Project Title:	To develop proven protocol and methodology for reducing production times for woody species
Project Number:	HNS 124
Project leader:	Dr Neil Hipps, East Malling Research
Report:	Final report, Year 3, June 2007
Previous reports:	Annual report, Year 2, July 2006
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Date project commenced:	1 July 2004
Date completion due:	31 July 2007
Key words:	Warmth, cool, day length extension, supplementary lighting, growth, production protocols, hardy nursery stock, scheduling, *Aucuba japonica, Azalea japonica, Camellia japonica, Choisya ternata, Convolvulus cneorum, Cytisus scoparius, Hydrangea macrophylla, Osmanthus heterophyllus, Pittosporum tenuifolium, Photinia fraseri, Viburnum tinus*

Disclaimer

The results and conclusions in this report are based on an investigation conducted over 3 years. The conditions under which the experiment was carried out and the results obtained 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 interpretation of the results, especially if they are used as the basis for commercial product recommendations.

AUTHENTICATION

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

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Grower Summary

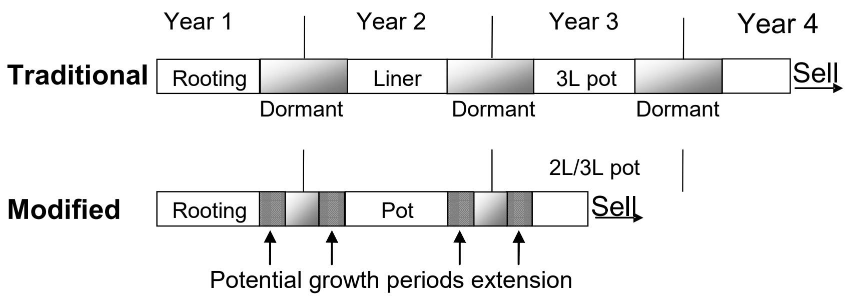
Headline

- Use of early spring warmth allows one year to be removed from the production cycle of Hardy Nursery Stock species and saleable quality to be achieved within 12-18 months of propagation.

Background and expected deliverables

The main aim of this project was to use techniques to schedule Hardy Nursery Stock (HNS) species (including elevated growing temperature and supplementary lighting) to increase the rate of plant development and reduce the time taken to produce a standard perennial plant by one whole year (Figure A).

Figure A: Traditional timescale for producing a 3 litre HNS plant *versus* modified schedule that takes a year out of production



Specific objectives were:

1. To screen a range of HNS species to determine their growth response to scheduling techniques in autumn and spring.

2. To demonstrate the techniques used in reducing the production times of woody species.

3. To verify that plants generated from shortened production times have the same quality by the point of sale as traditionally produced plants.

The methods employed to manipulate growth were established for a range of herbaceous species in HDC Project HNS 103, and include the use of photoperiodic extension and supplementary light. Building on the results of the first two years of this project which established the responses of growing temperatures, supplementary lighting and the importance of regular pruning on a range of HNS species, the techniques were applied to a range of different species as cuttings (Table A), to hasten growth in the production cycle and maintain plant quality.

During 2006/7, a second experiment using liners distinguished between the effects of spring and autumn application of warm conditions on plant growth and quality.

Summary of the project and main conclusions

The experiments used the following environmental conditions:

Cool environment (Heat set point 5°C, vent 8°C, fan vent 10°C)

1. Ambient daylight
2. Supplementary (SONT) light 8 h during natural daylight hours (to improve light quality)
3. Tungsten (photoperiod) light to give day length extension, greater than or equal to 15 h
4. Supplementary (SONT) light, 8 h during natural day light hours and tungsten light to give day length extension, greater than or equal to 15 h

Warm environment (Heat set point 15°C, vent 18°C, fan vent 20°C)

5. Ambient daylight
6. Supplementary (SONT) light, 8 h during natural daylight hours (to improve light quality)
7. Tungsten (photoperiod) light to give day length extension, greater than or equal to 15 h

8. Supplementary (SONT) light, 8 h during natural daylight hours and tungsten light to give day length extension, greater than or equal to 15 h

Full production cycle using rooted cuttings

Rooted cuttings of *Aucuba japonica, Choisya ternata, Cytisus scoparius, Hydrangea macrophylla, Osmanthus heterophyllus*, and *Pittosporum tenuifolium* that had been propagated during autumn 2005 were potted into 2 litre pots and placed into the different experimental environments on 17 February 2006. Those of *Camellia japonica* and *Photinia fraseri* were placed into the experimental environments on 16 March 2006. The environmental treatments were switched off on 2 May 2006. Increasing temperature from 5°C to 15°C benefited the initial growth of all the species (except *Camellia japonica*) and in May they were larger in the warm conditions. Day length extension light also benefited *Aucuba japonica*, *Cytisus scoparius*, *Hydrangea macrophylla* and *Pittosporum tenuifolium* plants.

Subsequently, the plants were maintained in a cool glasshouse receiving only natural day light, and a commercial pruning regime applied only as required. By September 2006 most of the size differences caused by the environmental treatments had disappeared. However, the *Choisya ternata*, *Cytisus scoparius*, *Hydrangea macrophyllus* and *Pittosporum tenuifolium* had achieved sufficient size that no further season extension was considered necessary. Thus, the combination of the acceleration of early growth in the spring by maintaining temperature above 5°C alone and use of 2 litre pots had removed more than a year from the production cycle for these species.

Following either cool or warm environmental treatments in autumn (5 September – 1 December 2006) and early spring (5 February – 4 May 2007), the *Photinia fraseri* and the *Aucuba japonica* achieved saleable size by May 2007, a year earlier than that achieved with a standard cutting – liner – shrub production cycle. The *Camellia japonica* and *Osmanthus heterophyllus* plants remained too small for sale.

Following the full production cycle (summer 2005 - April 2007), the growth of the experimental plants was compared with those of rooted cuttings of similar age grown as liners in a commercial nursery. This confirmed that the plants that had been maintained at 5°C with no supplementary light or day length extension treatments were substantially larger than those of the same age produced ‘traditionally’ (Table B). The only exception was for the *Osmanthus heterophyllus* which had grown better in the commercial nursery.

A second experiment separated the effects on plant growth caused by the application of warmth in spring and/or autumn. Species were chosen that were known to have potential to respond to either autumn or spring warmth. The control treatment was an unheated polytunnel. The results suggested that for the three species investigated (*Azalea japonica*, *Convolvulus cneorum*, and *Viburnum tinus*), application of early spring warmth (February – May) had a much greater benefit in increasing growth than application in the previous autumn (September – November).

Table A The cumulative effects of temperature, day length extension and supplementary light treatments applied to rooted cuttings (propagated in autumn 2005 and potted in winter 2006) during a full production cycle. (Warmth response of plants to raising temperature from 5°C to 15°C)

Propagated Sept/Oct 2005	**Spring 2006**			**Autumn 2006**			**Spring 2007**			**Saleable size**
	Warmth	**Day length extension light**	**Supple-mentary light**	**Warmth**	**Day length extension light**	**Supple-mentary light**	**Warmth**	**Day length extension light**	**Supple-mentary light**	
Aucuba japonica 'Goldstrike'	+ ✓	+	+	0	0	0	+ ✓	+	0	April 2007
Camellia japonica 'Guilio Nuccio'	0	0	0	0	+	0	0	0	0	Not achieved
Choisya ternata	+ ✓	0	0	Treatments not required						Sept 2006
Cytisus scoparius 'Burkwoodii'	+ ✓	+	0	Treatments not required						Sept 2006
**Hydrangea macrophylla* 'King George'	+	+	0	Treatments not required						Sept 2006
Osmanthus heterophyllus 'Goshiki'	+	0	0	+	0	0	✓	0	0	Not achieved
Photina x fraseri 'Red Robin'	+	0	0	0	0	0	-	0	0	April 2007
Pittosporum tenuifolium 'Goldstar'	+ ✓	+	0	Treatments not required						Sept 2006

Key: + = Positive response, - negative response
0 = No response
✓ = Number of shoots per plant increased,
* = Propagated July 2005

Table B The increase in plant growth (%) caused by maintaining a minimum temperature of 5° C to rooted cuttings (propagated in autumn 2005, potted in winter 2006 and assessed in May 2007) compared to similar plants maintained under unheated glass in a commercial nursery during the same period

	Period of heat application[1]	Height	Breadth	No. of new shoots per plant
Aucuba japonica 'Goldstrike'	S06 A06 S07	44	73	100
Camellia japonica 'Guilio Nuccio'	S06 A06 S07	46	58	50
Choisya ternata	S06	156	135	117
Cytisus scoparius 'Burkwoodii'	S06	65	88	202
**Hydrangea macrophylla* 'King George'	S06	13	52	233
Osmanthus heterophyllus 'Goshiki'	S06 A06 S06	-10	9	-21
Photina fraseri 'Red Robin'	S06 A06 S06	67	111	60
Pittosporum tenuifolium 'Goldstar'	S06	100	86	238

[1]S06 spring 2006, A06 autumn 2006, S07 spring 2007

Main conclusions

- There is considerable scope for reducing the production time for woody species
- The most consistent factor is the application of warmth to accelerate growth during the early growth phase in the spring following propagation from cuttings
- For some species, a combination of using a 2 litre pot and maintaining temperature above 5°C is sufficient to substantially accelerate growth within 12 months of propagation from cuttings
- Supplementary light was of no benefit in accelerating plant growth or improving plant quality
- Day length extension light may be appropriate for use on some species, particularly as it is a cheap method for improving shoot extension

Financial benefits

Determining the true financial benefit of the treatments has proved difficult as we have been unable to determine the actual industry costs of production per plant for individual species. Thus, it was not possible to determine the financial benefit of reducing production time, including higher through puts, changes in labour requirements, etc.

However, the additional energy costs of the treatments used in our experiments over a full production cycle have been quantified.

- The energy cost of using supplementary lights would add £37k/ha (for use over one spring) or £123 k/ha (for use over spring, autumn and another spring)

- Day length extension light energy costs would add £1-7.6k/ha on the same basis

- The energy costs alone of maintaining a glasshouse above 5ºC for 36 weeks (i.e. for the three periods described above) would cost £10-13k/ha, depending on fuel source and weather conditions, whereas maintaining it at 15ºC for this period of time would cost £87-111k/ha

- For the species that only required maintaining above 5°C for one spring, the energy costs would be £4-5k/ha. This is equivalent to 2p per plant at 25 pots/m^2

Action points for growers

- A year can be removed from the production cycle of certain HNS species by potting rooted cuttings into 2 litre pots and maintaining air temperatures above 5ºC from February to May.

- As not all the tested species respond to these conditions, it is not possible to predict the response of untested species, so it is important for growers to check the responses of species not covering in this and earlier projects reports on a small scale.

- Use of day length extension light may be justified under some circumstances particularly where heat is not available.

- Use of supplementary light to accelerate growth is unlikely to be effective or financially viable.

Science Section

Introduction

The rate of plant growth and development and the initiation and expression of flowers are influenced by environmental factors such as day length (photoperiod), light intensity, temperature and availability of water and nutrients.

Many species are influenced by the length of day over which light is received. The effects of light in determining growth are referred to as photoperiodic effects. For perennial plants these responses mainly concern bud dormancy, shoot extension and production of flowers and seeds.

Generally, long days (LD) promote elongation of stems and suppress branching of most species, and rarely cause flowering (which terminates shoot extension). Plants that do flower in response to long days usually do so by ‘bolting’, i.e. rapid stem elongation. Buds of woody plants break dormancy in spring in response to low temperatures of winter combined with long days extending photoperiod. Sometimes, long days promote bud break even without low temperatures, e.g. birch.

Short days (SD) lead to changes associated with autumn, i.e. reduced stem elongation, reduced chlorophyll production, increased formation of other pigments, terminal bud set, leaf abscission, dormancy and development of low temperature acclimation.

Generally, plants that grow at latitudes far away from the equator respond in different ways to longer days than those growing nearer the equator. So it is not surprising that temperate zone plants are often influenced by the short days (SD) of autumn, typically the SD response is strongly modified by temperature. However, different ecotypes of the same species may have different responses to day length. Most studies of photoperiodism have concentrated on only the flowering effects rather than the effects on vegetative growth.

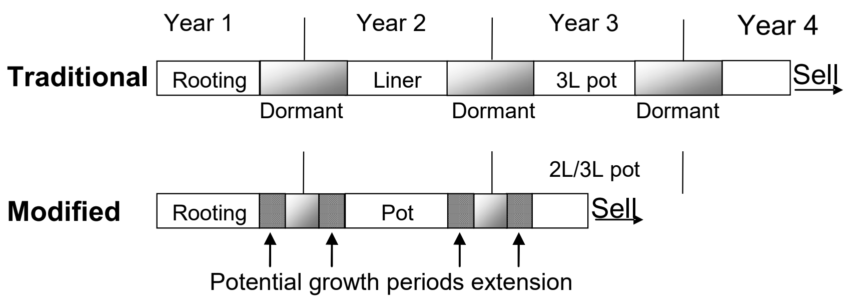
Manipulation of day length is commonly used by protected crop growers to schedule flowering out of season. Much previous scientific work has been directed at understanding of flowering and scheduling of plants. The largest screening programme of flowering responses was undertaken by Michigan State University, but the techniques have not been adopted in the UK. This led to an HDC-funded explanation and review of techniques for the scheduling flowering of hardy herbaceous perennials (HNS 103).

Practical applications from the HNS 103 review have been tested for herbaceous perennials (HNS 103a), which have demonstrated a practical method for growers to adopt screening techniques on their own nurseries, as well as enabling several species to be classified for their flowering responses. It showed also that the most cost-effective method for scheduling flowering for many species was using simple day length extension.

Other projects have shown the potential for using alternative scheduling techniques. HNS 65/65a demonstrated the value of cold storage and pruning for roses. HNS 69 demonstrated how the ‘designer liner’ concept using pre-branched and apical cuttings, optimising nutrition, chilling and single pruning operations could be used to improve quality and grade out of material. It also demonstrated reduced production time for several species.

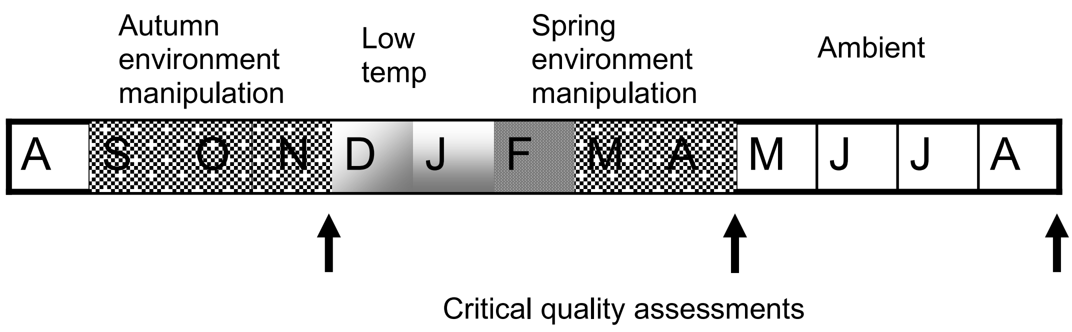
Therefore, important opportunity exists to shorten the production time of woody perennials using the scheduling techniques and facilities now available under glass. Currently, from a cutting being struck to the sale of a finished plant in a 3 litre pot can take up to 4 years (Figure A). This uses nursery space as well as labour in maintaining the crop through irrigation, grading and pruning. Thus, speeding up this process could reduce costs per unit of production whilst increasing throughput.

Figure A Traditional timescale for producing a 3 litre HNS plant *versus* modified schedule that takes a year out of production



If scheduling techniques could be used to reduce the dormant phases of production by forcing plants into shortened winters and early springs (Figures A and B) there is potential that sufficient time could be removed to sell the same plant in Year 3 rather than Year 4. However, the plant must be ready for sale one full year earlier, as a saleable plant 6 months early will miss the key UK marketing dates. A precedent for dramatically shortening production times has been demonstrated by faster propagation of broadleaf forest seedlings. Quality, uniform tree seedlings could be raised in modules under protection in one year rather than up to three years in the field.

Figure B Periods for the application of growing season extension



The commercial objective of this project was to use scheduling techniques for woody HNS species to attempt to remove a year from the production of a standard plant in a 2/3 litre container.

Overall aim of the project

To use the techniques for scheduling HNS species to attempt to remove a year from the production of a standard 3 litre woody plant.

Specific objectives:

1. To screen a range of HNS species to determine growth response to scheduling techniques in autumn and spring.

2. To demonstrate the techniques of reducing the production times of woody species.
3. To verify that plants from shortened production times have the same quality at marketing as traditionally produced products.

