistry (anthocyanin production) by altering the light environment of a crop at certain key stages in its development.

In conclusion, results from both the first and second season’s trials show that crop productivity can be significantly improved by growing both Lollo rosso and Endive under either the Standard or UV-transparent filter in single filter production. Future work will expand on early results from shelf and taste test and hopefully extend into assessments of P&D under the five filters.

**CP19: Horticultural crops:
Further demonstration of the potential benefits of
modified plastic crop covers**

Brassicas: Thasca (cauliflower) and Summer green (cabbage)

Part 4. Brassicas (propagation cabbage, cauliflower and broccoli)

Introduction

Horticultural brassicas (Brussels sprouts, cabbage, broccoli and cauliflower) are grown on about 32,500 hectares (MAFF Basic Horticultural Statistics Census, 2001) and are important crops for a large number of growers. Most of these crops are established from modules grown under protected structures for 6-8 weeks, depending on the time of year, before being machine planted.

The production of module plants has become a specialist business for several companies and there is a need to develop lower cost growing methods whilst not compromising plant quality. Carefully controlled conditions are required to optimise germination and early emergence for the first 1- 2 weeks after sowing. For outdoor crops, uniform emergence of drilled crops is known to influence crop uniformity at harvest. Therefore, uniform emergence of seeded crops in modules could also be critical to maximise plant establishment and the percentage of plants that are cut at the first harvest.

From the cotyledon stage onwards, plants must be grown under cooler, 'tougher' conditions to ensure that 'leggy' growth is avoided and this is achieved by a combination of careful temperature control and by liquid feeding. Plants must not become leggy as this can encourage disease development. Furthermore, if tissue is soft, brassicas can be damaged by pre-plant drenches applied for cabbage root fly control and also during the planting operation.

There is potential to use more ventilated structures for raising brassica plants. This would release glasshouse space for other uses, or increase output if the plants were grown in glasshouses for a shorter period, before being moved out into other cheaper structures. The aim of the 2003 work was to investigate the effects of using the five spectral filters on the growth and development of module raised plants. Both cauliflowers and cabbage were used. This years trial work was extended to include plants that were moved out into the tunnels after just 14 days (early treatment) and were compared to other trays of plants, which remained in the glasshouse for an additional 2 weeks (late treatment). In addition, a commercial 'Control' batch of plants was included. These plants were entirely propagated (6 weeks) under glass in a commercial manner.

Results

CABBAGE – EARLY & LATE TREATMENTS

EARLY TREATMENT

Solatrol significantly reduced total shoot fresh weight when compared to all other treatments (fig. 1.a). Shoot fresh weight was increased in Standard relative to UV-transparent and Solatrol only (fig. 1.a). A similar pattern was observed with regards to total leaf area (fig. 2.a) and plant height (fig. 3.a), where Solatrol exhibited reductions in both these parameters when compared to Standard, UV-transparent, Luminance and UV-opaque and Standard produced increases in leaf area and plant height relative to UV-transparent and Solatrol (figs. 2.a. & 3.a). Root fresh weight was significantly increased in UV-transparent and Solatrol, but this was only a significant increase in UV-transparent relative to Luminance and UV-opaque and in Solatrol when compared to UV-opaque only (fig. 4.a).

LATE TREATMENT

In contrast to ‘early’ treatment plants, Solatrol ‘late’ significantly increased total shoot fresh weight relative to both Standard and UV-transparent filter treatments (fig. 1.b). Solatrol also increased total leaf area but only when compared to UV-transparent (fig. 2.b). Plant height was increased in UV-opaque when compared to Standard, UV-transparent and Solatrol, although there was no effect relative to Luminance (fig. 3.b). With regards to root fresh weight, there was a significant increase in Luminance relative UV-transparent and Solatrol but not Standard or UV-opaque (fig. 4.b).

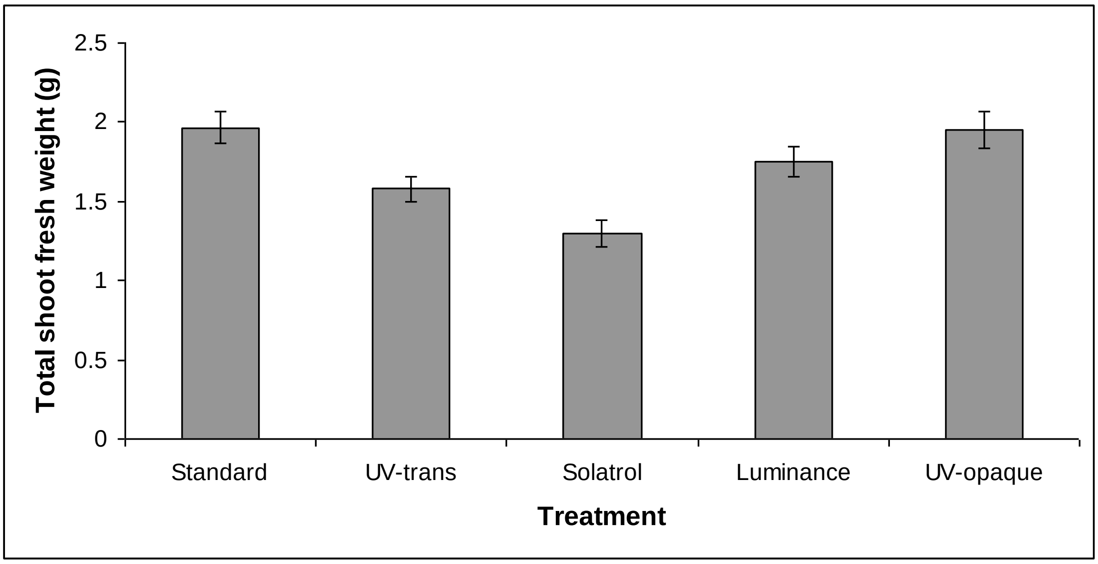
CABBAGE – EARLY, MID AND LATE SEASON FIELD TRIALS

In the early season field trial none of the filter treatments produced increases in fresh weight yield at time of harvest when compared to the Control (fig. 5.a). UV-opaque (late) treatment produced the highest yields and this was a significant increase in harvestable fresh weights when compared to Solatrol (early), UV-opaque (early) and all remaining (late) treatments only (fig. 5.a).

Results from the mid season field trial, again, produced no significant difference in harvestable fresh weights in filter treatments when compared to Control (fig. 5.b). Of the filter treatments UV-opaque (late) significantly increased fresh weights relative to UV-transparent (late) only (fig. 5.b).

In late season field trials the only significant effect of treatments was a reduction in fresh weight yield in Control when compared to Standard (early), UV-transparent (early), Solatrol (early) and Standard (late) (fig. 5.c).

a)



b)

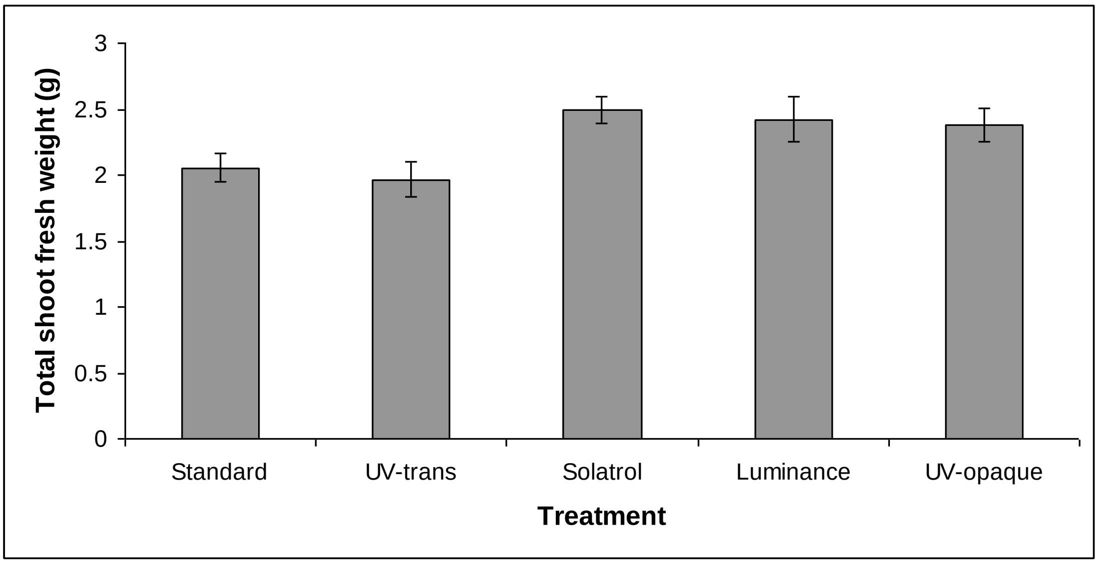
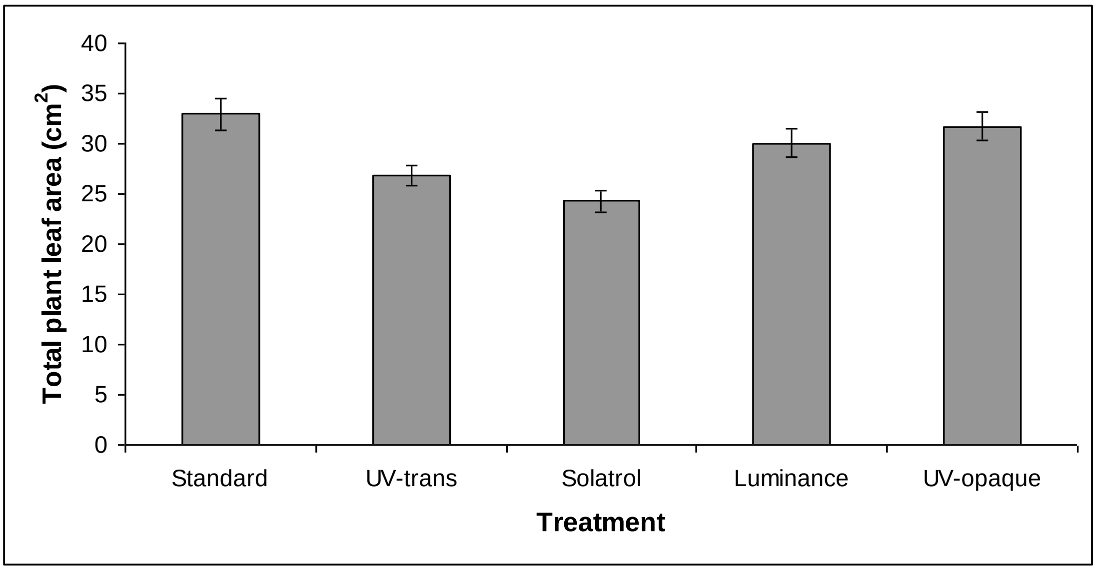


Figure 1. Effect of both (a) 'early' and (b) 'late' treatments on total shoot fresh weight at point of field planting in Cabbage. Each value is the mean $\geq$ S.E. of 20 replicates.

a)



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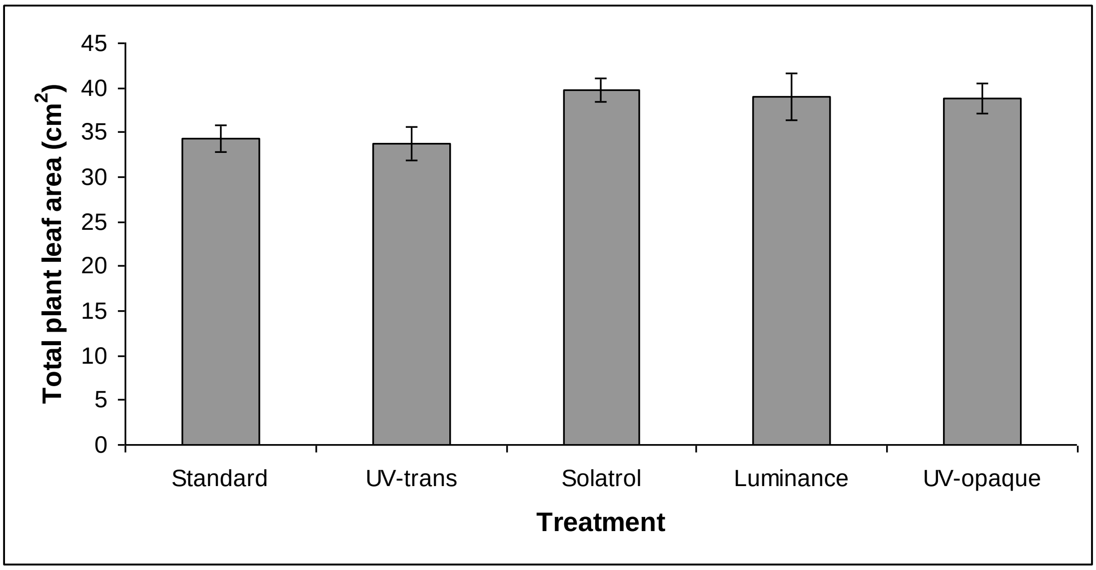
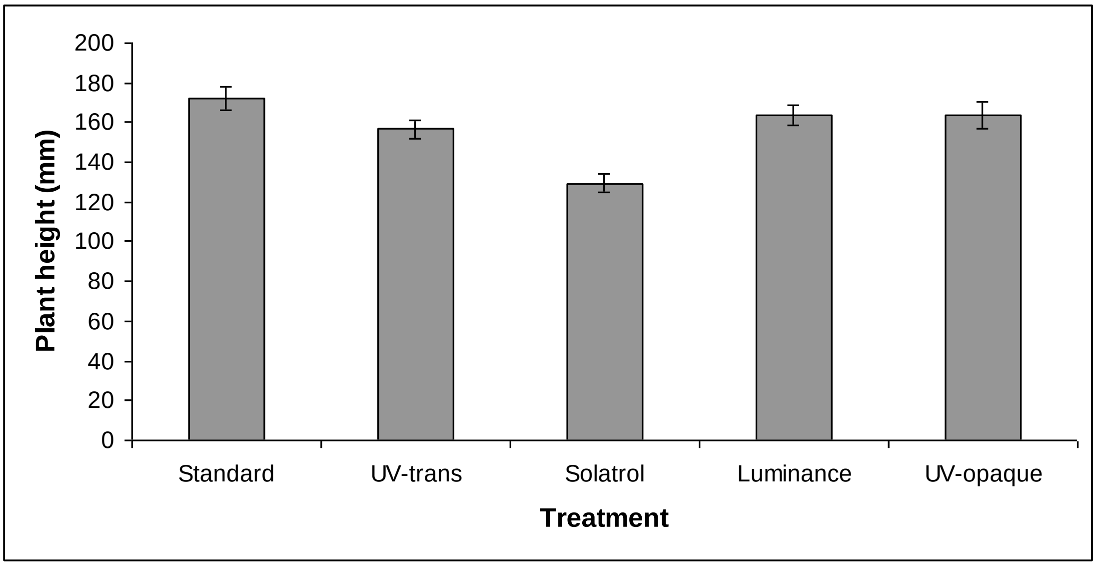


Figure 2. Effect of both (a) 'early' and (b) 'late' treatments on total leaf area at point of field planting in Cabbage. Each value is the mean $\geq$ S.E. of 20 replicates.

a)



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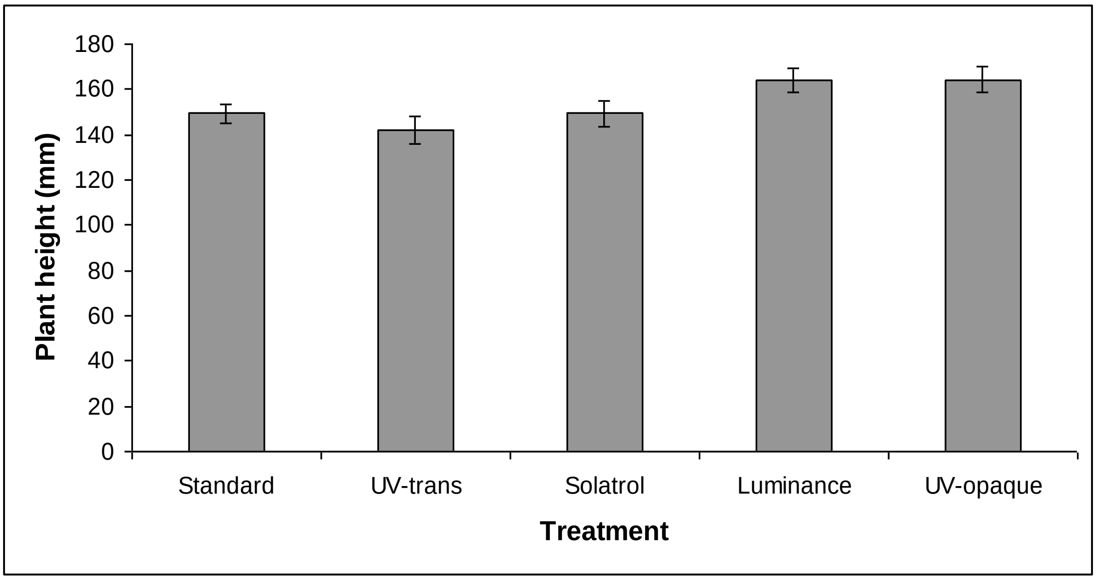
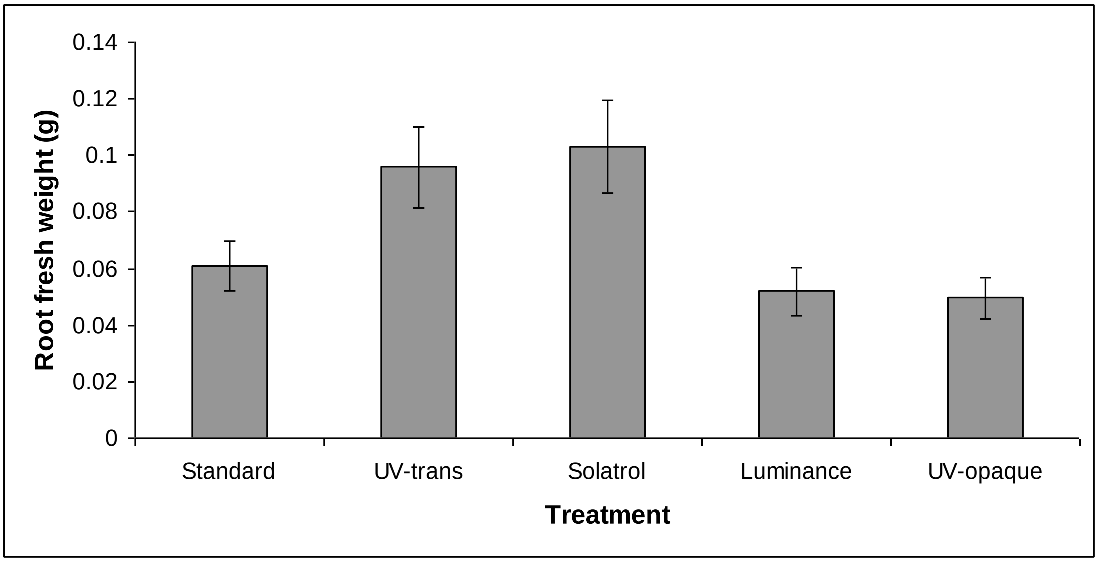


Figure 3. Effect of both (a) 'early' and (b) 'late' treatments on plant height at point of field planting in Cabbage. Each value is the mean $\geq$ S.E. of 20 replicates.

a)



b)

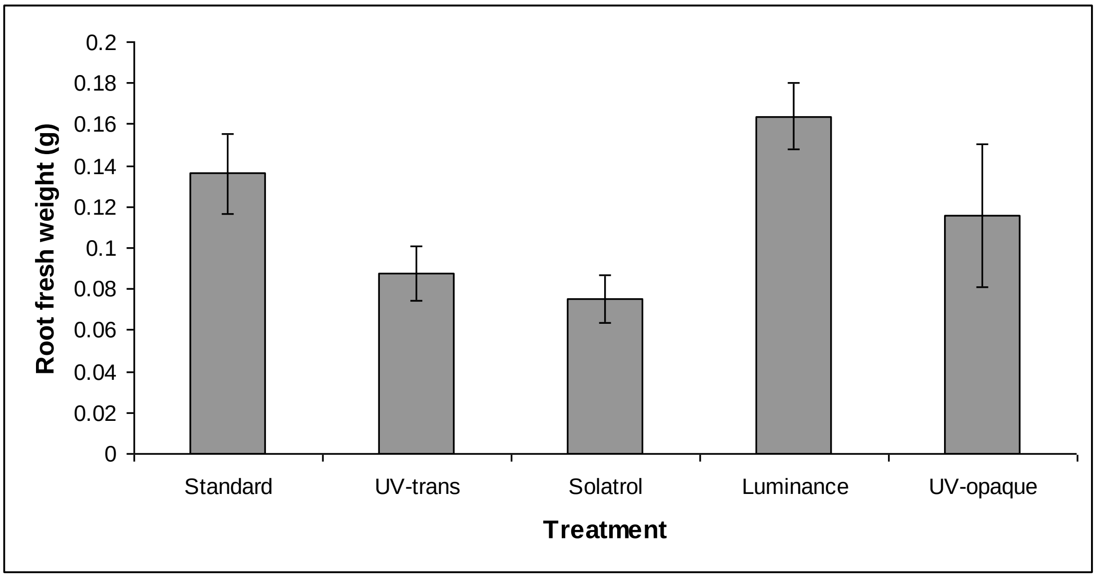
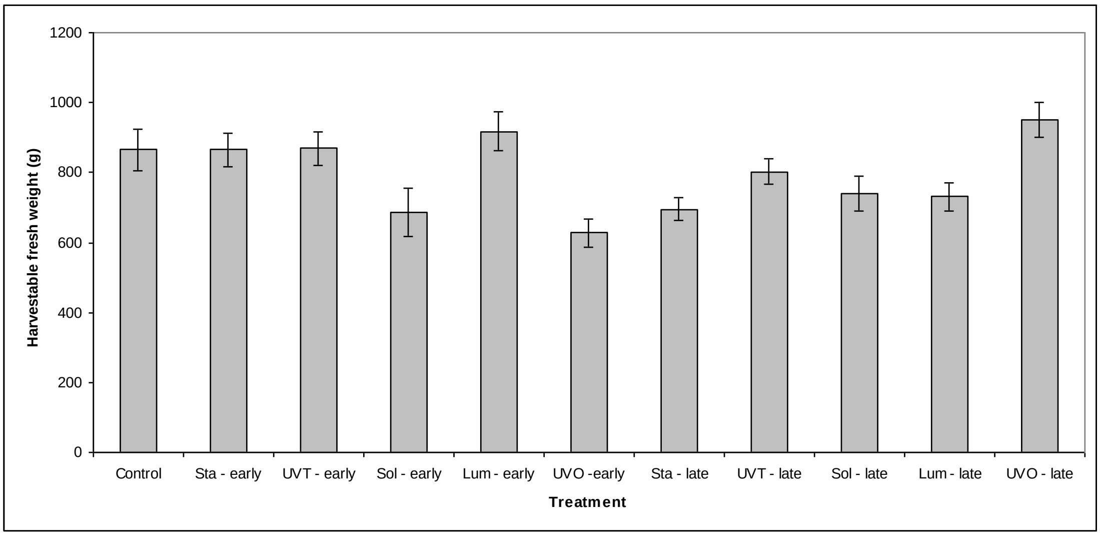


Figure 4. Effect of both (a) 'early' and (b) 'late' treatments on root fresh weight at point of field planting in Cabbage. Each value is the mean $\geq$ S.E. of 20 replicates.

a)



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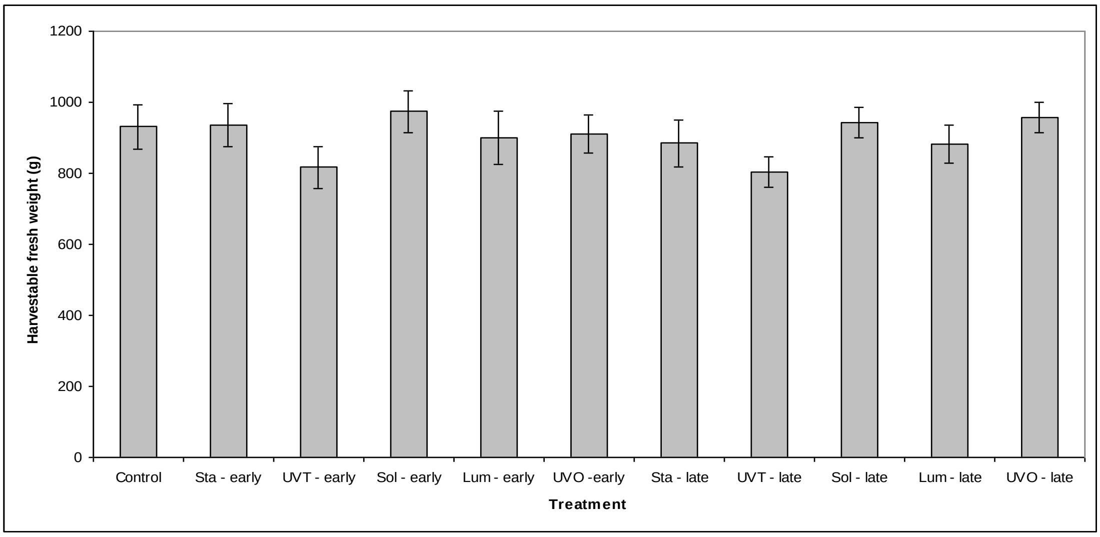


c)

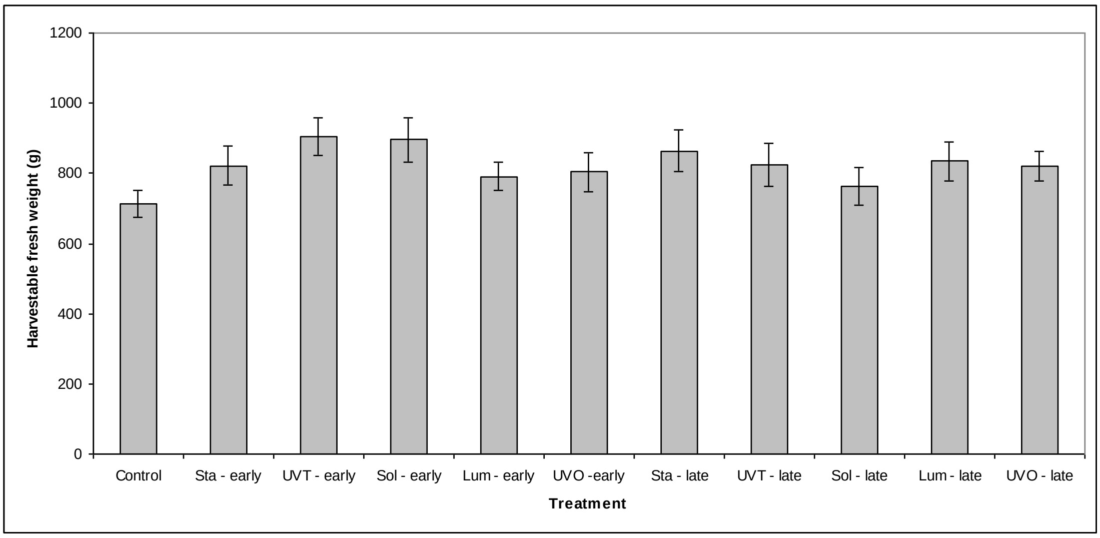


Figure 5. Effect of both 'early' and 'late' treatments on harvestable fresh weights in (a) early, (b) mid and (c) late field plantings in Cabbage. Each value is the mean $\geq$ S.E. of 20 replicates.

CAULIFLOWER EARLY & LATE TREATMENTS

EARLY TREATMENT

There was no significant effect of treatments on total shoot fresh weights (fig. 6.a). The only significant effect of treatments on total leaf area was an increase in Luminance when compared to Standard (fig. 7.a). Luminance also increased plant height relative to Standard and Solatrol only (fig. 8.a). Root fresh weight was significantly reduced in UV-transparent and Solatrol when compared to Standard, although there was no significant effect relative to Luminance and UV-opaque (fig. 9.a).

LATE TREATMENT

The only effect of treatments on shoot fresh weight was a reduction in Standard when compared to Solatrol (fig. 6.b). Total leaf area was increased in UV-opaque relative to Standard, although there was no effect when compared to UV-transparent, Solatrol and Luminance (fig. 7.b). The only significant effect of treatments on plant height was a reduction in Standard relative to UV-transparent and Solatrol (fig. 8.b). Root fresh weight was significantly increased in Standard when compared to UV-transparent, Luminance and UV-opaque, although there was no effect relative to Solatrol (fig. 9.b).

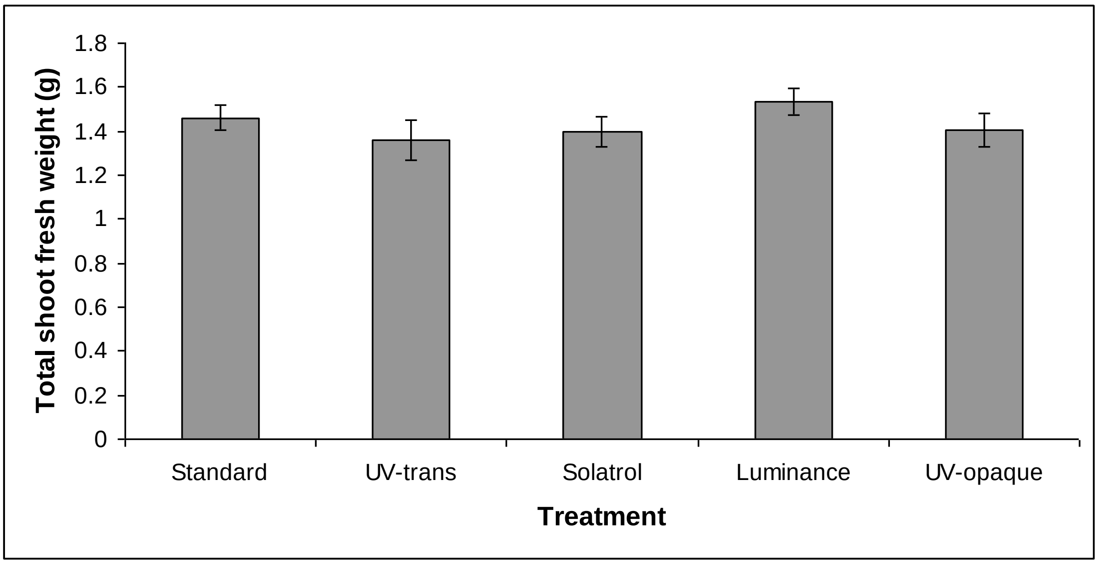
EARLY, MID AND LATE SEASON FIELD TRIALS

In the early season field trial there was a highly significant reduction in harvestable fresh weights in Control when compared to all filter treatments (fig. 10.a). Luminance (late) produced the highest harvested fresh weight yields and this was a significant increase when compared to Control, Standard (early), Solatrol (early) and UV-opaque (early) only (fig. 10.a).

Results from the mid season trial, again, showed a reduction in harvestable fresh weights in Control and this was significant when compared to all treatments except UV-transparent (late) and UV-opaque (late) (fig. 10.b). Solatrol (early) produced plants with the highest harvestable fresh weights and this was a significant increase when compared to Control, Standard (late), UV-transparent (late), Solatrol (late) and UV-opaque (late) only (fig. 10.b).

Results from the late season trial show that Control significantly reduced fresh weight when compared to Standard (early), UV-transparent (early), Solatrol (early) and Luminance (late) (fig. 10.c). Of the filter treatments, Solatrol (early) produced the highest harvestable fresh weights and this was significant increase relative to Control, Luminance (early), Standard (late), UV-transparent (late) and UV-opaque (late) only (fig. 10.c).

a)



b)

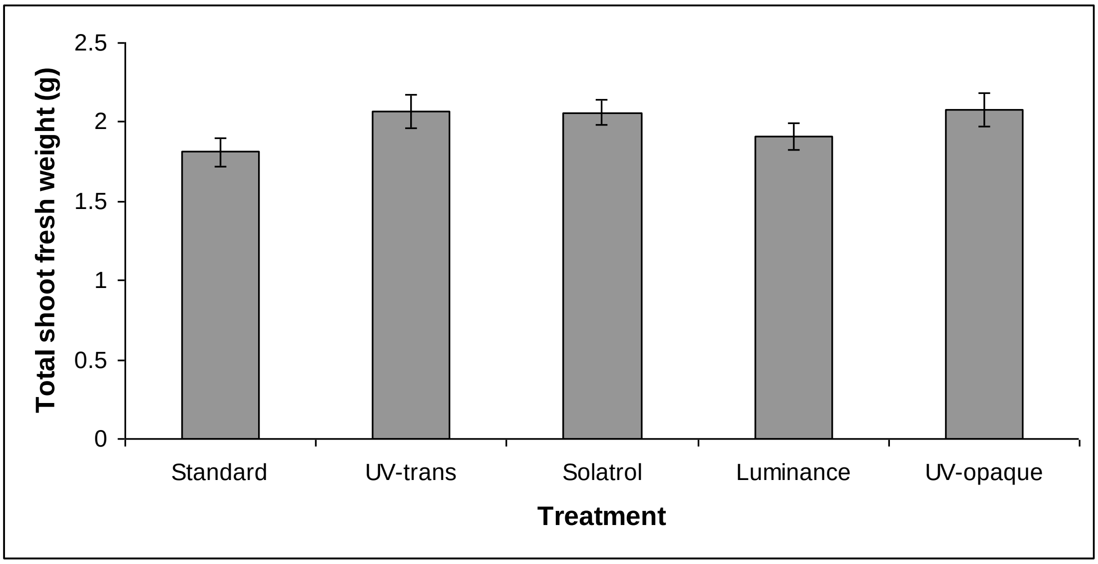
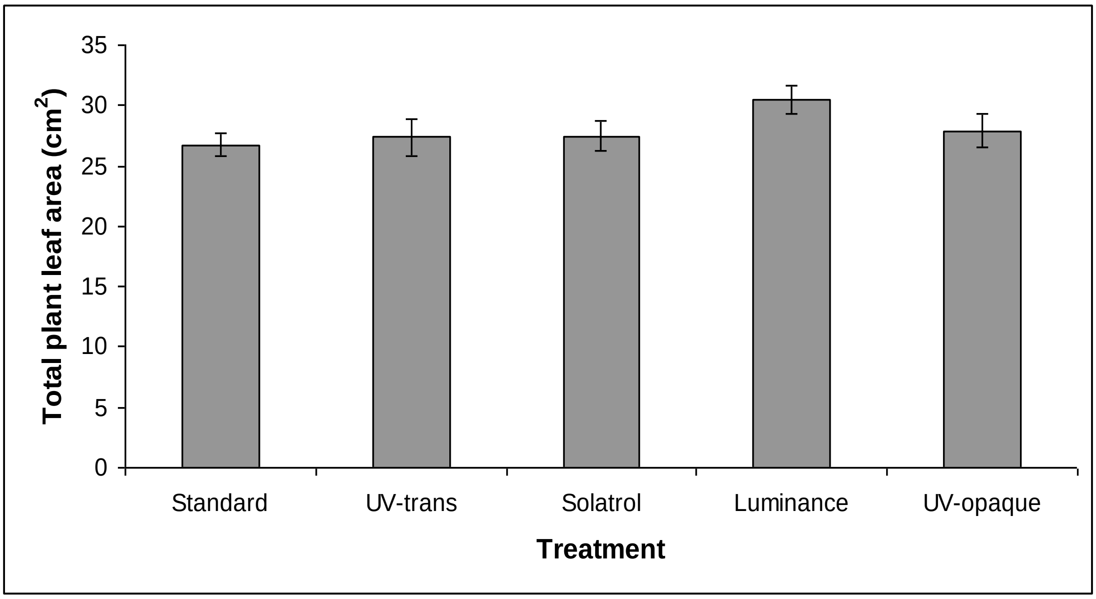


Figure 6. Effect of both (a) 'early' and (b) 'late' treatments on total shoot fresh weight at point of field planting in Cauliflower. Each value is the mean $\geq$ S.E. of 20 replicates.

a)



b)

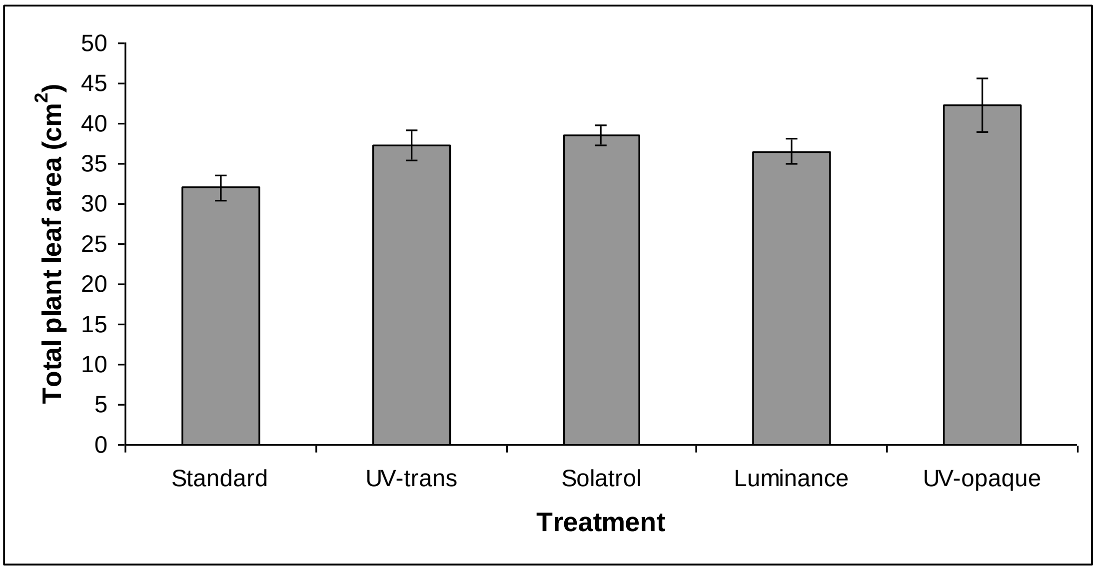
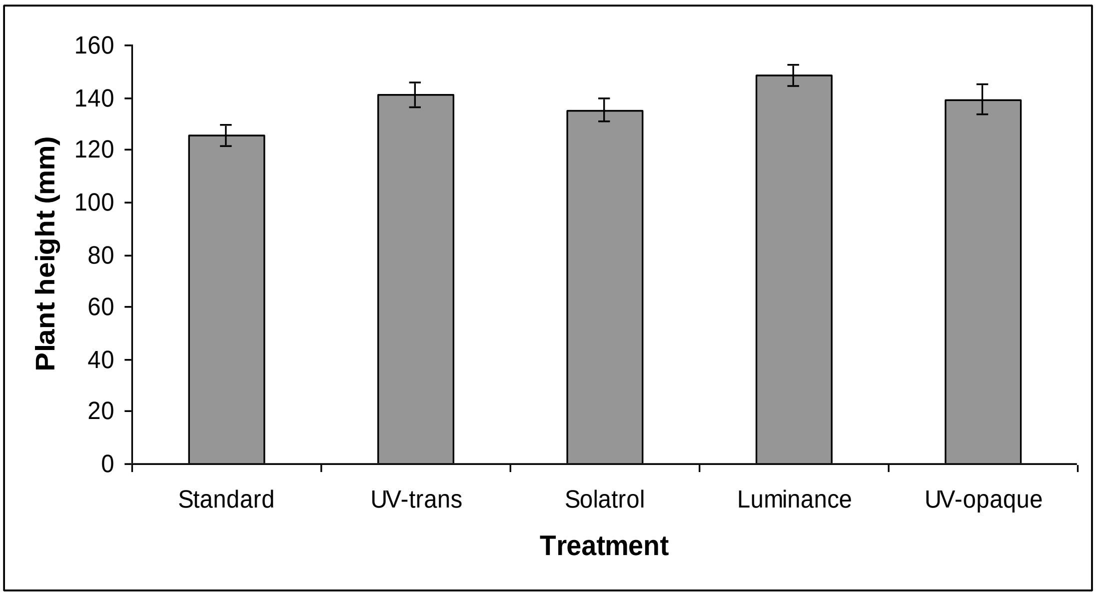


Figure 7. Effect of both (a) 'early' and (b) 'late' treatments on total leaf area at point of field planting in Cauliflower. Each value is the mean $\geq$ S.E. of 20 replicates.

a)



b)

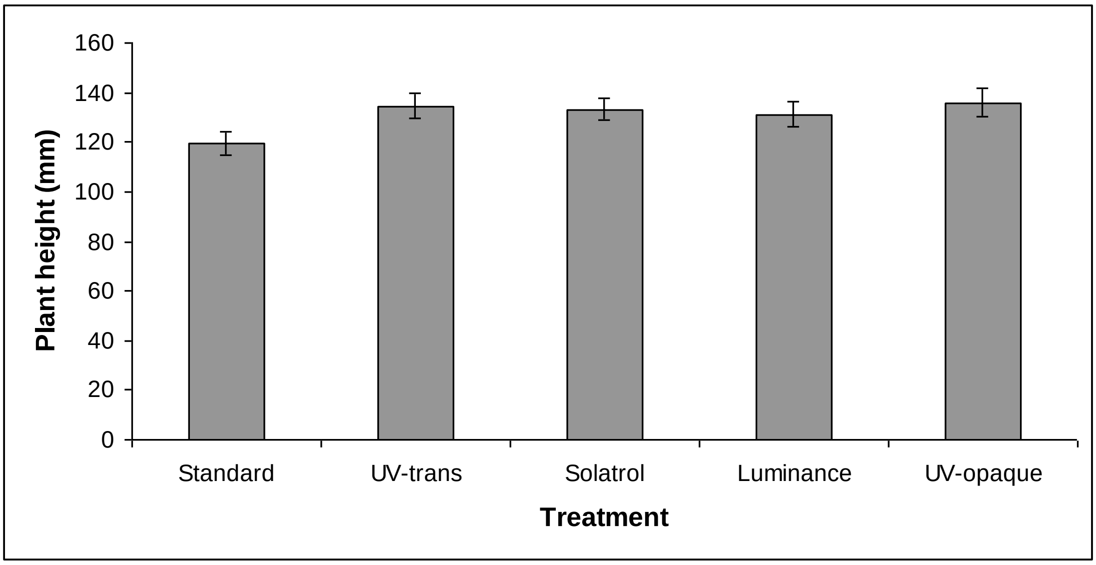
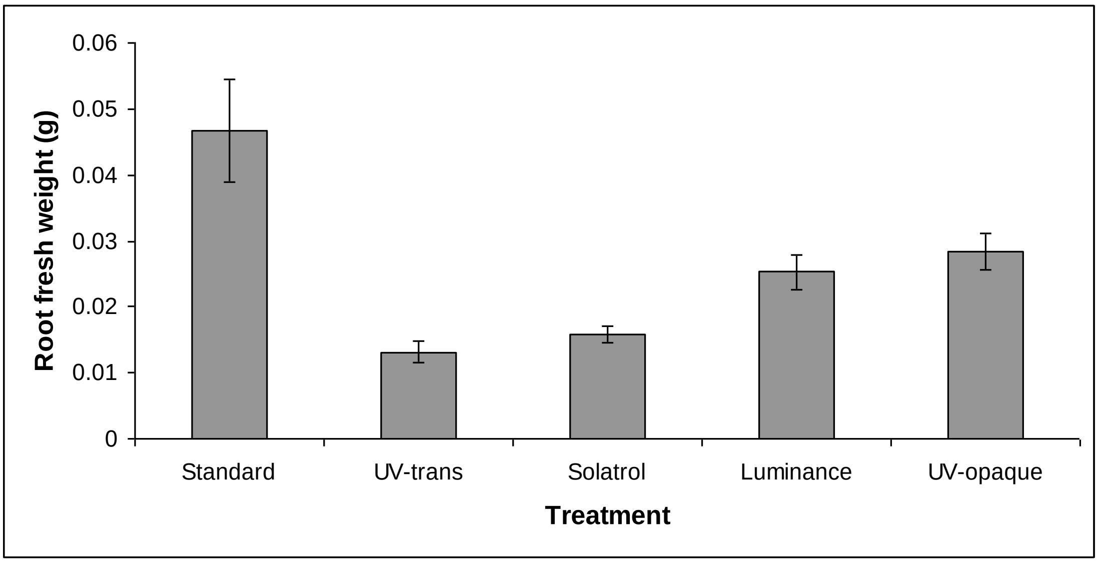


Figure 8. Effect of both (a) 'early' and (b) 'late' treatments on plant height at point of field planting in Cauliflower. Each value is the mean $\geq$ S.E. of 20 replicates

a)



b)

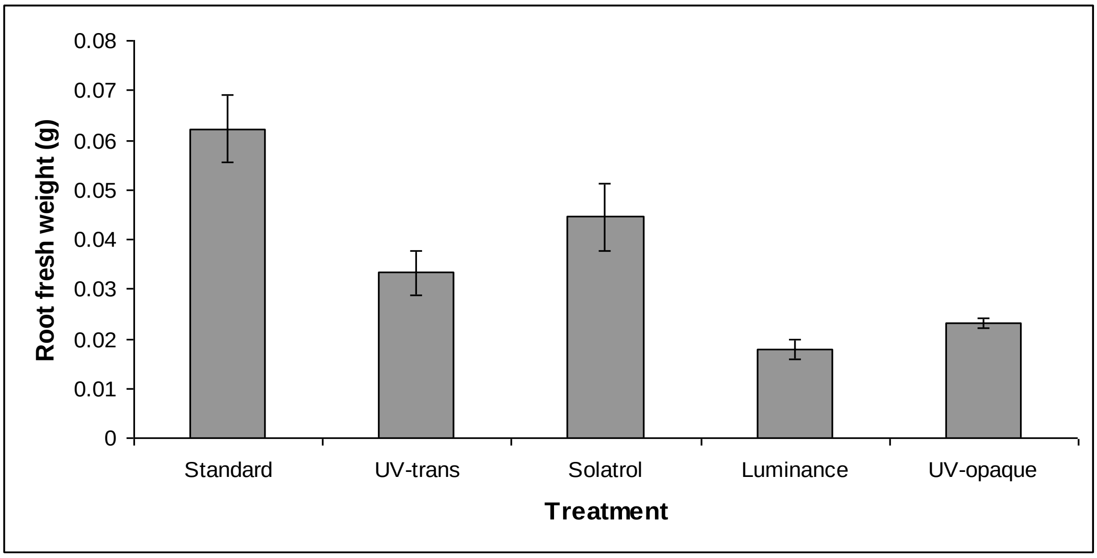
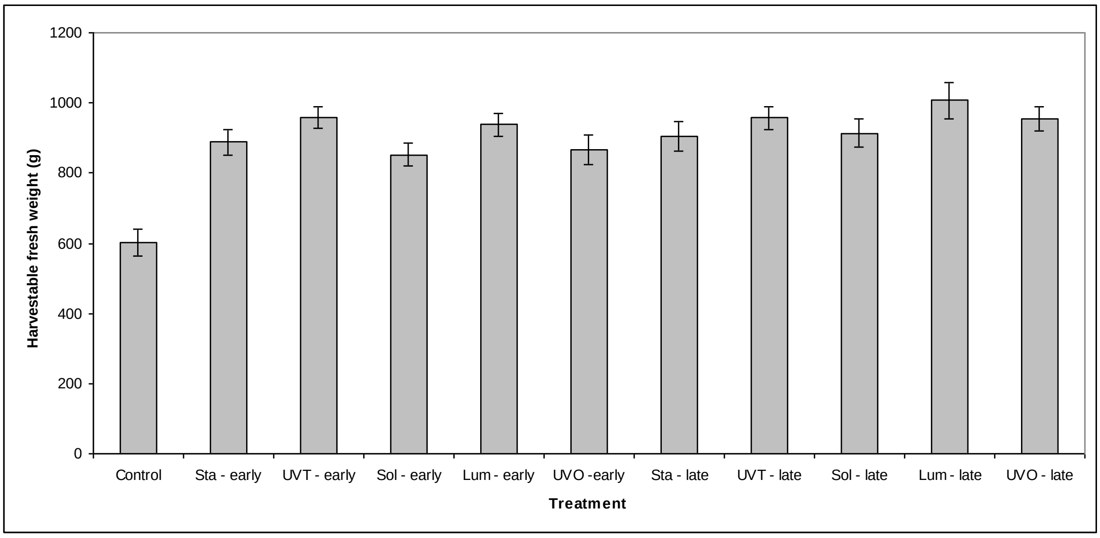
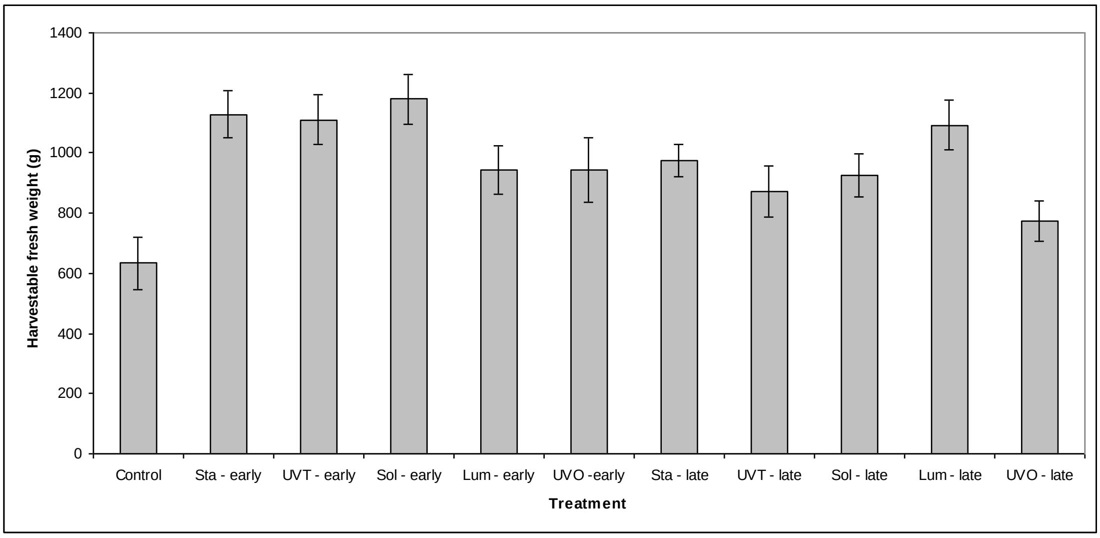


Figure 9. Effect of both (a) 'early' and (b) 'late' treatments on root fresh weight at point of planting in Cauliflower. Each value is the mean $\geq$ S.E. of 20 replicates.

a)



b)



c)

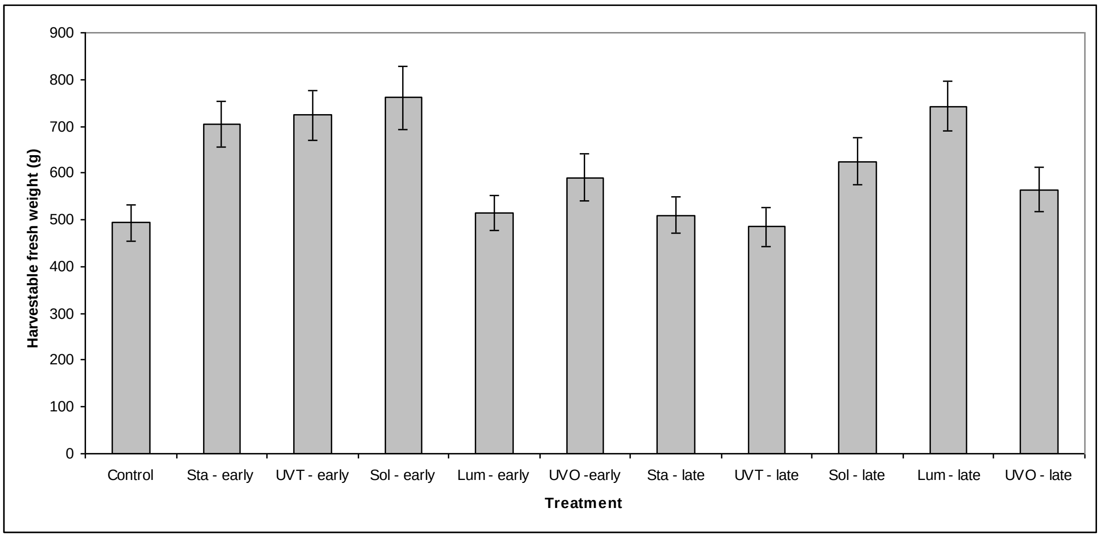


Figure 10. Effect of both early and late treatments on harvestable fresh weights in (a) early, (b) mid and (c) plantings in Cauliflower. Each value is the mean ≥ S.E. of 20 replicates.

BROCOLLI FIELD TRIAL

Standard (late) produced a significant increase in harvestable fresh weights relative to Luminance (early) only (fig. 11). There was no other significant effect of treatments on broccoli fresh weight at harvest (fig. 11).

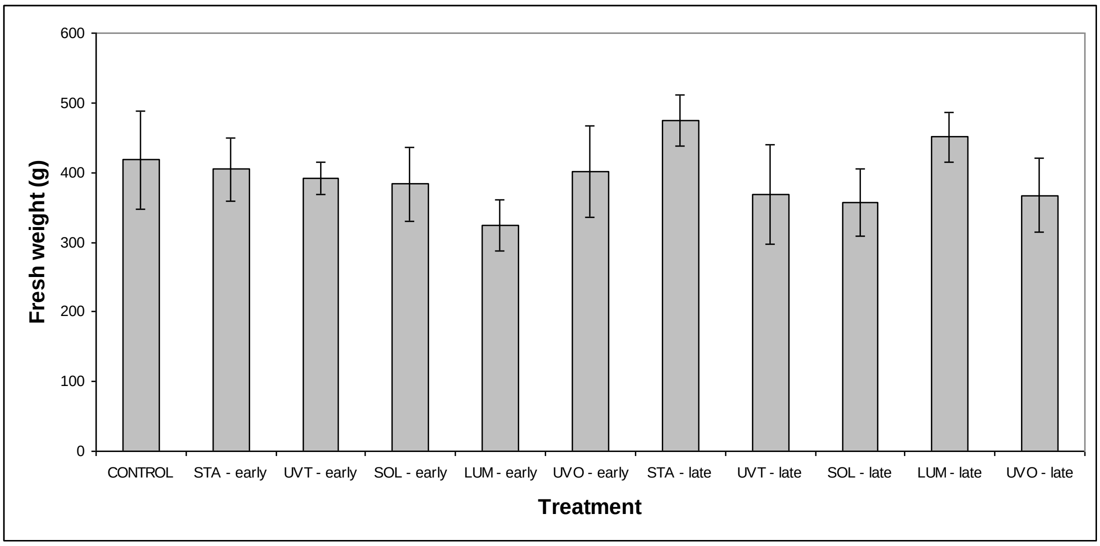


Figure 11. Effect of both 'early' and 'late' treatments on fresh weight in Broccoli at time of harvest. Each value is the mean $\geq$ S.E. of 10 replicates.

Discussion

The aim of the first years trial was to undertake preliminary investigations into the effects of the five spectral filters on brassica development for the particular purpose of identifying a filter(s) that alter plant physiology and morphology in such a way as to provide the propagator with a small, stocky plant and toughened vegetative tissue. This is of particular importance to the grower because such characteristics aid in the avoidance of disease development and mechanical damage caused by pre-plant drenches. A plant of this type might also be able to withstand stress at planting, possibly leading to faster establishment and increases in final harvestable yield.

Results from the first year suggested that Solatrol provided the shortest, stockiest Cabbage plant with a relatively well developed root system, although these changes at the propagation stage did not lead to changes in fresh weight yields in field trials. With regards to Cauliflower, the Standard filter produced the shortest, stockiest plant although at the expense of root development. We also observed a tendency for UV-opaque to produce short, stocky plants and increased leaf thickness. UV-opaque also outperformed all other treatments in field trials.

Results in Cabbage from 2004 would appear to reinforce preliminary results from 2003. Again, Solatrol produced short, stocky plants, especially in those plants transferred from the glasshouse at the earliest stage in development (Solatrol – early, fig. 3.a). While Solatrol (early) produced plants with reduced shoot fresh weights (fig. 3.a) and total leaf area (fig. 2.a) at the time of planting, root fresh weight was increased (fig. 4.a). In field trials, in both mid and late plantings, Solatrol (early) showed a non significant tendency to produce increased head fresh weights at the time of harvest relative to the majority of remaining treatments (see figs. 5.b. & 5.c). Results from the early planting suggest that Solatrol (early) reduced fresh weights at harvest when compared to a limited number of treatments, but not the commercial Control (fig. 5.a).

Results in Cauliflower in 2004 also largely mirrored findings from 2003. The Standard filter produced the shortest, stockiest plants in those plants transferred from the glasshouse at the later stage (Standard – late, fig. 12 below). Standard (late) produced reductions in shoot fresh weight (fig. 6.b), leaf area (fig. 7.b), plant height (fig. 8.b) and increases in root fresh weight (fig. 9.b) at time of planting when compared to the other filter treatments. However, these beneficial morphological changes at propagation stage, in contrast to Cabbage, did not lead to increases in harvestable fresh weights in field trials relative to the majority of the remaining filter treatments (figs. 10.a., 10.b. & 10.c). However, harvestable fresh weights in Standard (late) were marginally increased in all 3 seasonal plantings when compared to the commercial Control (figs. 10.a., 10.b. & 10.c). Indeed, the commercial Control produced consistently lower harvestable head fresh weights across early, mid and late season plantings (figs. 10.a., 10.b. & 10.c). With regards to the remaining filter treatments there was a tendency, especially in the mid and late season plantings, for Standard (early), UV-transparent (early), Solatrol (early) and Luminance (late) to increase fresh weights at time of harvest (figs. 10.b. & 10.c).

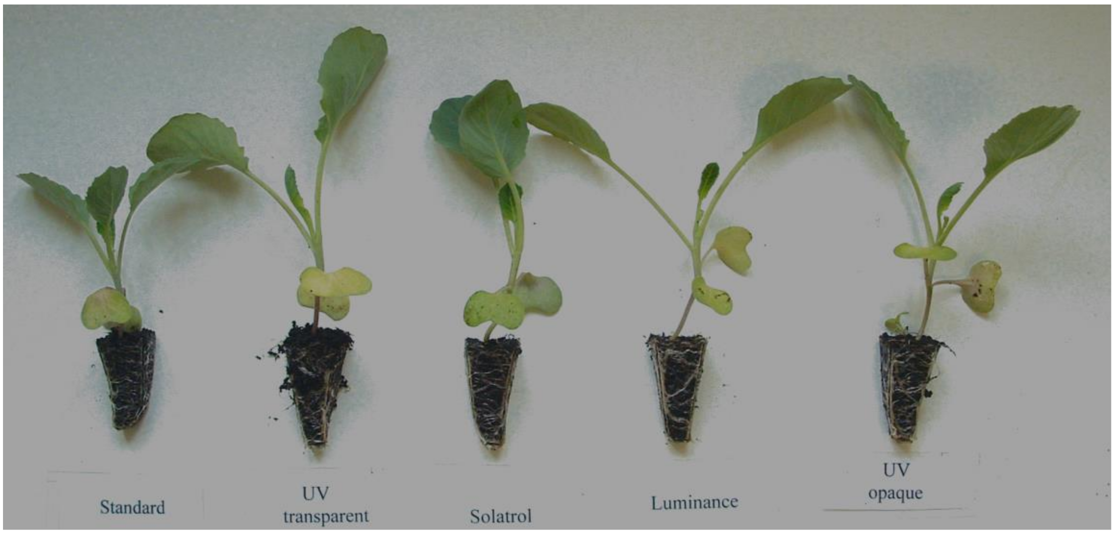


Figure 12. Cauliflower (late treatment) at time of transplantation into the field at Stockbridge Technology Centre, North Yorks.

In contrast to results in 2003 cabbage (Summer Green) did not exhibit visual changes in vegetative colouration under Solatrol, which we hypothesised was linked to changes in alkane production. This may be a result of the different weather conditions during the 2004 growing season; in contrast to last year the crop did not experience long periods of uninterrupted sunlight.

In conclusion, results from both the first and second year trials suggest that spectral filters do effect brassica development in economically beneficial ways and that cabbage and cauliflower respond differently to the various filter treatments. Future work in 2005 and 2006 will seek to clarify these results and hopefully not only quantify the yield benefits to be gained from propagation under spectral filters, but also qualify changes in crop quality and taste.

CP19: Horticultural crops:
Further demonstration of the potential benefits of modified plastic crop covers

Bedding plants

Part 5. Bedding plants

Introduction

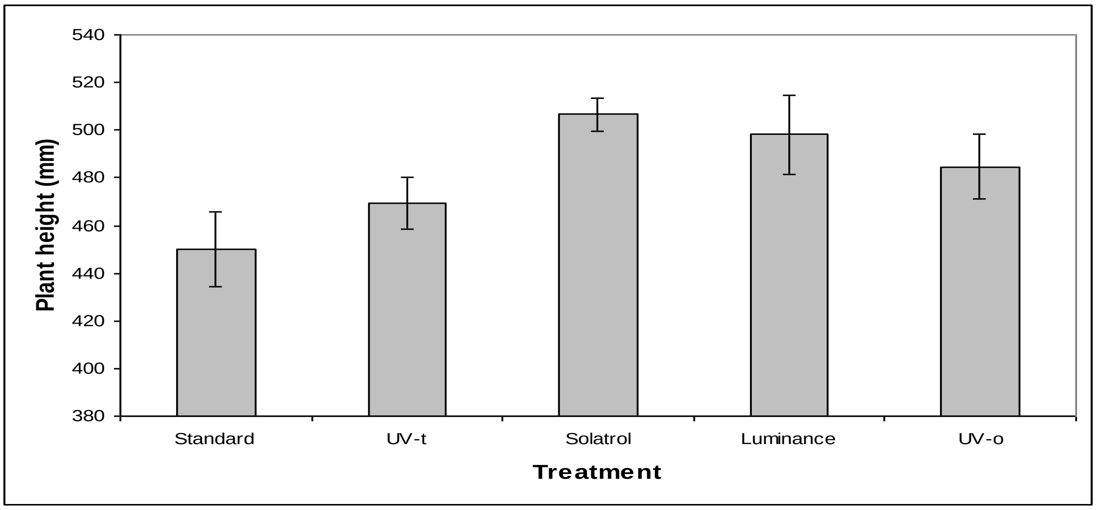
Although the bedding plant sector has enjoyed strong growth in the past four years (~7% year on year) and still remains one of the most profitable horticultural sectors (approx. £70k per acre, personal communication Mr Stuart Coutts), margins are now coming under increasing pressure as large retail outlets attempt to drive down prices. While traditionally the industry has relied heavily on glasshouse production, before moving its crop outdoors, this new market pressure may encourage growers to look for more cost effective alternatives to glass. One possibility is to employ large-scale spectral filters, which not only provide protection from the environmental (e.g. hail damage), but may also alter plant development in economically beneficial ways.

Preliminary studies in May 2003 with Pansy, Petunia, Impatiens, Dianthus, Geranium and Antirrhinums indicated that were distinct differences between treatments in terms of plant height, leaf colour and time to flowering. The 2004 study has been broadened to include 12 varieties of bedding plant of commercial interest to UK growers and extended to determine if short term treatments under spectral filters induce long term beneficial effects in plant development and morphology once they have been transplanted into ambient, outdoor conditions.

ANTIRHINNUM

One of the primary effects of treatments was a significant increase in plant height in Solatrol relative to Standard and UV-transparent, although there was no effect when compared to Luminance and UV-opaque (fig. 1.a). Both Luminance and UV-opaque filters significantly increased both shoot fresh and dry weight when compared to all remaining filters (figs. 1.b. & 2.a). There was an increase in the length of the terminal inflorescence in UV-opaque relative to UV-transparent and Solatrol (fig. 2.b) and an increase in the number of inflorescence in UV-opaque when compared to Solatrol and Luminance only (fig. 2.c).

a)



b)

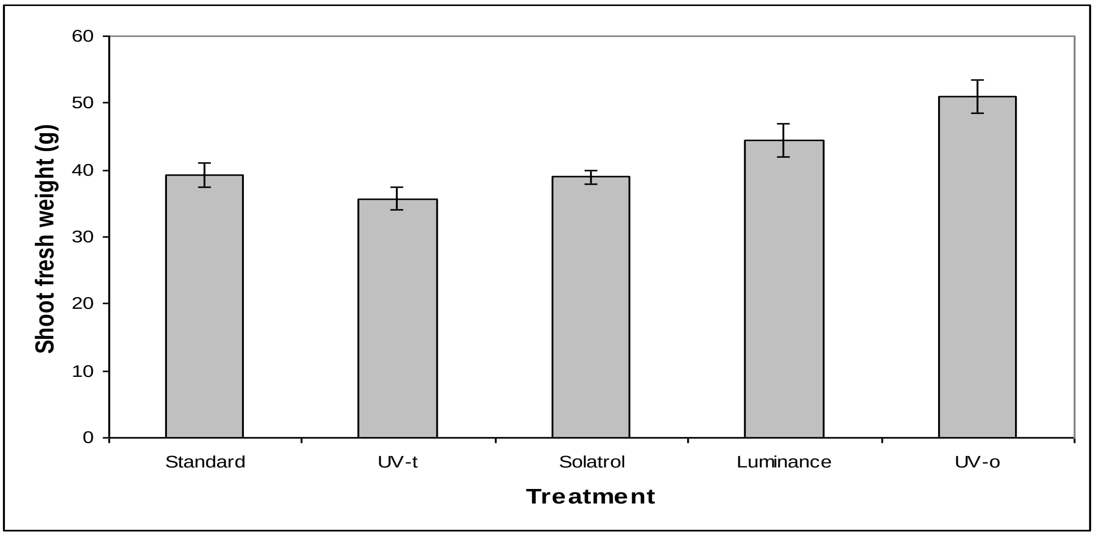
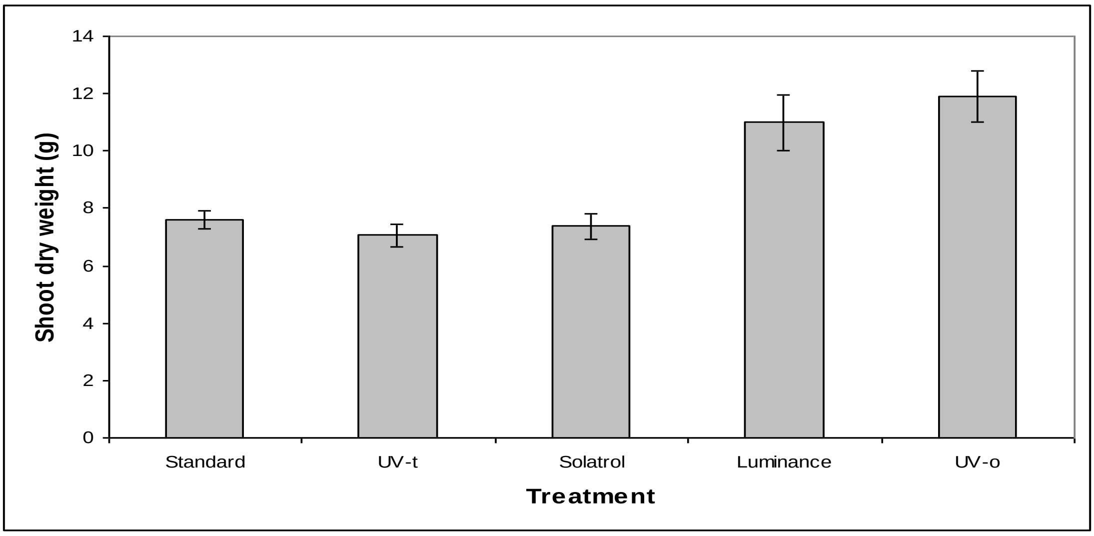
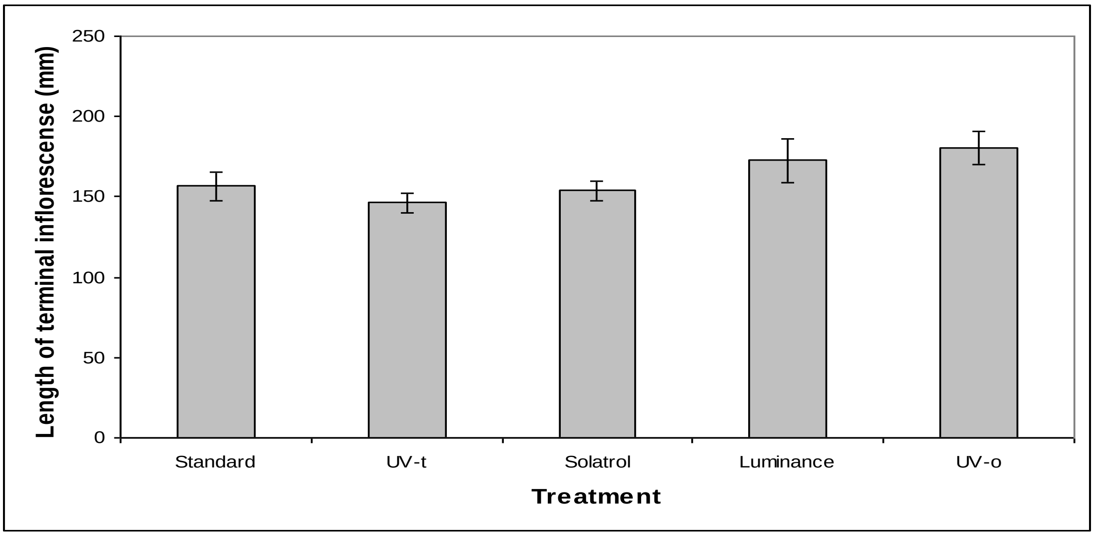


Figure 1. Effect of treatments on (a) plant height and (b) shoot fresh weight in Antirrhinum. Each value is the mean $\pm$ S.E. of $\geq$ 11 replicates.

a)



b)



c)

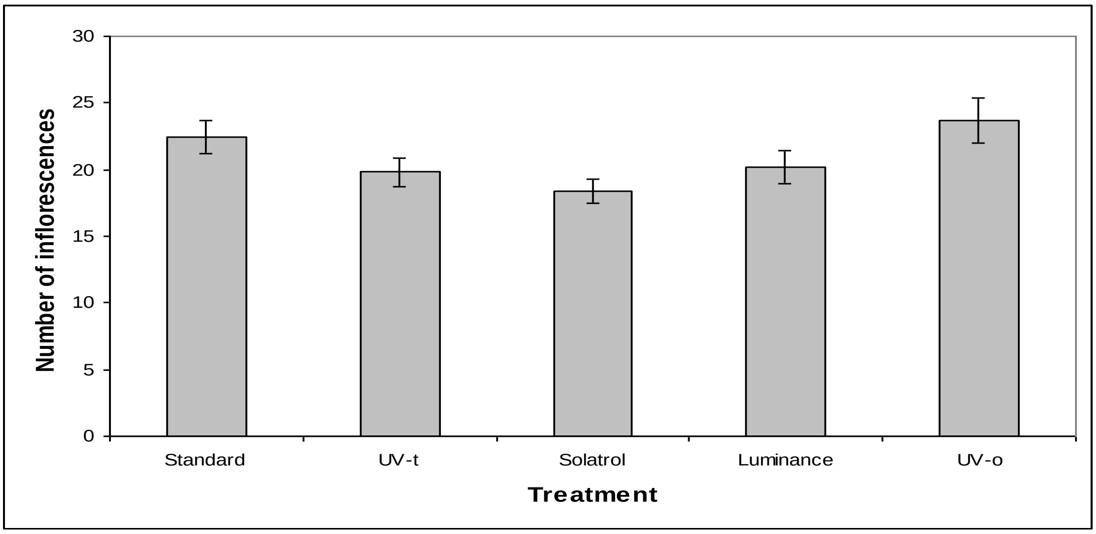
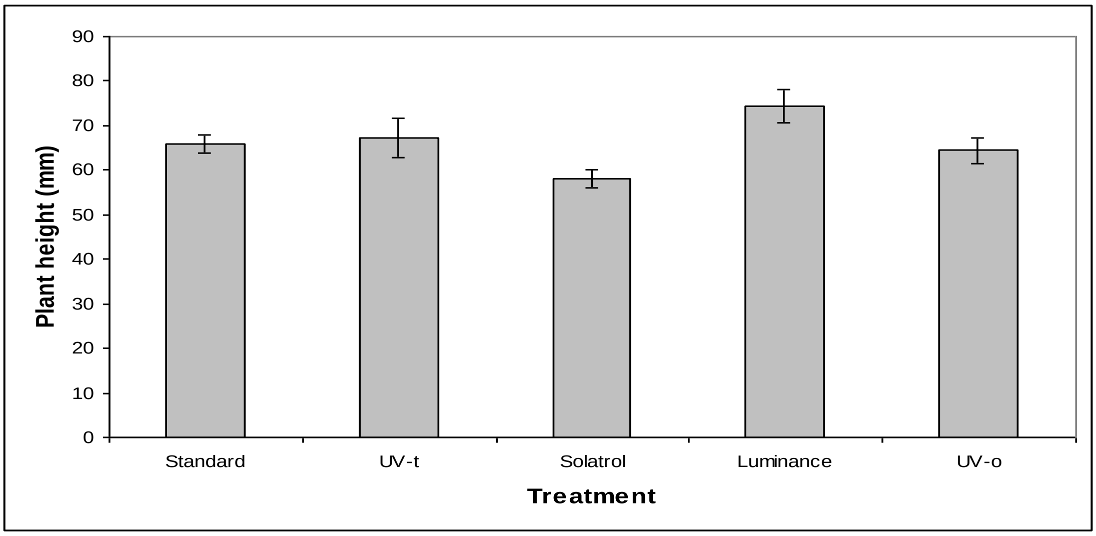


Figure 2. Effect of treatments on (a) shot dry weight (b) length of terminal inflorescence and (c) number of inflorescences in Antirrhinum. Each value is the mean + S.E. of > 11 replicates.

IMPATIEN – EXPO SELECT

There were no significant effects of treatments on time to flowering (data not presented). However, plant height was significantly reduced in Solatrol when compared to Standard and Luminance (fig. 3.a) and increased in Luminance relative to both Solatrol and UV-opaque (fig. 3.a). Shoot fresh weight was significantly reduced in Solatrol relative to all treatments except UV-transparent (fig. 3.b). Luminance produced an increase in the diameter of the terminal inflorescence and this increase was significant relative to Standard, Solatrol and UV-opaque filters (fig. 4).

a)



b)

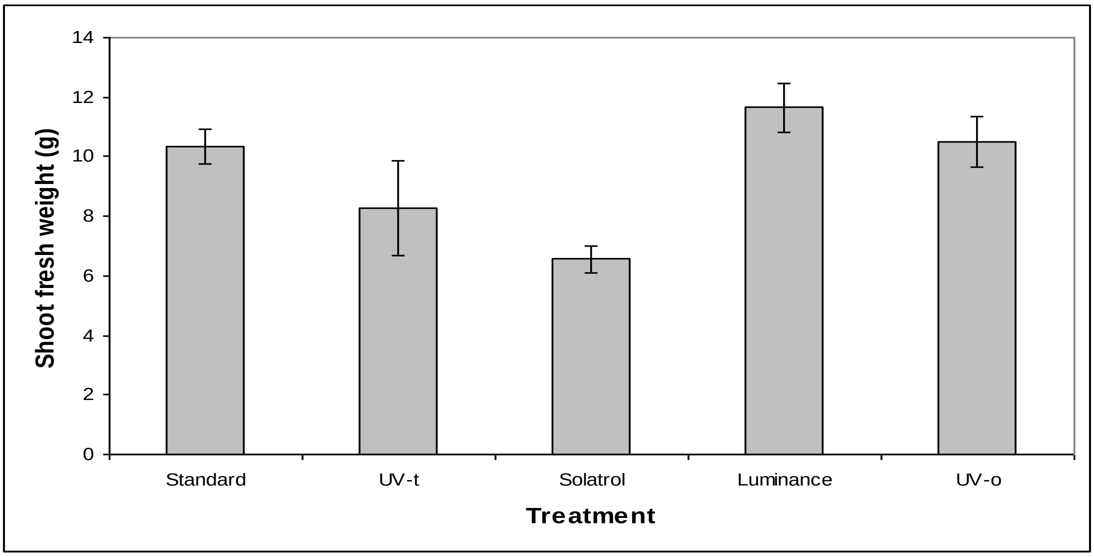


Figure 3. Effect of treatments on (a) plant height and (b) shoot fresh weight in Impatien. Each value is the mean + S.E. of > 11 replicates.