The methods employed to manipulate growth focus on the environmental techniques highlighted in HNS 103, and include the use of day length extension light, supplementary light and heat.

Summary of results from Year 1

In the first year of this project, 21 different species of hardy nursery stock were screened (see annual report for Year 1 – 2005). A wide variation in species response to different light and heat treatments occurred. Increasing temperature had the most consistent effect on increasing plant size. Eight species showed a positive growth response to increased temperature applied in the autumn, but this increased to 19 species when warmth was applied in the spring as well. Plants that responded to warm autumns also responded to warm in springs. Day length extension light applied in autumn increased plant size for eight species and in spring for twelve species out of the 21 tested. However, species that responded in autumn were not necessarily the same species that responded in spring. Supplementary light increased plant size of only four species in autumn and one species in spring.

Summary of results from Year 2

An experiment using liners of *Choisya ternata*, *Hydrangea macrophylla*, *Photinia fraseri* and *Viburnum tinus* indicated that the combination of judicious pruning in autumn in combination with warmth in autumn and/or spring improved plant visual quality (architecture) in spring of all the species except *Choisya ternata*. Supplementart light was beneficial for *Photinia fraseri* and *Viburnum tinus.*

In another experiment the impact of different periods of winter chilling on plant growth was determined. The effects of 0, 15, 30 and 45 days of cold storage at 2°C on the growth *Hydrangea macrophylla* and *Photinia fraseri* was compared with plants kept at >5^0C.

Surprisingly, the different periods of winter chilling had no impact on the growth of either species.

The full production cycle experiment using rooted cuttings was started in Year 2 and full details are given in this report.

Table B Species used in the full production cycle from cuttings experiment (C), and autumn *versus* spring warmth (AS) experiments in 2006/7

	Evergreen	***Display***
C	*Aucuba japonica* 'Goldstrike'	foliage (spring flower)
AS	*Azalea japonica*'Santa maria'	
C	*Camellia japonica* 'Guilio Nuccio'	spring flower
C	*Choisya ternata*	late spring flower
AS	*Convolvulus cneorum*	summer
C	*Cytisus scoparius* 'Burkwoodii'	summer flower
	Osmanthus heterophyllus 'Goshiki'	late summer flower
C	*Photinia fraseri* 'Red robin'	winter foliage
C	*Pittosporum tenuifolium* 'Gold star'	foliage (spring flower)
AS	*Viburnum tinus* 'French White' EM27	winter flower
	Deciduous	
C	*Hydrangea macrophylla*'King George'	summer flower

Materials and methods

An experiment took place in four compartments in Glasshouse C at East Malling Research. These compartments have full temperature control (vents and fans) and high pressure sodium (SONT) lighting. Each compartment contained two benches 0.8 m height, 1.2 m depth, 7.5 m length.

Each 8 × 3.2 m compartment was divided into two sections longitudinally (N-S direction) down the middle by the use of white reflective non-translucent plastic (mushroom tunnel) sheeting hung from above the lighting. This allowed the creation of eight environments (i.e. one per bench) which were as follows:

Cool (C) glasshouse (heat set point 5°C, vent 8°C, fan vent 10°C)

1. Ambient daylight (AL)
2. Supplementary (SONT) light 8 h during natural daylight hours (SL)
3. Tungsten (photoperiod) light to give day length extension $\geq$ 15 h (DL)
4. Supplementary (SONT) light 8 h during natural daylight hours and tungsten light to give day length extension $\geq$ 15 h (SL + DL)

Warm (W) glasshouse (heat set point 15°C, vent 18°C, fan vent 20°C)

5. Ambient day light (AL)
6. Supplementary (SONT) light 8 h during natural daylight hours (SL)
7. Tungsten (photoperiod) light to give day lengthening $\geq$ 15 h (DL)
8. Supplementary (SONT) light 8 h during natural daylight hours and tungsten light to give day length extension $\geq$ 15 h (SL + DL)

The photoperiod lighting was provided by 60 W tungsten spot lights. Sunrise and sunset times for Maidstone (http://www.onelineweather.com/v4/uk/sun/Maidstone.html) were used to calculate day length. Lights were activated using a time switch to extend the day to 15.5 h continuously from predawn. The time switch was adjusted on Monday each week based on the shortest day in that week, i.e. at the end of the week in autumn and at the beginning of the week in spring.

The supplementary lighting was provided by five SONTs per bench providing 20,000 mW per m^2 (i.e. 9000 lux).

Experiment 3 - Full production cycle

Eight species (Table A) were chosen for the cuttings experiment following consultation and agreement with the grower co-ordinators. These were chosen on the basis of their economic value and their potential to be influenced by manipulation of environmental conditions determined from the results of Experiment 1 carried out in Year 1.

Rooted cuttings of *Aucuba japonica, Choisya ternata, Cytisus scoparius, Hydrangea macrophylla, Osmanthus heterophyllus*, and *Pittosporum tenuifolium* were supplied by New Place Nurseries Ltd, on 15 February 2006. They were potted into 2 litre containers using compost supplied by New Place Nurseries on the 16 February 2006 and placed into the experimental compartments on 17 February 2006. Rooted cuttings of *Photinia fraseri* and *Camellia japonica* were collected from New Place Nurseries on 14 March 2006 and potted on into 2 litre pots on the 15 March 2006 and placed into the experimental compartments on 16 March 2006. For each species, each environmental treatment (glasshouse compartment) had twelve plants, the plants were arranged in two blocks in N–S direction, thus each block contained six pots of each species arranged E-W. Ericaceous compost supplied by New Place Nurseries was used for the *Camellias*. The lighting and supplementary heating were switched off on 2 May 2006, but the plants were maintained in the cool glasshouse in natural daylight.

On 31 August 2006 the plants were transferred into their respective glasshouse compartments, so that previous treatments could be continued. However, the pots were spaced further apart to allow more growth. Thus, the plants were arranged in three blocks in N–S direction, each block contained four pots of each species arranged E-W. On 5 September 2006 the cool (set point 5^0C) and warm (set point 15°C) and different light (SL and DL) environment conditions were re-established.

On the advice of the project grower co-ordinators, due to sufficient growth to saleable size, all of the *Pittosporum tenuifolium*, *Cytisus scoparius* and *Choisya ternata* plants were removed from the chambers on 3 October 2006 and placed into a glasshouse maintained above 5ºC. The *Hydrangea macrophylla* plants were placed into an unheated polytunnel at the same time. The remaining plants (*Photinia fraseri*, *Osmanthus heterophyllus*, *Camellia japonica* and *Aucuba japonica*) continued to receive the lighting and temperature treatments until 1 December 2006. Subsequently these plants and the *Pittosporum tenuifolium*, *Cytisus scoparius* and *Choisya ternata* were moved into an unheated polytunnel on 15 December 2006. The *Photinia × fraseri*, *Osmanthus heterophyllus*, *Camellia japonica* and *Aucuba japonica* plants were placed back into their original environmental conditions (i.e. treatments 1 … 8 respectively) on 5 February 2007. The heating and lights were switched off on 4 May 2007. The experiment used a total of 672 plants.

Between May and September 2006, the plants in the full production cycle were pruned as necessary to maximise plant quality using standard commercial nursery practice. The growing tips of *Aucuba japonica* plants were pinched out on two occasions for those that had been in the cool environment, and on three occasions for those that had been in the warm environment. The growing points of all of the *Osmanthus heterophyllus* plants were pinched back once. The *Pittosporum tenuifolium* plants were given a single light prune to remove the leading shoot tips. The *Cytisus scoparius* were pruned three times, the new growth being cut back to just above the previous cut. The growing tips of *Camellia japonica* shoots were pinched back twice. The *Hydrangea macrophylla* was pruned on three occasions, the growing tip being taken back to a mature leaf pair. *Choisya ternata* plants were pruned three times, the growing stems being taken back to the previous pair of mature leaves. The *Photinia fraseri* were pruned on two occasions for those that had been in the cool environment and on three occasions for those that had been in the warm house, the growing stems were taken back to the first or second leaf on the new stem.

Between February and March 2007, only the *Photinisa fraseri* and the *Aucuba japonica* were pruned again. The *Photinia fraseri* plants were pruned as above and the *Aucuba japonica* had their growing tips pinched out.

Experiment 4 - Winter Chilling

The results and conclusion from this experiment were given in the previous report.

Experiment 5 – Effects of autumn *versus* spring warmth

This experiment was designed to compare and contrast the effects of autumn *versus* spring applications of warmth on plant growth. In all of the previous experiments warmth was applied in both autumn and spring and so it was not possible to separate the cumulative autumn and spring effects. In addition, plants in the 'cool' environment were maintained above 5ºC, whereas in this experiment they were maintained at ambient in a polytunnel. The same four light treatments as used in all of the previous experiments were repeated in the warm, but not in the polytunnel environment. The species were chosen because in the initial screen (Experiment 1), they had shown their potential to respond to the warm temperature treatments applied in either autumn and/or spring.

Liners of *Azalea japonica,* and *Viburnum tinus* were supplied by New Place Nurseries Ltd, on 7 September, in 9 cm containers. They were potted on into 2 L containers using compost supplied by New Place Nurseries on the 8 September 2006. Sixty-four plants from each species were selected at random and 16 were placed into each of the four different light environments in the warm glasshouse treatment (i.e. treatments 5, 6, 7, 8) on 11 September 2006. The plants were placed in a N–S direction, thus each block contained four rows of four pots of each species arranged E-W. The rest of the plants (62) were placed into an unheated polytunnel and grouped according to species. *Convolvulus cneorum* liners supplied on 25 September 2006 were potted up in a similar way and placed into the experimental conditions on 26 September 2006.

The heating and supplementary lighting treatments were provided from 11 September until 1 December 2006, when the lighting in the SD and LD treatments was switched off and set point in the cool house was adjusted to 5ºC. The plants were moved to the unheated polytunnel on 15 December 2006. Eight of the sixteen plants from each species from each of the warm glasshouse environments were placed back into the same treatments that they had received previously on 5 February 2007. Each plant was placed into exactly the same position it had occupied previously. The other eight plants were left in the polytunnel. In addition, another thirty-two plants from each species were selected at random from the 62-64 plants that had remained in the polytunnel during autumn and eight were placed separately into each of the four warm glasshouse light environments in four rows of four plants. The set point in the warm house was adjusted to 15ºC and the supplementary and day length extension lighting was switched on 5 February 2006. The lighting and heating were switched off on 4 May 2007. Thus, it was possible to compare the effects of no application of heat (and light treatments), with autumn application only, spring application only and autumn and spring combined.

No pruning treatments were applied to the *Convolvulus cneorum* and *Azalea japonica*, the growing tips of the *Viburnum tinus* plants were removed on 27 February 2007. The experiment used a total of 380 plants.

Statistical analysis

The design of Experiment 3 was regarded as randomised block with heat, supplementary light and day length extension light as treatment factors in Experiment 3. The treatments formed a 2^3 factorial set for temperature (warm, cool) by day length extension light (ambient, extended to 15 h) by supplementary light (ambient, supplementary 8h/day). It was only possible to have one glasshouse compartment for each of the eight treatment combinations. However, within each compartment there were four replicates within each row of plants for each species arranged in three blocks. The variation between replicate rows per species within each treatment was therefore used as the residual variation against which to test treatment effects. Probabilities given in the text and tables are those associated with the F-tests of treatment effects from the ANOVA.

Experiment 5 was analysed using similar assumptions and procedures. Within each compartment there were four replicates within each row of plants for each species arranged in two blocks per timing treatment rather than three as in Experiment 3. The polytunnel was used as an integral part of the 2^3 factorial set for timing (autumn, spring) by day length extension light (ambient, extended to 15 h) by supplementary light (ambient, supplementary 8h/day). However, neither light treatment was applied in the polytunnel, so the design was unbalanced in this respect.

Growth measurements

Plant growth activity was characterised as active, i.e. apical tip growing, apical bud swelling, shoot breaking and fully extended. The stages of flowering were also recorded i.e. flower bud developing and in flower. These assessments were done separately on every plant on the same day at an approximately 10 – 14 d intervals, during autumn and late winter and spring depending on growth activity, i.e. the interval tended to increase as growth activity reduced.

The heights, breadth (across two positions at right angles) and number of new shoots (>1cm) in experiment 3 were recorded on 19 - 20 April 2006, again 30 - 31 August 2006, 7 - 11 December 2006 and 4 - 15 May 2007. For experiment 5 measurements were made on the last two dates only.

In addition, cuttings at New Place Nurseries that were of similar age to those used in the experiments at East Malling Research were measured on 19 December 2006 and 15 May 2007. Eight plants per species were measured, using the same criteria as above.

Plant quality

The quality of the liners in experiments 3 and 5 were determined using a visual assessment system. The details of this are given in the Appendix.

Photographs

Representative plants for each species from each treatment in experiment 3 were photographed on 20 April 2006, 4 September 2006, 14 December 2006 and 17 May 2007. Plants in experiment 5 were photographed on 14 December 2006 and 17 May 2007. Plants at New Place Nurseries were photographed on 19 December 2006 and 17 May 2007.

Environment

Temperature and external radiation was measured using sensors in the glasshouse compartment and external sensors.

Results and Discussion

Experiment 3 – Full production cycle

Aucuba japonica 'Goldstrike'

(Figure 1, Table 1, Plates 1, 2, 3)

Key points

- Plants achieved commercial size grade and quality within 18 months of propagation, i.e. one year was removed from the normal production period
- Supplementary light had no effect on plant size at completion of production
- Day length extension light caused a small increase in plant height
- Increasing temperature from 5 to 15°C caused a small increase in height
- Maintaining a minimum temperature >5°C during an extended autumn and two early springs in glass and increasing pot size, substantially increased plant size compared to similar aged plants grown for the same period in unheated glass

The plants started to grow earlier in the warm environment and nearly all the plants were active by the end of March, whereas this did not occur until the end of April 2006 for the cool environment. As a result, the warmed plants were much larger (80% taller). Plants in the warm environments had broken bud and new shoots were evident by the end of April, whereas the majority of those in the cool environment had only just broken bud. Supplementary and day length extension lighting also increased plant size, but not to the same extent as the increase in temperature.

Following their period in the unheated glasshouse during the summer, the plants continued to grow and those that had received the early warmth treatment remained 4 cm (25%) taller and 2 cm (8%) wider by September. There was no difference in the number of new shoots per plant. During autumn plants in the cool environment ceased growing earlier than those in the warm environment. Following the autumn warm treatment period, the size of the plants was more variable and although the plants in the warm environment had a larger mean size, the effect was not statistically significant. Following the application of the spring treatments, all of the plants rapidly responded and began to grow at the same time. By May 2007, the differences in sizes of plants between the treatments had disappeared and the number of new shoots per plant was similar. Likewise, there was no difference in plant quality.

The supplementary lighting had no benefit on growth during autumn 2006 and spring 2007. Day length extension lighting had a small effect on increasing plant height by May 2007. Neither of the light treatments influenced plant quality by the end of the production cycle.

Compared with cuttings grown in a commercial nursery under glass, with no supplementary heat or light over the same period (2006-7), plant size in our 'cool' treatment was 44% greater. The extra growth was particularly marked during spring 2007. Thus, our 'cool' treatment which maintained the minimum temperature above 5ºC and used 2 l pots (c.f. 9 cm) was highly beneficial for accelerating growth and one year was removed from the production cycle.