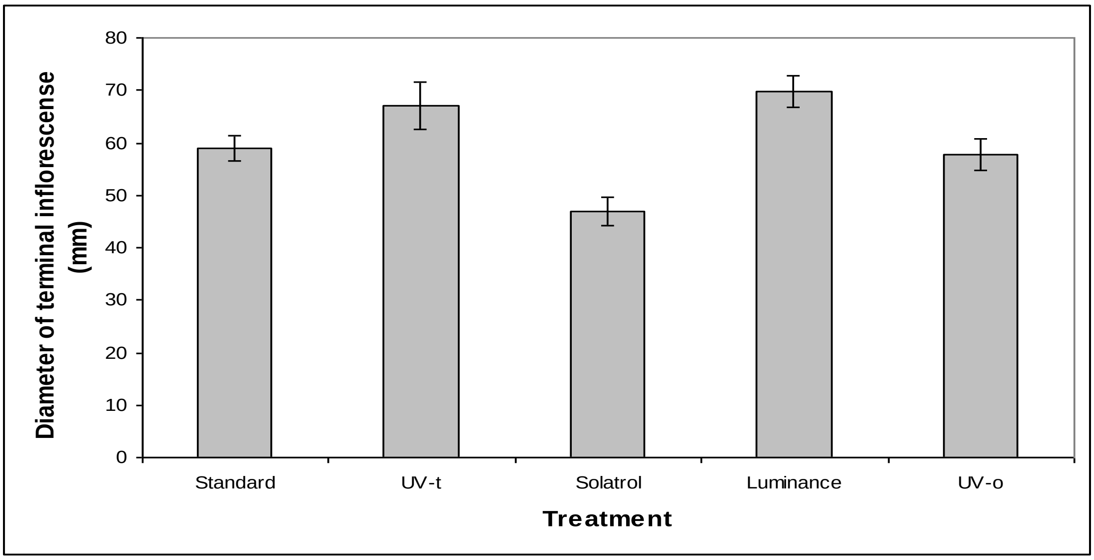


Figure 4. Effect of treatments on the diameter of the terminal inflorescence in Impatien. Each value is the mean + S.E. of > 11 replicates.

PANSY – VIVALDI MIXED

There were no significant effects of treatments on plant height (data not presented). The UV-opaque filter significantly increased the number of ancillary inflorescences when compared to both Standard and Luminance (fig. 5).

a)

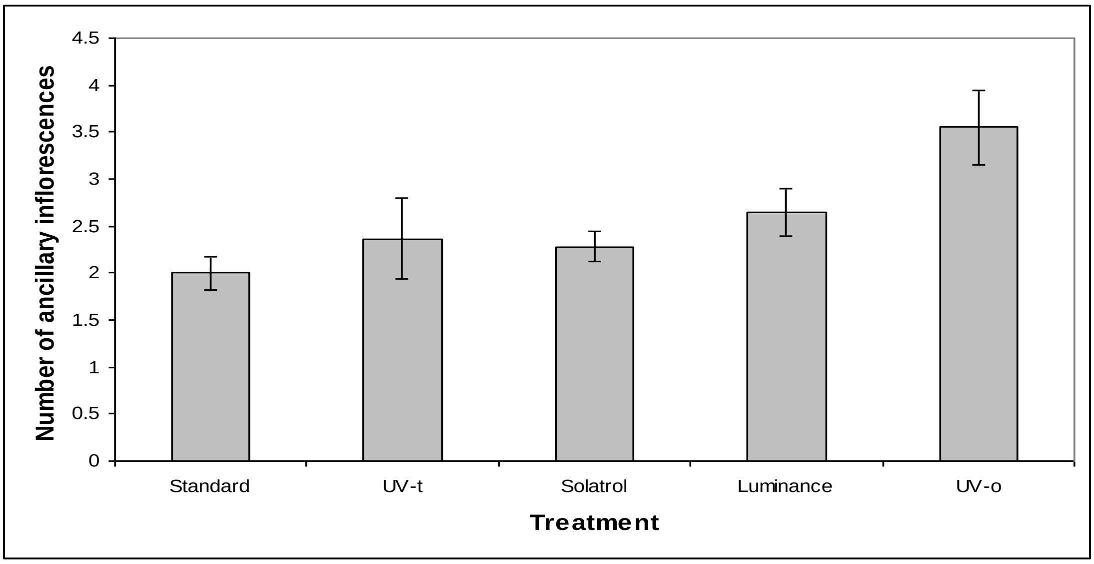
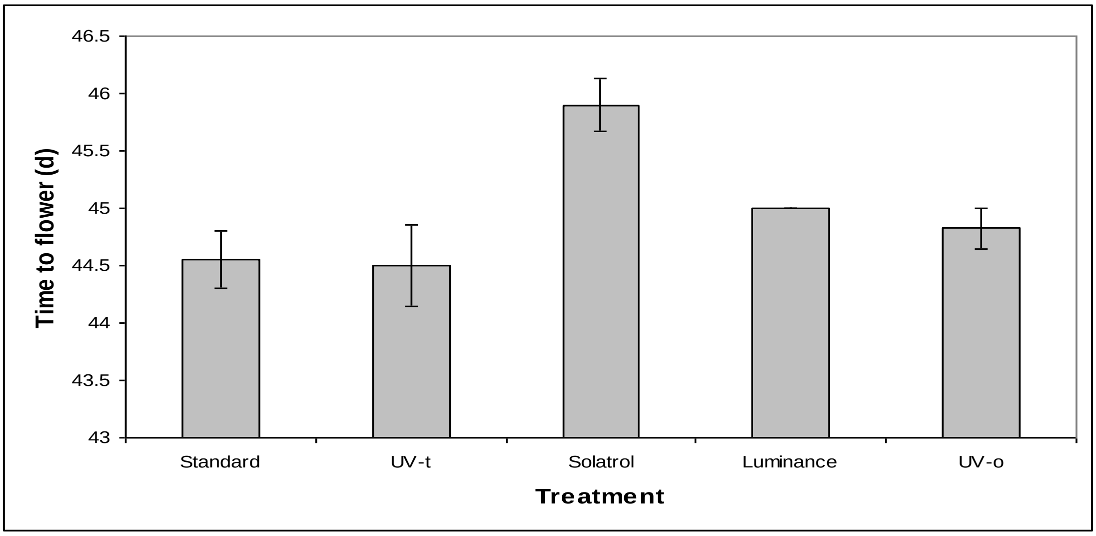


Figure 5. Effect of treatments on the diameter of the number of ancillary inflorescences in Pansy. Each value is the mean + S.E. of > 11 replicates.

PETUNIA – FRENZY BLUE

There was a delay in flowering in Solatrol of ~ 1 day when compared to all remaining treatments, although the delay was not significant (fig. 6.a). Plant height was significantly increased in UV-opaque when compared to Standard, UV-transparent and Solatrol, although there was no effect relative to Luminance (fig. 6.b). In contrast, Solatrol reduced plant height when compared to all remaining treatments except UV-transparent (fig. 6.b). The number of ancillary inflorescences was increased in Luminance when compared to Standard, UV-transparent and UV-opaque, although there was no effect when compared to Solatrol (fig. 7.a). Stem diameter at the base was significantly reduced in Luminance relative to all treatments (fig. 7.b).

a)



b)

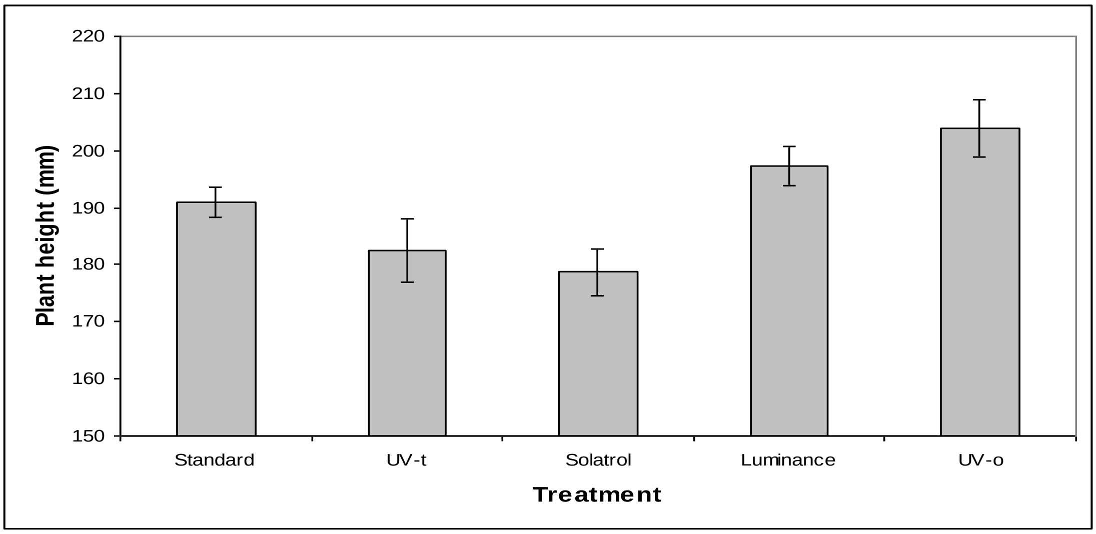
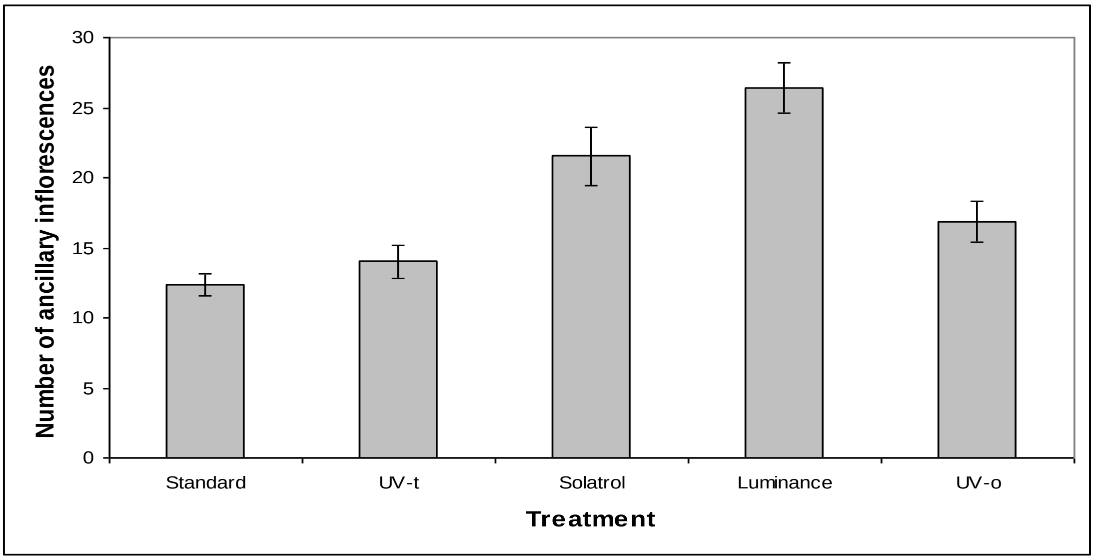


Figure 6. Effect of treatments on (a) time to flower and (b) plant height in Petunia – frenzy blue. Each value is the mean + S.E. of > 17 replicates.

a)



b)

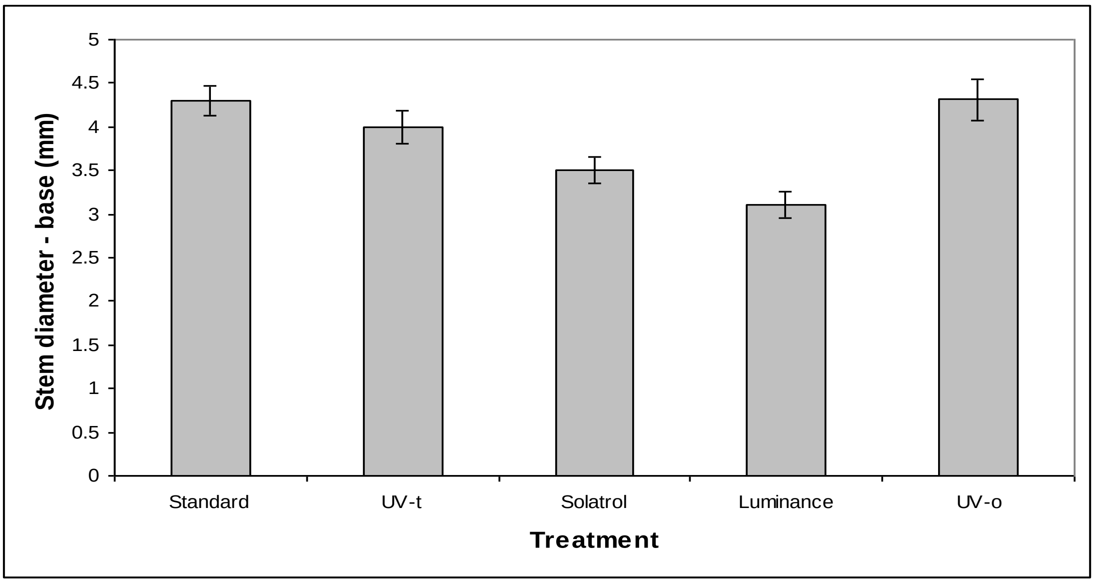
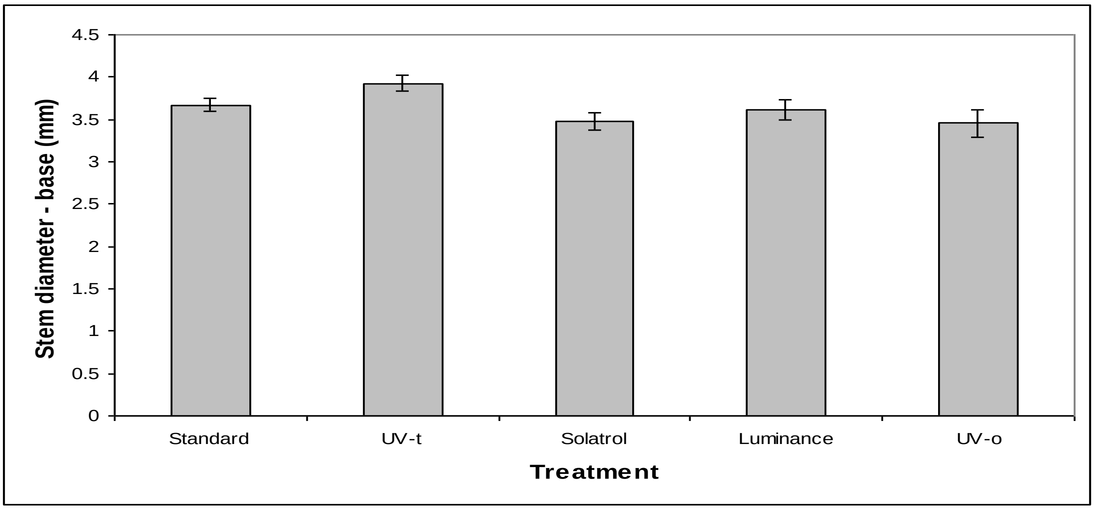


Figure 7. Effect of treatments on (a) number of ancillary inflorescences and (b) stem diameter – base in Petunia - frenzy blue. Each value is the mean ± S.E. of ≥ 11 replicates.

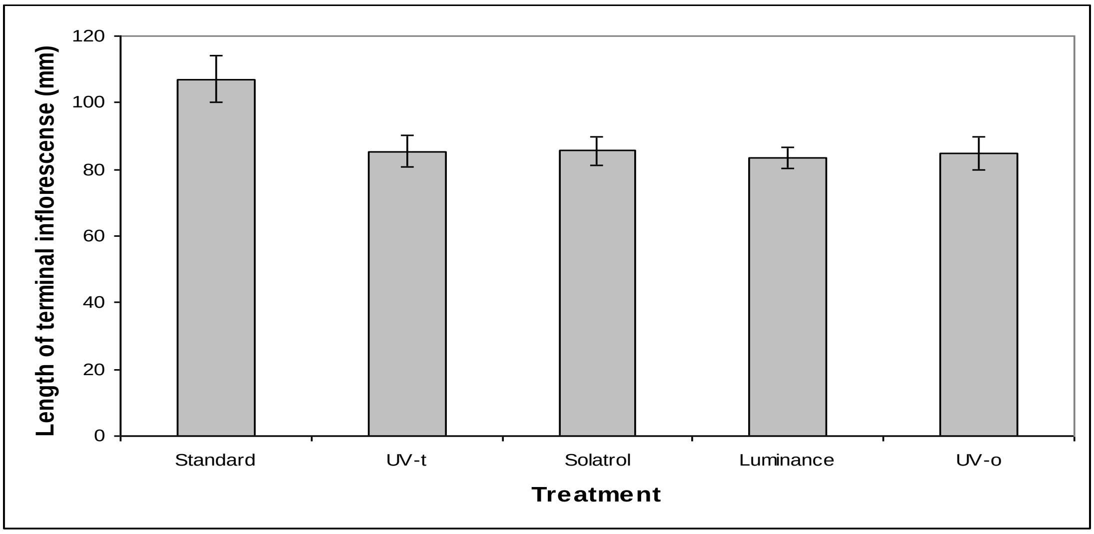
PETUNIA – DESIGNER RED

The thickness of the stem at the base was significantly increased in UV-transparent when compared to all treatments (fig. 8.a). The length of the terminal inflorescence was significantly increased in Standard relative to UV-transparent, Solatrol, Luminance and UV-opaque (fig. 8.b). There was also a significant increase in the number of individual flowers on the terminal inflorescence in Standard when compared to all treatments (fig. 8.c).

a)



b)



c)

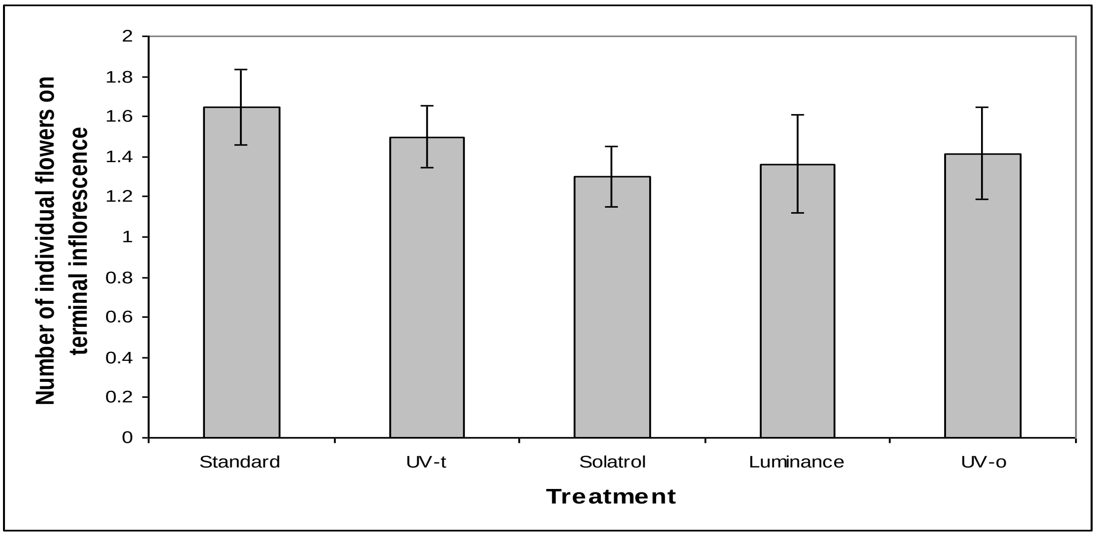
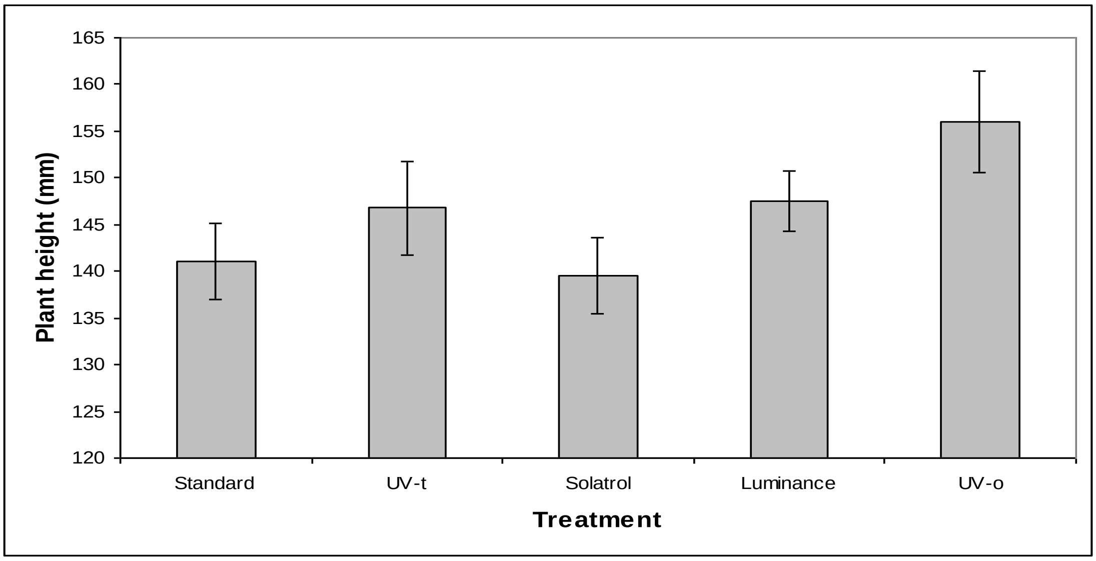


Figure 8. Effect of treatments on (a) stem diameter – base, (b) length of the terminal inflorescence and (c) number of individual flowers on the terminal inflorescence in Petunia – designer red. Each value is the mean ± S.E. of ≥ 12 replicates.

SALVIA – VISTA RED

Plant height was significantly increased in UV-opaque relative to Standard and Solatrol only (fig. 9.a). The UV-opaque treatment significantly increased the length of the terminal inflorescence when compared to all treatments (fig. 9.b). Similarly, the number of ancillary inflorescences was increased in both UV-opaque and Luminance when compared to the remaining three filter treatments, although there was no significant effect relative to each other (fig. 10.a). UV-transparent significantly increased shoot fresh when compared to all treatments except Solatrol (fig. 10.b).

a)



b)

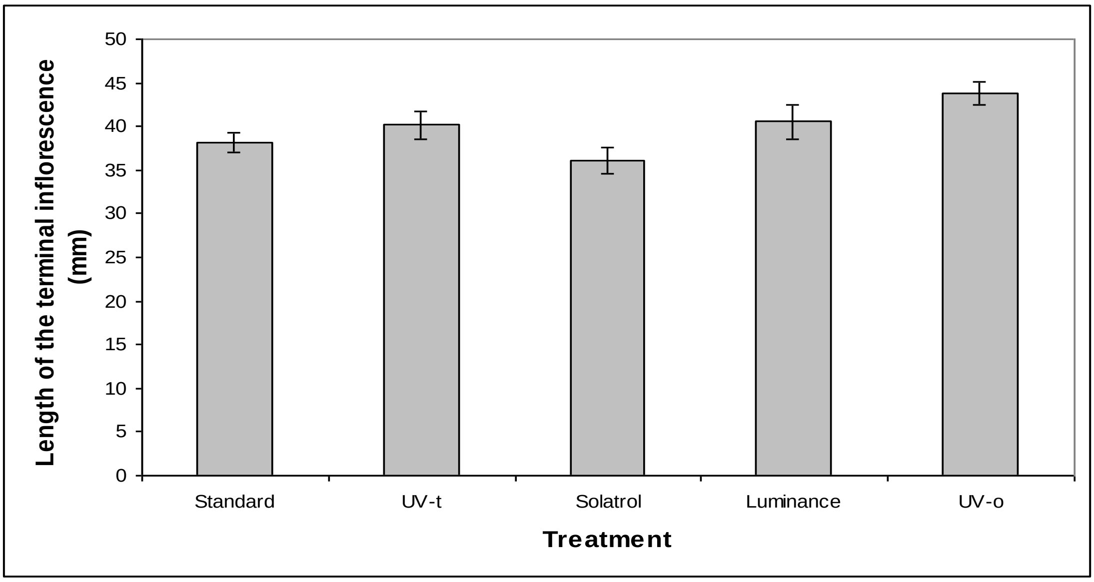
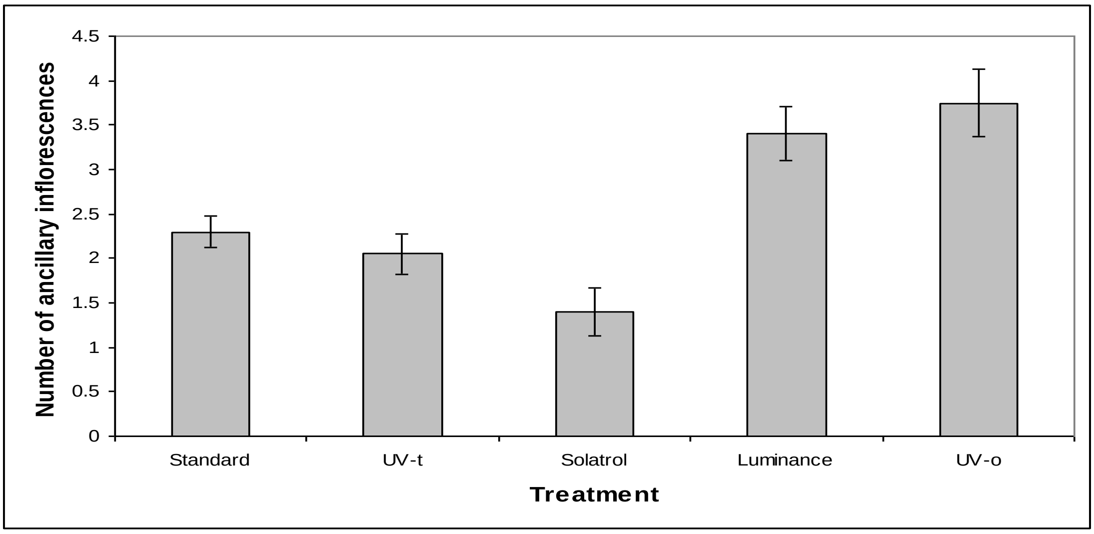


Figure 9. Effect of treatments on (a) plant height and (b) inflorescence length in Salvia – vista red. Each value is the mean ± S.E. of ≥ 12 replicates.

a)



b)

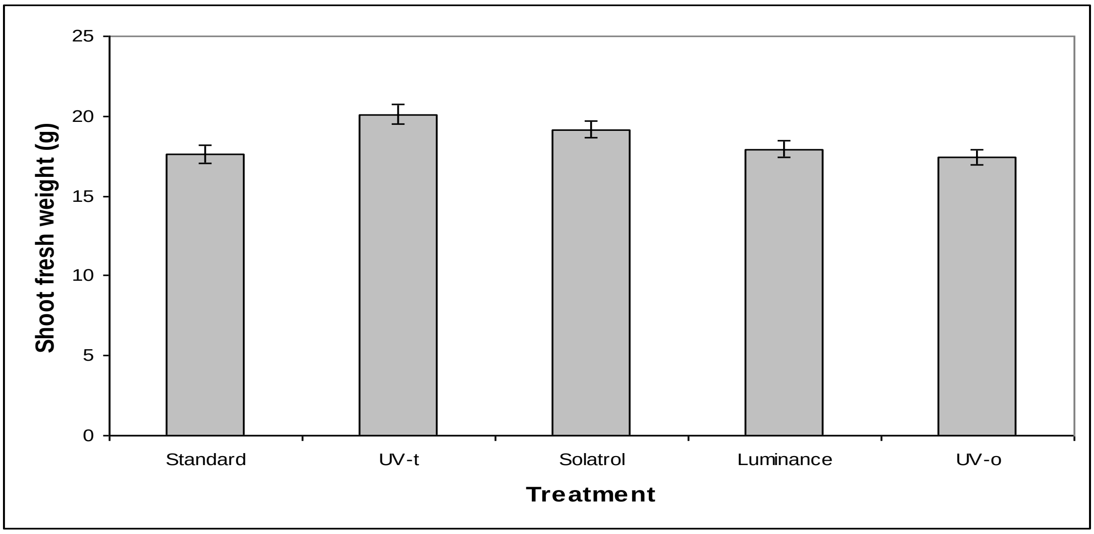


Figure 10. Effect of treatments on (a) number of ancillary inflorescences and (b) shoot fresh weight in Salvia – vista red. Each value is the mean $\pm$ S.E. of $\geq$ 12 replicates.

ARGYRANTHEMUM – BUTTERFLY

Shoot fresh weight was significantly increased in Solatrol when compared to Standard, UV-transparent and Luminance, although there was no effect relative to UV-opaque (fig. 11). UV-opaque increased shoot fresh weight when compared to Standard and Luminance only (fig. 11).

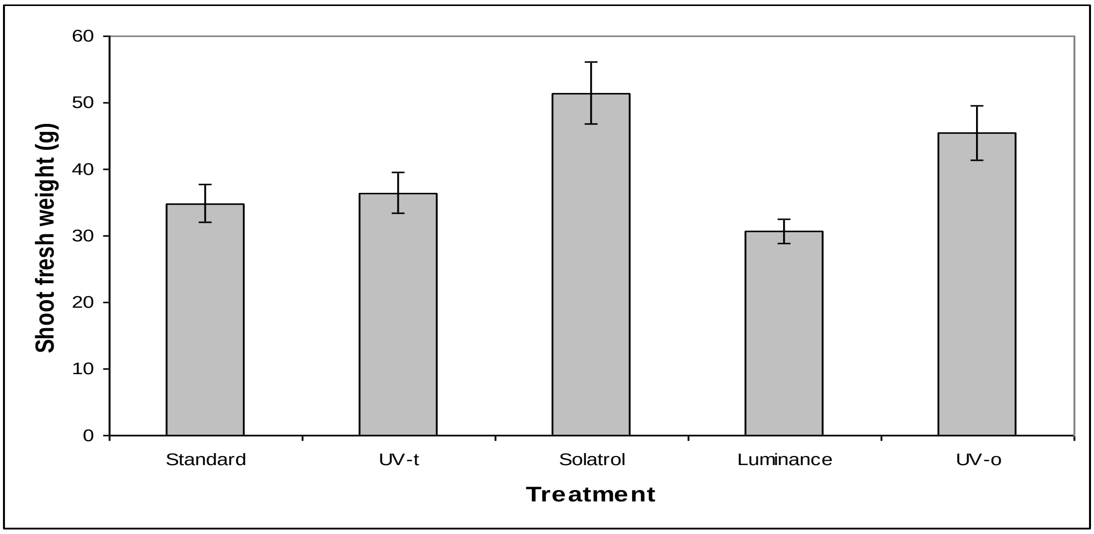


Figure 11. Effect of treatments on shoot fresh weight in Argyranthemum – butterfly. Each value is the mean ± S.E. of ≥ 11 replicates.

ARGYRANTHEMUM – SULTANS DREAM

Time to flower was significantly reduced in UV-transparent when compared to both Standard and Luminance, although there was no effect relative to Solatrol and UV-opaque (fig. 12). Luminance significantly increased plant height relative to all treatments except UV-opaque (fig. 13.a). Root dry weight was significantly increased in Standard when compared to UV-transparent and Solatrol only (fig. 13.b).

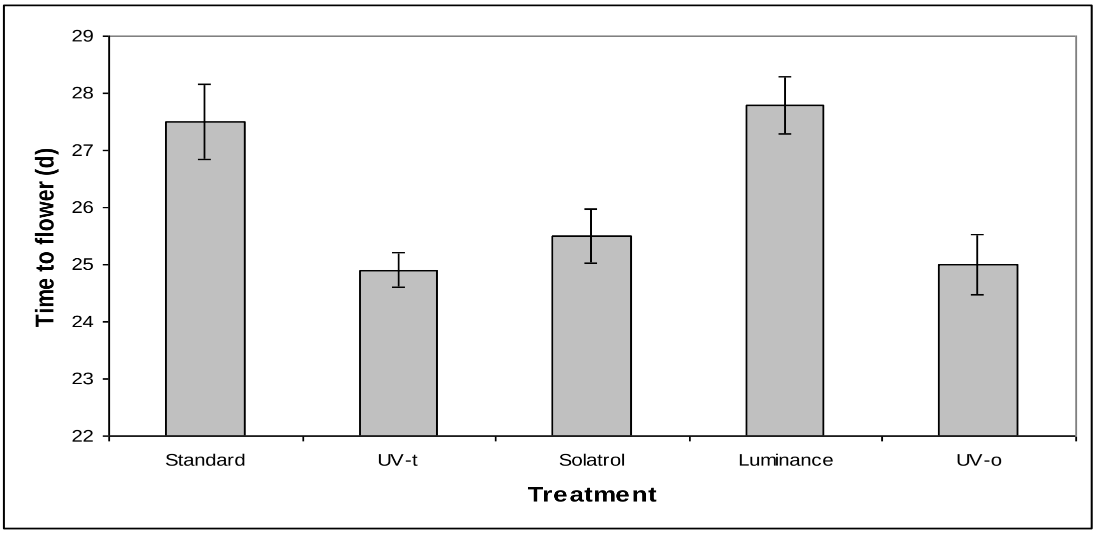
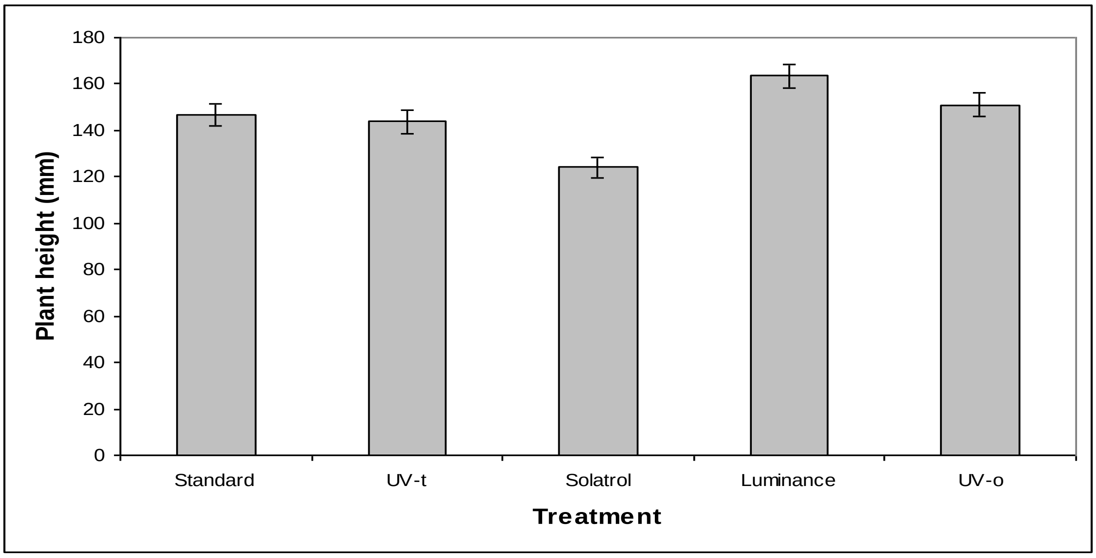


Figure 12. Effect of treatments on time to flower in Argyranthemum – sultans dream. Each value is the mean ± S.E. of ≥ 20 replicates.

a)



b)

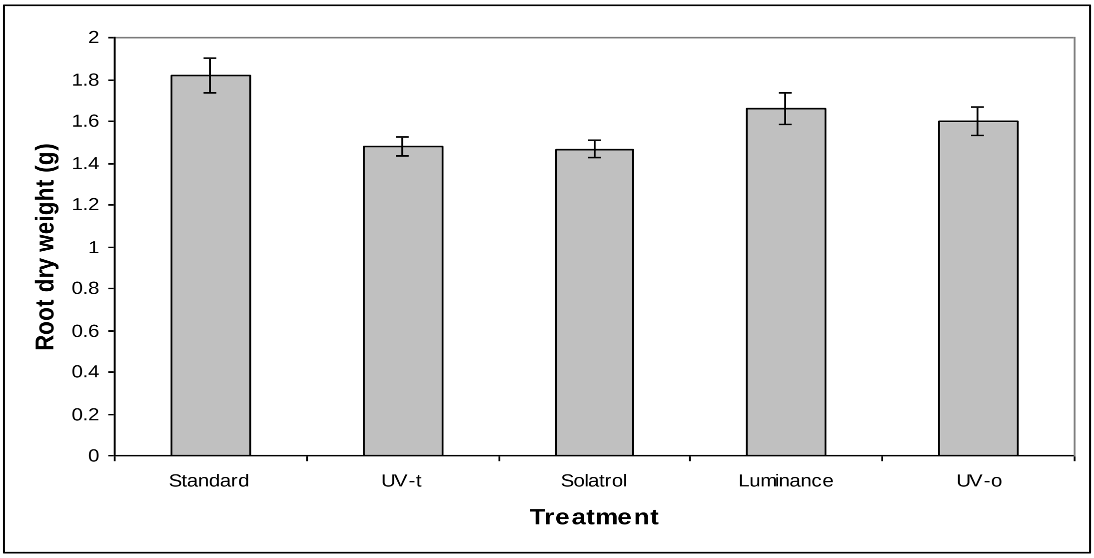
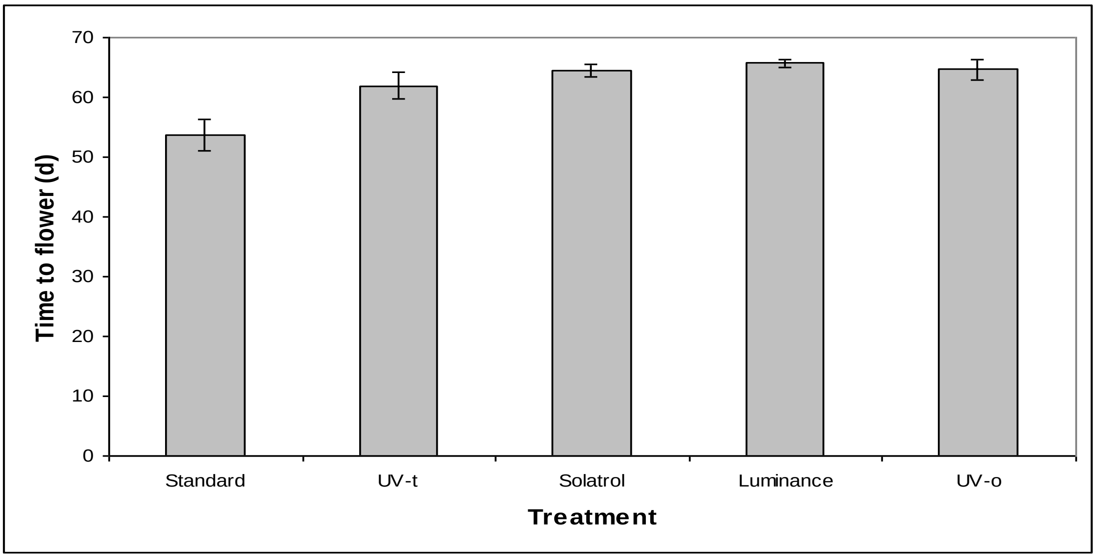


Figure 13. Effect of treatments on (a) plant height and (b) root dry weight in Argyranthemum – sultans dream. Each value is the mean ± S.E. of ≥ 20 replicates.