Figure 1 The effect of different environmental conditions on % of *Aucuba japonica* rooted cuttings growing during extended spring 2006, extended autumn 2006 and extended spring 2007 growth seasons. AL ambient light, DL day length extension light, SL supplementary light

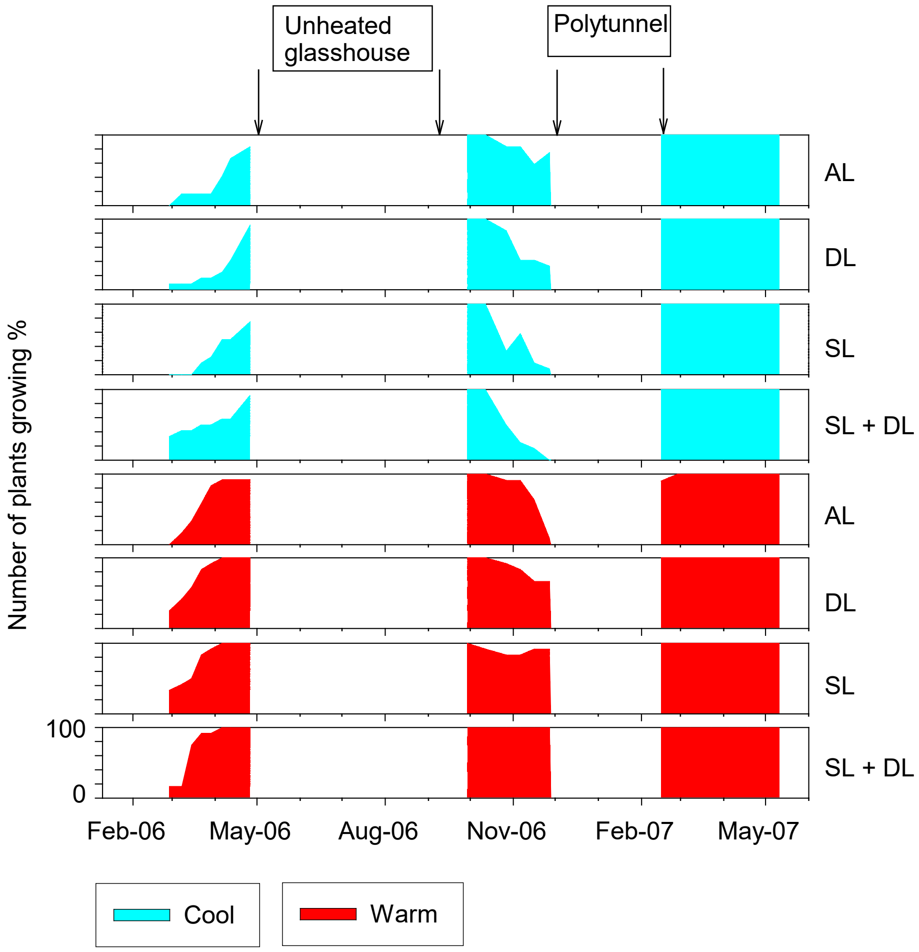
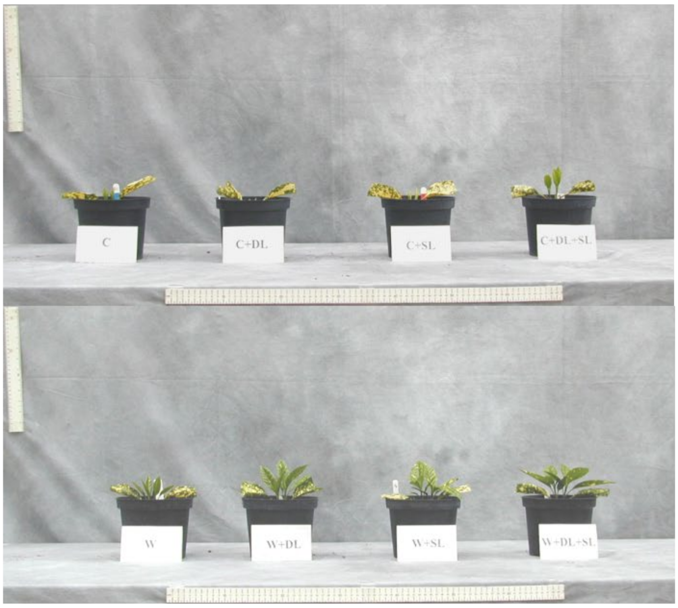


Plate 1 Representative examples of *Aucuba japonica* rooted cuttings size following a spring 2006 extended growth season. C = cool house, W= warm house, C = ambient light, DL day length extension light, SL supplementary light, (Vertical ruler =30 cm; horizontal ruler = 70cm)

April 2006



September 2006

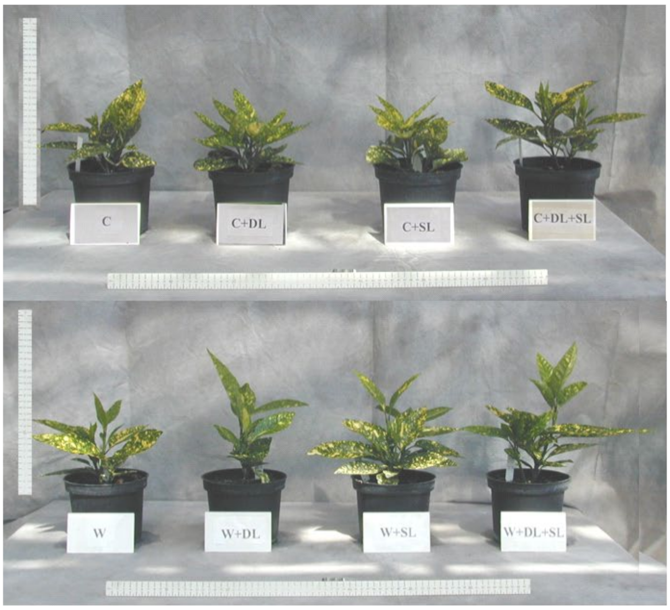


Plate 2 Representative examples of *Aucuba japonica* rooted cuttings growth in December 2006 following a spring 2006 extended growth season and an autumn 2006 extended growth season. C = cool house, W = warm house, no second letter ambient light, DL day length extension light, SL supplementary light. (Vertical ruler =30 cm; horizontal ruler = 70cm)

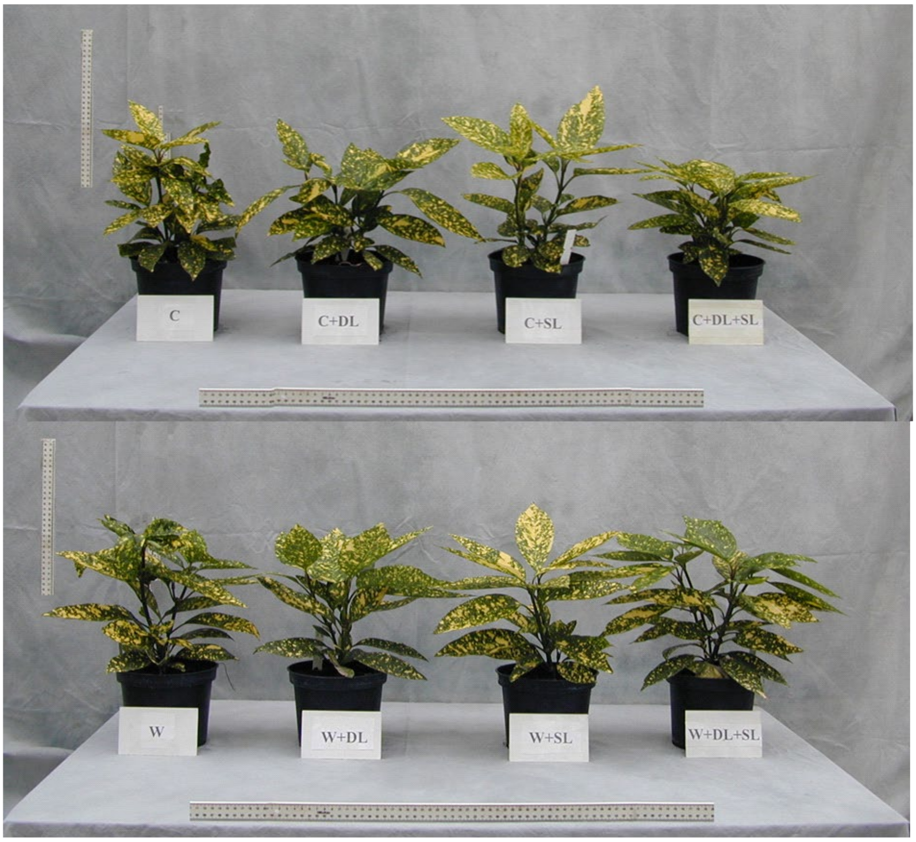


Plate 3 Representative examples of *Aucuba* rooted cuttings size in May 2007 following a spring 2006 extended growth season, an autumn 2006 extended growth season and a spring 2007 extended growth season. C = cool house, W= warm house, no second letter = ambient light, DL day length extension light, SL supplementary light, P plant grown using a traditional liner method. (Vertical ruler =30 cm; horizontal ruler = 70cm)

May 2007

Table 1 The main effects of temperature, supplementary and day length extension light on plant size and number of new shoots (breaks) of *Aucuba japonica* rooted cuttings following spring extended growth season (May 2006), summer in an unheated glasshouse (August 2006), autumn extended growth season (December 2006) and spring extended growth season (May 2007)

		Height (cm)				**Width (cm)**				**No. new shoots per plant**				**Quality**
Main effect		May 2006	Aug 2006	Dec 2006	May 2007	May 2006	Aug 2006	Dec 2006	May 2007	May 2006	Aug 2006	Dec 2006	May 2007	May 2007
Temperature	Cool	5	16	25	36	13	24	24	50	1	3	4	6	2
	Warm	10	20	29	40	16	26	26	50	2	3	5	7	2
Probability		***	***	ns	*	***	**	ns	ns	***	ns	ns	***	ns
Supplementary light	-	7	17	25	38	14	25	24	49	1	3	4	6	2
	+	8	16	28	38	15	25	26	51	1	3	5	7	2
Probability		ns	ns	ns	ns	*	ns	ns	ns	ns	ns	ns	ns	ns
Day length extension			17	26	36			24	49	1	3	5	6.	2
light	-	7				14	26							
	+	8	19	28	40	15	24	26	51	1	3	4	7	2
Probability		*	ns	ns	*	*	*	ns	ns	ns	ns	ns	ns	ns
SED[1] (8 d.f)		0.4	0.7	3.5	1.4	0.5	0.7	4.7	1.4	0.2	0.2	0.7	0.5	0.2
Interactions		T x SL x DL	T x DL	None	None	T x DL	None	None	T x DL	None	None	None	None	None
Traditional liner [2]				16	25			21	30			3	4	

Probability * is statistically significant (<0.05), ** is highly significant (< 0.01) and *** is very highly significant (< 0.001), ns is not statistically significant
[1]SED for comparison between main effects, [2]traditional liner for comparison was grown for same period in a commercial nursery

***Camellia japonica* 'Guilio Nuccio'**

(Figure 2, Table 2, Plates 4, 5, 6)

Key points

- Commercial sale quality and size was not achieved within the shortened production cycle
- None of the glasshouse environmental treatments had any effect on plant size
- Maintaining a minimum temperature >5ºC during an extended autumn and two early springs in glass and increasing pot size, substantially increased plant size compared to similar aged plants grown for the same period in unheated glass.

The plants in all the different treatments started to grow at approximately the same time in the cool and warm environments in spring 2006. However, the plants only had one month in the experimental conditions prior to the measurements, if it had been possible to place the plants into the experimental environments earlier, treatment effects on growth may have been greater.

Following the period in the unheated glasshouse during the summer, most of the plants continued to grow. By December 2006, following another application of the environmental treatments, the size of the plants and number of new shoots was unaffected by warmth and/or supplementary lighting. Day length extension light caused a small mean increase (2 cm) in plant width. After the final application of the environmental treatments in spring 2007, warmth had increased plant height, but reduced plant width. Supplementary light increased the number of new shoots from 6 to 8 per plant, whereas the other treatments had no effect. None of the treatments influenced plant quality.

Compared with cuttings grown in a commercial nursery under glass, with no supplementary heat or light over the same period (2006-7), the plants in the cool treatment were 63% taller and 74% wider. The extra growth was particularly marked during spring 2007. Thus, our cool treatment which maintained the minimum temperature above 5°C and used 2 l pots (c.f. 14 cm) was highly beneficial for accelerating growth. However, these larger plants still had not achieved sufficient size and quality for sale in April/May 2007.

Figure 2 The effect of different environmental conditions on % of *Camellia japonica* rooted cuttings growing during extended spring 2006, extended autumn 2006 and extended spring 2007 growth seasons. AL Ambient light, DL day length extension light, SL Supplementary light

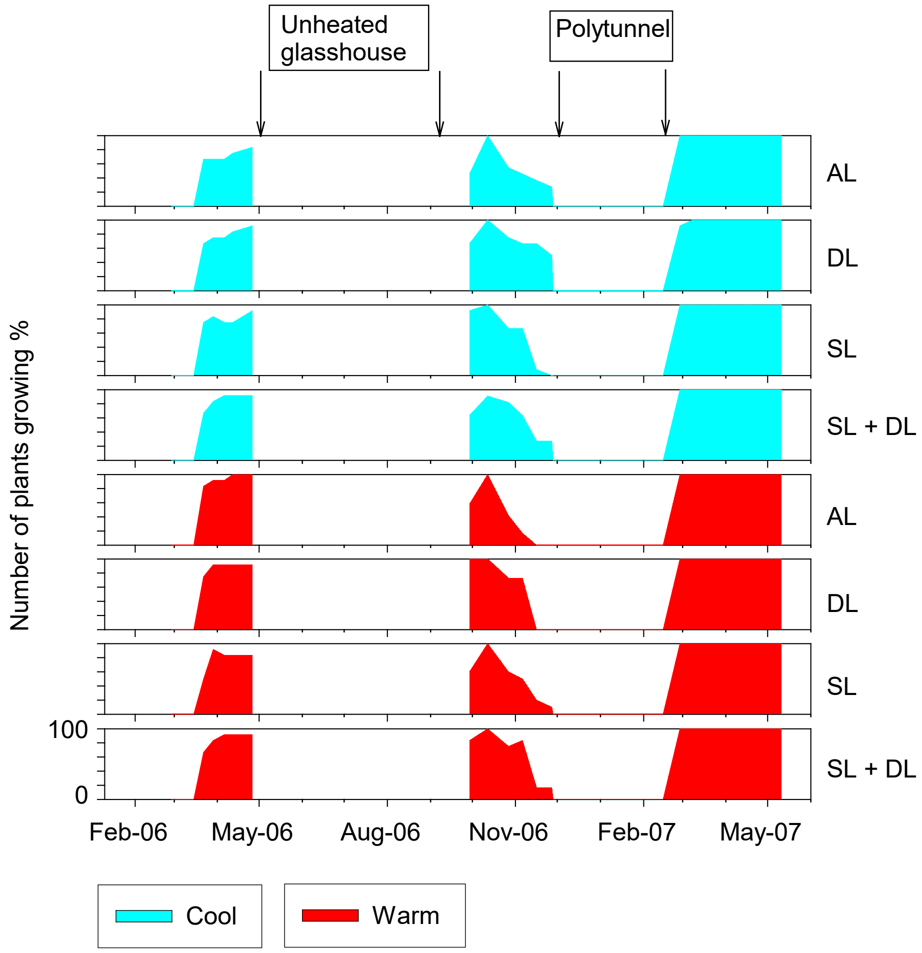
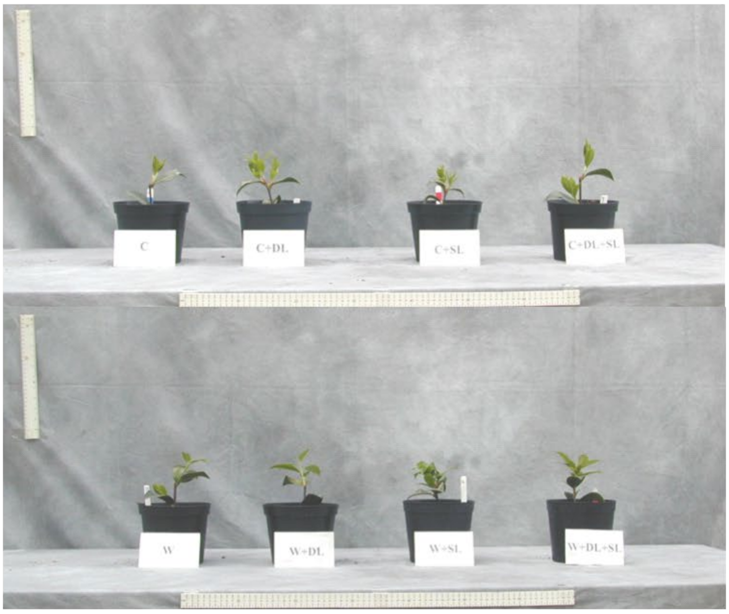


Plate 4 Representative examples of *Camellia japonica* rooted cuttings growth following a spring 2006 extended growth season. C = cool house, W= warm house, no second letter = ambient light, DL day length extension light, SL supplementary light, (Vertical ruler =30 cm; horizontal ruler = 70cm)