FUCHSIA – BRUTUS

Time to flower was significantly reduced in Standard by ~7d when compared to all remaining treatments (fig. 14.a). Solatrol increased plant height relative to Standard and UV-transparent only (fig. 14.b).

a)



b)

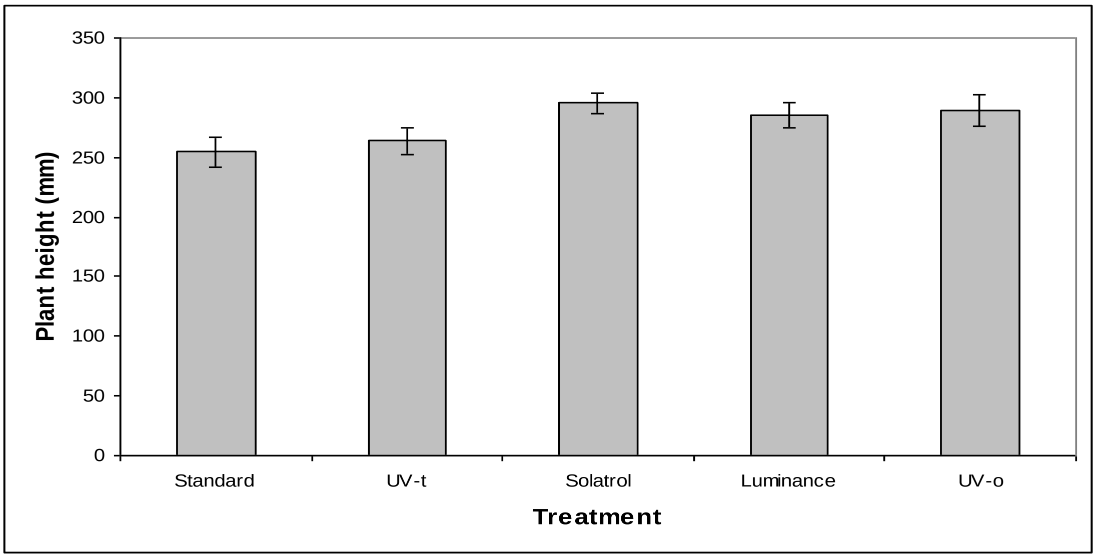


Figure 14. Effect of treatments on (a) time to flower and (b) plant height in Fuchsia - brutus. Each value is the mean $\pm$ S.E. of $\geq$ 18 replicates.

FUCHSIA – HELEN FAHEY

UV-opaque significantly increased plant height when compared to all treatments except Luminance (fig. 15.a). Furthermore, the length of the terminal inflorescence was significantly increased in UV-opaque relative to all remaining filter treatments (fig. 15.b). The UV-opaque filter increased both shoot fresh and dry weights (figs. 15.c & 16) when compared to all treatments with the exception that there was no significant difference in shoot dry weights between Standard and UV-opaque (fig. 16).

a)

b)

c)

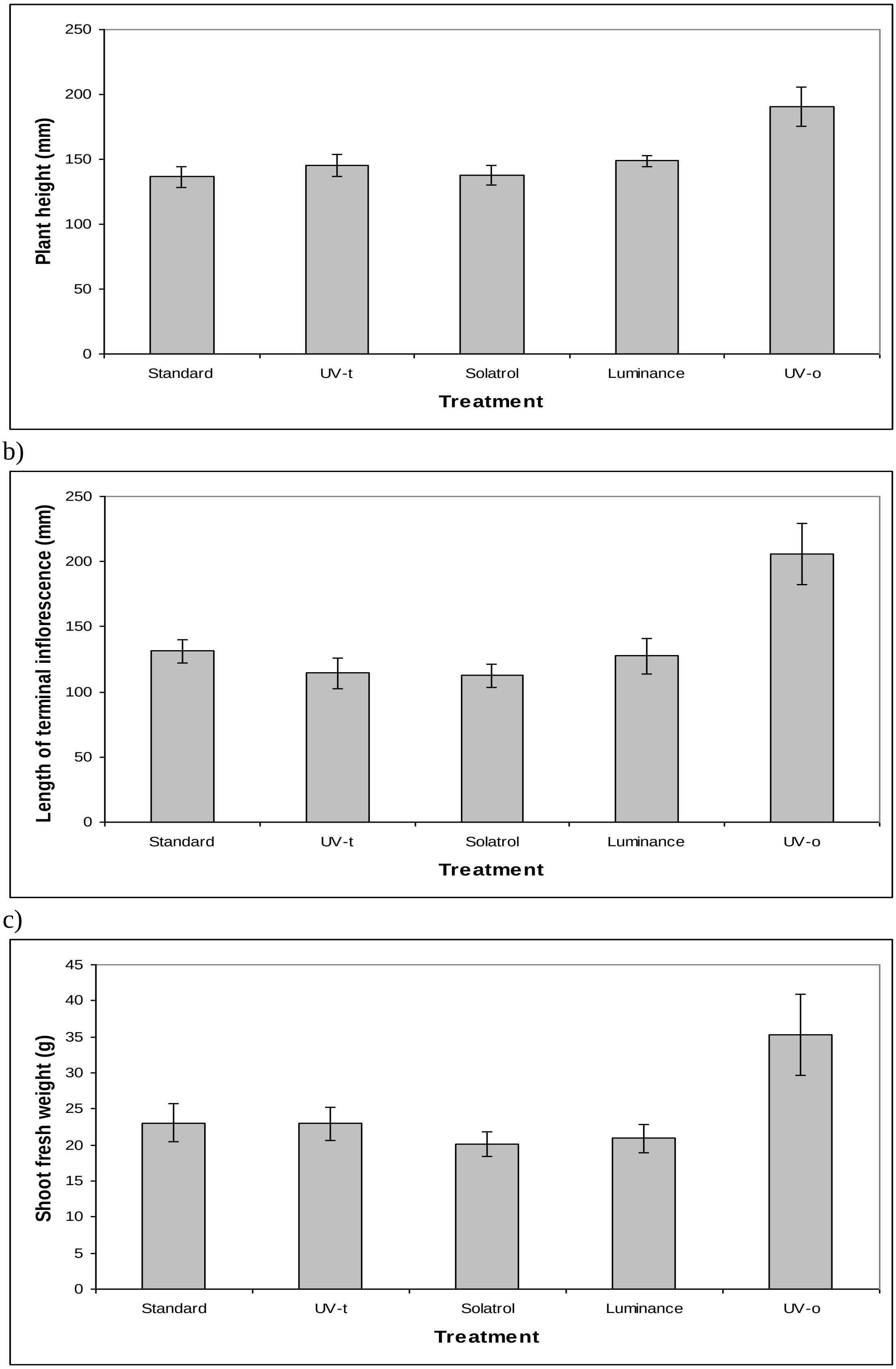


Figure 15. Effect of treatments on (a) plant height (b length of terminal inflorescence and (c) shoot fresh weight in Fuchsia – helen fahey. Each value is the mean + S.E. of > 10 replicates.

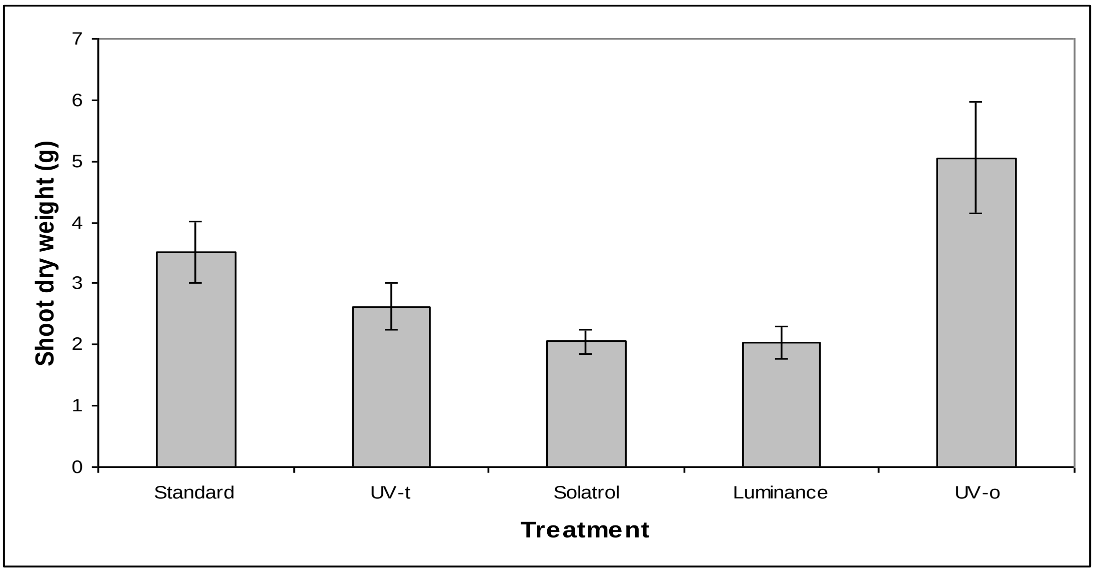


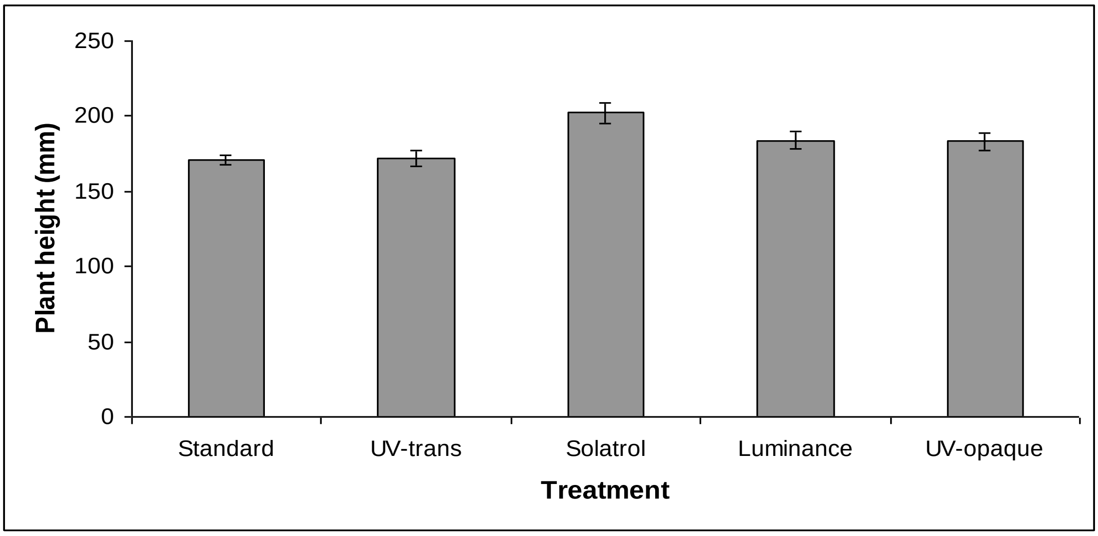
Figure 16. Effect of treatments on shoot dry weight in Fuchsia – helen fahey. Each value is the mean ± S.E. of ≥ 10 replicates.

FIELD TRIALS OF FUCHSIA – HELEN FAHEY & ARGYRANTHEMUM - BUTTERFLY

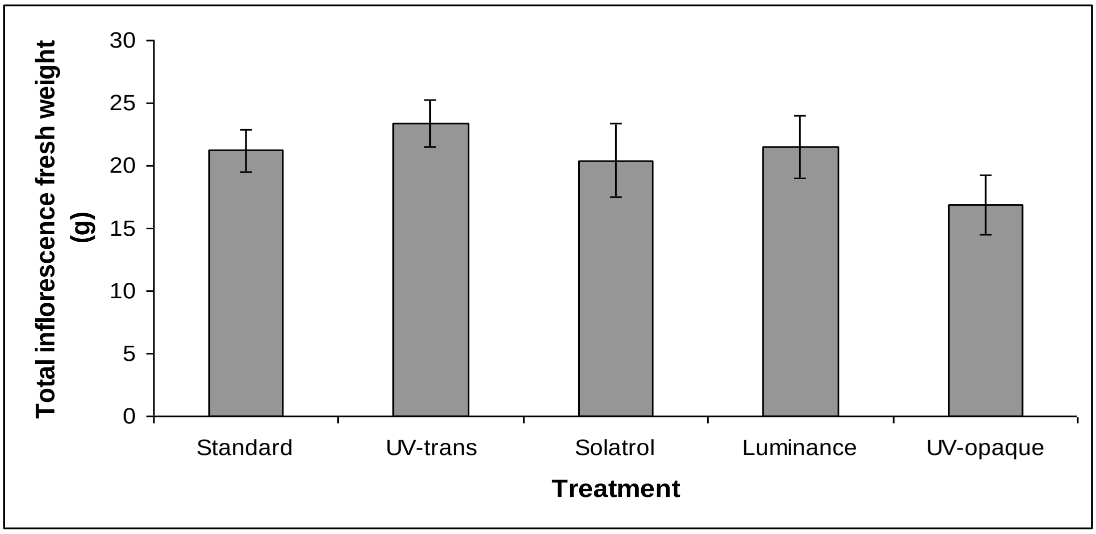
FUCHSIA – HELEN FAHEY

Plant height was significantly increased in Solatrol when compared to Standard, UV-transparent and UV-opaque, although there was no effect relative to Luminance (fig. 17.a). Total fresh weight of all inflorescences at the time of harvest was not affected by treatments (fig. 17.b), nor was the total number of inflorescences (fig. 17.c), shoot fresh weight (fig. 18.a) or shoot dry weight (fig. 18.b). Stem diameter at the base was significantly increased in Solatrol when compared to Standard and UV-transparent, although there was no effect relative to the Luminance and UV-opaque treatments (fig. 18.c).

a)



b)



c)

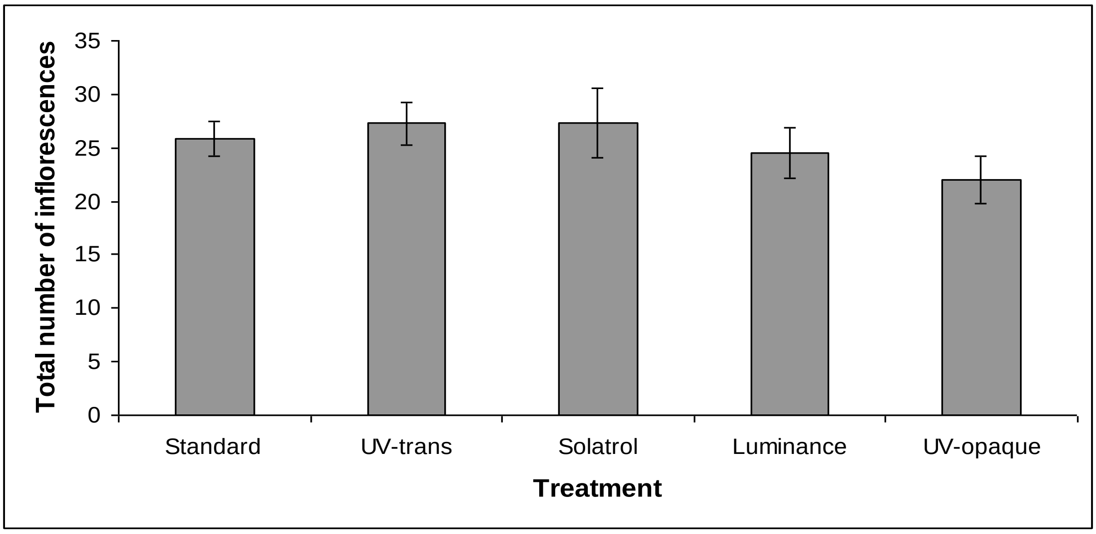
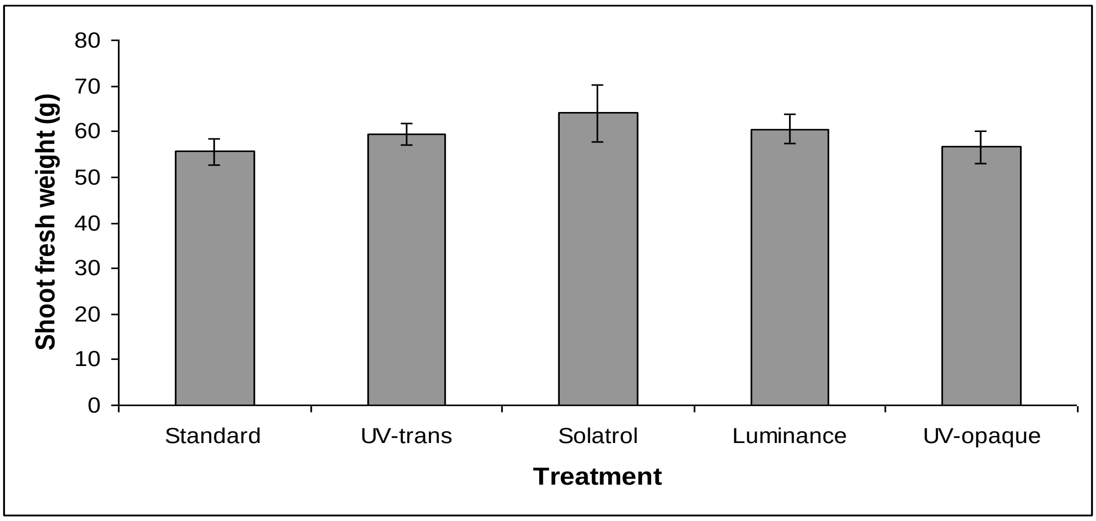
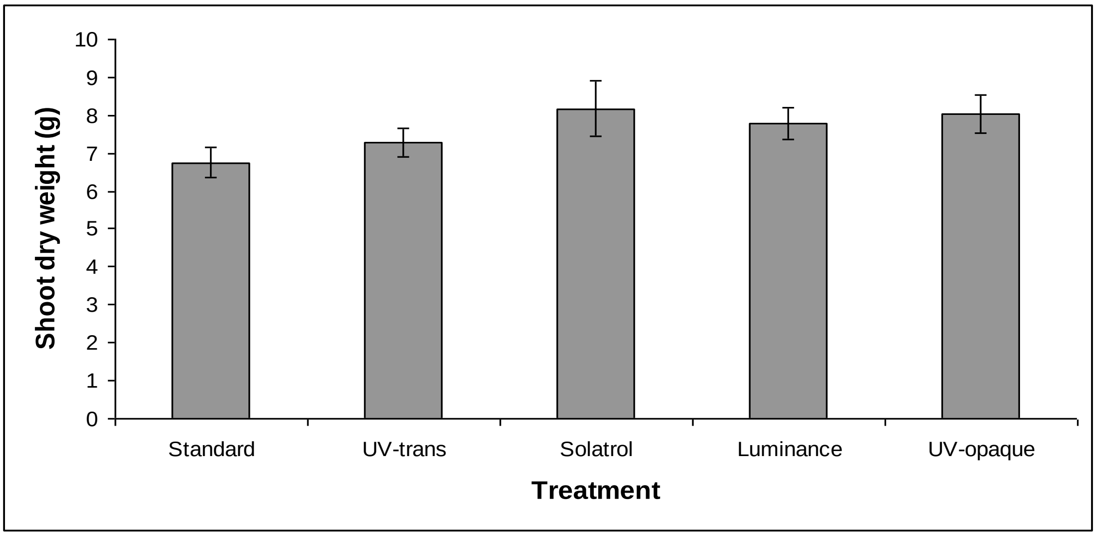


Figure 17. Effect of treatments on (a) plant height (b) total inflorescence fresh weight and (c) total number of inflorescences in Fuchsia – helen fahey. Each value is the mean ± S.E. of ≥ 12 replicates.

a)



b)



c)

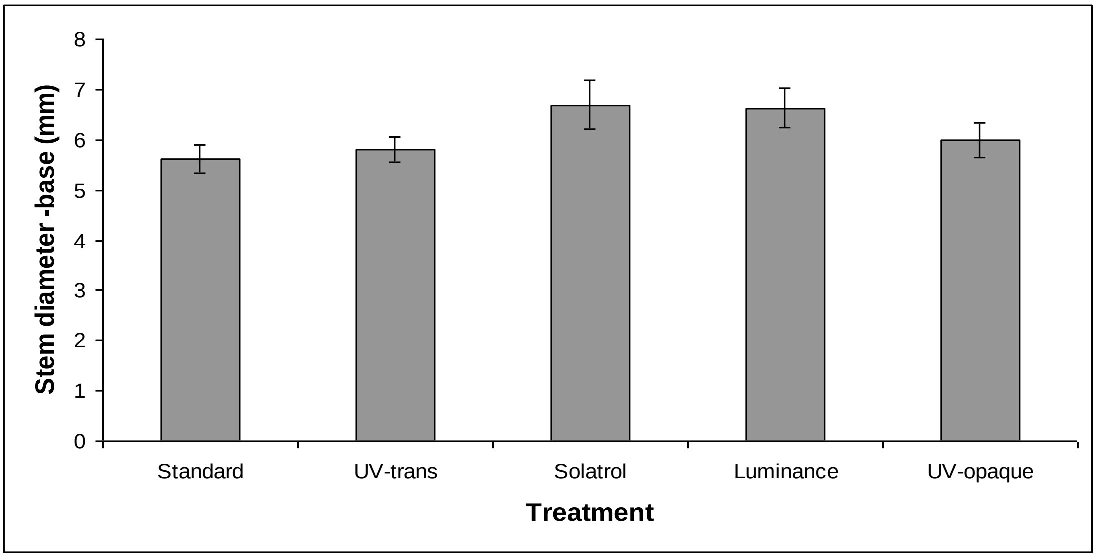
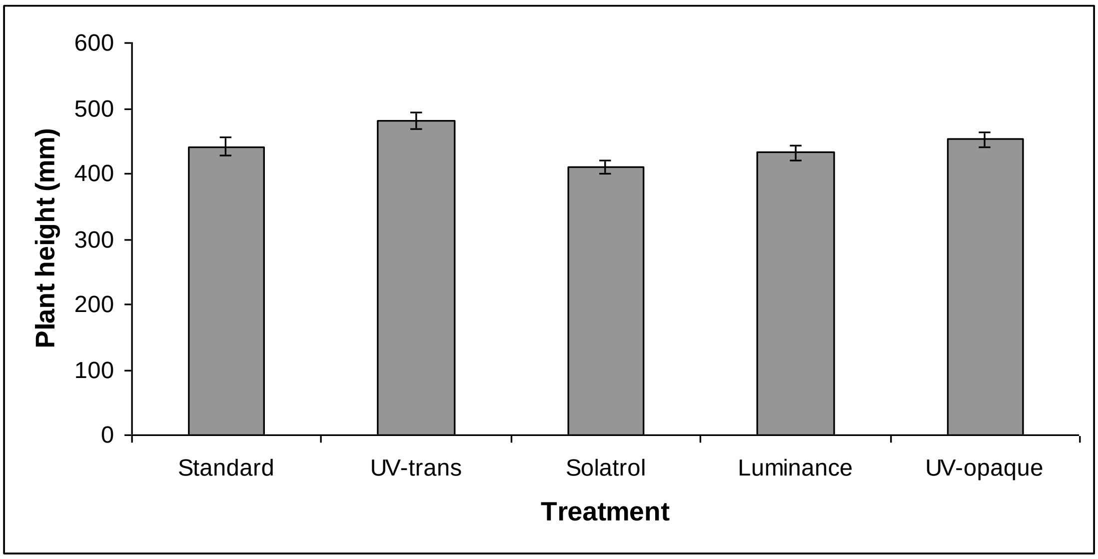


Figure 18. Effect of treatments on (a) shoot fresh weight (b) shoot dry weight and (c) stem diameter at the base in Fuchsia – helen fahey. Each value is the mean $\pm$ S.E. of $\geq$ 12 replicates.

ARGYRANTHEMUM – BUTTERFLY

Plant height at the time of harvest was significantly increased in UV-transparent when compared to all remaining treatments except UV-opaque (fig. 19.a). Terminal inflorescence diameter was reduced in UV-transparent relative to all remaining treatments, although this was not a significant reduction (fig. 19.b). The total number of inflorescences was increased in Luminance when compared to UV-transparent and Solatrol (fig. 20.a) and in UV-opaque relative to Solatrol only (fig. 20.a). Shoot fresh and dry weights were significantly reduced in UV-transparent relative to Luminance only (figs. 20.b. & 20.c). There was also a significant increase in the thickness of leaves, both the youngest and the oldest, in Solatrol, Luminance and UV-opaque when compared to both the Standard and UV-transparent treatments (figs. 21.a. & 21.b).

a)



b)

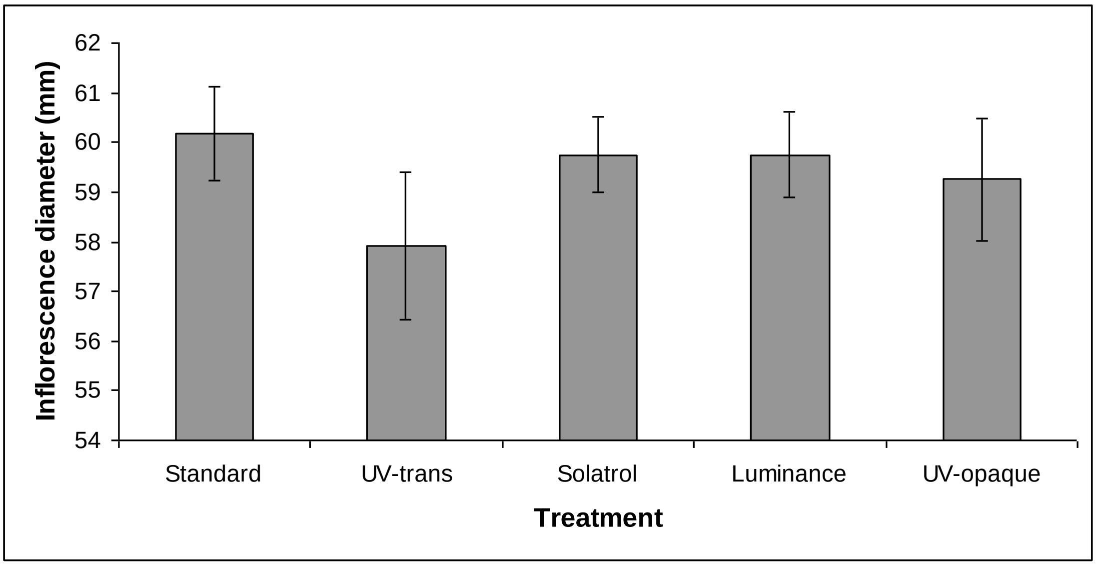
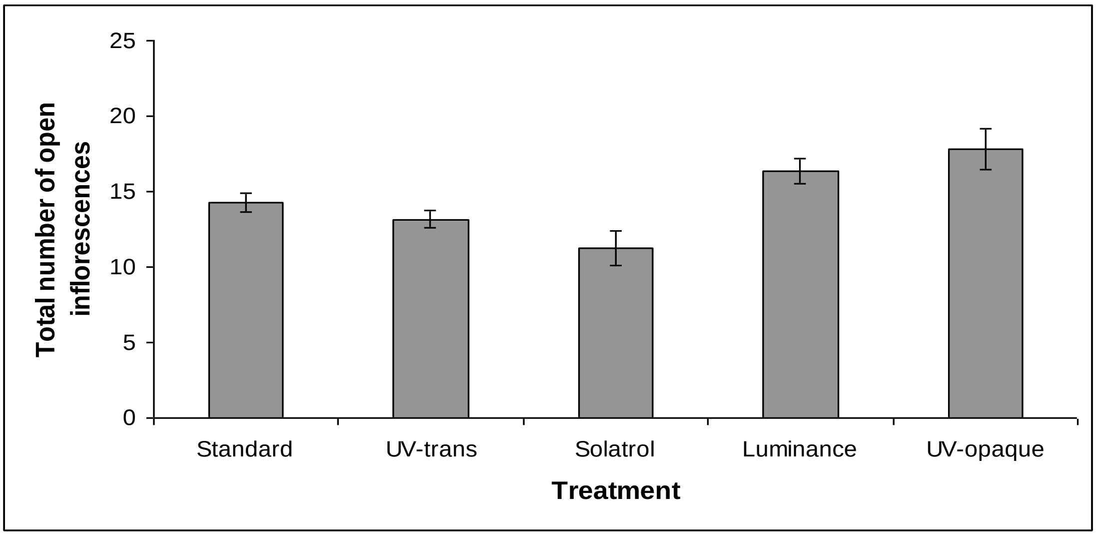
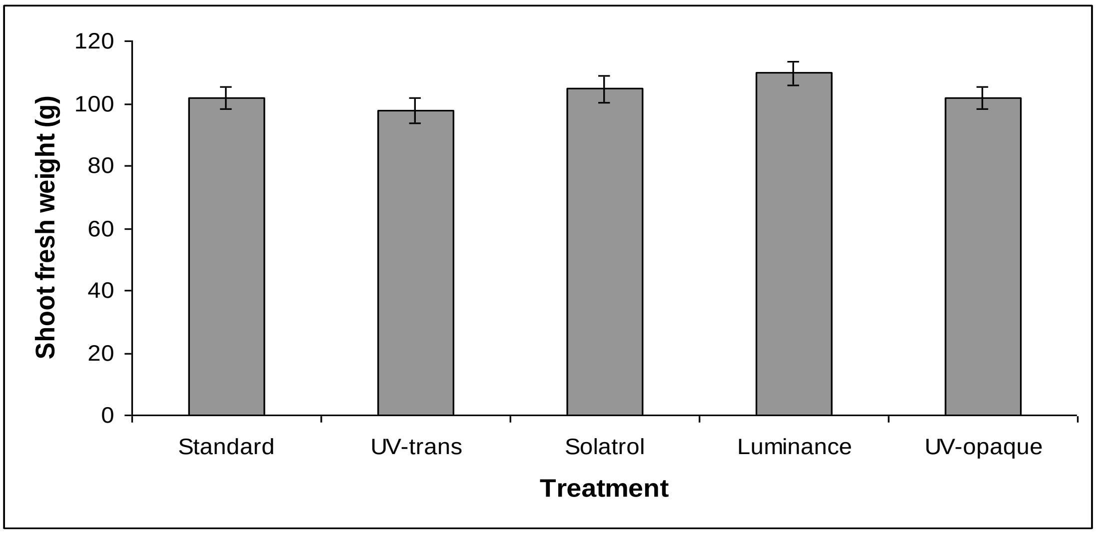


Figure 19. Effect of treatments on (a) plant height and (b) inflorescence diameter in Argyranthemum - butterfly. Each value is the mean ± S.E. of ≥ 12 replicates.

a)



b)



c)

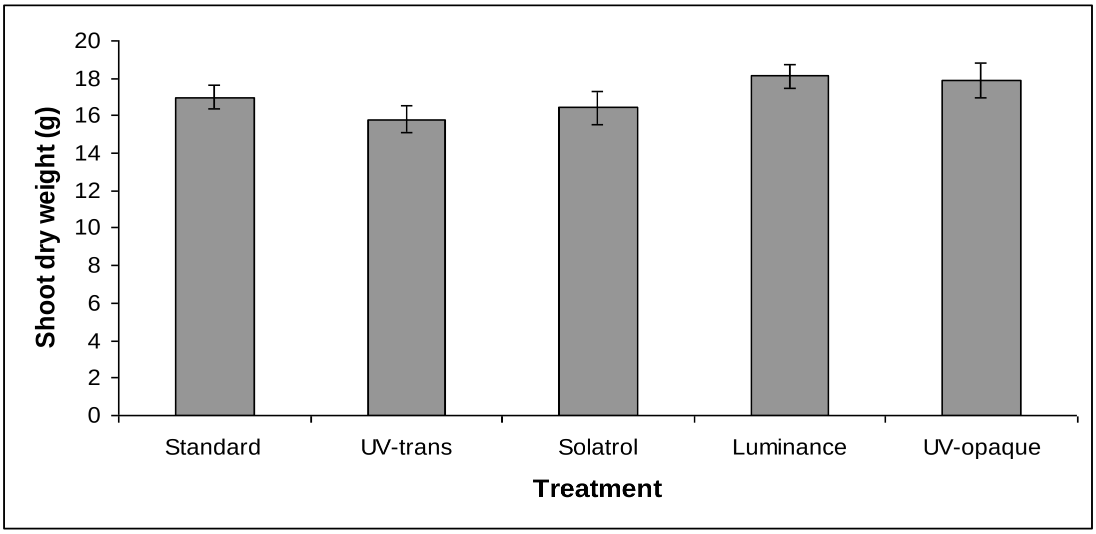
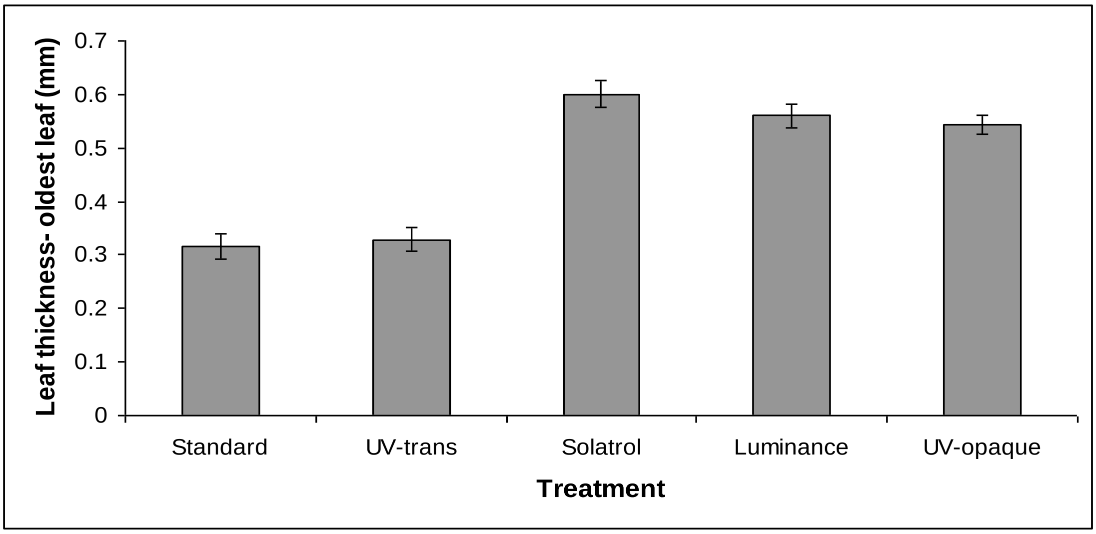


Figure 20. Effect of treatments on (a) total number of inflorescences (b) shoot fresh weight and (c) shoot dry weight in Argyranthemum - butterfly. Each value is the mean + S.E. of > 12 replicates.

a)



b)

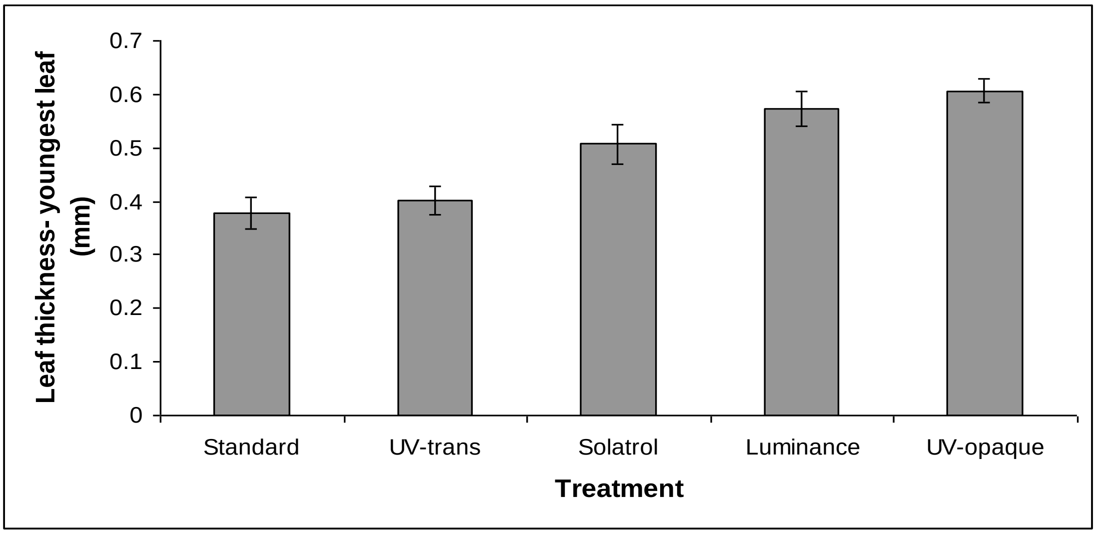


Figure 21. Effect of treatments on (a) leaf thickness of the oldest leaf and (b) leaf thickness of the youngest leaf in Argyranthemum - butterfly. Each value is the mean ± S.E. of ≥ 12 replicates.

Discussion

Results from the first years study provided preliminary evidence of the effects of the 5 filters on both vegetative growth and flower development and colouration in bedding. More intense flower colouration was observed in blue and red Pansy grown under the UV-transparent filter, suggesting that certain cultivars of Pansy respond to high levels of UV light by increasing the synthesis of anthocyanonins, which as well as been integral in flower colouration, are utilised by plants for protection against the damaging effects of high UV. Although the effects of the filters were not uniform across varieties, there was evidence for trends in changes in time to flowering, total number of flowers produced and flower diameter.

This season’s results, using a much increased assortment of plant varieties, highlight the complexity of responses induced by the five filters. For instance, while in

Impatien – expo select (fig. 3.a) Salvia – vista red (fig. 9.a), Petunia – frenzy blue (fig. 6.b), Argyranthemum – sultans dream (fig. 13.a) and Fuchsia – helen fahey (fig. 15.a) there was a tendency for Solatrol to reduce plant height as was expected from results in 2003, in Antirhinnum (fig. 1.a) and Fuchsia – brutus (fig. 14.b) plant height was increased. With regards to shoot biomass, both the Luminance and the UV-opaque filters produced consistent increases in total fresh and dry weights (see figs. 1.a., 3.b. & 15.c). In a limited number of varieties, most notably Antirrhinum, Impatien – expo select, Petunia - frenzy blue, Salvia – vista red and Fuchsia – helen fahey, there was also a tendency for either Luminance or UV-opaque to produce increases in inflorescence length / diameter (see figs. 2.b, 4, 9.b, 15.b) and / or the number of ancillary flowers (see figs. 2.c., 4, 7.a., 10.a. & 15.b). We did not observe the increased flower pigmentation under the UV-transparent filter that was so apparent in 2003 but this could be linked to the very different weather conditions experienced during the 2004 growing season.

When Fuchsia – Helen fahey & Argyranthemum – butterfly were planted out in field trials (after just 3 weeks under filters) long-term ‘carry over’ effects were observed (see figs 22-27 below). In Fuchsia, plant height was significantly increased in those plants that had undergone treatment under Solatrol eight weeks after being removed from that treatment (fig. 17.a). Although inflorescence pigmentation was not quantified, visual observations suggest that UV-transparent treated plants produced inflorescences with more intense colouration, even in flowers that emerged post filter treatment (see figs. 26 & 27). In Argyranthemum – butterfly, plant height was increased in UV-transparent treated plants (fig. 19.a & 22) and the total number of inflorescences was increased in Luminance when compared to UV-transparent and Solatrol (fig. 20.a, 23 &24) and in UV-opaque relative to Solatrol (fig. 20.a). Results from this small scale field trial have produced sufficient evidence for a ‘carry over effect’ of short term filter treatments; enough to warrant more extensive trials in the third year.

Figure 22. Field trials of Argyranthemum – butterfly 8 weeks post planting out (from left to right: Standard, UV-transparent, Solatrol, Luminance and UV-opaque).

Figure 23. Argyranthemum – butterfly 8 weeks post planting out in Luminance treated plants.

Figure 24. Argyranthemum – butterfly 8 weeks post planting out in Solatrol treated plants.


Figure 25. Field trials of Fuchsia – helen fahey 8 weeks post planting out (from left to right: Standard, UV-transparent, Solatrol, Luminance and UV-opaque).

Figure 26. Fuchsia – helen fahey 8 weeks post planting out in UV-transparent treated plants.

Figure 27. Fuchsia – helen fahey 8 weeks post planting out in Luminance treated plants.

CP19: Horticultural crops:
Further demonstration of the potential benefits of modified plastic crop covers

Cut flowers

Part 6. Cut Flowers

The consumption of cut flowers in the UK remains very buoyant with total imports in 2003 valued at over £550 million and production from UK growers approaching £60 million. This could well be an under estimate as the statistics rely heavily on information from The Netherlands, which may under-estimate direct imports into the UK from Kenya, Colombia and Ecuador etc. Primarily the supermarkets have driven growth in the cut flower market with growth year on year approaching 15-20%. It is now thought that growth is slowing but is still above 10%. For the purpose of analysis the UK cut flower industry can be divided into two main sectors: the greenhouse protected crops sector and the outdoor / polythene tunnel sector.

According to ministry (DEFRA) returns the greenhouse-protected sector covers an area of 150 Ha. Bulbous crops cover a total area of 4,500 Ha. The majority of the remaining area is either used for the production of Chrysanthemums or Alstroemeria. Rose production in the UK has declined to zero because of overseas competition, mainly from Kenya. The production of Carnations and pinks has declined over the last ten years but now appears to have stabilized. The area of Matthiola being grown under glass has steadily increased over the last five years and is now approaching 25 Ha (Simon Crawford - personal assessment). The expansion of this crop is now limited by the lack of adequate greenhouses and lower cost alternatives are being sought by growers in an attempt to further expand production without raising the price of the product to the consumer.

Outdoor production in the UK is reported to cover a total area of 5,500 Ha. The greater part of this area, 4,500 Ha, is devoted to bulbous crops. Daffodil bulb production, outdoor Tulips and Gladioli are still major crops in the eastern counties of the country. The production of seed raised crops is highly fragmented, but a few large growers producing Sunflowers, Chinese Asters, Larkspur and Carthamus are responsible for at least 150 Ha of production. Current outdoor cut flower producers and other farmers and growers seeking to diversify their business into cut flowers are searching for lower cost alternatives to glasshouses and traditional polythene tunnels. A facility that would allow growers to protect their crops from the weather and give a basic level of environmental control in order to ensure ‘on-time’ delivery of crops is essential when serving UK supermarkets with high volume products.

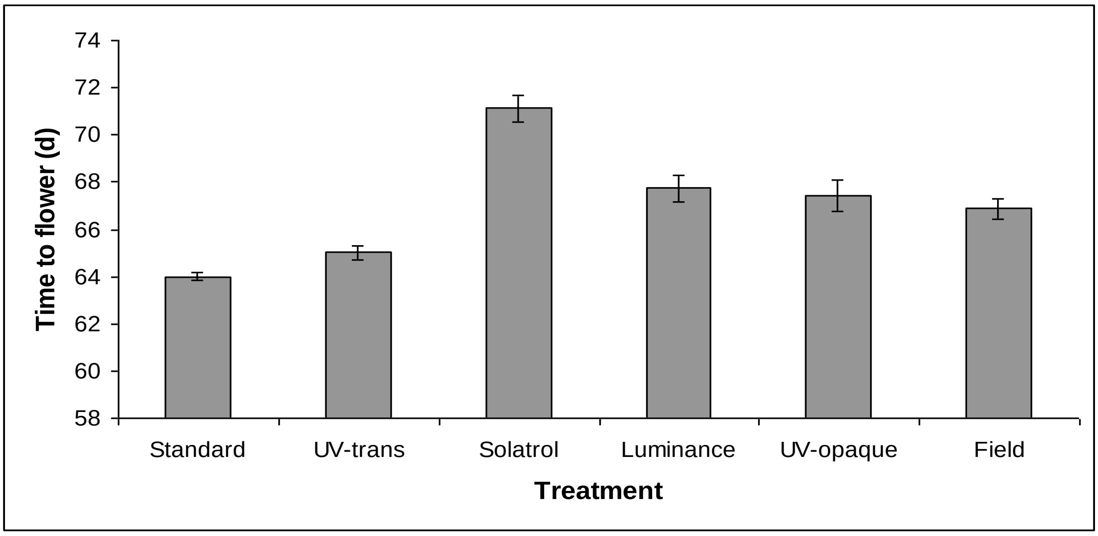
The development of low cost Spanish tunnel systems for strawberries and other soft fruit crops has presented growers with a real option in the search for an adequate solution to their need for a basic level of lower cost environmental control and assured harvesting. Therefore improvement of these systems through technical developments in more sophisticated tunnel designs and plastic coverings for the structures is essential for the progress of these systems in the UK.

Outdoor flower production during the 2004 season has been complicated by a cold spring and a very wet August. Many growers have reported significant losses in outdoor Lilies, Larkspur and sunflower either through disease or interruptions in the harvesting process. As well as demonstrating to growers how cut flower crops can be manipulated under spectral filters it will also be important to show the simple cost effectiveness of Spanish tunnel systems in 2005.

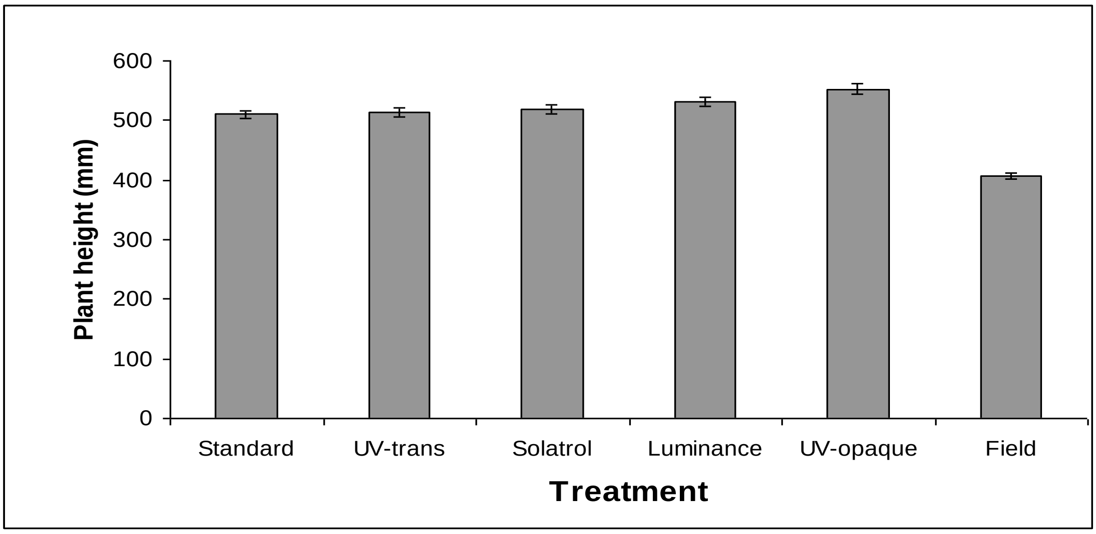
STOCKS

There was a significant reduction in the time to flower in Standard when compared to all remaining filter treatments by ~ 2 days (fig. 1.a). In contrast, Solatrol significantly increased the time to flowering by ~5 days (fig. 1.a). Plant height was significantly reduced in Field plants by ~ 33% when compared to all remaining treatments (fig. 1.b). Of the filter treatments UV-opaque produced the tallest plants and this was a significant increase in plant height relative to all treatments except Luminance (fig. 1.b). The length of the terminal inflorescence was significantly increased in UV-opaque when compared to all treatments except Luminance (fig. 1.c). Field plants had significantly reduced inflorescence lengths relative to all filter treatments (fig. 1.c). Shoot fresh weight was significantly reduced in Solatrol and Field plants when compared to all remaining treatments (fig. 2.a). UV-opaque produced an increase in shoot fresh weight; however, this was only a significant increase relative to UV-transparent, Solatrol and Field (fig. 2.a). Stem thickness at the tip was increased in UV-opaque when compared to Standard, UV-transparent and Field only (fig. 2.b). Basal stem thickness was largely unaffected by treatments, the only exception being a reduction in Solatrol relative to Luminance, UV-opaque and Field (fig. 2.c). Similarly, only the Solatrol filter treatment significantly reduced leaf thickness in the youngest (fig. 3.a) and oldest (fig. 3.b) leaves. Total leaf area was significantly increased in UV-opaque when compared to Solatrol and Field only, and Field reduced total leaf area at the time of harvest relative to all filter treatments (fig. 3.c). Field also significantly reduced the total number of inflorescences produced when compared to all remaining treatments, while Solatrol increased inflorescence numbers relative to Standard, UV-transparent and Field only (fig. 4).

a)



b)



c)

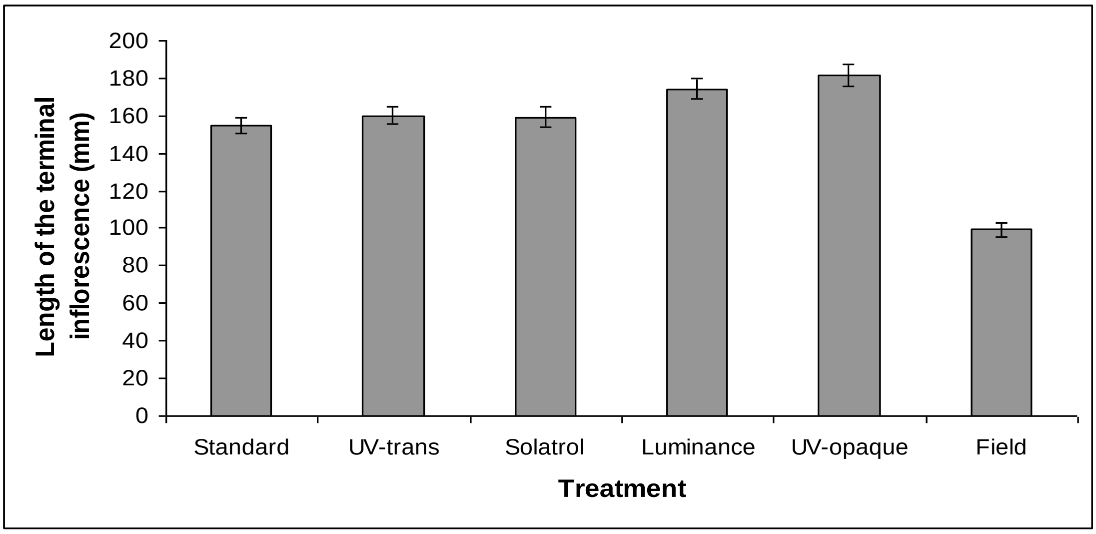


Figure 1. Effect of treatments on (a) time to flower (b) plant height and (c) length of the terminal inflorescence in Stocks. Each value is the mean ± S.E. of 35 replicates.

a)

b)

c)

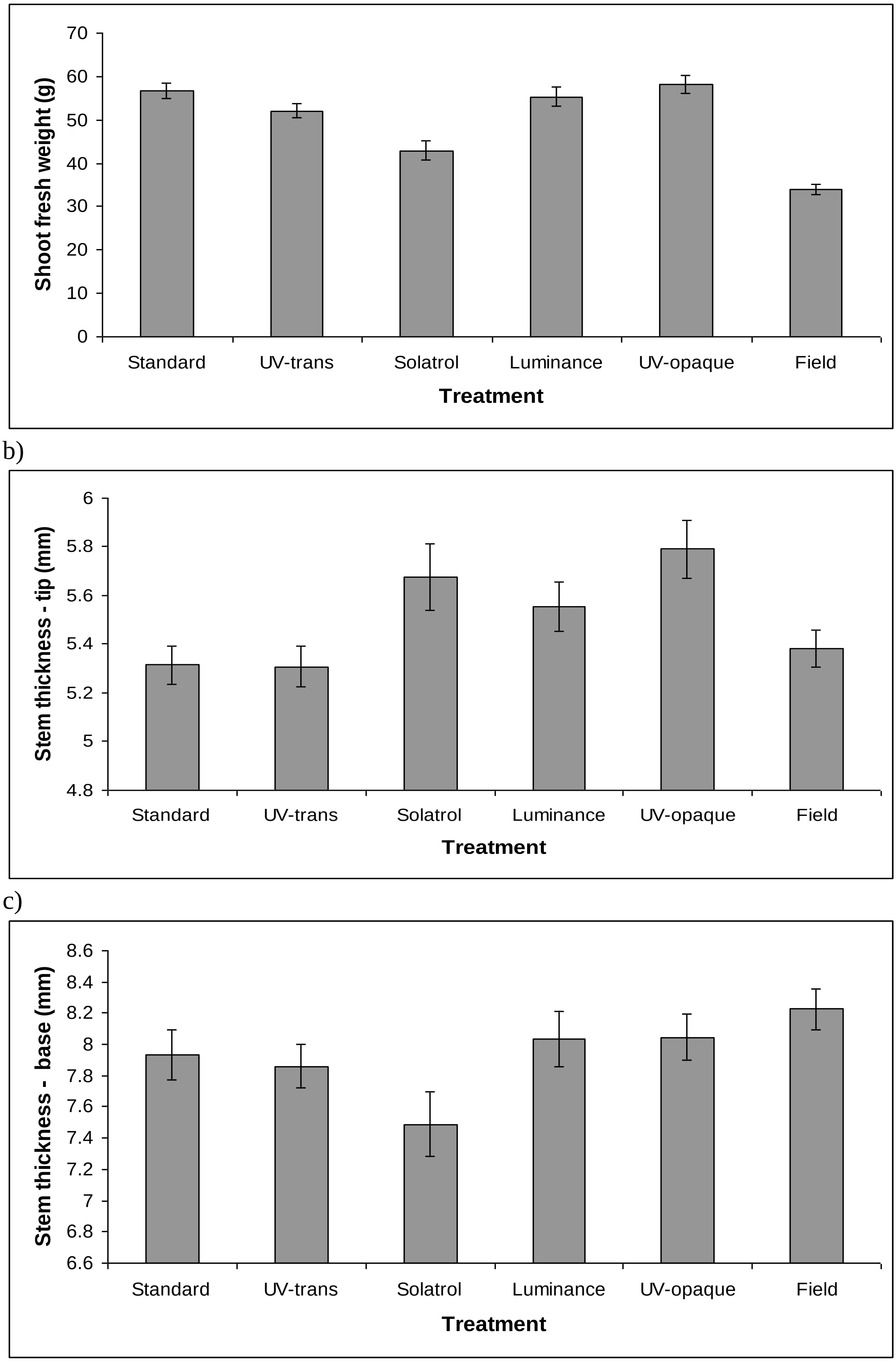


Figure 2. Effect of treatments on (a) shoot fresh weight (b) stem thickness at the tip and (c) stem thickness at the base in Stocks. Each value is the mean ± S.E. of 35 replicates.

a)

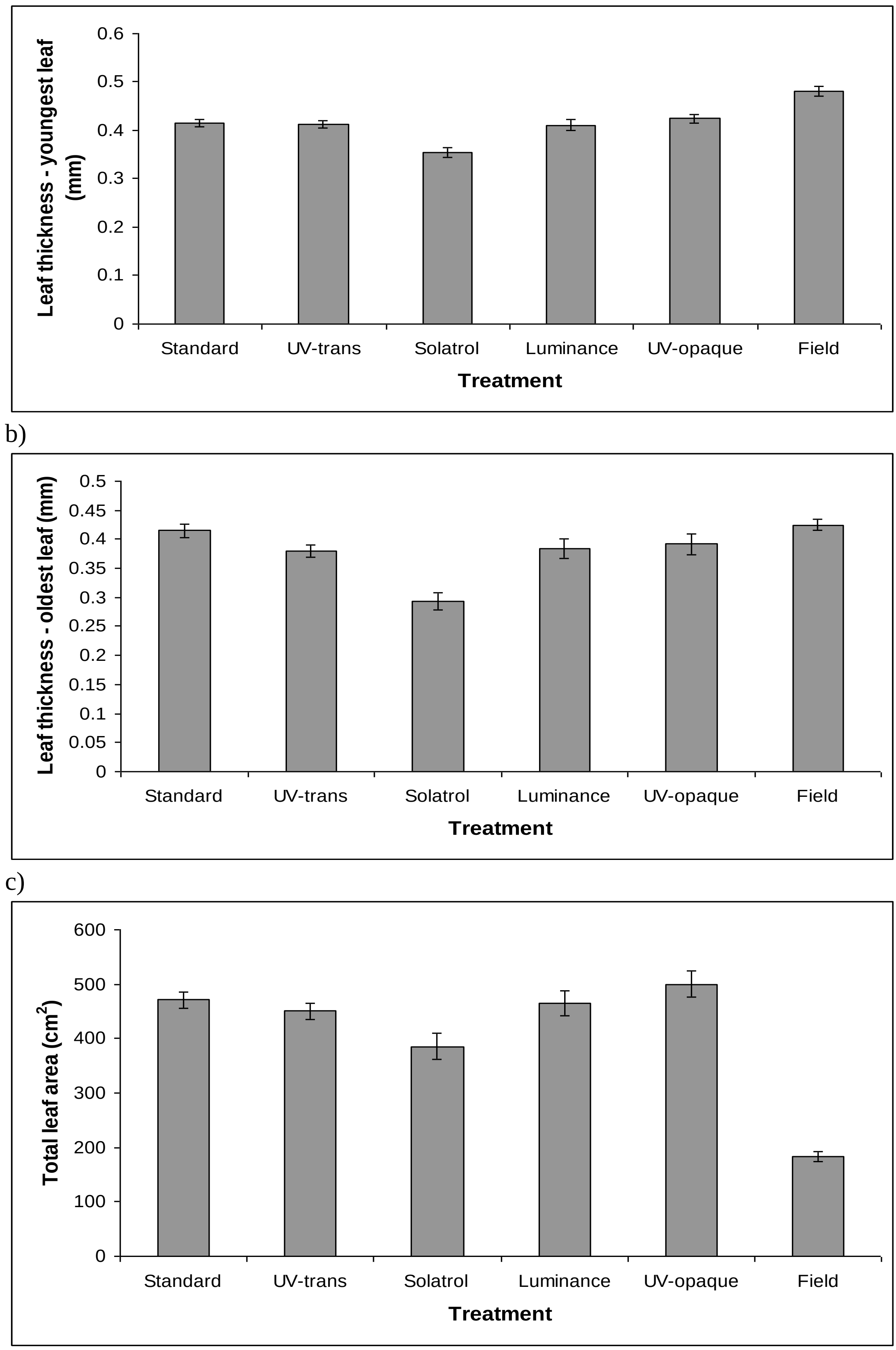


Figure 3. Effect of treatments on (a) leaf thickness in youngest leaf (b) leaf thickness in oldest leaf and (c) total leaf area in Stocks. Each value is the mean ± S.E. of 35 replicates.

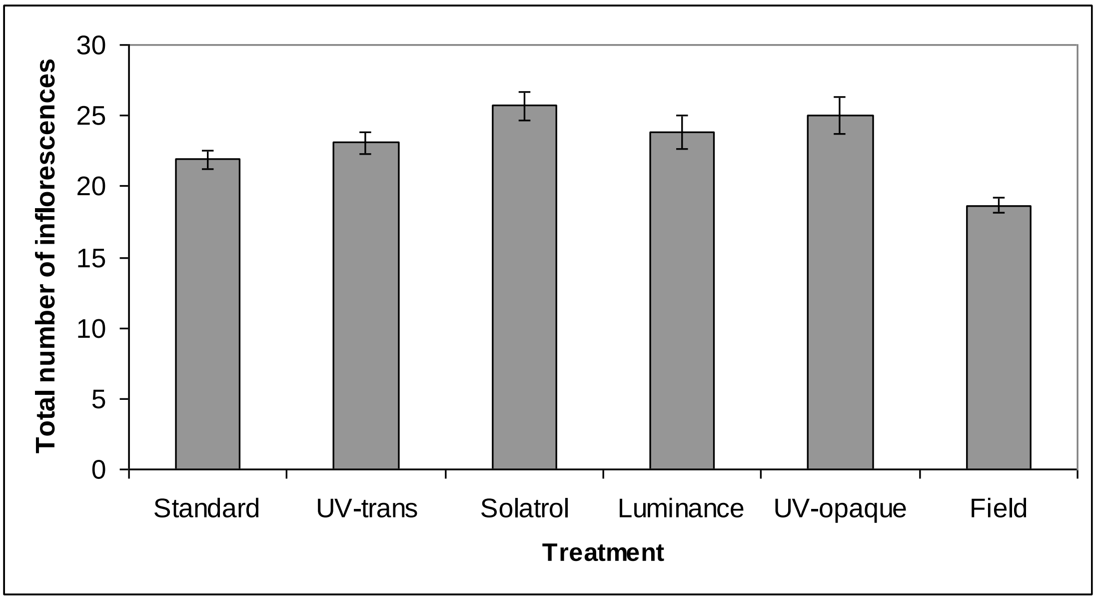
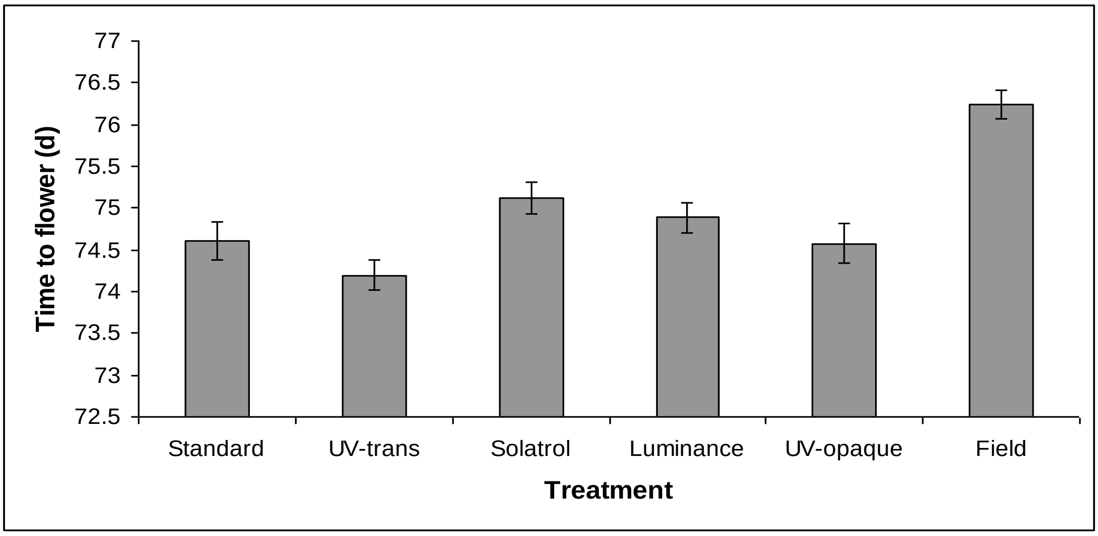


Figure 4. Effect of treatments on the number of inflorescences in Stocks. Each value is the mean ± S.E. of 35 replicates.

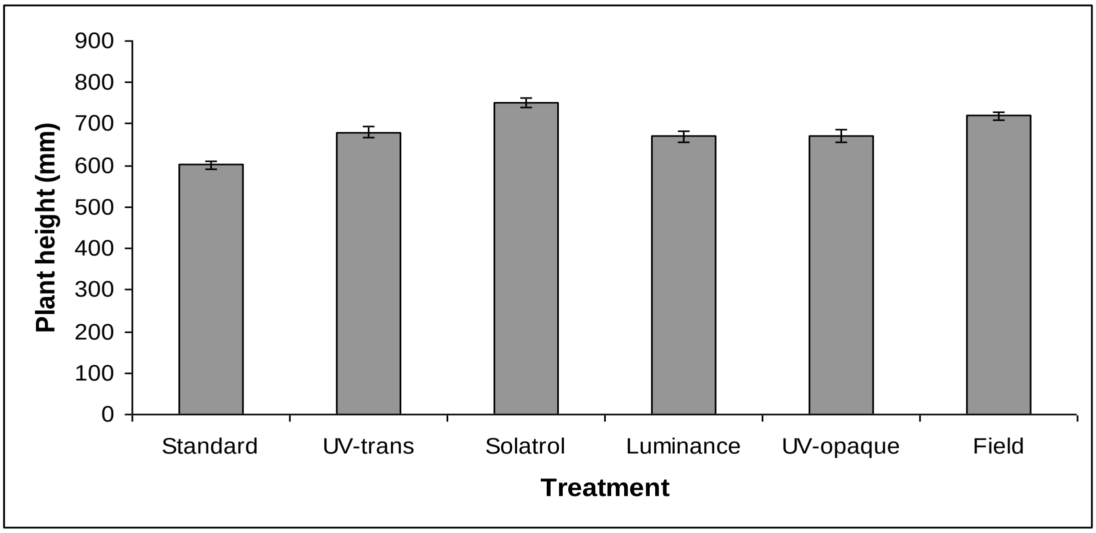
LILIES

Time to flower was significantly reduced in UV-transparent when compared to Solatrol, Luminance and Field only, while Field increased time to flower relative to all filter treatments (fig. 5.a). Solatrol significantly increased total plant height when compared to all treatments (fig. 5.b). The only effect of treatments on the total number of inflorescences was a reduction in Standard relative to Field (fig. 5.c). Furthermore, Standard increased the length of the terminal inflorescence when compared to UV-transparent, Solatrol and Field (fig. 6.a), while the total fresh weight of all inflorescences per plant at the time of harvest was significantly increased in Field plants, and reduced in Solatrol, when compared to all remaining treatments (fig. 6.b). Similarly, shoot fresh weight was significantly increased in Field plants when compared to all remaining filter treatments (fig. 6.c). Of the filter treatments, Solatrol produced plants with the highest total shoot fresh weight (fig. 6.c). Stem thickness at the base of the plant was significantly increased in Field when compared to all filter treatments, and of the filters, Solatrol produced plants with the thickest basal stem (fig. 7.a). There was no effect of treatments in the thickness of the stem at the tip of the plant (fig. 7.b). Total leaf area was significantly increased in Solatrol when compared to Standard, UV-transparent, Luminance and Field treatments, although there was effect relative to UV-opaque (fig. 7.c).

a)



b)



c)

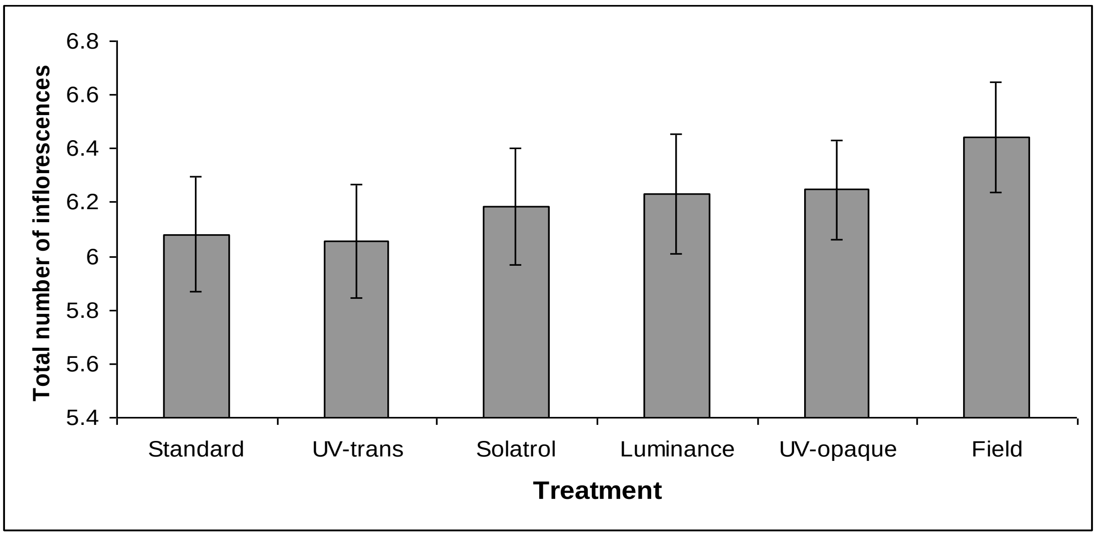


Figure 5. Effect of treatments on (a) time to flower (b) plant height and (c) the total number of inflorescences in Lilies. Each value is the mean ± S.E. of 61 replicates.

a)

b)

c)

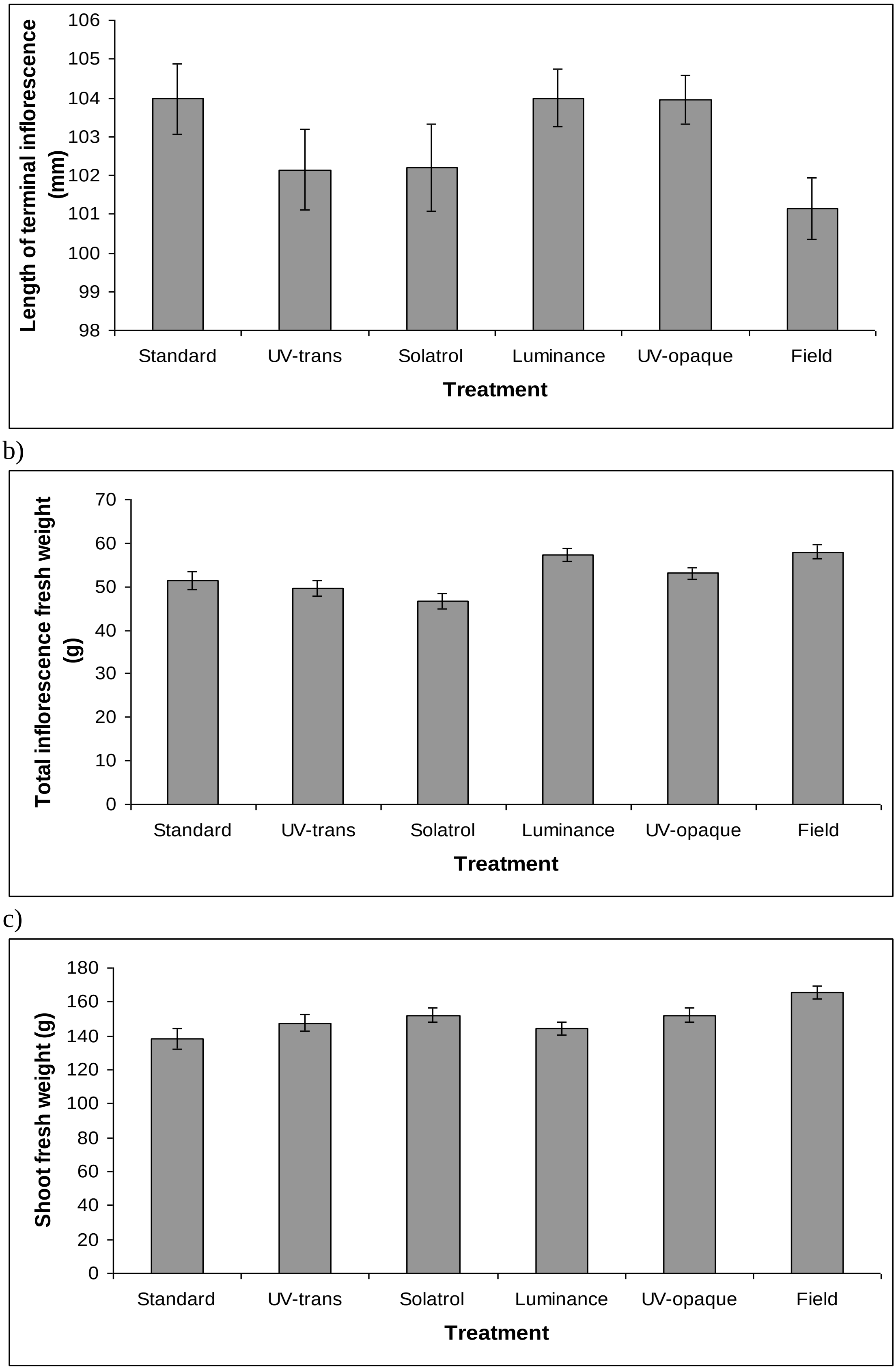


Figure 6. Effect of treatments on (a) length of terminal inflorescence (b) total inflorescence fresh weight and (c) shoot fresh weight in Lilies. Each value is the mean ± S.E. of 61 replicates.