April 2006



September 2006

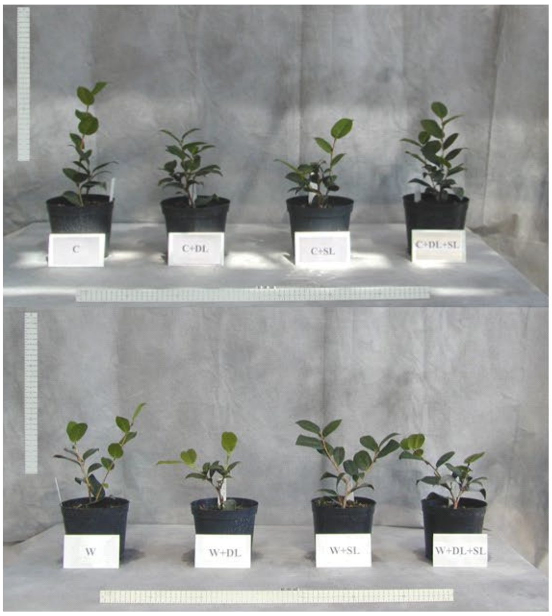


Plate 5 Representative examples of *Camellia japonica* rooted cuttings size in December 2006 following a spring 2006 extended growth season and an autumn 2006 extended growth season. C = cool house, W= warm house, no second letter = ambient light, DL day length extension light, SL supplementary light. (Vertical ruler =30 cm; horizontal ruler = 70cm)

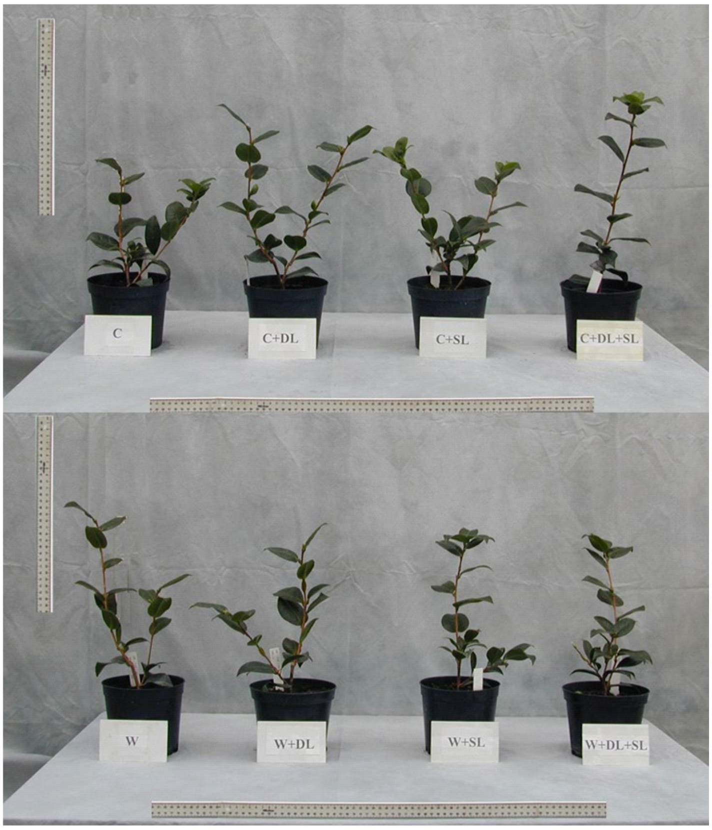


Plate 6 Representative examples of *Camellia japonica* rooted cuttings size in May 2007 following a spring 2006 extended growth season, an autumn 2006 extended growth season and a spring 2007 extended growth season. C = cool house, W= warm house, no second letter = ambient light, DL day length extension light, SL supplementary light, P plant grown using a traditional liner method. (Vertical ruler =30 cm; horizontal ruler = 70cm)

Table 2 The main effects of temperature, supplementary and day length extension light on plant size (height and width) and number of new shoots (breaks) of *Camellia japonica* rooted cuttings following spring extended growth season (May 2006), summer in an unheated glasshouse (end August 2006), autumn extended growth season (December 2006) and spring extended growth season (May 2007)

		Height (cm)				Width (cm)				No. new shoots per plant				Quality
Main effect		May 2006	Aug 2006	Dec 2006	May 2007	May 2006	Aug 2006	Dec 2006	May 2007	May 2006	Aug 2006	Dec 2006	May 2007	May 2007
Temperature	Cool	11	22	28	39	12	19	20	33	2	3	3	8	2
	Warm	12	24	30	46	12	20	22	30	2	3	3	6	2

Probability	ns	ns	ns	ns	ns	ns	ns	*	ns	ns	ns	ns	ns
Supplementary light -	11	24	27	37	12	20	20	32	2	3	3	6	2
+	12	23	30	49	12	20	22	31	2	3	3	8	2
Probability	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	*	ns
Day length extension light -	12	23	28	46	12	19	20	31	2	3	3	7	2
+	12	24	30	40	12	20	22	33	2	3	3	7	2
Probability	ns	ns	ns	ns	ns	ns	**	ns	ns	ns	ns	ns	ns
SED[1] (8 d.f)	0.6	1.8	2.3	8.1	0.4	1.0	0.7	1.2	0.2	0.2	0.2	0.6	0.2
Interactions	None	None	None	None	None	None	None	None	None	None	None	None	None
Traditional liner[2]			19	24			19	19			4	3	

Probability * is statistically significant (<0.05), ** is highly significant (< 0.01) and *** is very highly significant (< 0.001), ns is not statistically significant.
[1]SED for comparison between main effects, [2]traditional liner for comparison was grown for same period in a commercial nursery

Choisya ternata **(Mexican Orange Blossom)**

(Figure 3, Table 3, Plates 7, 8, 9)

Key points

- Plants achieved commercial grade out within 12 months of propagation
- Supplementary and day length extension light had no influence on plant size and quality
- Maintaining a minimum temperature >5ºC during an early spring and extended autumn under glass and increasing pot size, substantially increased plant size compared to similar aged plants grown for the same period in unheated glass

Choisya ternata has episodic growth and it is quite apparent that the plants in the warm environment completed a growth episode in the extended spring treatment before those in the cool environment had started. Thus, by late April 2006 plants in the warm environment were almost three times taller, double in width and quadruple numbers of new shoots compared to those in the cool environment. Supplementary light and day length extension light had no effect on plant growth.

Unfortunately, the plants suffered from an infection of Phytophora. This was treated with the systemic phosphonic fungicide fosetyl-aluminium (Aliette 80 WG, Certis) at standard dose rate on three occasions during the summer. This did not prevent the loss of a large proportion of the plants during May to October 2006. Thus, all the plants from the natural photoperiod cool environment, and the day length extension treatment (DL) in the warm environment were lost. Missing values were used in the Genstat statistical analysis, which allowed the main effects of the environment treatments to be compared.

In the opinion of the project grower coordinators, the plants had reached 'commercial size' by 25 September 2006. Therefore, they were removed from all the environmental treatments and maintained in a glasshouse at >5ºC on 3 October 2006.

They were transferred to an unheated polytunnel on 15 December 2006 and remained there until May 2007.

The early differences in growth caused by the warm environment were not apparent by September as the size of the plants and the number of new shoots per plant was similar. By December those plants that had previously been in the cool environment were larger than those that had been in the warm environment, but the number of new shoots was unaffected. This affect persisted until May 2007. Ultimately the different warm and cool environments produced no differences in plant quality. However, the plants were approximately three times the height and width of similar aged plants that had been grown in a commercial nursery under glass with no supplementary heat or light. This appears to indicate the value of maintaining the plants above 5°C compared to ambient during the spring and autumn growth periods.

The supplementary light treatment had no affect on plant growth and quality. The residual effects of the day length extension light applied during between February and May 2006, caused a small increase in plant height in September and December 2006. This effect was not significant by May 2007 and had no impact on plant quality.

Figure 3 The effect of different environmental conditions on % of *Choisya ternata* rooted cuttings growing during extended spring 2006. AL Ambient light, DL day length extension light, SL Supplementary light

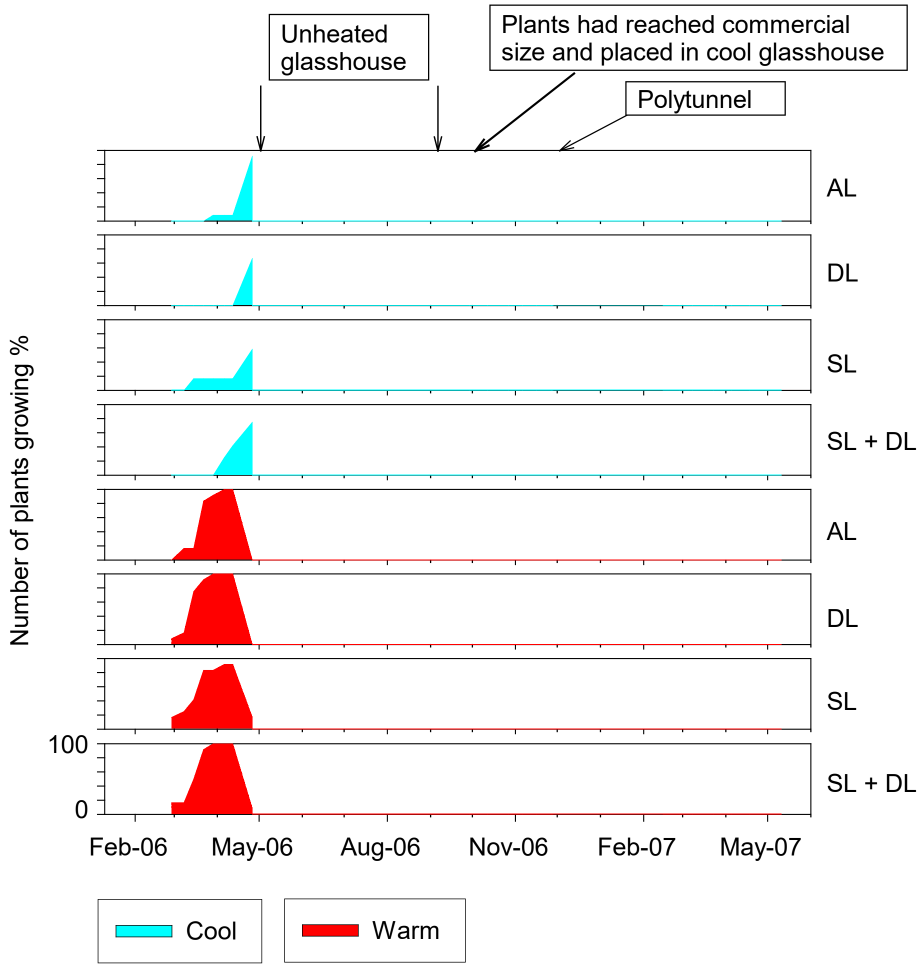
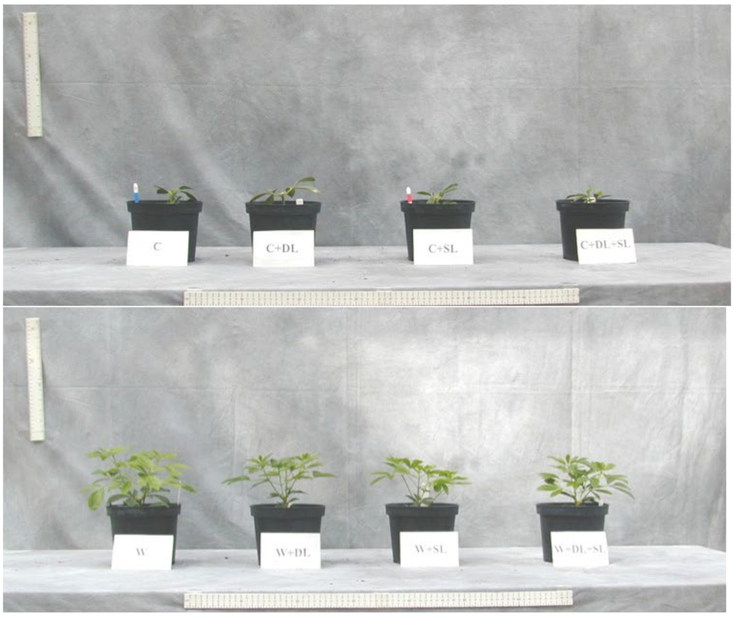


Plate 7 Representative examples of *Choisya ternata* rooted cuttings size following a spring 2006 extended growth. C = cool house, W= warm house, no second letter = ambient light, DL day length extension light, SL supplementary light, (Vertical ruler =30 cm; horizontal ruler = 70cm)

April 2006



September 2006

Plate 8 Representative examples of *Choisya ternata* rooted cuttings size in December 2006 following a spring 2006 extended growth season. C = cool house, W= warm house, no second letter = ambient light, DL day length extension light, SL supplementary light, (Vertical ruler =30 cm; horizontal ruler = 70cm)

Plate 9 Representative examples of *Choisya ternata* rooted cuttings size in May 2007 following a spring extended growth season in 2006. C = cool house, W= warm house, no second letter = ambient light, DL day length extension light, SL supplementary light, P plant grown using a traditional liner method. (Vertical ruler =30 cm; horizontal ruler = 70cm)

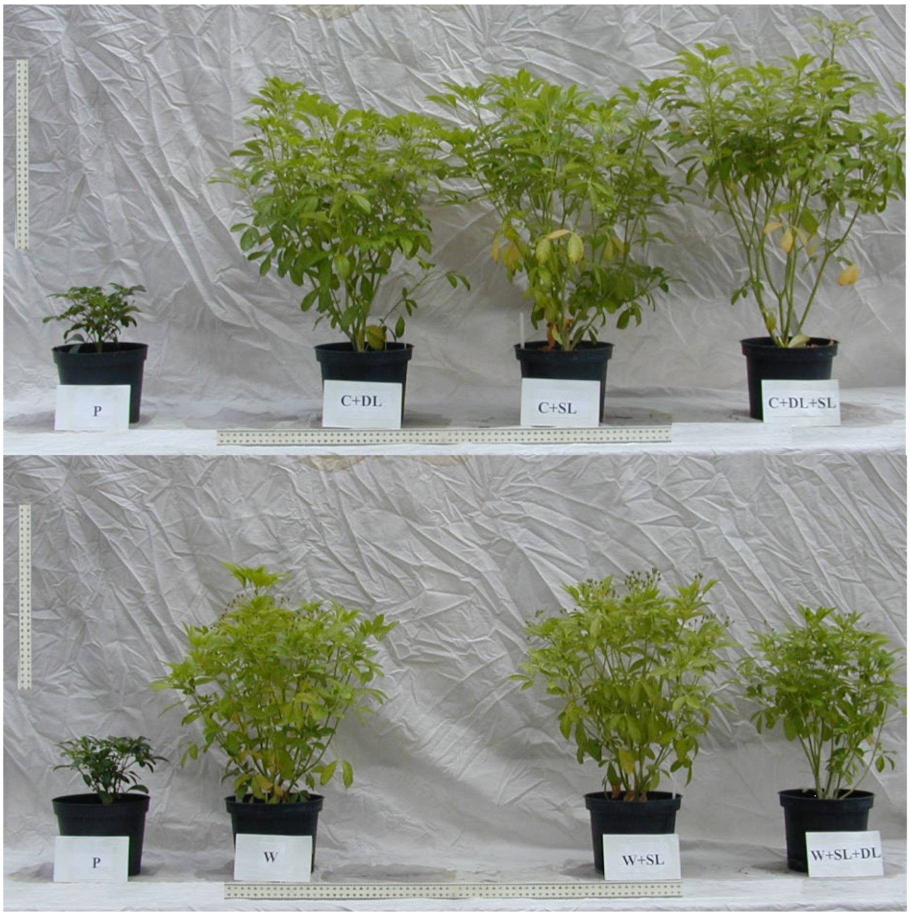


Table 3 The main effects of temperature, supplementary and day length extension light on plant size (height and width) and number of new shoots (breaks) of *Choisya ternata* rooted cuttings following spring extended growth season (May 2006), summer in an unheated glasshouse (end August 2006), autumn in an unlit cool glasshouse (December 2006) and spring in an unheated unlit polytunnel (May 2007)

		Height (cm)				Width (cm)				No. new shoots per plant				Quality
Main effect		May 2006	Aug 2006	Dec 2006	May 2007	May 2006	Aug 2006	Dec 2006	May 2007	May 2006	Aug 2006	Dec 2006	May 2007	May 2007
Temperature	Cool	6	29	38	45	11	31	38	42	0	15	26	23	2
	Warm	14	27	33	39	20	31	35	38	4	15	23	23	2
Probability		***	ns	**	**	***	ns	*	**	***	ns	ns	ns	ns
Supplementary light	-	10	27	34	42	16	31	36	40	2	16	24	24	2
	+	10	29	37	41	15	31	36	40	2	14	25	21	2
Probability		ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	*	ns
Day length extension light	-	10	26	34	40	16	31	36	40	2	14	26	22	2
	+	10	30	37	43	15	31	37	41	2	15	27	23	2
Probability		ns	*	*	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
SED[1] (8 d.f.)		0.5	1.4	1.5	1.6	0.7	0.7	1.5	1.4	0.2	0.6	1.5	1.1	0.2
Interactions		None	DL x SL	T x DL	T x DL	DL x SL	None	T x DL	T x DL	None	None	None	T x DL	None
Traditional liner[2]				13	16			13	17			12	12	

Probability * is statistically significant (<0.05), ** is highly significant (< 0.01) and *** is very highly significant (< 0.001), ns is not statistically significant.
[1]SED for comparison between main effects, [2]traditional liner for comparison was grown for same period in a commercial nursery

***Cytisus scoparius* 'Burkwoodii' (Broom)**

(Figure 4, Table 4, Plate 10, 11, 12)

Key points

- Plants achieved commercial grade within 1 year of propagation
- Increasing temperature from 5ºC to 15ºC increased initial plant growth
- Maintaining a minimum temperature >5ºC during an early spring and extended autumn under glass and increasing pot size, increased the size of plants by 2.5 times and number of shoots per plant three-fold compared to those of similar age grown in unheated glass

The plants in the warm environment started to grow soon after placing in the chamber, whereas those in the cool environment did not show any growth activity until approximately one month later. As a result, the warmed plants had doubled in height and width compared to those in cool environment by late April. Furthermore, those in the cool environment had produced no new shoots by the end of April (they were active by the end March, but the process of bud break and leafing out was slow), whereas those in the warm environment had produced eight shoots. *Cytisus scoparius* was also responsive to changes in the light environment. Supplementary light also increased plant width and number of new shoots per plant, whereas day length extension increased width, and height, but had no effect on the number of shoots per plant. However, these effects were small compared to those produced by additional warmth.