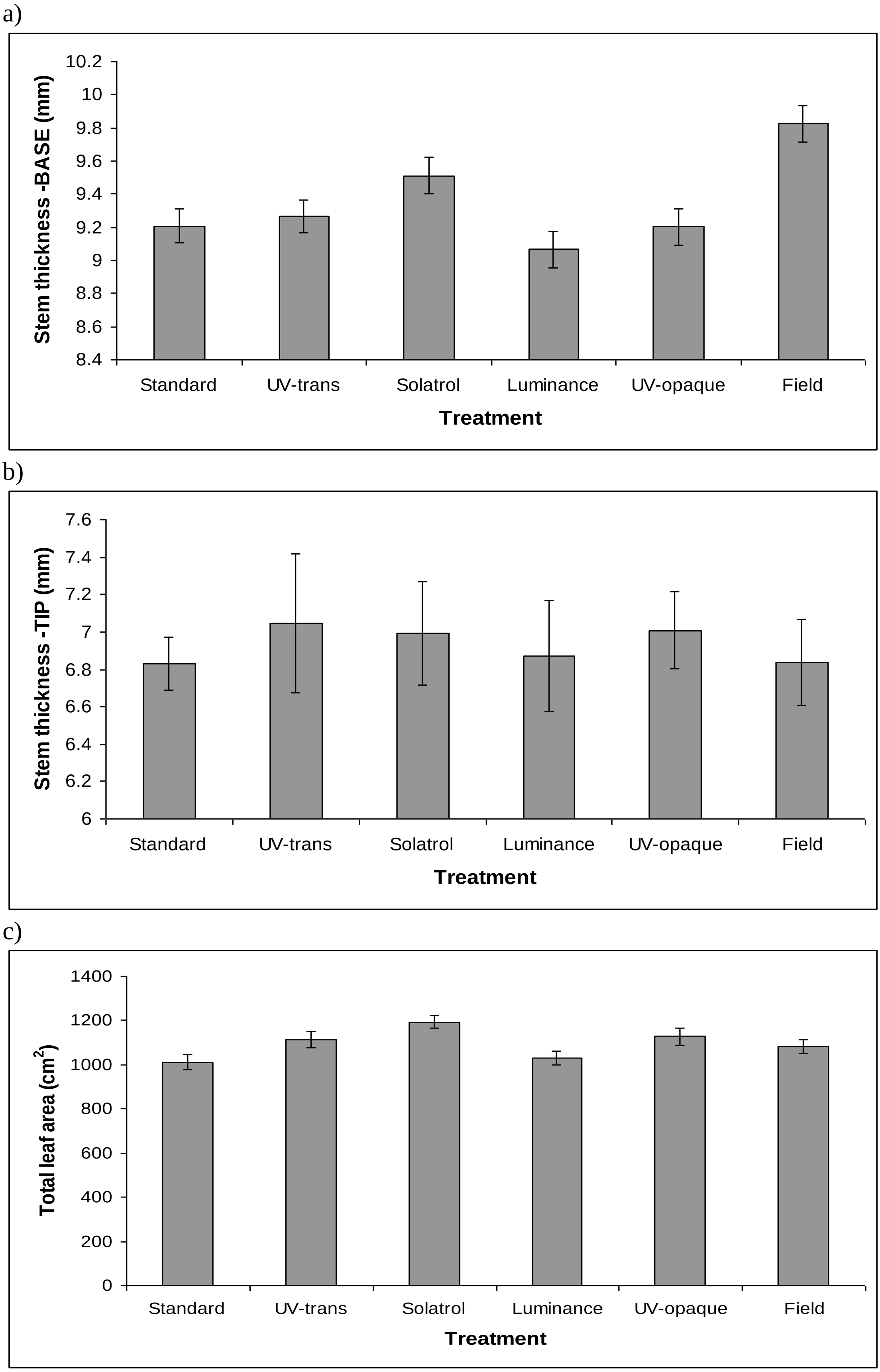
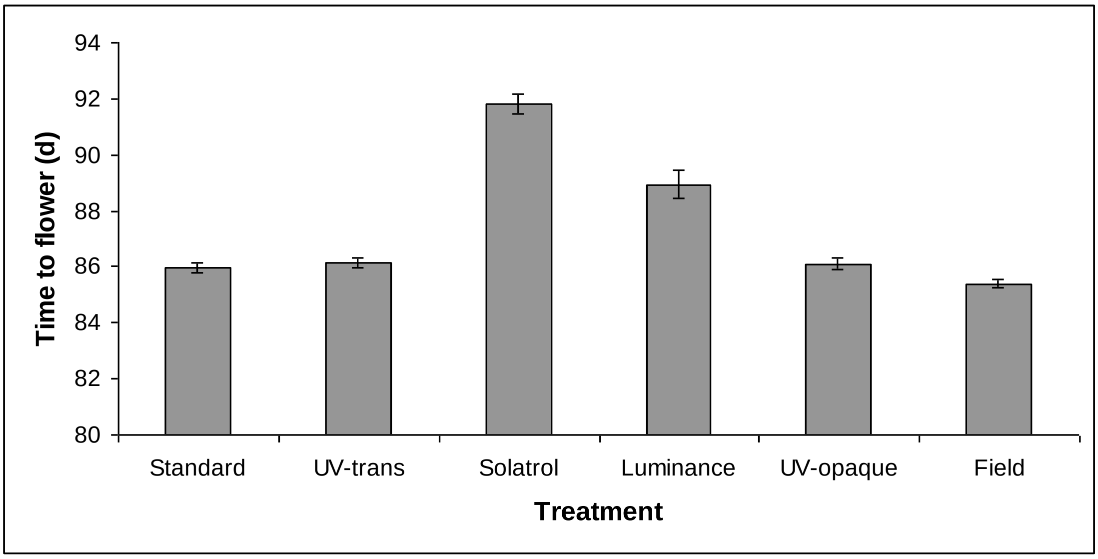


Figure 7. Effect of treatments on (a) stem thickness at the base (b) stem thickness at the tip and (c) total leaf area in Lilies. Each value is the mean <u>+</u> S.E. of 61 replicates.

LARKSPUR

Solatrol significantly increased time to flower when compared to all remaining treatments by ~4 days (fig. 8.a). Total plant height was significantly increased in Standard relative to Solatrol and Field treatments only (fig. 8.b). The only significant effect of treatments on the total number of ancillary stems (fig. 9.a) and the total number of inflorescences (fig. 9.b) was a reduction in Field when compared to all filter treatments. Similarly, Field plants had significantly reduced fresh weight at the time of harvest relative to the remaining filter treatments (fig. 9.c). Stem thickness in Field at the base of the plant was significantly reduced when compared to all treatments (fig. 10.a). Stem thickness at the tip was similarly reduced in Field relative to all filter treatments except Luminance (fig. 10.b).

a)



b)

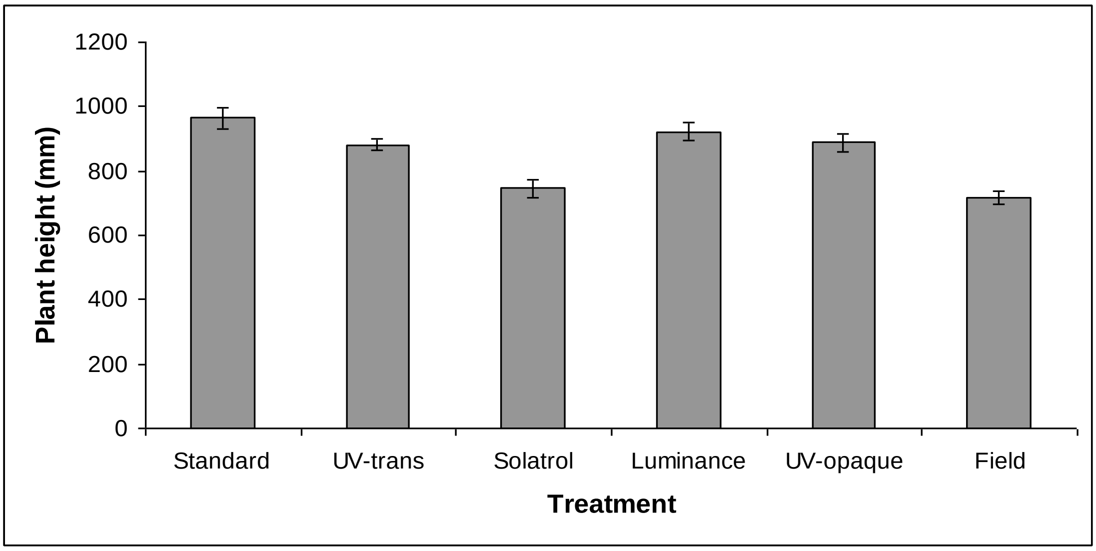
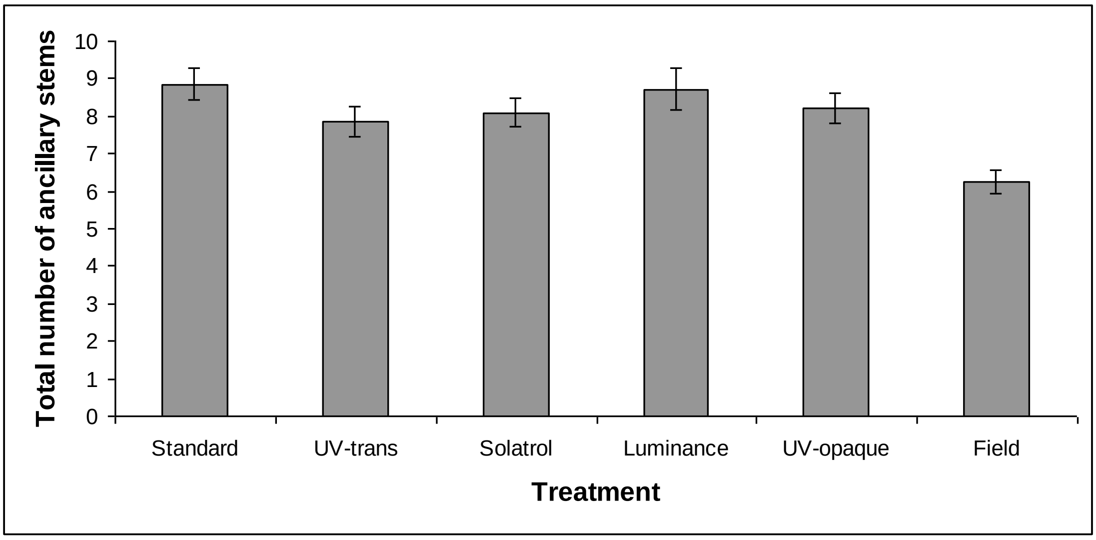
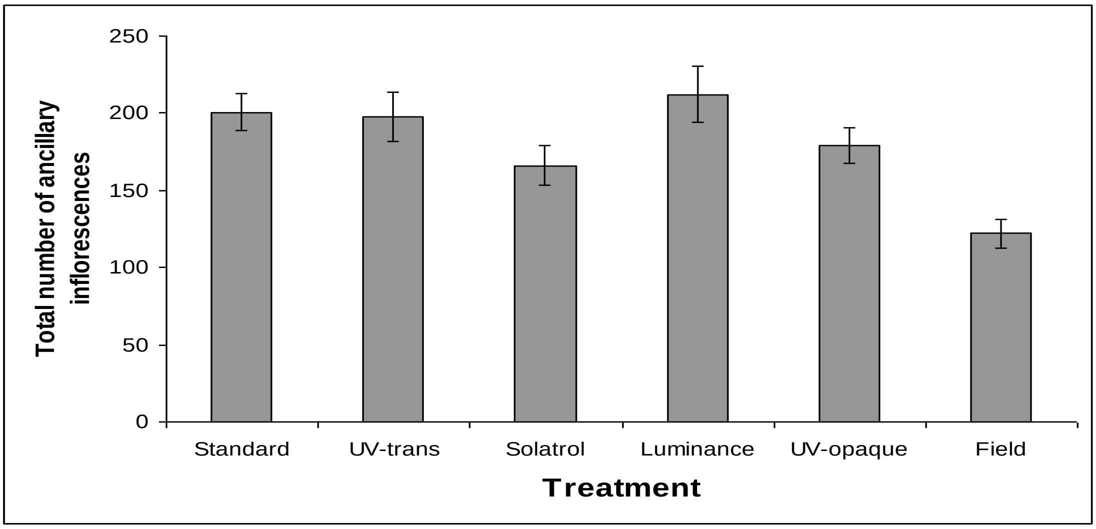


Figure 8. Effect of treatments on (a) time to flower and (b) plant height in Larkspur. Each value is the mean ± S.E. of 30 replicates.

a)



b)



c)

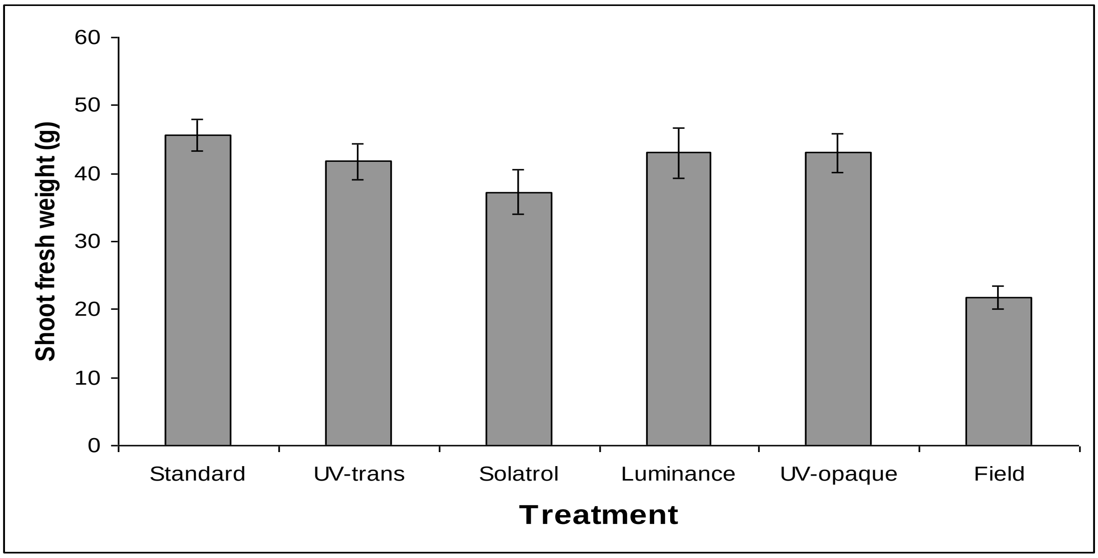
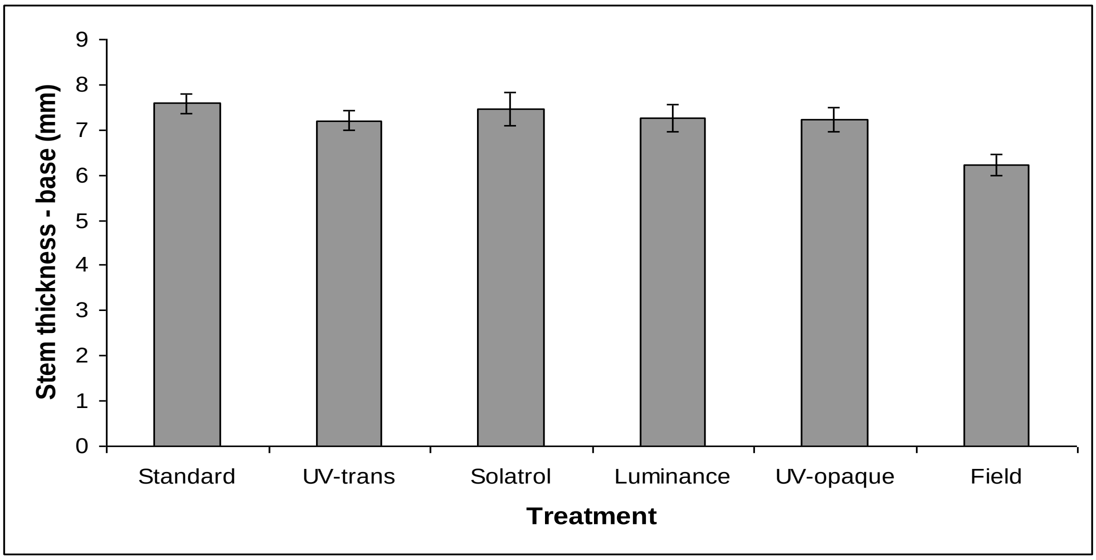


Figure 9. Effect of treatments on (a) total number of ancillary stems (b) total number of ancillary inflorescences and (c) shoot fresh weight in Larkspur. Each value is the mean ± S.E. of 30 replicates.

a)



b)

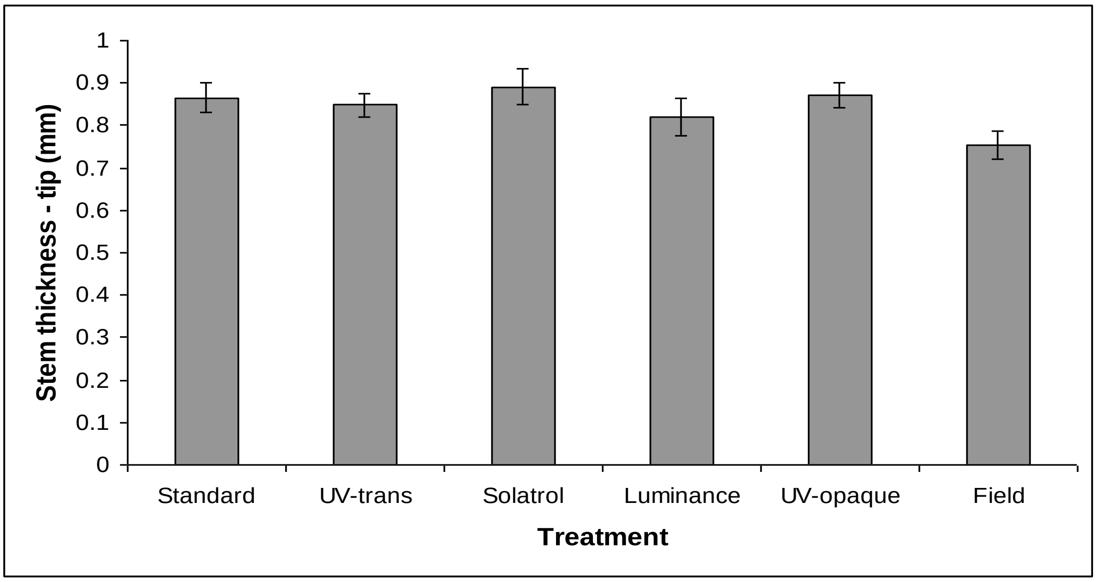
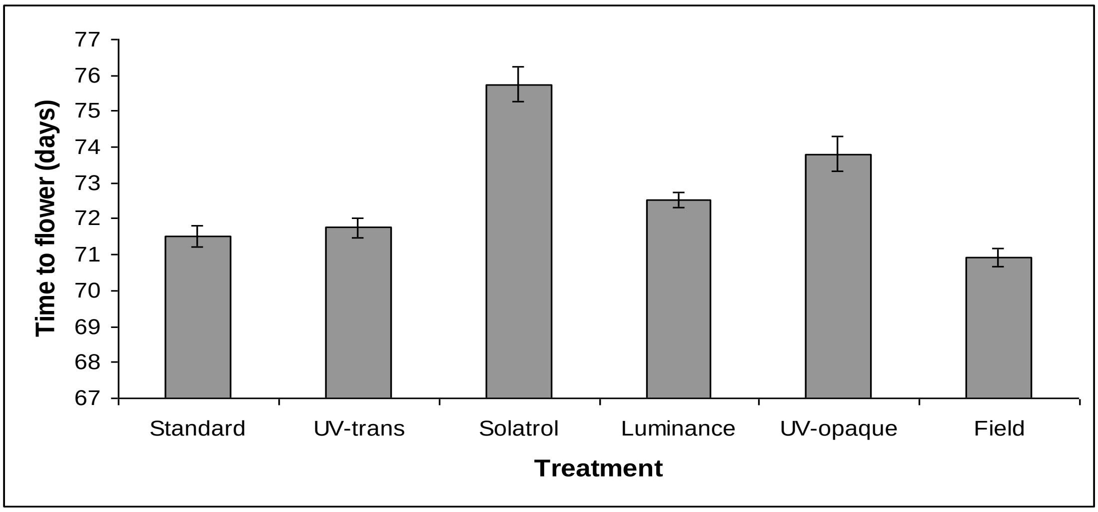


Figure 10. Effect of treatments on (a) stem thickness at the base and (b) stem thickness at the tip in Larkspur. Each value is the mean + S.E. of 30 replicates.

ASTERS

Time to flower was significantly increased in Solatrol when compared to all remaining treatments (fig. 11.a) Time to flower was reduced in Field relative to all treatments except UV-transparent (fig. 11.a). There was no difference in plant heights at time of harvest between filter treatments, although Field did reduce plant height when compared to all remaining treatments (fig. 11.b). Solatrol significantly increased primary inflorescence diameter when compared to Standard, UV-transparent, Luminance and Field, although there was no effect relative to UV-opaque (fig. 12.a). The total number of ancillary inflorescences (fig. 12.b) and ancillary stems (fig. 12.c) was significantly increased in Standard when compared to all treatments except UV-opaque. Shoot fresh weight was significantly increased in Standard relative to Solatrol and Field treatments only (fig. 13.a). In UV-transparent, stem thickness at the base was reduced when compared to all remaining treatments except Solatrol (fig. 13.b) and at the tip relative to all treatments but Field (fig. 13.c). Leaf thickness, in both the oldest and the youngest leaves, was significantly increased in Field plants when compared to all filter treatments (figs. 14.a. & 14.b). Standard significantly increased total leaf area at the time of harvest relative to UV-transparent, Luminance, UV-opaque and Field, although there was no effect when compared to Solatrol (fig. 14.c).

a)



b)

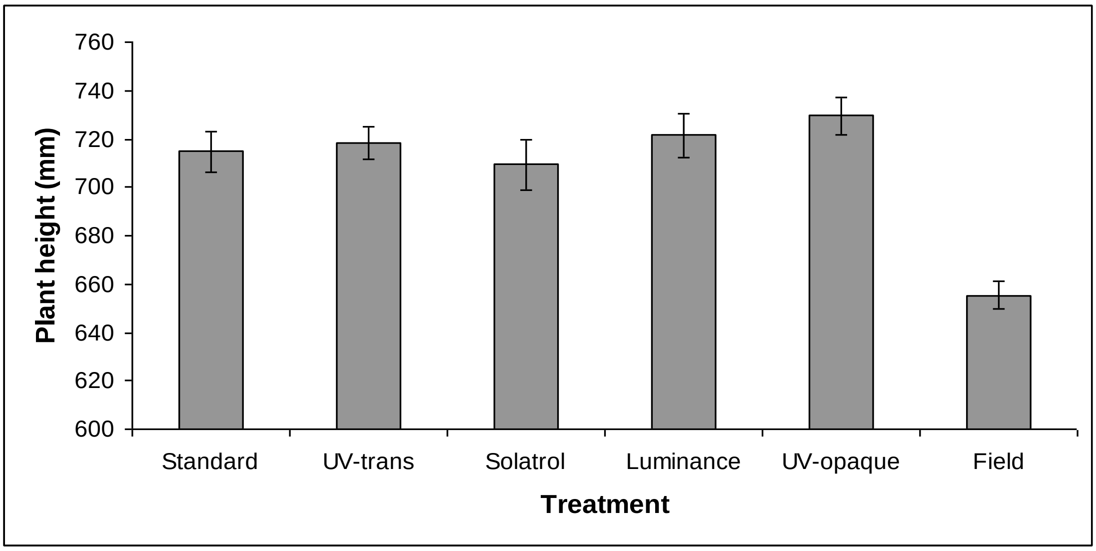
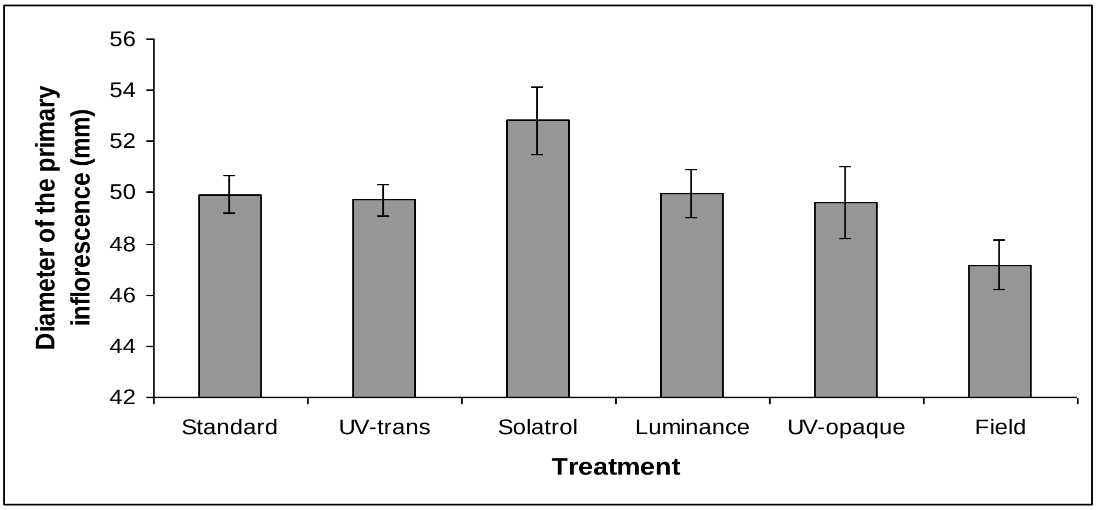
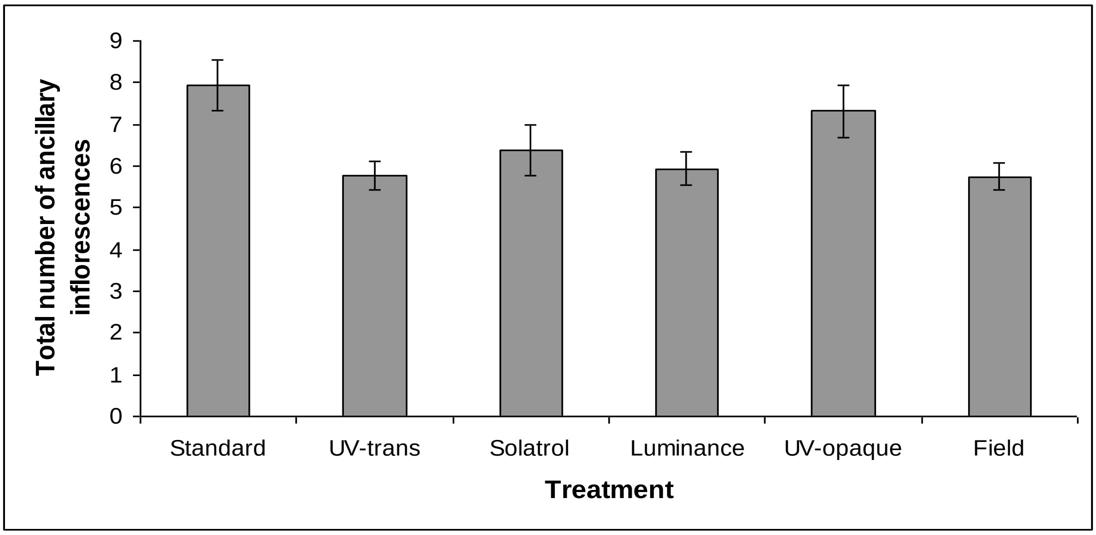


Figure 11. Effect of treatments on (a) time to flower and (b) plant height. Each value is the mean ± S.E. of 30 replicates.

a)



b)



c)

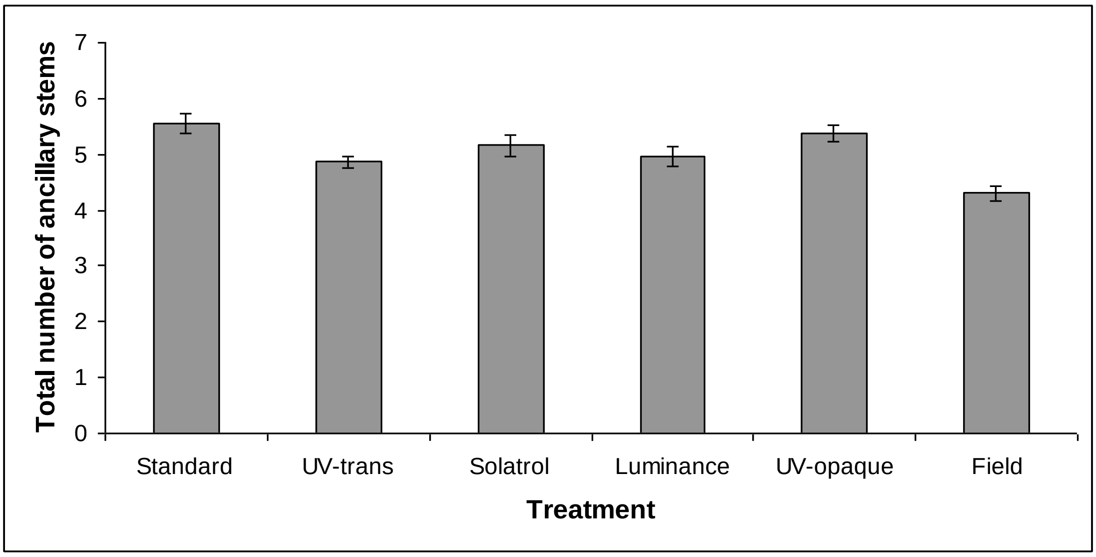
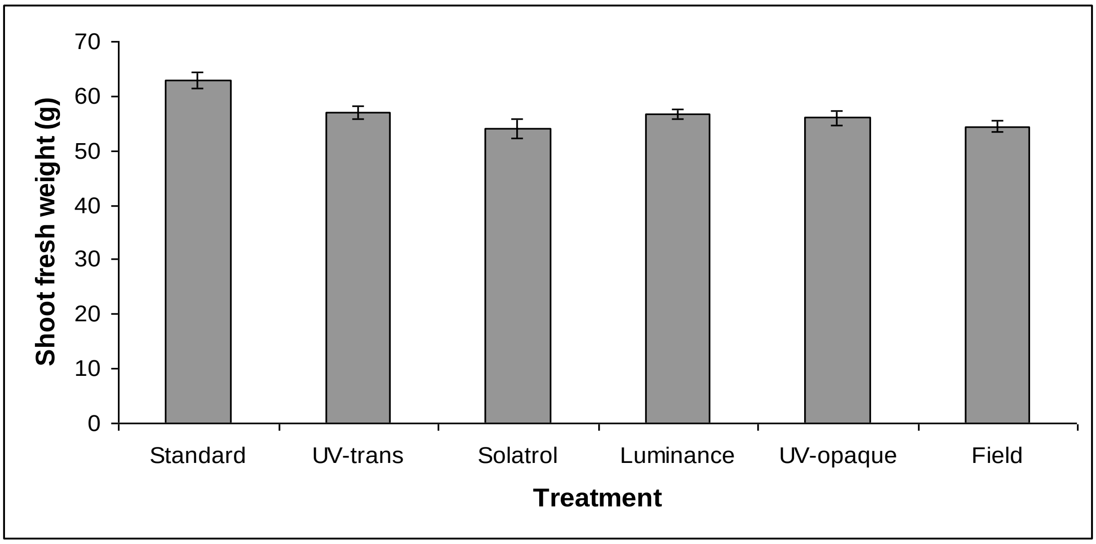
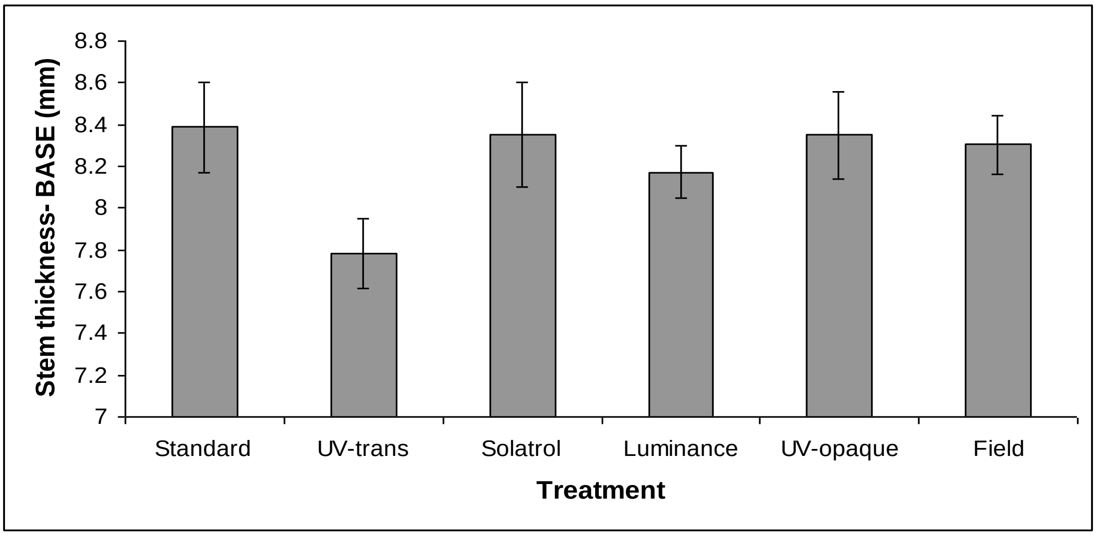


Figure 12. Effect of treatments on (a) diameter of the primary inflorescence (b) total number of ancillary inflorescences and (c) total number of ancillary stems in Aster. Each value is the mean ± S.E. of 30 replicates.

a)



b)



c)

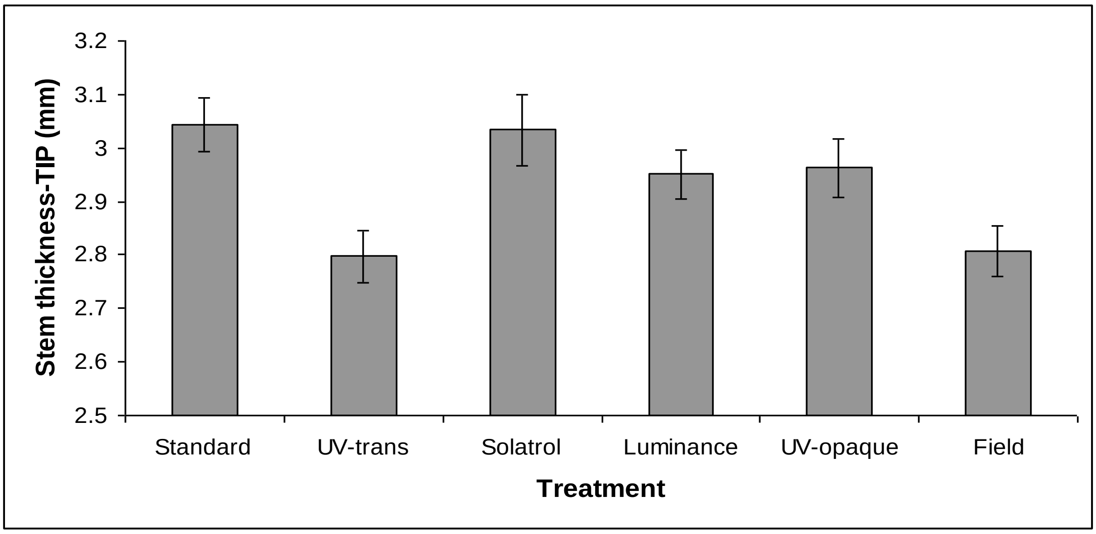


Figure 13. Effect of treatments on (a) shoot fresh weight (b) stem thickness at the base and (c) stem thickness at the tip in Aster. Each value is the mean ± S.E. of 30 replicates.

a)

b)

c)

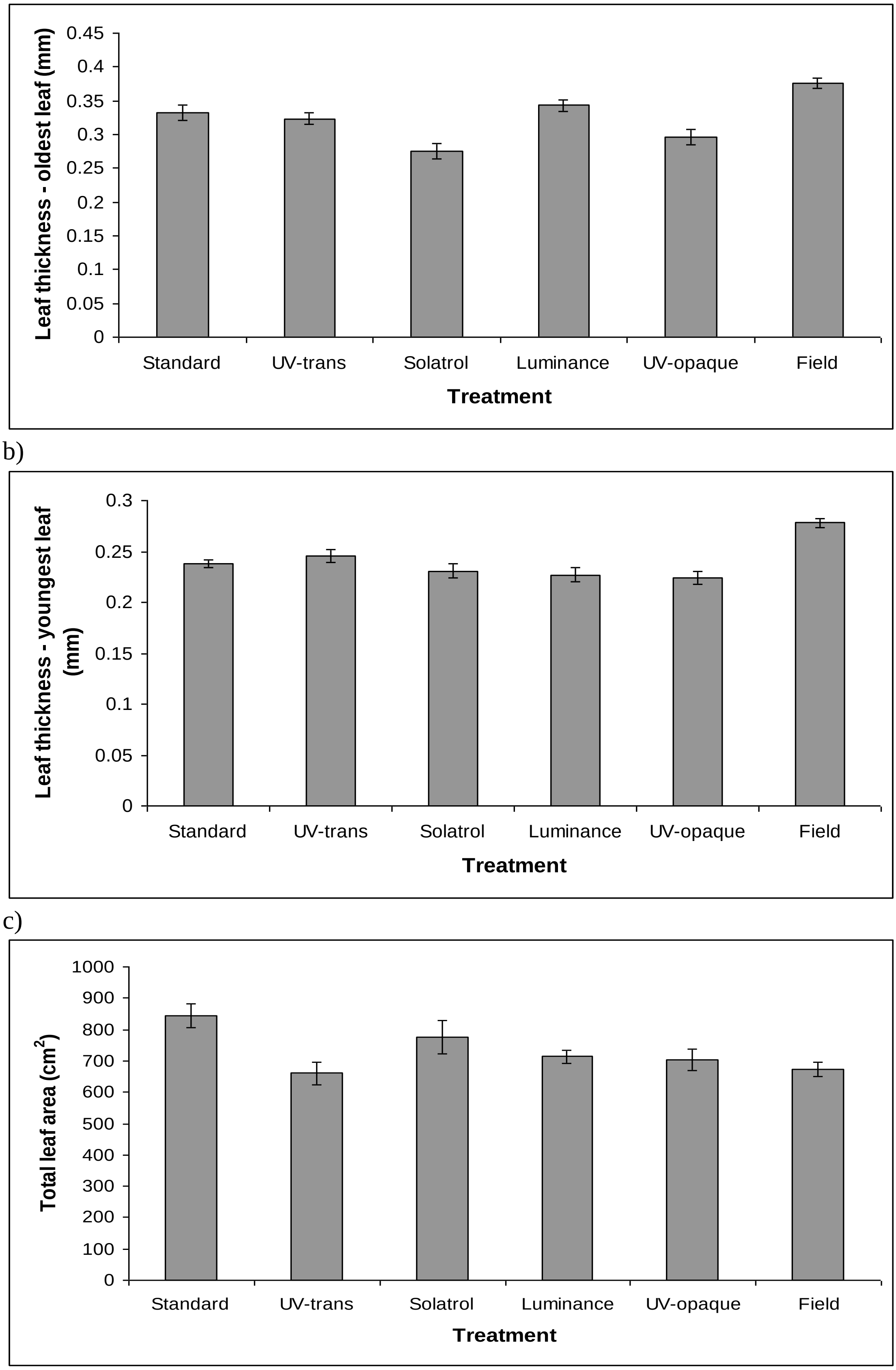


Figure 14. Effect of treatments on (a) leaf thickness in the oldest leaf (b) Leaf thickness in the youngest leaf and (c) total leaf area in Aster. Each value is the mean + S.E. of 30 replicates.