Following the period in the unheated glasshouse during the summer, the plants continued to grow. The plants had been pruned three times between early May and and August. When the plant sizes were measured in late August it was less than 3 weeks since they had been pruned. Therefore it is not surprising that there was little apparent effect of any of the environmental treatments.

In the opinion of the project grower coordinators, plants had reached ‘commercial size’ by 25 September 2006. Therefore, they were removed from all of the different environmental treatments into a glasshouse maintained at >5ºC on 3 October 2006.

By December 2006, there remained either no or only small differences in sizes between the plants that had received the different glasshouse environmental treatments in spring and the number of new shoots per plant was similar. Likewise, there was no difference in plant quality caused by the warmth or day length extension treatments quality by May 2007. Supplementary light improved plant quality. However, compared to plants of similar age grown on a commercial nursery, under glass in 9 cm pots the glasshouse experiment plants had double their width and height and had three times as many new shoots per plant.

Figure 4 The effect of different environmental conditions on % of *Cytisus scoparius* rooted cuttings growing during extended spring 2006. AL ambient light, DL day length extension light, SL supplementary light

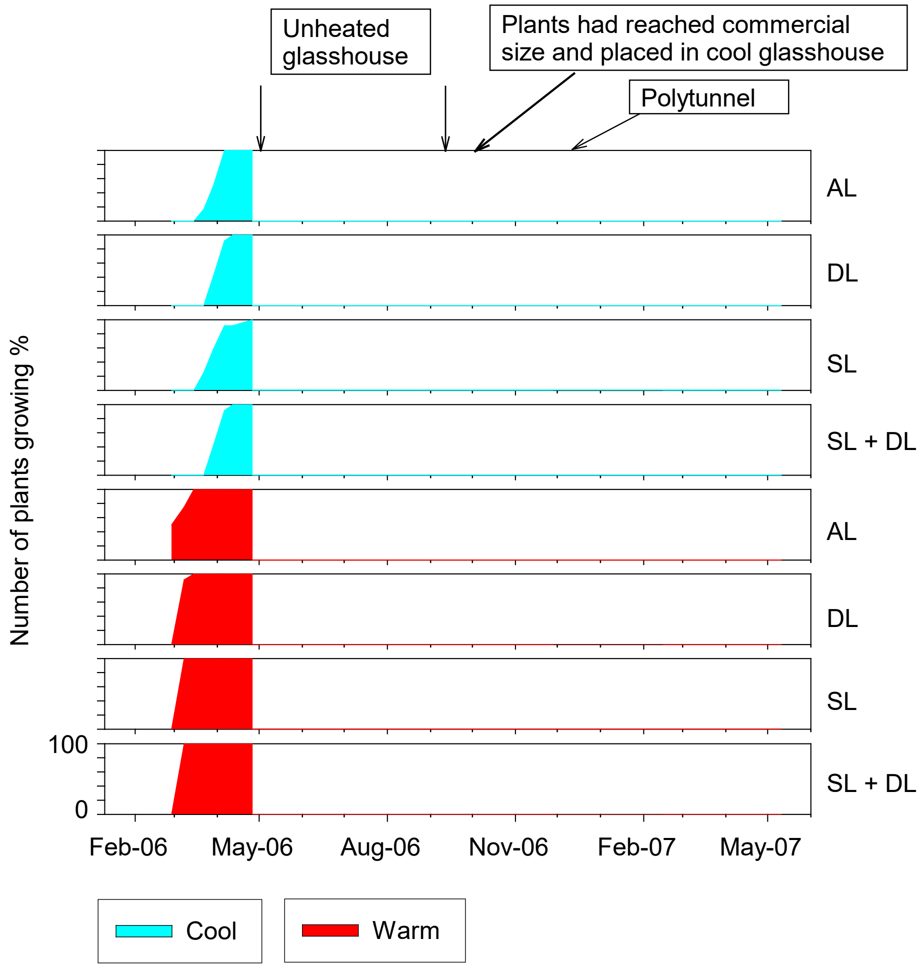


Plate 10 Representative examples of *Cytisus scoparius* rooted cuttings growth following a spring 2006 extended growth season. C = cool house, W= warm house, no second letter = ambient light, DL day length extension light, SL supplementary light, (Vertical ruler =30 cm; horizontal ruler = 70cm)

April 2006

September 2006

Plate 11 Representative examples of *Cytisus scoparius* rooted cuttings size in December 2006 following a spring 2006 extended growth season. C = cool house, W= warm house, no second letter = ambient light, DL day length extension light, SL supplementary light, (Vertical ruler =30 cm; horizontal ruler = 70cm)

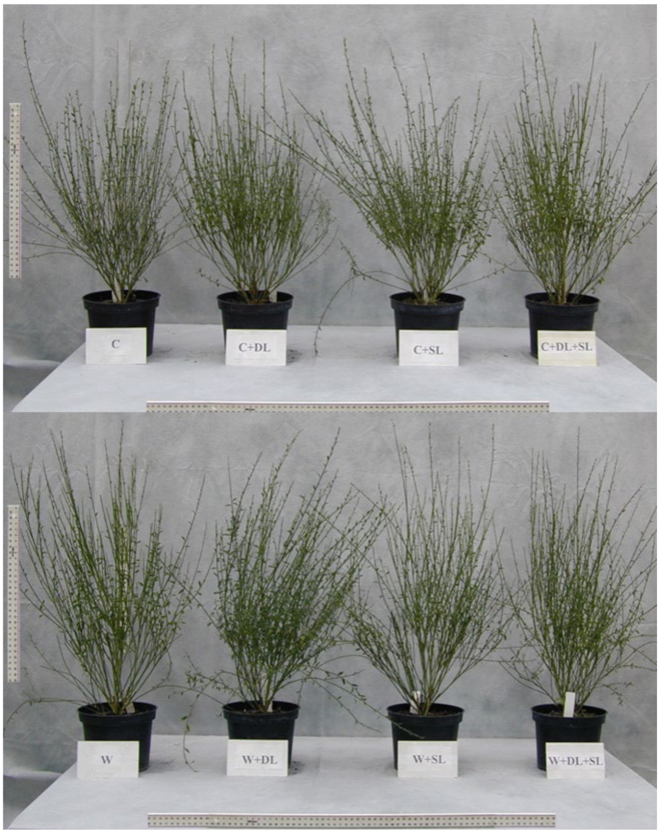


Plate 12 Representative examples of *Cytisus scoparius* rooted cuttings size by May 2007 following a spring 2006 extended growth season. C = cool house, W= warm house, no second letter = ambient light, DL day length extension light, SL supplementary light, P plant grown using a traditional liner method. (Vertical ruler =30 cm; horizontal ruler = 70cm)

Table 4 The main effects of temperature, supplementary and day length extension light on plant size (height and width) and number of new shoots (breaks) of *Cytisus scoparius* rooted cuttings following spring extended growth season (May 2006), summer in an unheated glasshouse (August 2006), autumn in an unlit cool glasshouse (December 2006) and spring in an un lit unheated polytunnel (May 2007)

		Height (cm)				Width (cm)				No. new shoots per plant			Quality
Main effect		May 2006	Aug 2006	Dec 2006	May 2007	May 2006	Aug 2006	Dec 2006	May 2007	May 2006	Aug 2006	Dec 2006	May 2007
Temperature	Cool	7	19	53	54	5	26	42	50	0	90	155	2.1
	Warm	13	21	56	57	12	24	43	53	8	99	166	2.2
Probability		***	ns	ns	ns	***	***	ns	*	***	ns	ns	ns
Supplementary light	-	10	20	56	57	7	24	43	52	3	89	153	2.0
	+	10	20	54	54	9	26	41	52	5	100	169	2.4
Probability		ns	ns	ns	ns	***	*	ns	ns	***	ns	*	**
Day length extension light	-	9	20	54	54	7	25	41	50	4	99	159	2.3
	+	11	20	56	56	9	25	44	53	4	90	162	2.1
Probability		**	ns	ns	ns	**	ns	ns	ns	ns	ns	ns	ns
SED[1] (8 d.f.)		0.5	0.6	1.5	1.9	0.4	0.5	1.5	1.8	0.4	5.4	7.5	0.14
Interactions		T x DL	T x DL	None	T x DL	T x SL x DL	T x SL x DL	None	SL x DL	T x SL	T x SL x DL	T x SL x DL	None
Traditional liner[2]				12	31			10	25			47	

Probability * is statistically significant (<0.05), ** is highly significant (< 0.01) and *** is very highly significant (< 0.001), ns is not statistically significant.
[1]SED for comparison between main effects, [2]traditional liner for comparison was grown for same period in a commercial nursery

***Hydrangea macrophylla* 'King George'**

(Figure 5, Table 5, Plate 13, 14, 15)

Key points

- Plants achieved commercial grade within just over one year of propagation
- Increasing temperature from 5ºC to 15ºC substantially increased plant size initially, but subsequently had little effect
- Day length extension light had a small effect on increasing plant size initially, but subsequently had little effect
- Maintaining a minimum temperature >5ºC during an early spring and extended autumn under glass and increasing pot size, substantially increased the size of plants compared to similar aged plants grown for the same period in unheated glass

Growth activity was similar for all the treatments during the extended spring, i.e. all the plants started to grow at the same time. However, rates of growth were substantially different as the average width and height of plants in the warm environment was 5 cm and 2 cm greater respectively than those in cool environment by late April. Supplementary light had no effect on plant growth, but day length extension light increased plant width and height by 1 cm. The early effect of the warm environment had disappeared by September as there was no difference in the size of the plants.

In the opinion of the project grower coordinators, the plants had reached 'commercial size' by 25 September 2006. Therefore, they were removed from all of the different environmental treatments into an unheated polytunnel on 3 October 2006 and they remained there until May 2007.

The size and number of new shoots per plants was unaffected by the previous warm treatments by September 2006. In May 2007, the plants previously in the warm environment produced slightly fewer new shoots. The quality of the plants was also unaffected by warming. However, compared to plants of similar age produced under unheated glass on a commercial nursery, the plants were wider and had three times as many new shoots, i.e., they were bushier by May 2007.

The supplementary light treatment applied between February and May 2006 had a small residual effect on increasing plant height in September that persisted until December, but this had disappeared by May 2007. Extension lighting had no effect on growth after its initial use between February and May 2006. Neither light treatment affected plant quality.

Figure 5 The effect of different environmental conditions on % of *Hydrangea macrophylla* rooted cuttings growing during extended spring 2006. AL Ambient light, DL day length extension light, SL supplementary light

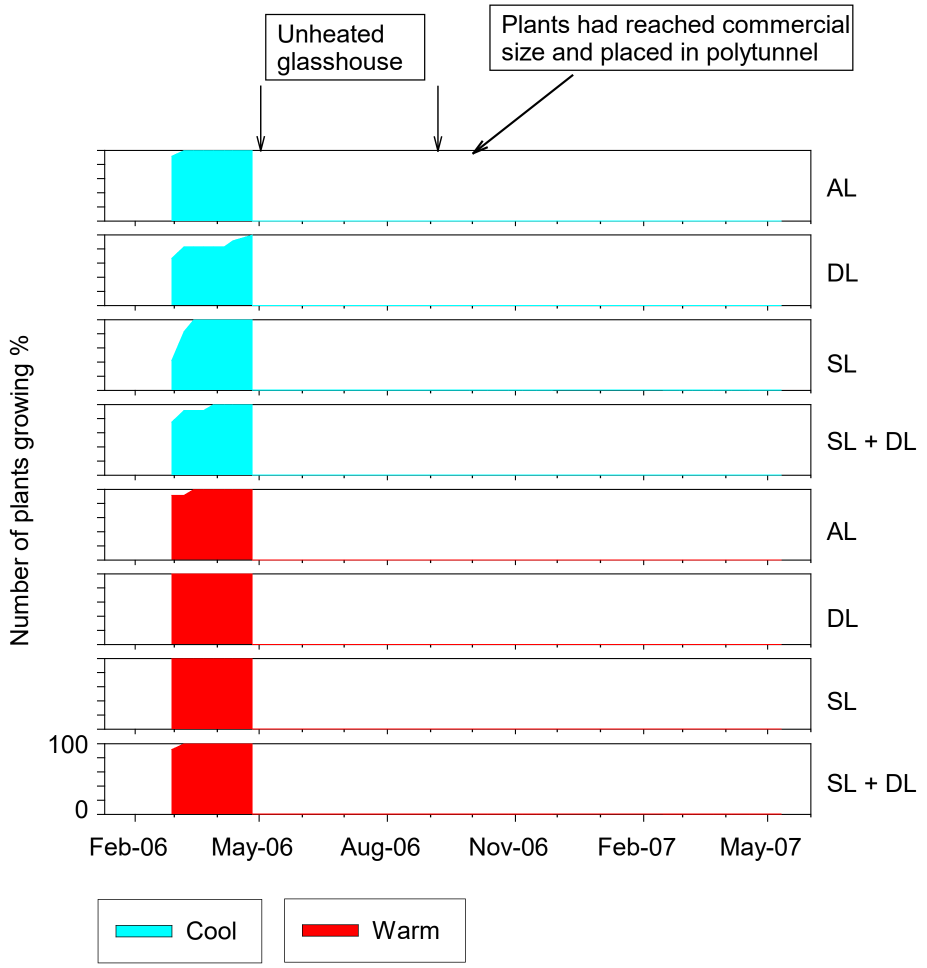
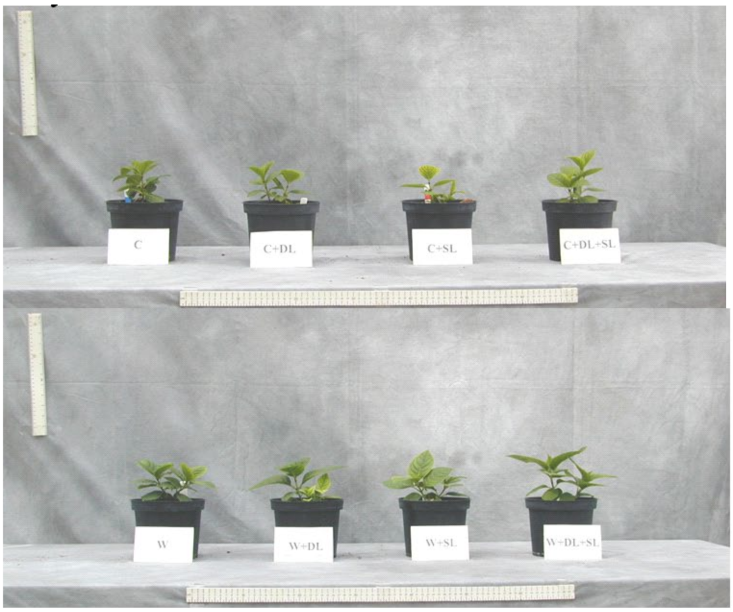