Discussion

Cut flower producers are coming under increasing pressure from large retailers to both diversify their business and to reduce production costs. One possible way of achieving this is by substituting traditional glasshouse production with large-scale plastic protection. Further 'added value' could be achieved if the protective filters were shown to alter crop development in such a way as to increase both the quantity and quality of the marketable product. Results from both the first season, and now the second years trial, suggest that the four cut flower varieties trialled here do respond to particular filter treatments in potentially economically beneficial ways.

Conclusions drawn from the first season's trial suggested a general trend in Stocks for increased length of the terminal inflorescence and the number of individual inflorescences under the Solatrol filter. Field grown Larkspur produced plants with increased vegetative growth in the form of increased numbers of ancillary breaks, although there was no statistical difference between the filter treatments. The effects of the five filter treatments on Larkspur were somewhat more complex but early, tentative evidence from the first year's trial suggests that both terminal inflorescence and ancillary flower numbers were increased under Luminance. There is also evidence in the data to suggest that the length of the terminal inflorescence was generally increased under both Solatrol and UV-opaque. In Asters we observed a clear effect of certain filters on canopy development. Under Luminance and in the open plot (Field), canopy development was visually poor. However, Solatrol produced a visually 'deeper' canopy, which could translate into a more marketable product for retailers through customer perception of more attractive foliage and increased plant weight, which helps gives a 'feel' of value. Perhaps, more interesting than the spectral filters effects on vegetative development, was the structural and colour changes observed in the primary inflorescence of Aster. In the open plot (Field) and under the UV-transparent filter inflorescence colouration was visually more intense and in Solatrol inflorescence structure was markedly altered (see fig. 15).

Results from this years study, which took place during one of the wettest Augusts on record, showed very similar effects of the filters on flower colouration and structure in Asters (fig. 16). Field plants (all varieties) were subjected to flooding for a period of at least 7 days prior to flowering, which led to a reduction in the visual quality of the crop (see fig. 17 below) and possibly led to the reduction in plant height when compared to all remaining treatments (fig. 11.b). Of the filter treatments both Standard and UV-transparent [potentially] produced plants of the highest commercial quality (see figs. 18 & 19 below) since Standard increased the total number of ancillary inflorescences (fig. 12.b) and ancillary stems (fig. 12.c), while UV-transparent gave increased pigmentation in both inflorescence and vegetative organs (figs. 16 & 18).

Results in Lilies showed the benefit of producing under any filter when compared to the open field. The quality of Field grown plants was considerably reduced (fig.) and time to flower was significantly increased (fig. 5.a) when compared to all the filter treatments. Of the filter treatments, Solatrol produced [potentially] the most marketable crop due to the significant increase in plant height (fig. 5.b), stem thickness (fig. 7.a), total leaf area (fig. 7.c) and, relative to the remaining filter treatments, increased total plant fresh weight (fig. 6.c), which provided ‘the feel’ of a more substantial product (see fig. 20 below). The data suggests that the increase in vegetative biomass was at the cost of a reduction in inflorescence fresh weight (fig. 6.b), although this was not visually apparent at the time of harvest.

Of all the varieties Stocks responded the most negatively to the heavy rainfall experienced in August (see fig. 22 below). Indeed, we lost 100% of the crop, which according Mr Simon Crawford, our consultant on the project, was typical of many other Stock growers across the country. Of the remaining five filter treatments both Luminance and UV-opaque produced the most marketable crop (see figs. 24 & 25 below) largely because of the increase in both the length (fig. 1.c) and the number of individual inflorescences on the bud (see fig. 4 & 23).

Evidence from the first two seasons suggests that Larkspur does not respond to the various filter treatments to the same degree as other varieties since the major effects were largely limited to a delay in flowering (fig. 8.a), and a reduction in plant height (fig. 8.b), under Solatrol. Other morphological data suggests that, especially with regards to changes in the inflorescence numbers and fresh weights, the variability between filter treatments is high and certainly there were no clear visual differences between treatments at time of harvest.

Results from the first years trials suggested that cut flower productivity and quality could be manipulated by switching to production under spectral filters (see HDC report for CP19, 2003). This has largely been confirmed by results from this season’s trial, which has provided supplementary evidence to direct decisions on which cut flower varieties responds in economically beneficial manners to the various filters. During 2004 Lilies, Stocks, Larkspur and Asters were trialled. Although all four species are still very useful examples of outdoor cut flowers benefiting from tunnel protection, it would be useful to review the list before finalising the project for 2005. Lilies remain a very important product for the UK and should perhaps remain, as should Asters. The importance of including Stocks and Larkspur as model crops for next year must be decided before the end of 2004 but also other crops such as Dianthus, Nigella, Sunflower and Delphinium should be reconsidered for a place in the project. Work at Stockbridge Technology Centre over the last twelve months has reconfirmed the usefulness of low cost tunnel systems and the necessity for further research work into the advantages of spectral filters used in this type of cropping system.

Figure 15. Inflorescence colouration and structure in Aster in 2003.

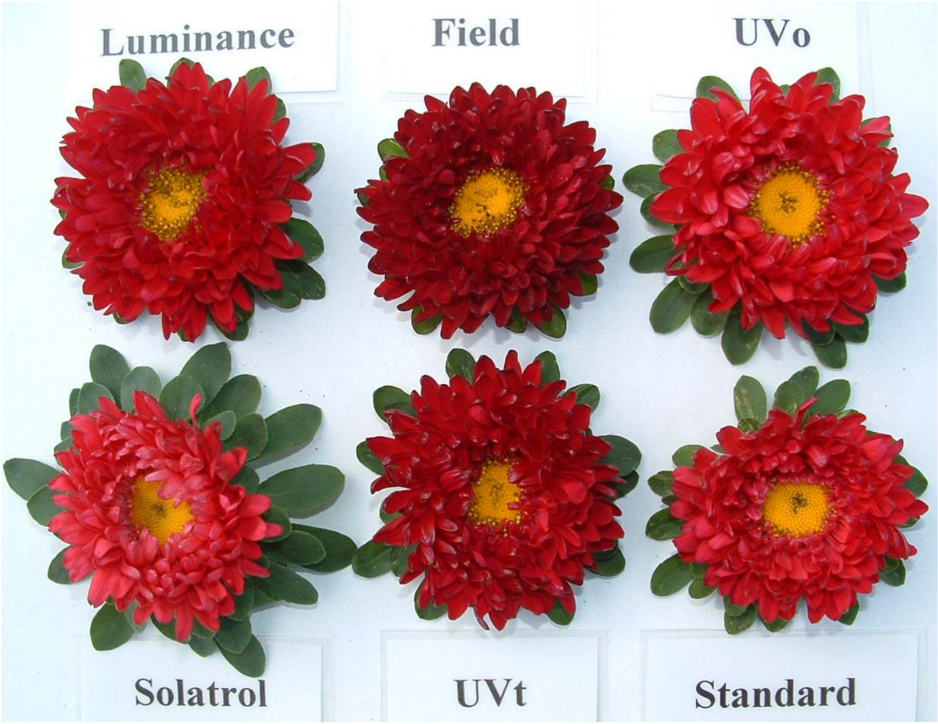


Figure 16. Inflorescence colouration and structure in Aster in 2004.

Figure 17. Canopy development in open Field in Aster in 2004.

Figure 18. Canopy development under UV-transparent in Aster in 2004.

Figure 19. Canopy development under Standard in Aster in 2004.

Figure 20. Lilies under the Solatrol filter in August 2004.

Figure 21. Lilies under the UV-transparent filter in August 2004.

Figure 22. Stocks in the Field plot. Photo taken in mid August 4 days after ~5 inches of standing water had cleared.

Figure 23. Inflorescence colouration and structure in Stocks in 2004.


Figure 24. Canopy development under Luminance in Stocks July 2004.


Figure 25. Canopy development under UV-opaque in Stocks July 2004.

Acknowledgements

The authors wish to thank Tim Crossman and Simon Crawford for helpful discussions and helpful insights into cut flower production and into the condition of the cut flower market.

CP19: Horticultural crops:
Further demonstration of the potential benefits of modified plastic crop covers

Herbs & essential oil analysis

Part 7. Herbs and essential oil analysis.

Introduction

Approximately 1,000 ha of herbs are cultivated in the UK and the potential for market growth is considerable since the majority of UK consumed produce is imported from Mediterranean countries. The industry supplies primarily to the food-manufacturing sector, which accounts for 50-60% of total sales (fresh, dried, frozen and volatile oils) and is second only to the retail and catering sector; with a small market developing in the medicinal industry. Herb growers also supply the culinary industry, with the current market valued at approximately 32m and consumption increasing by about 10% per year. Both culinary and medicinal herbs are utilised in the food, cosmetic, pharmaceutical and beverage industries and are currently supplied between a variety of both small and large-scale herb producers throughout the UK.

A wide variety of herbs can be successfully cultivated in Northern Europe, with a number of exceptions, including plants grown for seed production, or plants with specific growth requirements. Incorporating the use of spectral filters into UK herb production may provide several benefits to UK growers. These include standard protection from the unpredictable climate and the ability to time production to more accurately meet market demand. Furthermore, there is preliminary evidence that suggests that a number of new spectral filters modify plant development in such a way as to increase both herb fresh and dry weights, while modifying essential oil production in an economically beneficial way.

Results

FRESH WEIGHTS

SAGE
The greatest effect of treatments was observed in Field plants, which exhibited highly significantly reductions in fresh weights relative to all five filters (fig. 1.a). In contrast, fresh weight was increased in UV-opaque compared to all remaining treatments, although this was only a significant increase when compared to Standard, Solatrol and Field (fig. 1.a).

THYME
Again, the greatest effect of treatments was observed in Field plants, which exhibited highly significantly reductions in fresh weights relative to all five filters (fig. 1.b). UV-opaque significantly increased fresh weights when compared to all treatments (fig. 1.b).

ROSEMARY
Fresh weights were significantly reduced in Field relative to all treatments (fig. 1.c). The UV-opaque filter produced the highest fresh weights when compared to all treatments except UV-transparent (fig. 1.c).

BLACK PEPPERMINT

In Peppermint, UV-opaque plants exhibited increased fresh weights when compared to UV-transparent and Luminance only (fig. 2.a). UV-transparent and Field produced plants with the lowest fresh weights when compared to all remaining treatments (fig. 2.a).

LAVENDER

Standard significantly increased plant fresh weights when compared to UV-transparent, Solatrol, Field and Luminance, although there was no effect relative to UV-opaque (fig. 2.b). Again, Field significantly reduced fresh weights when compared to all treatments (fig. 2.b).

a)

b)

c)

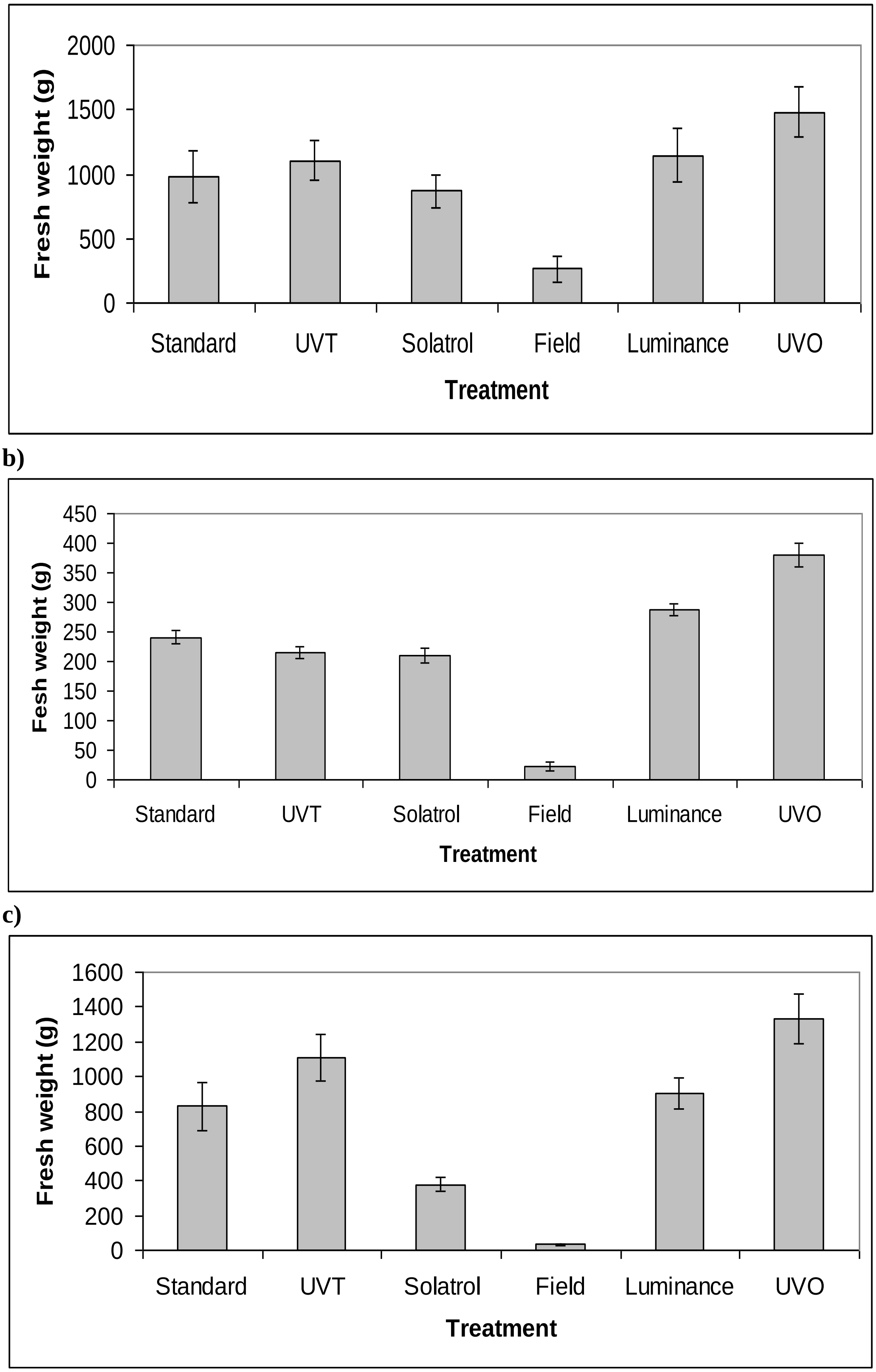
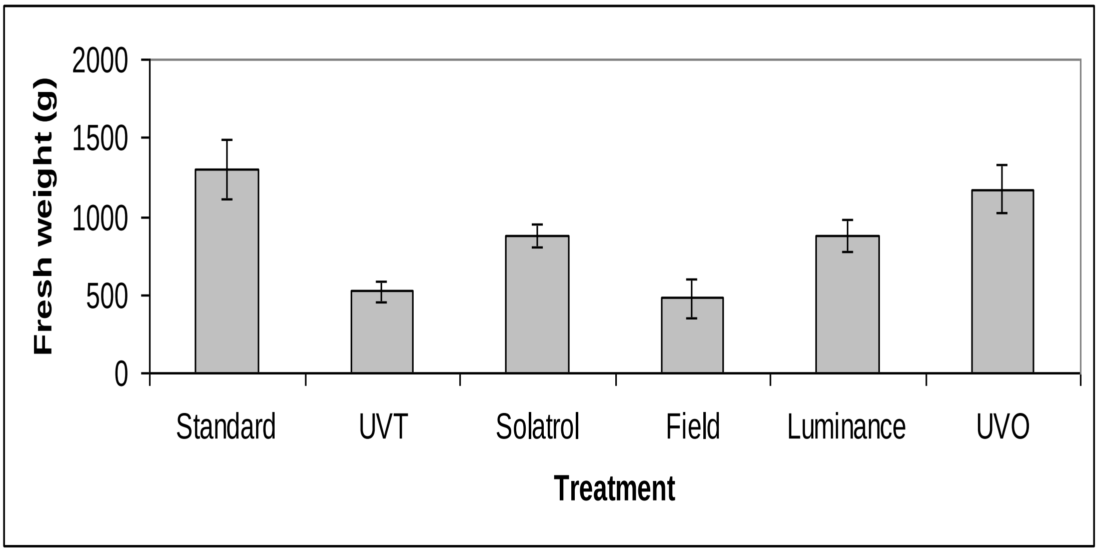


Figure 1. Effect of treatments on fresh weight at harvest in (a) Sage (b) Thyme and (c) Rosemary. Each value is the mean ± S.E. of 15 replicates.

a)



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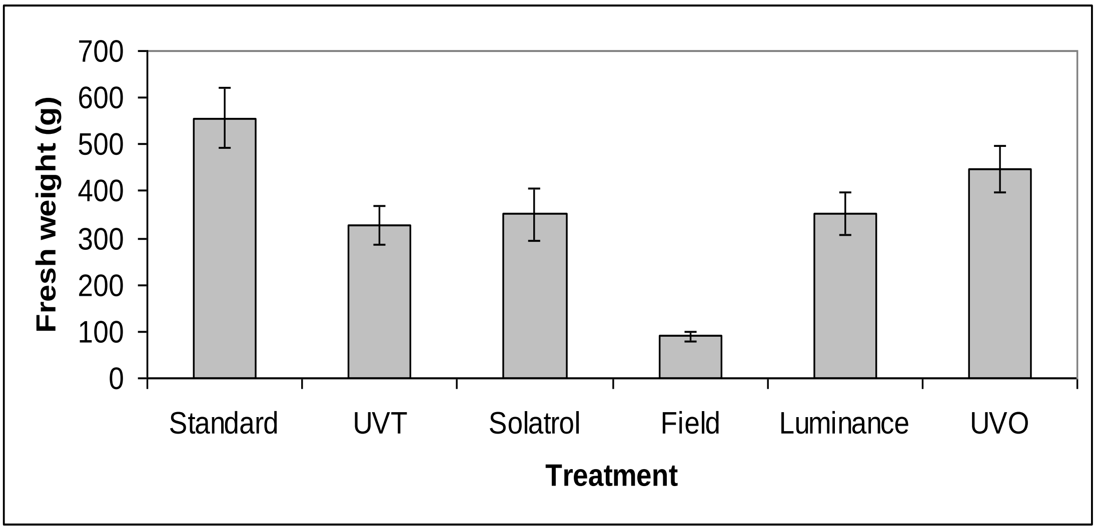


Figure 2. Effect of treatments on fresh weight at harvest in (a) Peppermint and (b) Lavender. Each value is the mean ± S.E. of 15 replicates.

DRY WEIGHTS

SAGE

There was a highly significant reduction in final dry weights in Field relative to all five filters (fig. 3.a). In contrast, fresh weight was increased in UV-opaque compared to all remaining treatments, although these were not significant increases (fig. 3.a).

THYME

The greatest effect of treatments was observed in Field plants, which exhibited highly significantly reductions in dry weights relative to all five filters (fig. 3.b). UV-opaque significantly increased fresh weights when compared to all treatments (fig. 3.b).

ROSEMARY

Dry weights were significantly reduced in Field relative to all treatments (fig. 3.c). The UV-transparent filter produced the highest fresh weights when compared to all treatments, although this was only a significant increase relative to Solatrol and Field (fig. 3.c).

BLACK PEPPERMINT

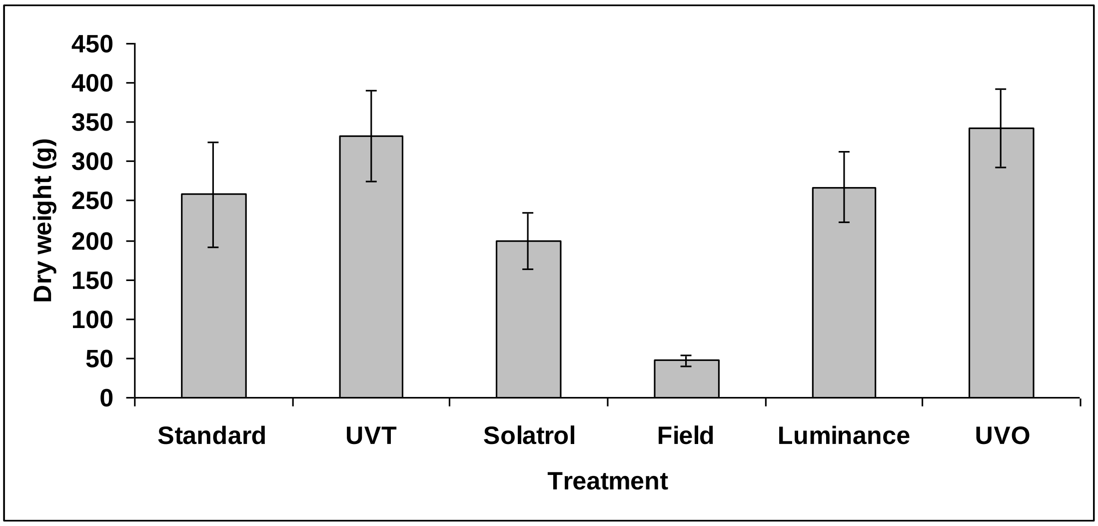
In Peppermint, Standard exhibited significantly increased dry weights when compared to all remaining treatments, although this was only a significant increase relative to UV-transparent and Field (fig. 4.a).

LAVENDER

Field significantly reduced plant dry weights when compared to all remaining treatments (fig. 4.b). Standard produced increases in dry weights relative to all remaining treatments (fig. 4.b).

Dry weight yields per plant in 2004 were not significantly greater than those in 2003 for standard, solatrol, luminance or the field plot (which was the only treatment where yield tended to be lower in 2004 than 2003). By contrast, plant dry weights under UV-T and UV-O were significantly higher in 2004 than 2003 (110 and 55% respectively)

a)



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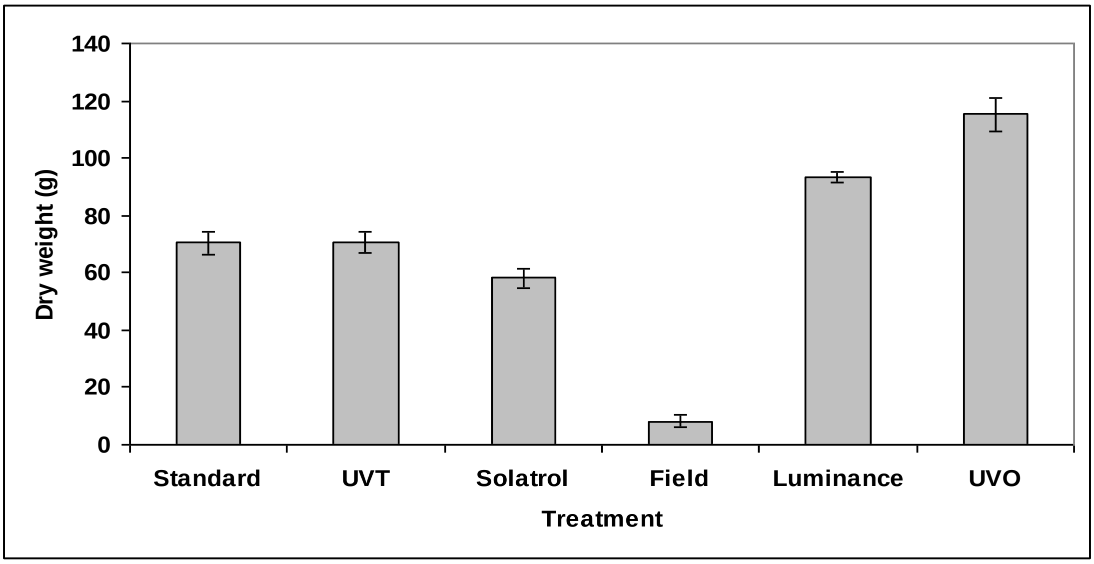

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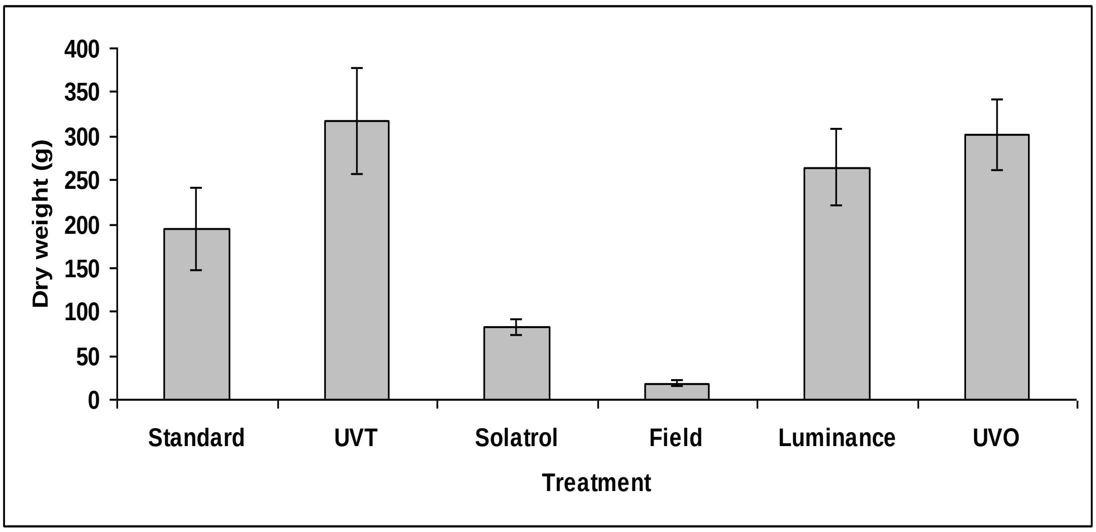


Figure 3. Effect of treatments on dry weight at harvest in (a) Sage (b) Thyme and (c) Rosemary. Each value is the mean ± S.E. of 15 replicates.

a)
b)

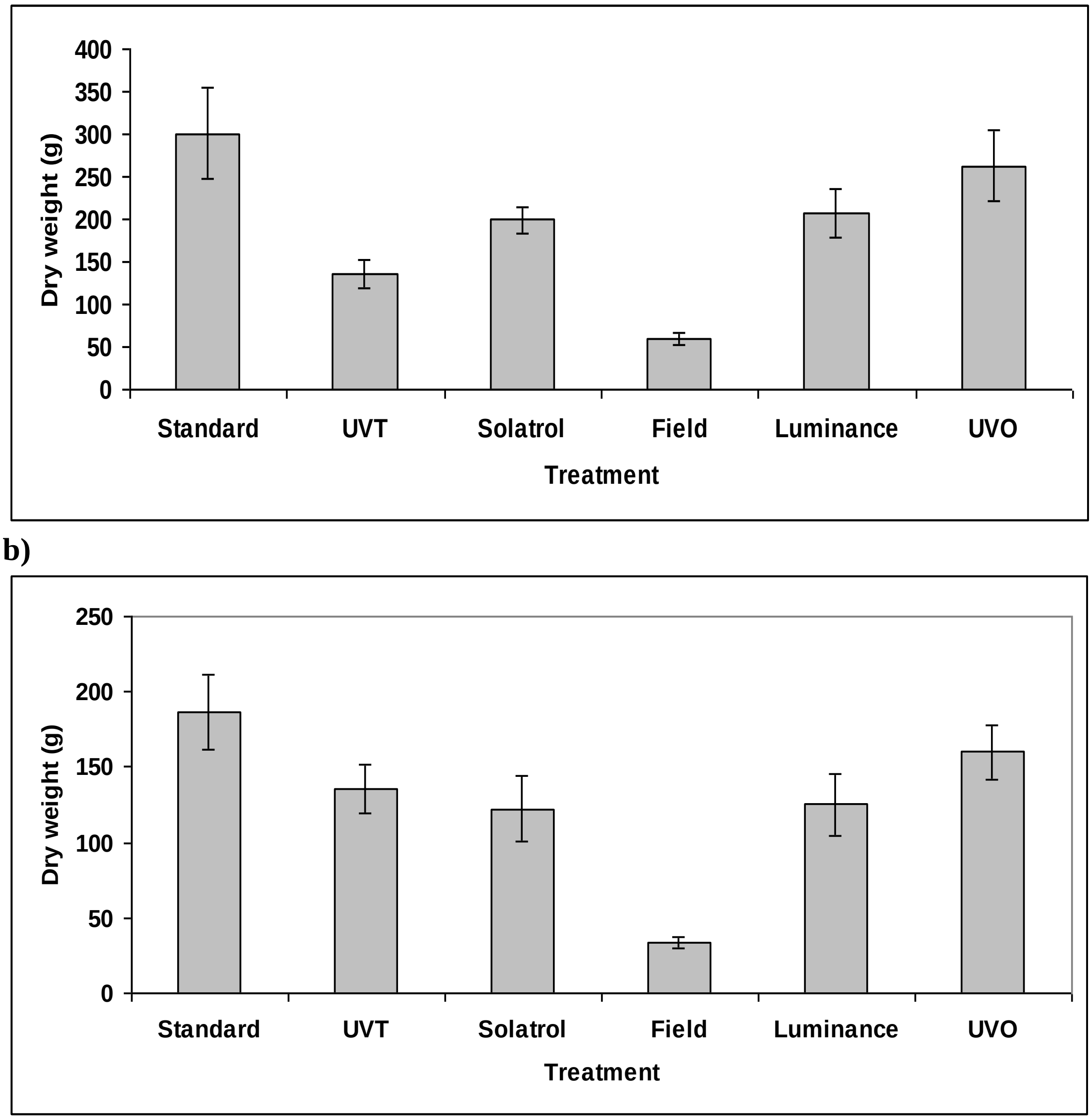


Figure 4. Effect of treatments on dry weight at harvest in (a) Peppermint and (b) Lavender. Each value is the mean + S.E. of 15 replicates.

OIL CONTENT AND YIELD

SAGE
There were no significant differences between in oil concentration in sage (Figure 5a) but differences in biomass led to substantial differences in oil yield per plant. Oil yield in the field was significantly lower than under any plastic (Figure 5b). Both UV-T and UV-O gave significantly greater yields than Solatrol or Standard, with Luminance intermediate. UV-T and UV-O gave approximately 6x higher yield than the field and 60% higher yield than standard plastic. Yield benefits from the use of plastics where similar to or greater in 2004 than 2003 and when the two year's data are combined UV-O have the highest yield (the 6x increase occurring in both years).

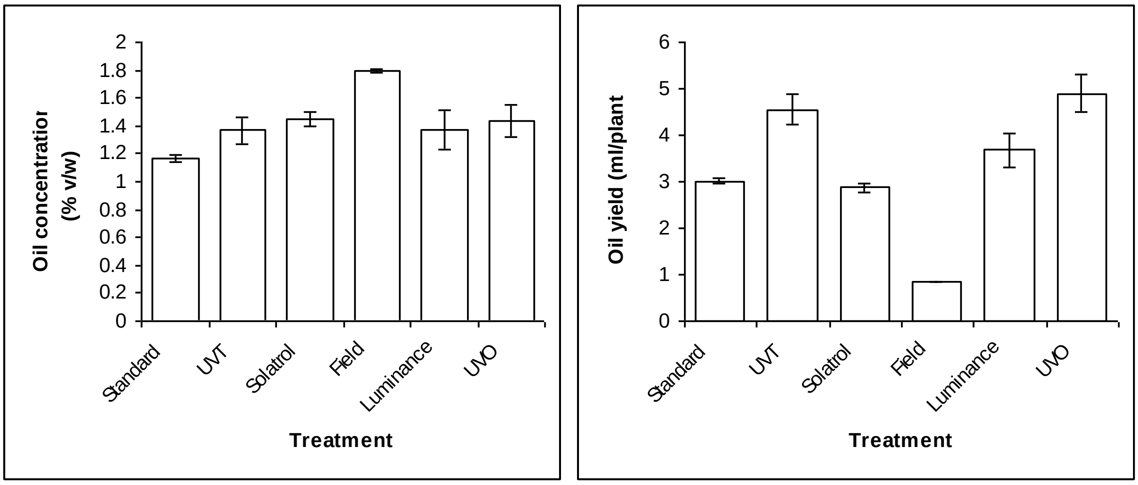


Figure 5. Effect of treatments on (a) oil concentration and (b) oil yield per plant in sage. Data are means of three replicate oil analyses ± S.E.

BLACK PEPPERMINT
As in sage, there were no significant differences between in oil concentration in peppermint (Figure 6a) but differences in biomass led to substantial differences in oil yield per plant. Oil yield in the field was significantly lower than under any plastic except UV-T (Figure 6b). Standard and UV-O gave the highest yields, and that under UV-O was significantly than all other plastics except standard. UV-O and standard gave 3-3.5x higher yield than the field. Increases in peppermint oil yield from growing under plastics were massively greater in 2004 than 2003. Averaged across all five plastics, the yield benefit in 2003 was only 4% whilst the best plastic (UV-O) increased yield by 19%. In 2004, the average increase across all plastics was 4-fold, with UV-O again the best giving almost a 6x increase. These differences between years were driven by biomass production and a key factor was the substantially lower biomass of the field grown crop in 2004. Whilst pest and disease attack was not formally quantified, it was clear that in 2004 but not 2003 the open field plots suffered so badly from rust (*Puccinia menthae*) as to cause almost complete defoliation. All the protected crops suffered little rust and were not defoliated, leading to the large biomass differences. Thus we believe that in 2004 the effect of protection on disease was the major influence on rust, while in the relative absence of rust in the 2003 season differences in biomass were primarily due to the direct effects of light quality on crop growth.

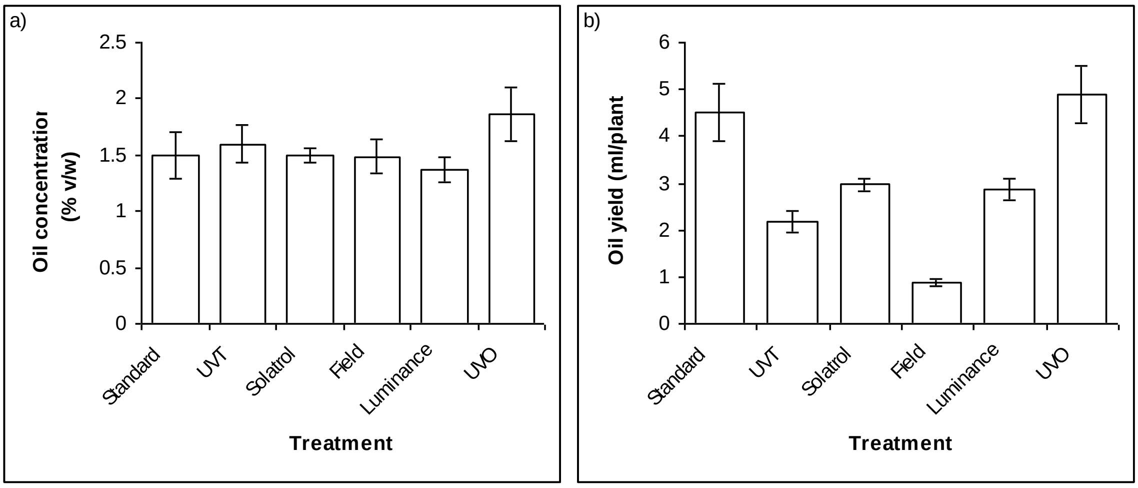


Figure 6. Effect of treatments on (a) oil concentration and (b) oil yield per plant in black peppermint. Data are means of three replicate oil analyses ± S.E.

ROSEMARY

In contrast to sage and black peppermint, in rosemary there was some effect of plastics on oil concentration, with that under solatrol being significantly higher ($p<0.05$, 40%) than that in the field: all other plastics were intermediate (Figure 7a). However, this change was small compared with differences in biomass, which led to substantial differences in oil yield per plant. All plastics tended to give higher oil yield that the field, but this was only significant for the two best plastics, UV-O and UV-T, which both increased rosemary oil yield by approximately 20x (Figure 7b). These increases in rosemary oil yield were much greater than those in 2003.