Plate 13 Representative examples of *Hydrangea macrophylla* rooted cuttings size following a spring 2006 extended growth season. C = cool house, W= warm house, no second letter = ambient light, DL day length extension light, SL supplementary light, (Vertical ruler =30 cm; horizontal ruler = 70cm)

April 2006



September 2006

Plate 14 Representative examples of *Hydrangea macrophylla* rooted cuttings size in December 2006 following a spring 2006 extended growth season. C = cool house, W= warm house, no second letter = ambient light, DL day length extension light, SL supplementary light, (Vertical ruler =30 cm; horizontal ruler = 70cm)

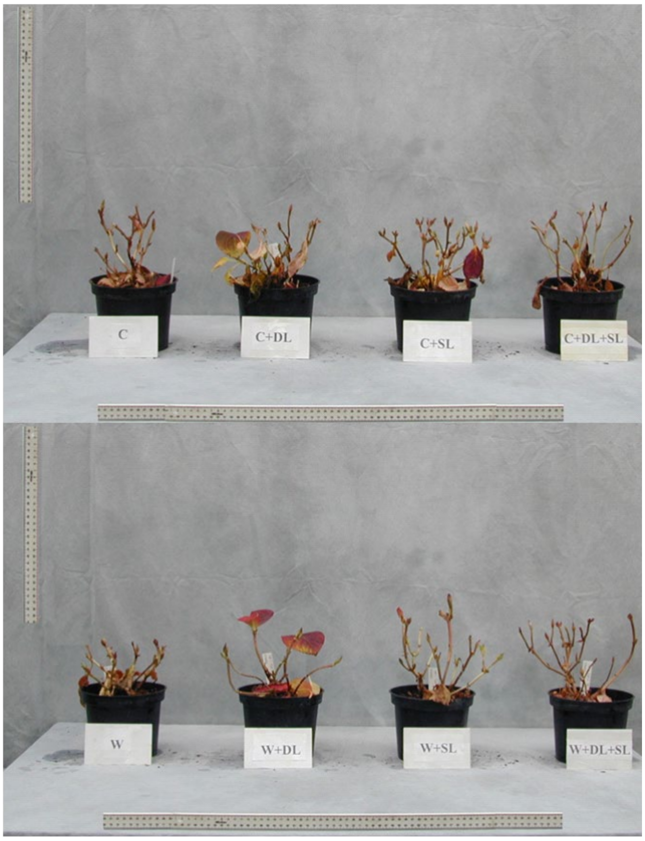


Plate 15 Representative examples of *Hydrangea macrophylla* rooted cuttings size in May 2007 following a spring 2006 extended growth season. C = cool house, W= warm house, no second letter = ambient light, DL day length extension light, SL supplementary light, P plant grown using a traditional liner method. (Vertical ruler =30 cm; horizontal ruler = 70cm)

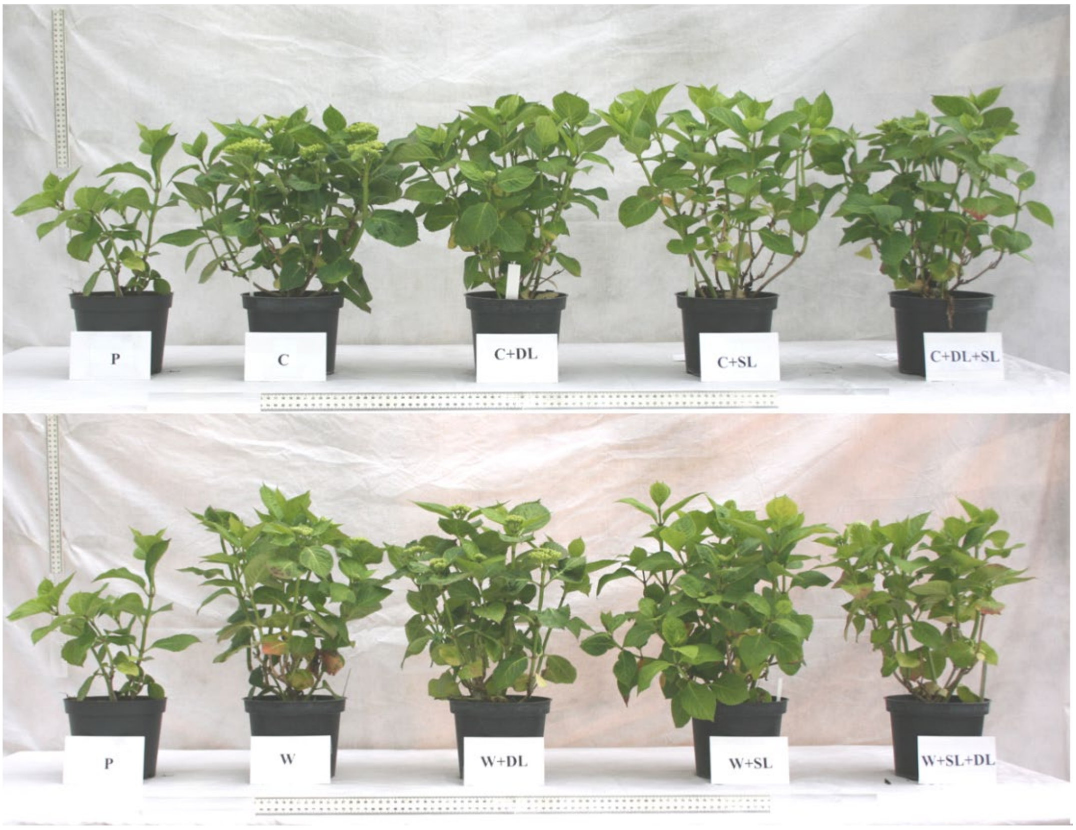


Table 5 The main effects of temperature, supplementary and day length extension light on plant size (height and width) and number of new shoots (breaks) of *Hydrangea macrophylla* rooted cuttings following spring extended growth season (May 2006), summer in an unheated glasshouse (end August 2006), autumn in an unlit and unheated polytunnel (December 2006) and spring in an unheated and unlit polytunnel (May 2007).

		Height (cm)				**Width (cm)**				**No. new shoots per plant**				**Quality**
Main effect		May 2006	Aug 2006	Dec 2006	May 2007	May 2006	Aug 2006	Dec 2006	May 2007	May 2006	Aug 2006	Dec 2006	May 2007	May 2007
Temperature	Cool	10	18	14	36	13	29	19	36	2	9	9	11	2
	Warm	11	17	13	36	18	29	17	37	2	8	8	9	2
Probability		**	ns	ns	ns	***	ns	ns	ns	ns	ns	ns	*	ns
Supplementary light	-	10	16	13	36	16	28	18	37	2	8	8	9	2
	+	11	18	14	36	15	30	18	36	2	9	9	10	2
Probability		ns	*	*	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Day length extension light	-	10	17	13	37	15	29	18	37	2	8	8	10	2
	+	11	17	14	36	16	29	18	36	2	9	9	9	2
Probability		**	ns	ns	ns	*	ns	ns	ns	ns	ns	ns	ns	ns
SED[1] (8 d.f.)		0.5	0.7	0.6	0.6	0.8	1.1	0.7	0.6	0.2	0.6	0.6	0.5	0.2
Interactions		T x DL T x DL x SL	None	T x DL	T x DL T x SL	T x DL x SL	None	None	T x DL x SL SL x DL	SL x DL	T x DL	T x DL	None	None
Traditional liner [2]				10	32			13	25			3	3	

Probability * is statistically significant (<0.05), ** is highly significant (< 0.01) and *** is very highly significant (< 0.001), ns is not statistically significant.
[1]SED for comparison between main effects, [2]traditional liner for comparison was grown for same period in a commercial nursery.

***Osmanthus heterophyllus* 'Goshiki'**

(Figure 6, Table 6, Plates 16, 17, 18)

Key points

- Commercial sale size and quality was not achieved using the shortened production cycle as the experimental conditions did not accelerate the growth compared to a traditional liner of the same age
- Warmth substantially accelerated growth during the spring after propagation
- Day length extension light had no effect on plant size
- Supplementary light increased the number of new shoots (breaks) per plant
- None of the environmental treatments influenced plant quality

The *Osmanthus heterophyllus* plants were placed into the different environments in mid February 2006, but initially showed no growth activity. By mid April all the plants in the warm environments had started growing, unlike plants in the cool environments where very few plants were actively growing by late April. This difference was reflected in plant size as the plants in the warm environment were on average 4 cm taller and 2 cm wider than those in the cool environment at the end of April. In addition, the warmed plants had several new shoots growing whereas the those in the cool environmemt had none. Supplementary and day length extension light had no effect on plant growth and size.

By September 2006 the initial differences in plant size caused by the warm environment persisted and continued after the subsequent autumn treatment, although the difference in sizes between the plants remained small (1 cm). The number of new shoots was also increased in the warm environment. After the spring 2007 treatment the size differences were not significant. The plants in cool environment continued to grow longer into the autumn and those in the warm environment started to grow earlier in the new year and these factors may have cancelled each other out. Following the spring 2007 warmed treatment the previous trend in new shoot production was reversed as the plants in the cool environment had produced almost twice as many new shoots as those in the warm environment. The plants of similar age produced in a conventional nursery in ambient conditions under glass were of a similar size to those produced in the experimental conditions.

Supplementary light applied in autumn 2006 had no effect on growth, but following the spring application, the width of the plants was slightly increased and the number of new shoots was increased by five per plant. Day length extension light generally had no effect on plant growth in autumn 2006 or spring 2007.

None of the treatments influenced plant quality at completion of the production cycle.

Figure 6 The effect of different environmental conditions on % of *Osmanthus heterophyllus* rooted cuttings growing during extended spring 2006, extended autumn 2006 and extended spring 2007 growth seasons. AL Ambient light, DL day length extension light, SL Supplementary light

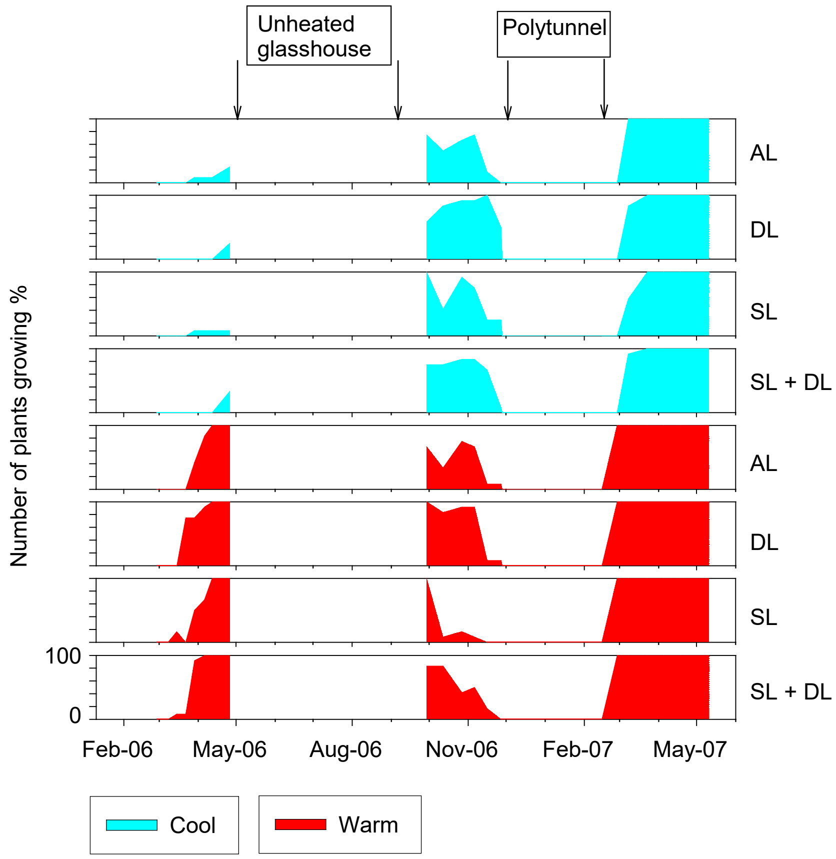
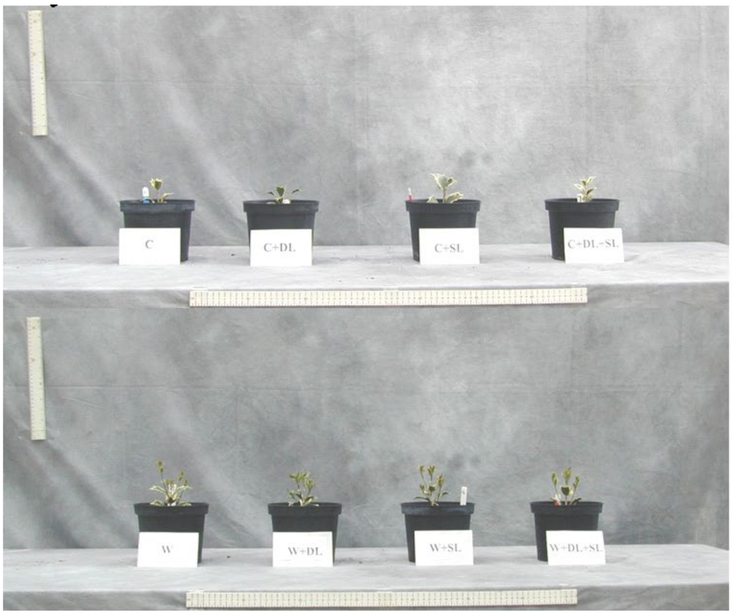


Plate 16 Representative examples of *Osmanthus heterophyllus* rooted cuttings size following a spring 2006 extended growth season. C = cool house, W= warm house, no second letter = ambient light, DL day length extension light, SL supplementary light, (Vertical ruler =30 cm; horizontal ruler = 70cm)

April 2006



September 2006

Plate 17 Representative examples of *Osmanthus heterophyllus* rooted cuttings size in December 2006 following a spring 2006 extended growth season and an autumn 2006 extended growth season. C = cool house, W= warm house, no second letter = ambient light, DL day length extension light, SL supplementary light, (Vertical ruler =30 cm; horizontal ruler = 70cm)

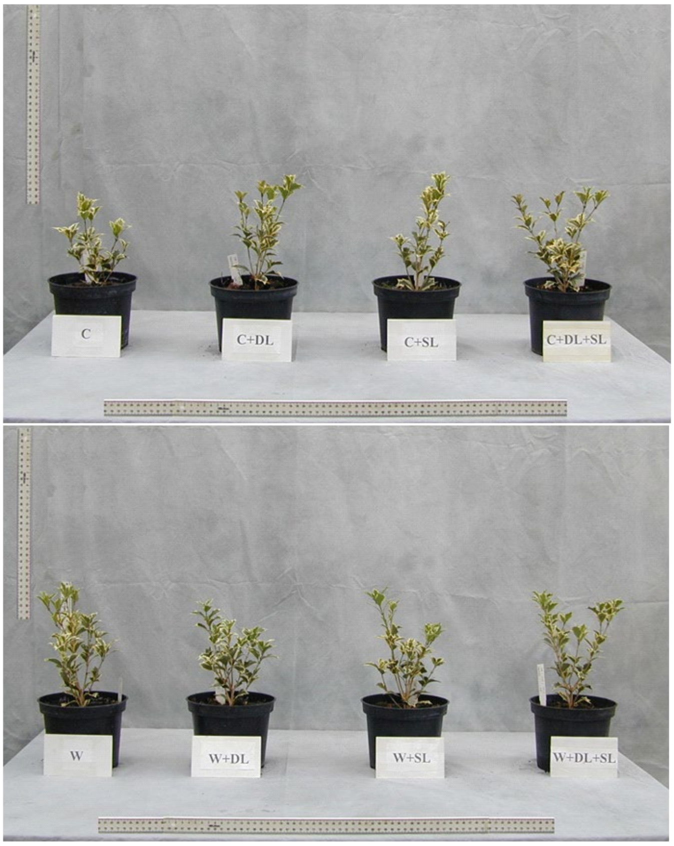


Plate 18 Representative examples of *Osmanthus heterophyllus* rooted cuttings size in May 2007 following a spring 2006 extended growth season, an autumn 2006 extended growth season and a spring 2007 extended growth season. C = cool house, W= warm house, no second letter = ambient light, DL day length extension light, SL supplementary light, P plant grown using a traditional liner method. (Vertical ruler =30 cm; horizontal ruler = 70cm)

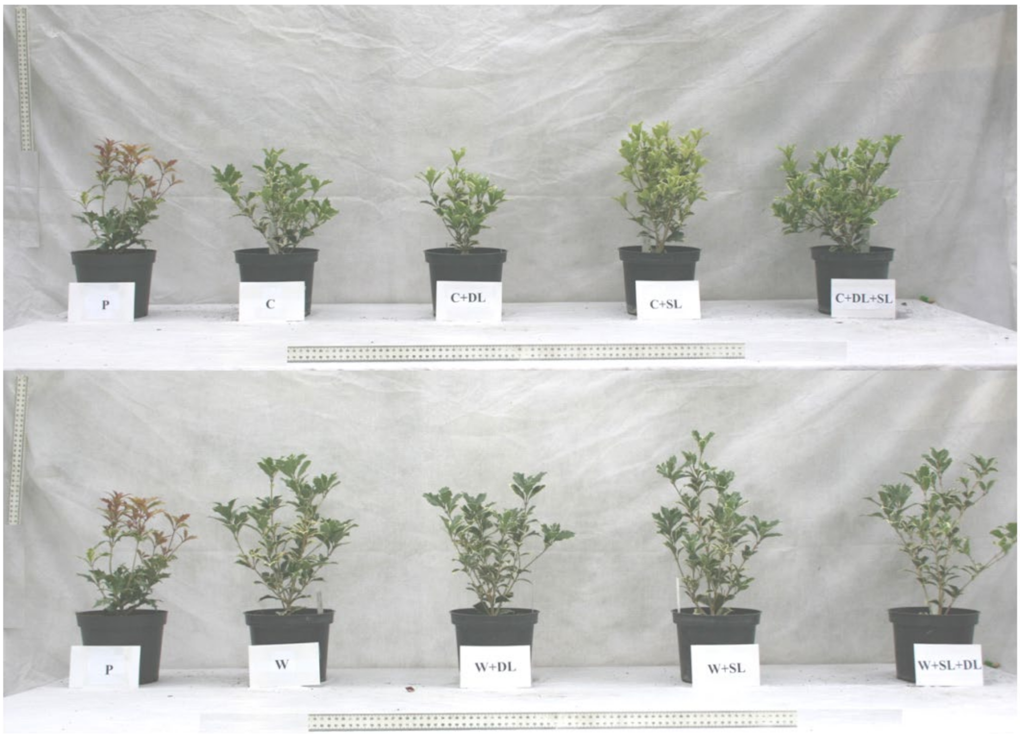


Table 6 The main effects of temperature, supplementary and day length extension light on plant size and number of new shoots (breaks) of *Osmanthus heterophyllus* rooted cuttings following spring extended growth season (May 2006), summer in an unheated glasshouse (end August 2006), autumn extended growth season (December 2006) and spring extended growth season (May 2007)

		Height (cm)				Width (cm)				No. new shoots per plant				Quality
Main effect		May 2006	Aug 2006	Dec 2006	May 2007	May 2006	Aug 2006	Dec 2006	May 2007	May 2006	Aug 2006	Dec 2006	May 2007	May 2007
Temperature	Cool	6	16	24	25	7	14	15	23	0	5	6	21	2
	Warm	10	17	22	27	9	16	16	24	4	7	8	12	2
Probability		***	ns	ns	ns	***	**	**	ns	***	***	**	***	ns
Supplementary light	-	8	16	24	26	8	15	16	23	2	6	7	14	2
	+	8	17	22	27	8	15	15	25	2	7	8	19	2
Probability		ns	ns	ns	ns	ns	ns	ns	*	ns	ns	ns	*	ns
Day length extension light	-	8	16	21	26	8	15	15	24	2	7	8	16	2
	+	8	16	25	26	8	15	16	24	2	6	7	17	2
Probability		ns	ns	ns		*	ns	ns	ns	ns	*	ns	ns	ns
SED[1] (8 d.f)		0.3	0.7	4.1	1.5	0.2	0.4	0.6	1.1	0.2	0.4	0.6	2.0	0.2
Interactions		None	None	None		SL x DL	None	None	T x SL	None	None	None	None	None
Traditional liner[2]				12	30			13	23			11	19	

Probability * is statistically significant (<0.05), ** is highly significant (< 0.01) and *** is very highly significant (< 0.001), ns is not statistically significant
[1]SED for comparison between main effects, [2]traditional liner for comparison was grown for same period in a commercial nursery

***Photinia fraseri* 'Red robin'**

(Figure 7, Table 7, Plates 19, 20, 21)

Key points

- Plants achieved commercial size and sale quality within a production cycle shortened by one year
- Increasing temperature from 5ºC to 15ºC initially increased plant size, but subsequently the plants in the cooler environment were larger
- Supplementary light caused a small increase in plant size, but day length extension light had no effect
- Maintaining a minimum temperature >5ºC during an extended spring, extended autumn and second extended spring almost doubled the size of plants compared to similar aged plants grown for the same period in unheated glass in a commercial nursery

None of the environmental treatments consistently influenced the growth activity of the plants during the whole of the production cycle. The plants in the cool and the warm environments started to grow at the same time, but the rate of growth was greater for the plants in the warm environment as they were taller (3 cm) and wider (1 cm) by late April. Following the autumn application of the warming treatment no differences in the size of the plant or production of new shoots occurred. Surprisingly, following the second spring application of the warming treatments in 2007, the plants grown in the cool were larger (6 cm taller, 6 cm wider) than those in the warm environment. The number of new shoots produced was unaffected. The warm treatment increased plant quality.

By December 2006, the plants in the experiment at East Malling Research were almost double the size of plants and had more shoots than those of similar age grown under unlit and unheated glass in a commercial nursery. This increase in size continued following the spring environmental treatment and in May 2007 the plant achieved commercial sale size and quality.

Changes in day length had no influence on growth during the whole cycle. The effects of supplementary light were inconsistent, although plants were taller following the autumn and spring applications. Neither light treatment influenced plant quality.

Figure 7 The effect of different environmental conditions on % of *Photinia fraseri* rooted cuttings growing during extended spring 2006, extended autumn 2006 and extended spring 2007 growth seasons. AL Ambient light, DL day length extension light, SL Supplementary light

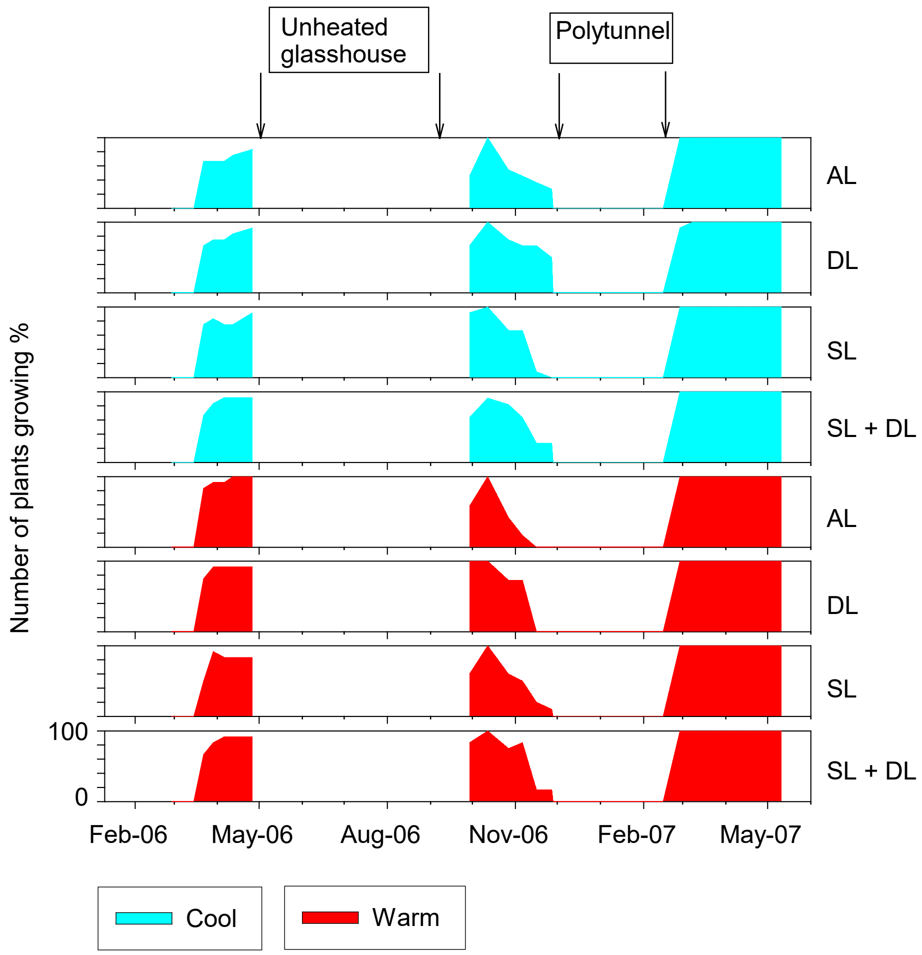
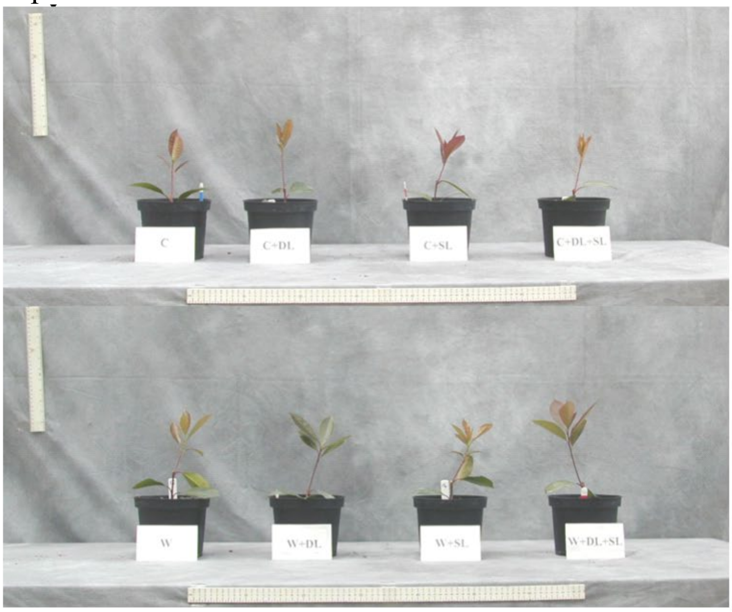


Plate 19 Representative examples of *Photinia fraseri* rooted cuttings size following a spring 2006 extended growth season. C = cool house, W= warm house, no second letter = ambient light, DL day length extension light, SL supplementary light, (Vertical ruler =30 cm; horizontal ruler = 70cm)

April 2006



September 2006

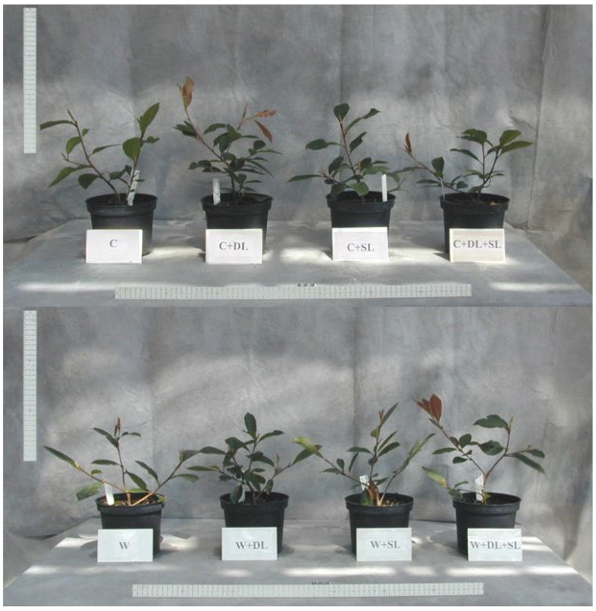


Plate 20 Representative examples of *Photinia fraseri* rooted cuttings size in December 2006 following a spring 2006 extended growth season and an autumn 2006 extended growth season. C = cool house, W= warm house, no second letter = ambient light, DL day length extension light, SL supplementary light. (Vertical ruler =30 cm; horizontal ruler = 70cm)

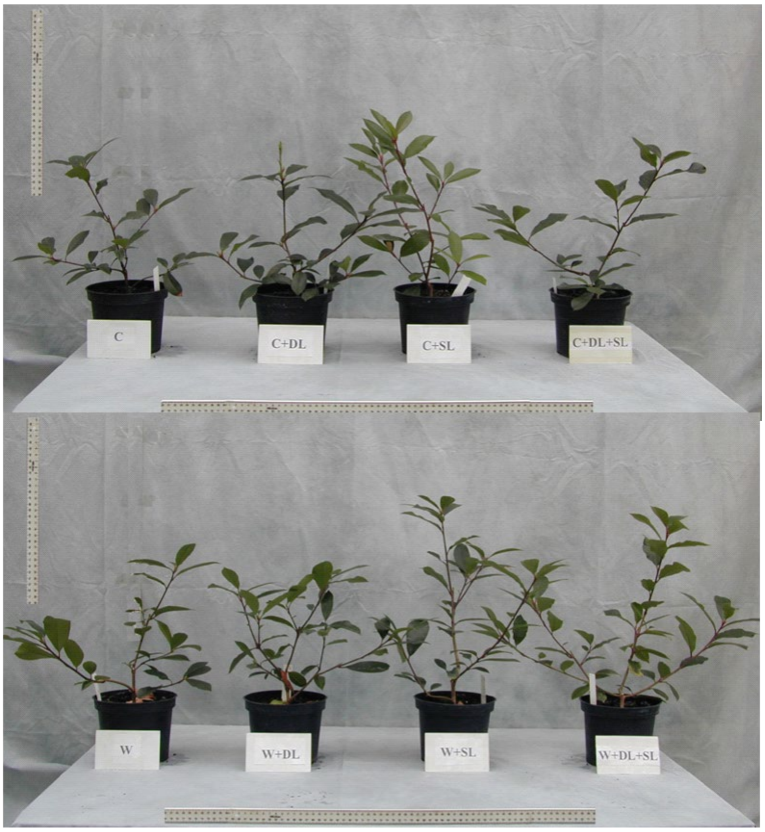


Plate 21 Representative examples of *Photinia fraseri* rooted cuttings size by May 2007 following a spring 2006 extended growth season, an autumn 2006 extended growth season and a spring 2007 extended growth season. C = cool house, W= warm house, no second letter = ambient light, DL day length extension light, SL supplementary light, P plant grown using a traditional liner method. (Vertical ruler =30 cm; horizontal ruler = 70cm)

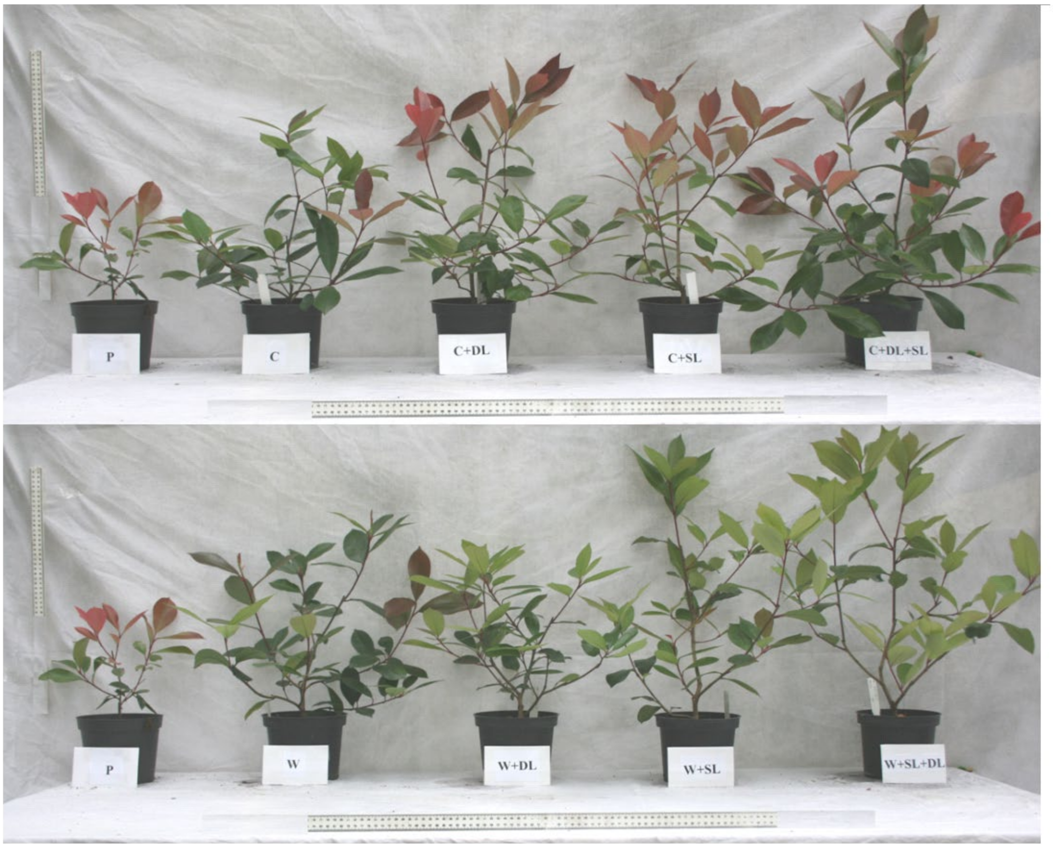


Table 7 The main effects of temperature, supplementary and day length extension light on plant size (height and width) and number of new shoots (breaks) of *Photinia fraseri* rooted cuttings following spring extended growth season (May 2006), summer in an unheated glasshouse (end August 2006), autumn extended growth season (December 2006) and spring extended growth season (May 2007)