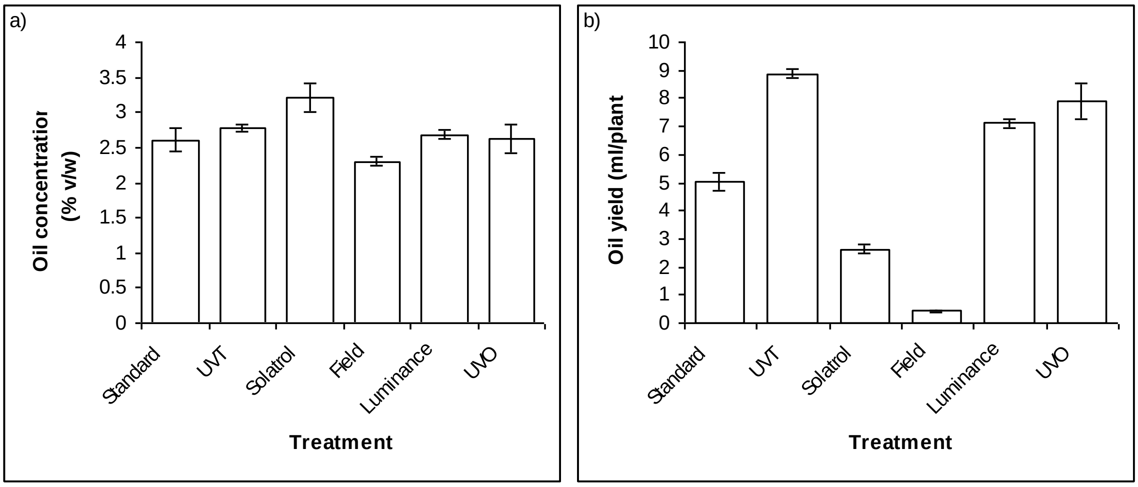


Figure 7. Effect of treatments on (a) oil concentration and (b) oil yield per plant in rosemary. Data are means of three replicate oil analyses ± S.E.

Averaged across all five plastics, the yield benefit in 2003 was only 4-fold while in 2004, the average increase across all plastics was 15-fold. This reflected how yield differed between the two seasons in the field and under plastic. In the field, rosemary yield was significantly ($p<0.01$: 60%) lower in 2004 than 2003, but under plastics yields were higher in 2004, significantly so in Luminance, UV-O and UV-T (2.3, 2.4

and 2.7x respectively, all $p<0.05$). The poorer yield of field grown rosemary in 2004 was associated with poor growth under cool, moist and cloudy conditions, and we believe that responses to plastics in 2004 were largely a function of protection from cold and wet. This may explain the rather small effect of UV-T is 2003, when direct reductions in growth cancelled out the effect of protection per se (as seemed to occur with Solatrol in both seasons). By contrast, UV-O was consistent in given good yield benefits in both years and may be preferable to UV-T on the basis of this consistency.

LAVENDER

In lavender UV-O and UV-T gave the highest oil concentrations which were significantly greater than under solatrol, standard film or in the field (Figure 8a). Increases in oil concentration under these plastics compared with the field were large (5-7 fold) although it should be noted that the yields obtained from the clone used in this experiment were rather low (K. Svoboda pers. comm.), and responses may not fully represent responses occurring in commercial clones. In addition, oil concentration in lavender was not analysed in 2003, so it is not clear whether the large response to plastics is consistent. Nonetheless, based on 2004 data lavender was unusual in that changes in oil concentration made a contribution to total oil yield greater than that of increased biomass. Taking the two factors together oil yield per plant was significantly lower in the field than in all plastics except Solatrol (Figure 8b). Oil yield appeared to be higher in UV-O and UV-T than under Standard (by around 1.8x), but this was not statistically significant (Figure 8b).

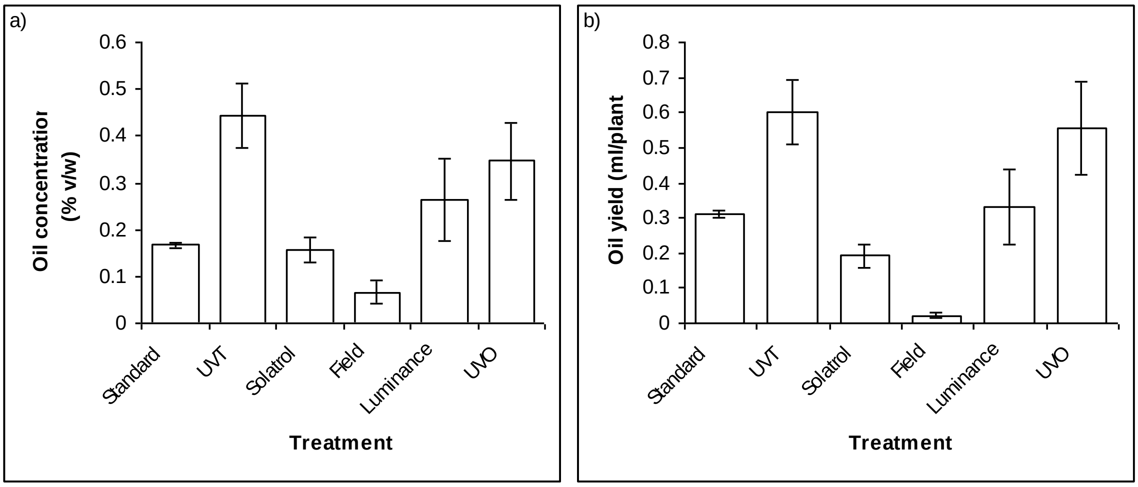


Figure 8. Effect of treatments on (a) oil concentration and (b) oil yield per plant in lavender. Data are means of three replicate oil analyses ± S.E.

THYME

Due to lack of material, it was not possible to make replicated oil analyses in thyme (Figure 9a). Based on the analyses it appeared that the only plastic that might have increased oil concentration was the standard. All other filters gave concentrations similar to that obtained in the field. However, all plastics have greater increases in yield in 2004 than 2003 due to the much greater differences in biomass (Figure 9b). Biomass under all plastics was significantly higher in 2004 than 2003 (by as much as 40% which occurred under the UV-O film) but in the field plant dry weight in 2004 was only 20% of that in 2003. This major decline in production can be attributed to the poor growing conditions in 2004, which led to much more marked effects on biomass than evident in 2003. When changes in biomass were taken in to account UV-O gave the highest oil yield approximately 18x that is the field. Luminance and UV-T also gave yield increases in excess of 10-fold, and had also bene the second and third best plastics in 2003. Despite the great differences between seasons it was noticeable that there was broad consistency in the relative effects of the different plastics across the two seasons. UV-O gave the highest yield in both years, with the yield increase over the field averaging approximately 10-fold.

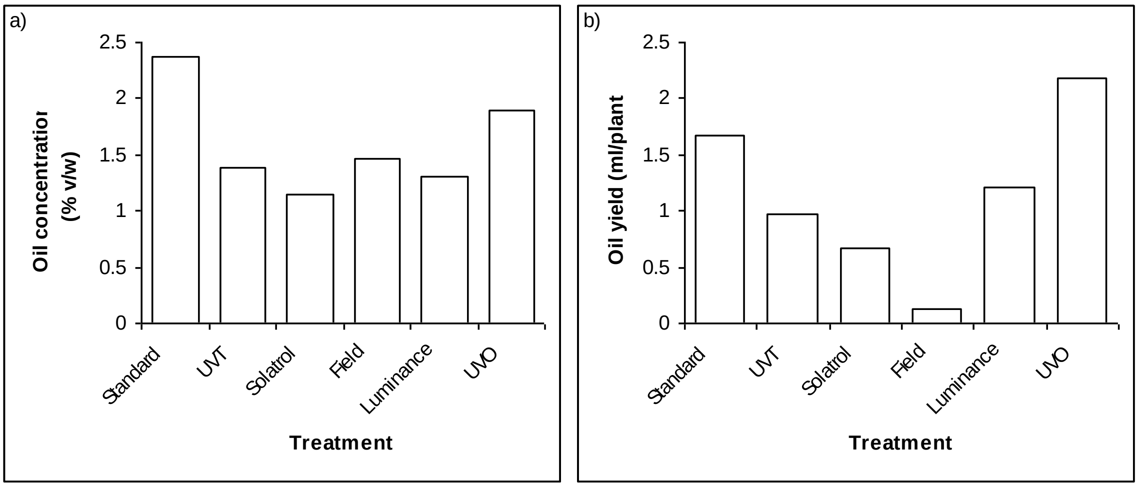


Figure 9. Effect of treatments on (a) oil concentration and (b) oil yield per plant in thyme. Data are means of three replicate oil analyses + S.E.

Discussion

The data obtained during the two years of these herb trials has shown the clear and substantial benefits of growing these herbs under protection. Across all crops and both seasons the average yield increase relative to the field was 6.9+1.0 fold. Especially in the wet, dull growing conditions of 2004, protection with almost all plastics led to significant increases in yield since crops were not exposed to cold and wet, the average increase in yield being 9.9 + 1.4 fold. Even in the good growing conditions of 2003 most plastics gave clear benefits for most crops (with the average benefit across crops being 2.7 + 0.5 fold).

There were contrasting effects of some plastics between the two seasons, especially in UV-T which performed well in 2004 but led to marked growth restrictions in 2003 which limited yields (Figure 10). Averaged across all plastics and crops the two outstanding plastics in 2004 were UV-T and UV-O. However, under the sunnier conditions of 2003, UV-O had consistently better yields and it was most often the highest yielding treatment. One this basis, UV-O seems to be a good general choice for the cultivation of these herbs for oil, with the main driver being the increase in crop biomass, which occurs without loss of oil quality or concentration (Figure 10, Table 1). There was no evidence from any crop or season that UV-O would be inferior to standard plastic i.e. there is added benefit to be gained from using a suitable spectral modification beyond that gained from simply covering the crop. At the other extreme, the strong growth limiting effect of solatrol led to consistently low oil yields, making this plastic a poor choice for growing herbs for oil (Figure 10,

Table 1). However, solatrol may be useful for pot-grown herbs where compact habit is important, and this will be one focus for the herb element of CP19 during 2005.

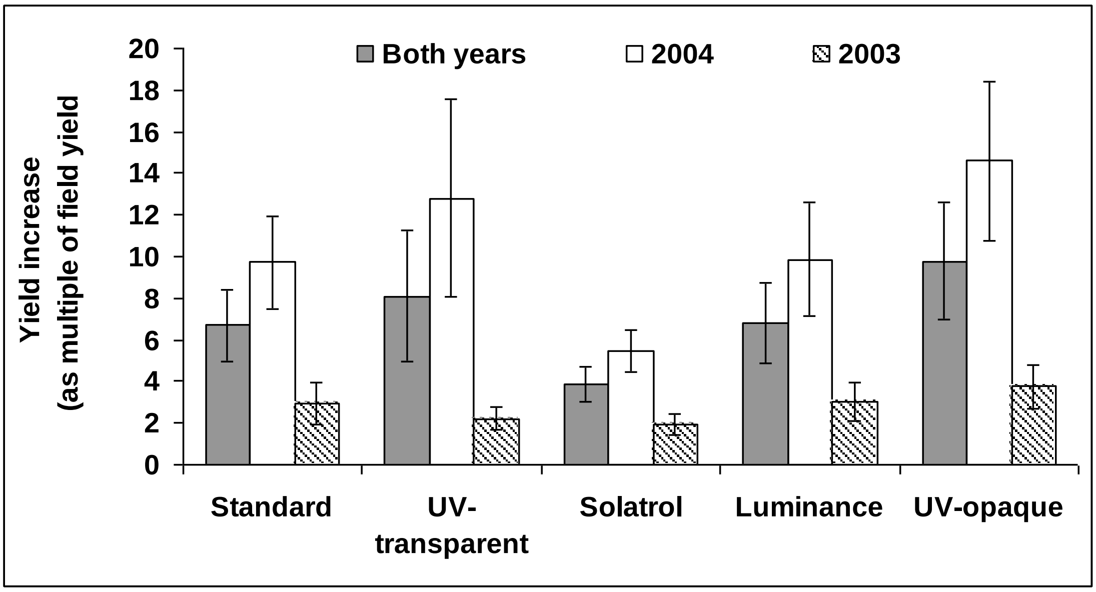


Figure 10. Effect of plastics on oil yield per plant average across crops and/or season.

Table 1 Oil yield per plant under different plastics relative to that of field-grown plants. Data for 2004 and, in brackets, 2003.

	Black peppermint	Rosemary	Sage	Thyme	Lavender
Standard	5.1 (1.2)	12.1 (6.0)	3.6 (3.2)	13.9 (1.3)	13.9
UV-transparent	2.5 (1.1)	21.2 (3.3)	5.4 (3.2)	8.1 (1.3)	26.8
Solatrol	3.38 (0.81)	6.3 (2.5)	3.4 (3.2)	5.6 (1.1)	8.6
Luminance	3.25 (0.93)	17.0 (3.8)	4.3 (5.5)	10.1 (1.9)	14.7
UV-opaque	5.56 (1.19)	18.8 (5.1)	5.8 (6.4)	18.1 (2.3)	24.7

CP19: Horticultural crops:
Further demonstration of the potential benefits of modified plastic crop covers

Asparagus

Part 8. Asparagus

Introduction

The retail value of asparagus in the UK is approximately £50 million per annum. 35% of this is home grown, being produced in a short season, lasting a maximum of ten weeks and often less. In 2004 during the UK season (April, May, June), the value of imports was £2 ½ million.

As with most fresh produce, the multiples are now marketing a high percentage of the crop, making it available to a larger customer base. Additionally a solid PR campaign in 2004 has achieved increased market penetration and annual, per capita, consumption is now 120gm in the UK. There are currently 1000Ha of asparagus production in the UK being grown by some 200 businesses using production systems that have changed little for many years. In an expanding market place, the industry needs to understand whether cost effective, cultural techniques, can improve yield, quality and therefore return. Therefore the inclusion of asparagus in the project being undertaken at Stockbridge House, evaluating the technical and economic benefits of modified plastic crop covers, is an opportune one.

The project will investigate which, if any, of the spectral filters could assist in:

- Accelerating the plants establishment in its early, non-productive, years. Specifically, can the time taken to achieve its critical root mass, currently accepted as five years, be reduced significantly?
- Giving season extension/yield improvement with particular focus on improved percentage class 1.
- Showing reduced period of carbohydrate recharge in the fern phase.
- The reduction of disease in the fern phase offered by the improved environment.

While preliminary results are reported here from the first season, the productive stage of the crop begins in the third year and so what follows are preliminary data and should be treated as such.

Results

JERSEY GIANT

There was no effect of treatments on the number of spears produced (fig. 1.a). Solatrol did increase plant height when compared to all treatments and Field plant height was reduced relative to Standard, Solatrol Luminance and UV-opaque (fig. 1.b). Spear length was significantly increased in Standard and UV-transparent when compared to Luminance and UV-opaque only (fig. 1.c). The only measurable effect on spear thickness at the base was an increase in UV-transparent relative to UV-opaque and Field plants (fig. 2.a) and at the tip a reduction in Field when compared to all filter treatments except UV-opaque (fig. 2.b). In an approximate determination of biomass (we were unable to harvest at this stage) we measured the circumference of the vegetative tissue at the widest point, which showed an increase in UV-opaque relative to UV-transparent and Field (fig. 2.c). In Field plants the circumference of vegetative biomass was reduced when compared to all filter treatments (fig. 2.c).

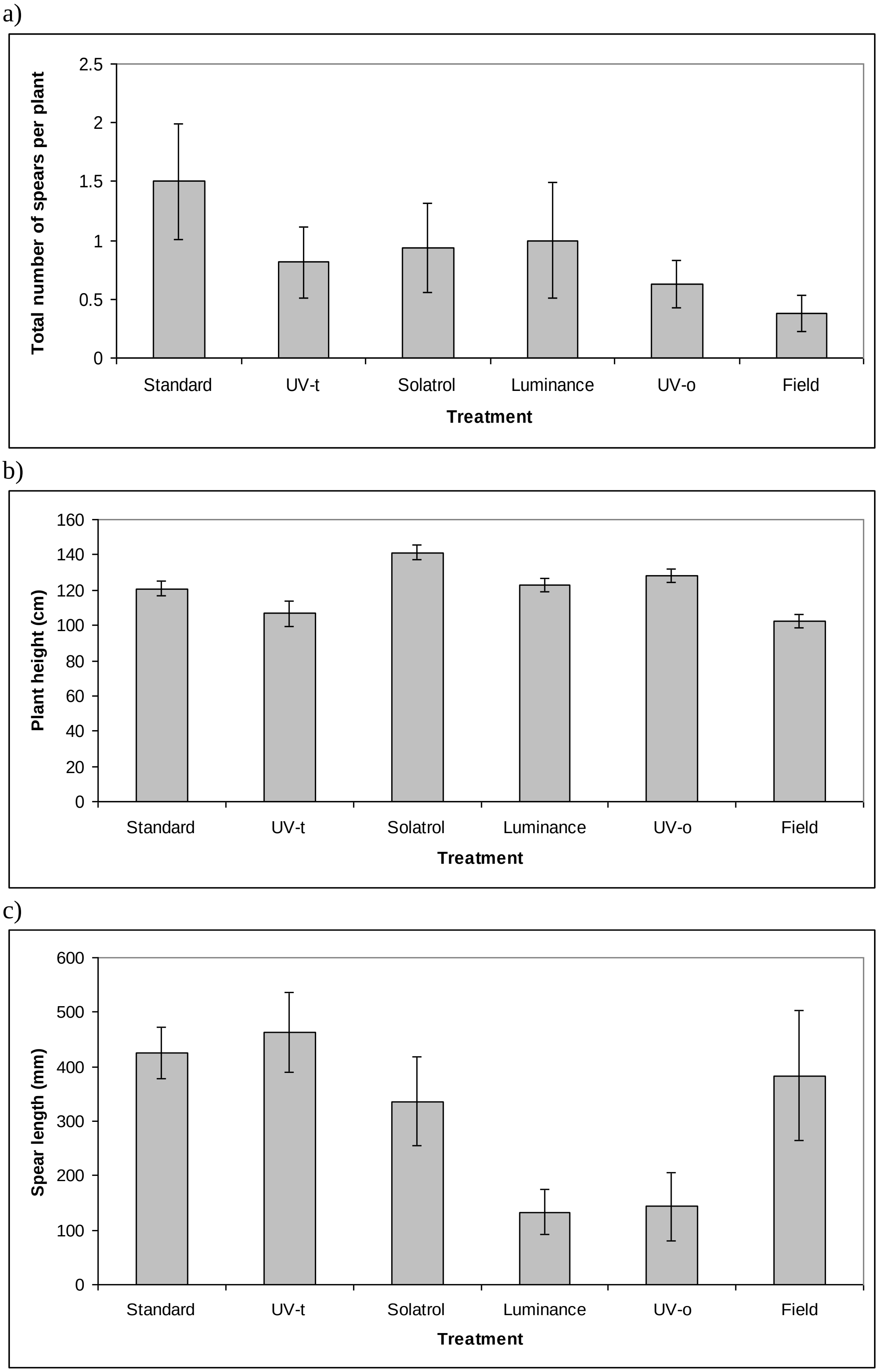
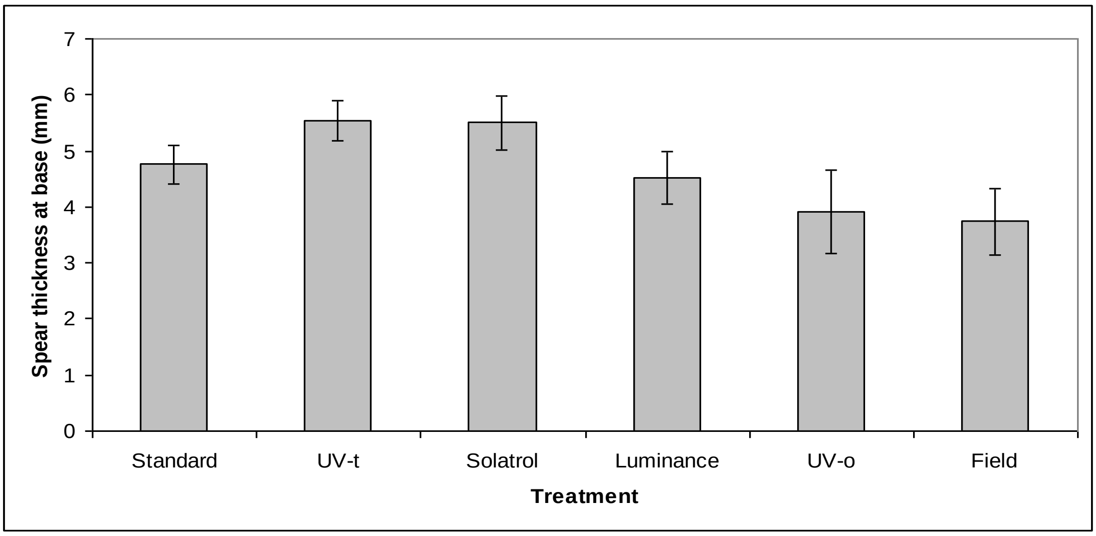


Figure 1. Effect of treatments on (a) total number of spears per plant (b) plant height and (c) spear length in Asparagus. Each value is the mean $\geq$ S.E. of 16 replicates.

a)



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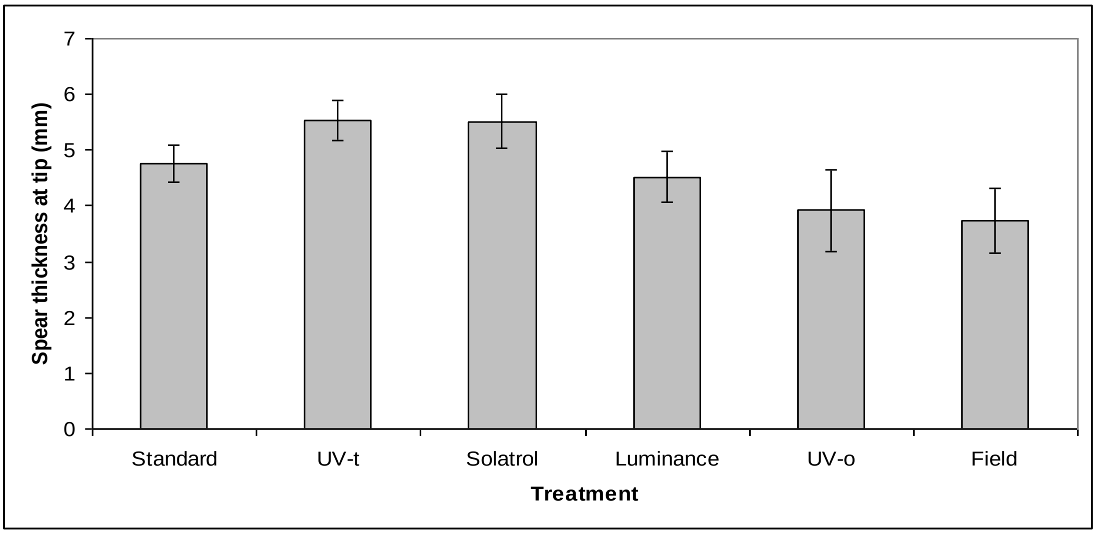

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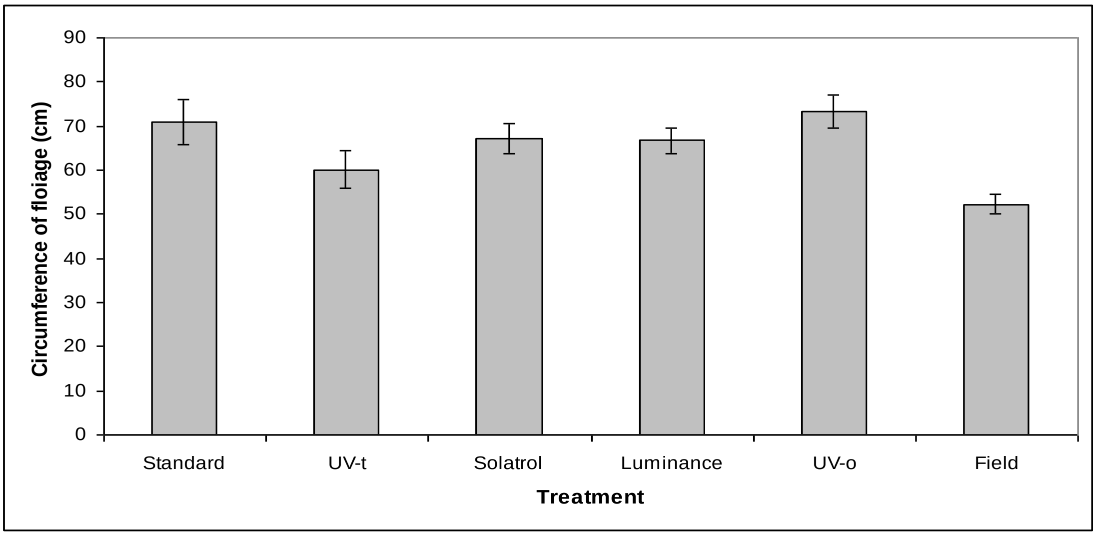
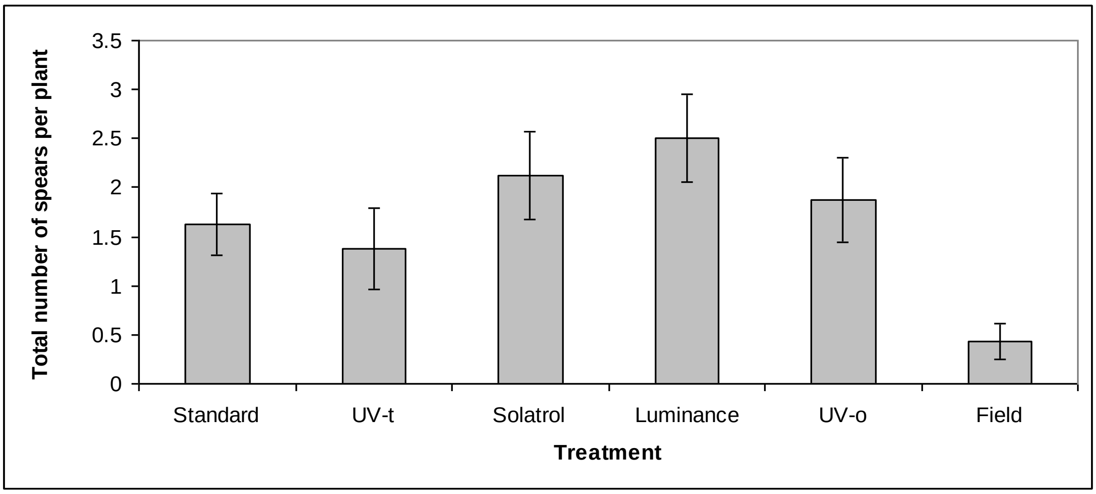


Figure 2. Effect of treatments on (a) spear thickness at the base (b) spear thickness at the tip and (c) circumference of foliage in Asparagus. Each value is the mean $\geq$ S.E. of 16 replicates.

The total number of spears produced was significantly reduced in Field plants when compared to Standard, Solatrol, Luminance and UV-opaque, although there was no effect relative to UV-transparent (fig. 3.a). Plant height was significantly increased in Solatrol when compared to all treatments (fig. 3.b). Spear length was significantly increased in UV-opaque and Field relative to Standard, UV-transparent, Solatrol and Luminance (fig. 4.a). There was no significant effect of treatments on spear thickness at the base (fig. 4.b) or tip (fig. 4.c). In an identical analysis to that used in Jersey Giant results show a significant increase in vegetative biomass in UV-opaque when compared to Standard, UV-transparent and Field only (fig. 5).

a)



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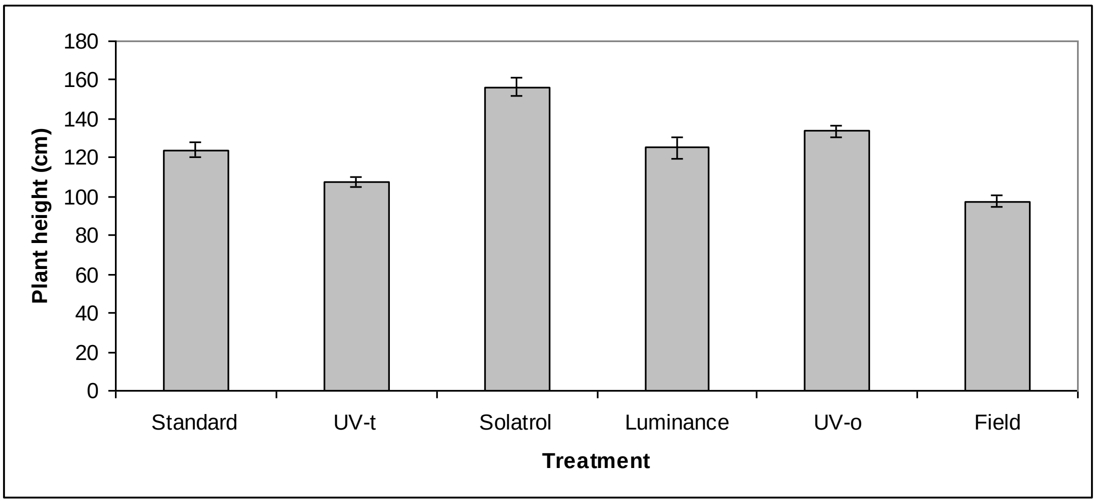
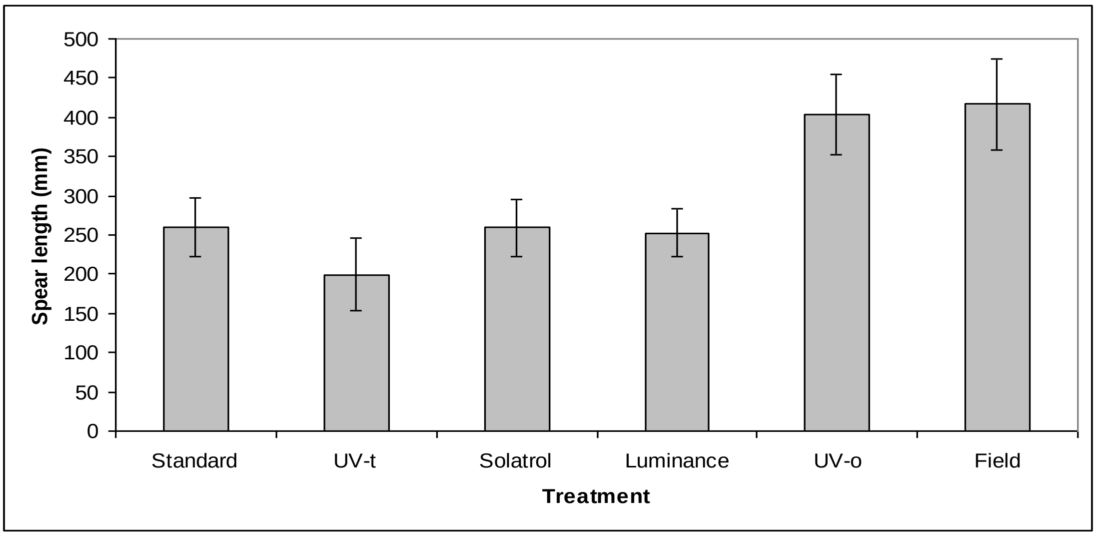
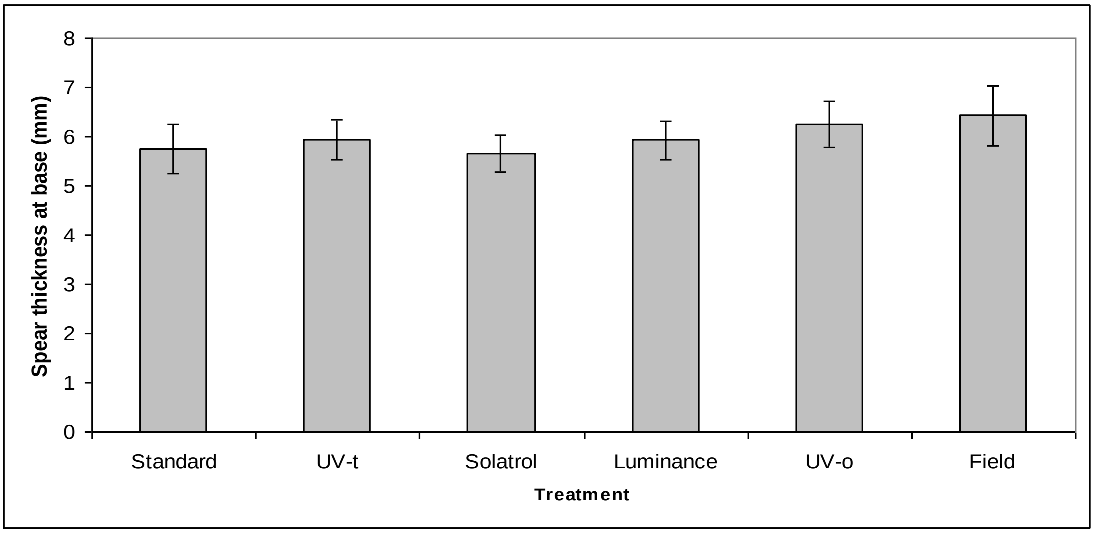


Figure 3. Effect of treatments on (a) total number of spears per plant and (b) plant height in Asparagus. Each value is the mean $\geq$ S.E. of 16 replicates.

a)



b)



c)

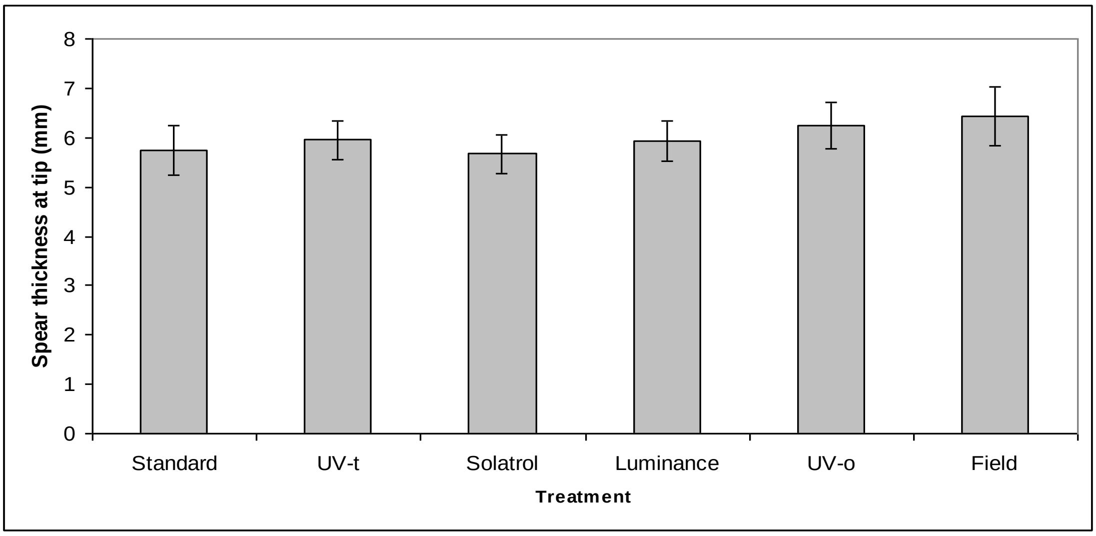


Figure 4. Effect of treatments on (a) spear length (b) spear thickness at base and (c) spear thickness at tip in Asparagus. Each value is the mean $\geq$ S.E. of 16 replicates.

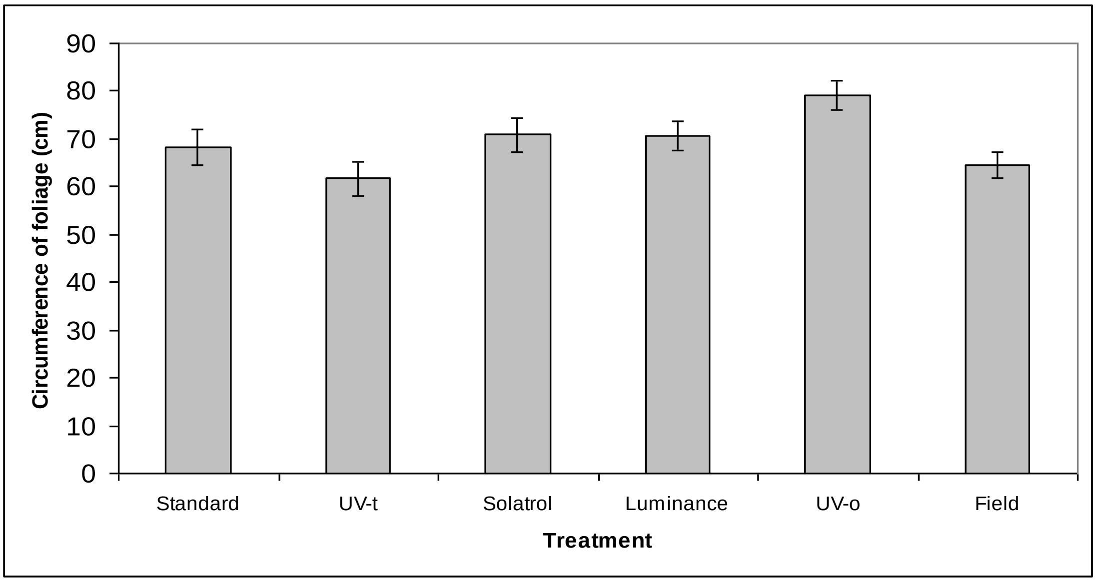


Figure 5. Effect of treatments on circumference of foliage in Asparagus. Each value is the mean ≥ S.E. of 16 replicates.

Discussion

The purpose of the first year's trial was to first establish the crop and then to monitor the development of subsequent plant biomass, paying particular attention to the filters ability to accelerate plant establishment and susceptibility to pests and disease. Interim results and visual observations made during the first years study suggest that both varieties of Asparagus respond very quickly to filter treatments (see figs 6 -11 below). Solatrol significantly increases plant height in both Jersey Giant (fig. 1.b) and Gymly (fig. 3.b) and there would appear to be a tendency for the UV opaque filter to increase total biomass (figs. 2.c., 5 & 11), although these results cannot the confirmed without destructive harvests.

Of particular interest in the second year will be assessment of the five spectral filters ability to extend the growing season and reduce the incidence of pest and disease.

Figure 6. Photo taken under Standard in early September 0f 2004.

Figure 7. Photo taken under UV-transparent in early September of 2004.


Figure 8. Photo taken under Solatrol in early September of 2004.


Figure 9. Photo taken in Field in early September of 2004.

Figure 10. Photo taken under Luminance in early September of 2004.

Figure 11. Photo taken under UV-opaque in early September of 2004.