		Height (cm)				Width (cm)				No. new shoots per plant				Quality
Main effect		May 2006	Aug 2006	Dec 2006	May 2007	May 2006	Aug 2006	Dec 2006	May 2007	May 2006	Aug 2006	Dec 2006	May 2007	May 2007
Temperature	Cool	16	20	35	49	17	25	40	57	1	3	4	8	1.9
	Warm	19	21	34	43	18	26	41	51	1	3	6	8	2.6
Probability		*	ns	ns	*	*	ns	ns	*	ns	ns	ns	ns	**
Supplementary light	-	17	19	31	44	18	26	41	54	1	3	4	8	2.2
	+	17	22	37	48	17	25	41	55	1	3	4	8	2.3
Probability		ns	*	*	*	ns	ns	ns	ns	ns	ns	ns	ns	ns
Day length extension light	-	17	20	34	47	18	25	40	53	1	3	4	8	2.3
	+	18	20	35	46	17	26	42	56	1	3	5	8	2.2
Probability		ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
SED[1] (8 d.f.)		0.8	0.9	2.6	2.3	0.7	0.9	1.7	1.7	0.1	0.2	0.4	0.6	0.18
Interactions		T x SL	None	None	None	None	None	T x DL X SL	T x DL x SL	None	None	None	None	None
Traditional liner[2]				19	27			20	27			4	5	

Probability * is statistically significant (<0.05), ** is highly significant (< 0.01) and *** is very highly significant (< 0.001), ns is not statistically significant
[1]SED for comparison between main effects, [2]traditional liner for comparison was grown for same period in a commercial nursery

***Pittosporum tenuifolium* 'Goldstar'**

(Figure 8, Table 8, Plate 22, 23, 24)

Key points

- Plants achieved commercial grade out within 12 months of propagation
- Increasing temperature from 5ºC to 15ºC increased plant growth
- The experiment conditions increased the size of plants by 2.5 times compared to those of similar age grown in a commercial nursery
- Supplementary and day length extension light had small and inconsistent effects on growth and no effect on plant quality

The plants were slow to initiate growth with no activity within the first month after placement into the experimental environments. All plants in the warm environments were growing by the end of March. Generally, most of the plants in the cool environment did not become active until late April. Therefore, it was not surprising that the warm environment produced larger plants that had greater mean height (2 cm) and width (2 cm) than those in the cool environment. Neither supplementary nor day length extension light influenced growth activity or plant size.

Following their period in the unheated glasshouse during the summer, the plants continued to grow. By September most of the treatment size differences caused by the environments in spring had disappeared. In the opinion of the project grower coordinators the plants had reached 'commercial size' by 25 September 2006. Therefore, they were transferred into a glasshouse maintained at >5ºC on 3 October 2006. They were transferred to an unheated polytunnel on 15 December 2006 and remained there until May 2007.

By December, the plants which had received the warming treatment in early spring and briefly in September were larger than those that remained in the cool treatment, but the number of new shoots per plant was not significantly different. Despite having received no further treatment after early October, the plants grown in the warm environment had higher quality than those in the cool environment by May 2007. Compared to plants of similar age produced in a commercial nursery in 9 cm pots under ambient conditions, the plants were approximately 2.5 times taller and wider and had four times as many new shoots in December 2006.

The main effects of the two different light treatments on growth and quality were either small or non-significant after May 2006.

Figure 8 The effect of different environmental conditions on % of *Pittosporum tenuifolium* rooted cuttings growing during extended spring 2006. AL Ambient light, DL day length extension light, SL Supplementary light

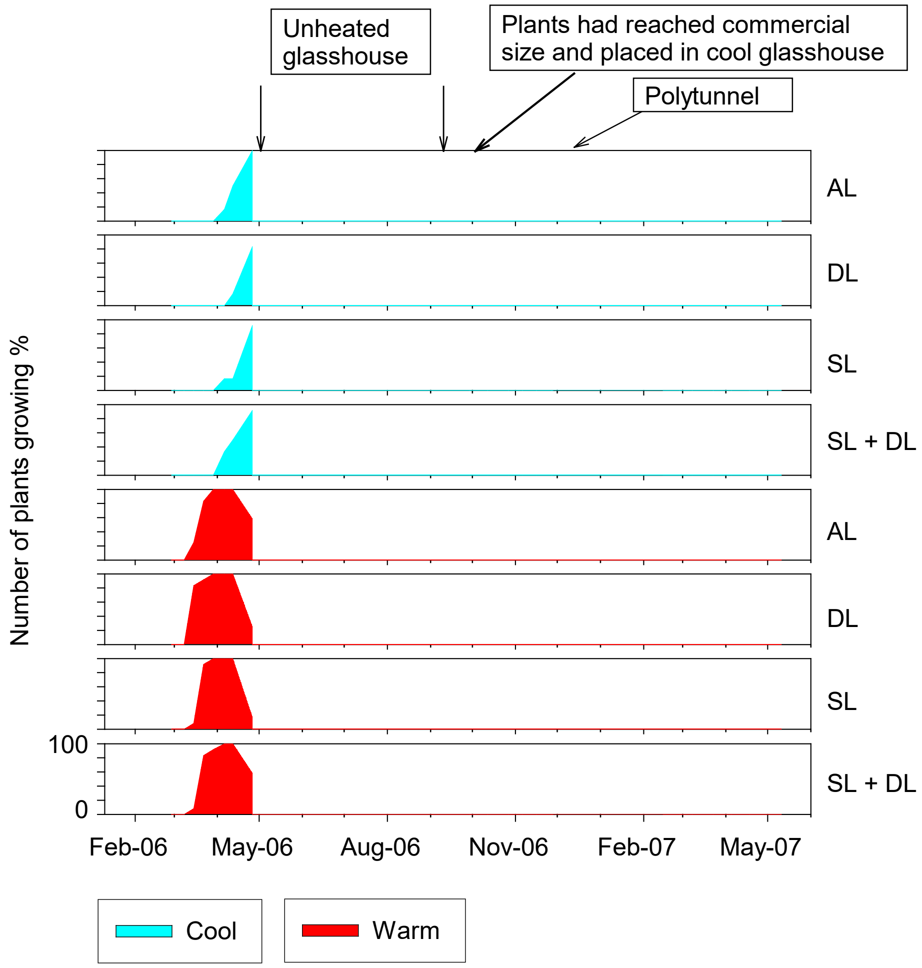
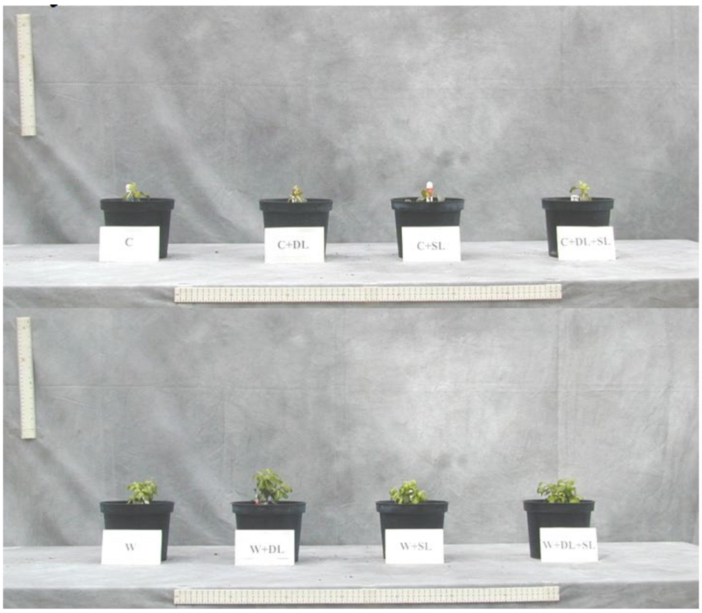


Plate 22 Representative examples of *Pittosporum tenufolium* rooted cuttings size following a spring 2006 extended growth season. C = cool house, W= warm house, no second letter = ambient light, DL day length extension light, SL supplementary light, (Vertical ruler =30 cm; horizontal ruler = 70cm)

April 2006



September 2006

Plate 23 Representative examples of *Pittosporum tenufolium* rooted cuttings size in December 2006 following a spring extended growth season. C = cool house, W= warm house, no second letter = ambient light, DL day length extension light, SL supplementary light, (Vertical ruler =30 cm; horizontal ruler = 70cm)

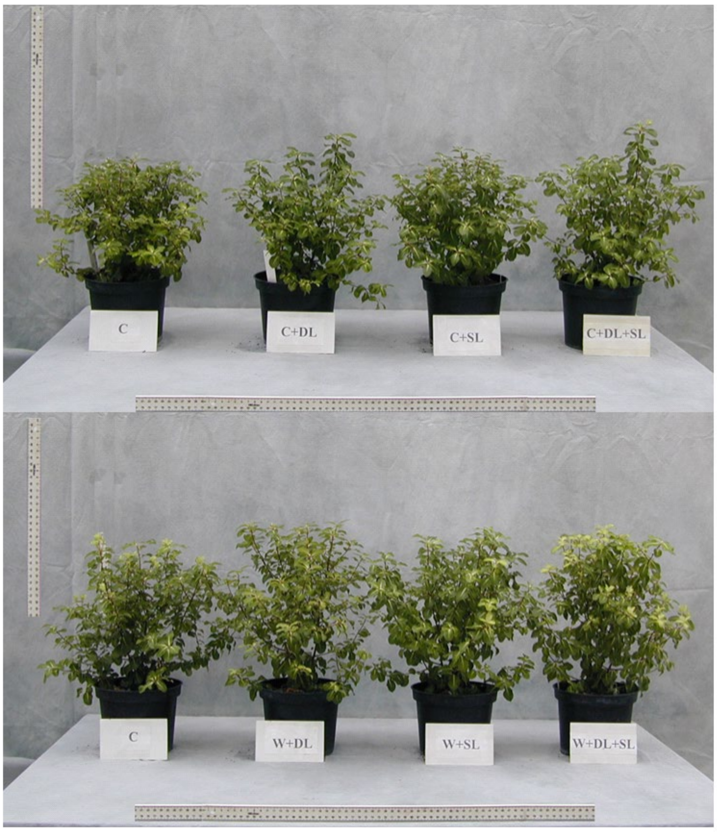


Plate 24 Representative examples of *Pittosprum tenufolium* rooted cuttings size in May 2007 following a spring extended growth season in 2006. C = cool house, W= warm house, no second letter = ambient light, DL day length extension light, SL supplementary light, P plant grown using a traditional liner method. (Vertical ruler =30 cm; horizontal ruler = 70cm)

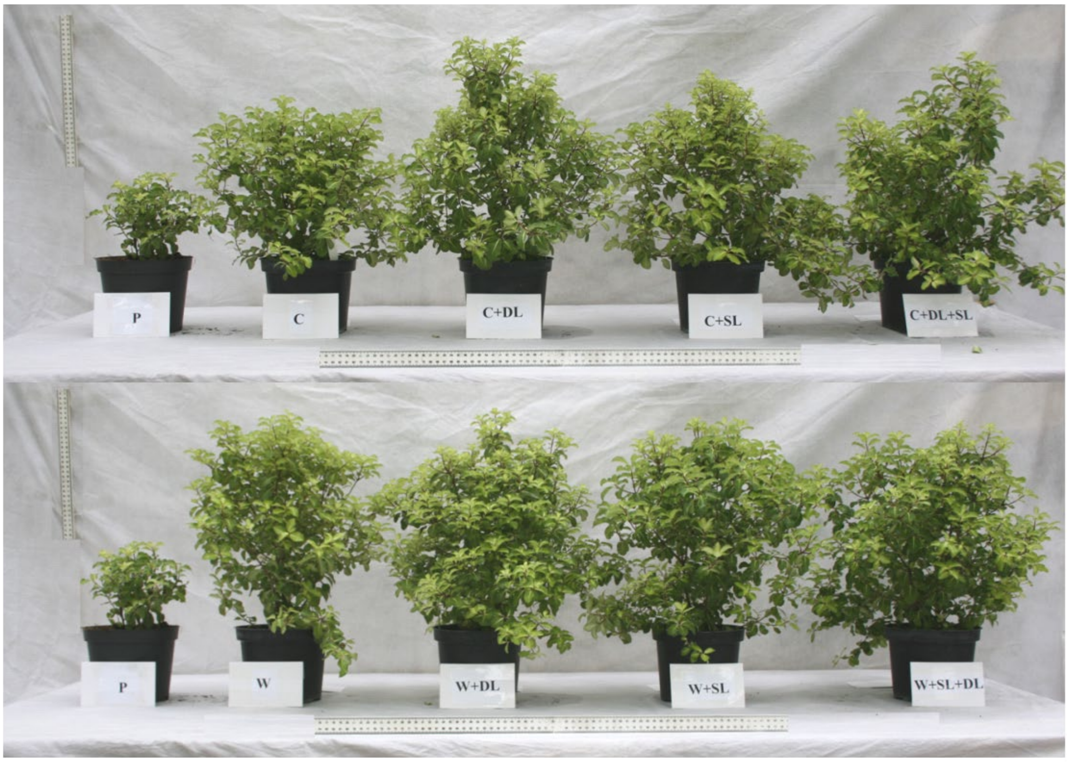


Table 8 The main effects of temperature, supplementary and day length extension light on plant size (height and width) and number of new shoots (breaks) of *Pittosporum tenuifolium* rooted cuttings following spring extended growth season (May 2006), summer in an unheated glasshouse (September 2006), autumn in an unheated glasshouse with no additional lighting (December 2006) and spring in a polytunnel with no additional lighting (May 2007)

		Height (cm)				**Width (cm)**				**No. new shoots per plant**			**Quality**
Main effect		May 2006	Aug 2006	Dec 2006	May 2007	May 2006	Aug 2006	Dec 2006	May 2007	May 2006	Aug 2006	Dec 2006	May 2007
Temperature	Cool	5	19	29	39	7	24	33	38	1	27	53	2.0
	Warm	7	23	31	38	9	27	35	41	5	36	67	2.5
Probability		***	**	ns	ns	***	**	*	***	***	***	ns	*
Supplementary light	-	6	22	31	40	8	26	35	40	3	31	57	2.3
	+	6	21	29	37	8	25	34	39	3	32	64	2.1
Probability		ns	ns	ns	*	ns	ns	ns	ns	ns	ns	ns	ns
Day length extension light	-	6	22	30	38	8	26	35	39	3	32	61	2.2
	+	7	21	30	39	8	25	33	40	3	32	59	2.2
Probability		*	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
SED[1] (8 d.f.)		0.1	1.0	1.3	1.2	0.3	0.9	0.8	0.7	0.3	2.2	8.0	0.18
Interactions		SL x DL	None	None	T x DL	None	None	None	SL x DL	SL x DL	None	None	None
Traditional liner[2]				12	20			14	21			16	

Probability * is statistically significant (<0.05), ** is highly significant (< 0.01) and *** is very highly significant (< 0.001), ns is not statistically significant
[1]SED for comparison between main effects, [2]traditional liner for comparison was grown for same period in a commercial nursery

Financial benefits

The major aim of this project was to determine whether HNS plants could be ready for sale over a 3, rather than 4 year production cycle, by use of appropriate techniques. This would have clear economic advantages, in that a crop could be produced for sale more rapidly, with a 1.4 times as rapid turnover. However, the use of heating and lighting entails significant energy costs. Therefore, whether or not application of the techniques used in this project is economically feasible depends on whether the extra income from the earlier sales is greater than the combined costs of the extra consumables and of the energy inputs.

There are also other factors which play a role. The more rapidly produced crop may require more or less input in terms of labour, irrigation, pesticides, etc. Light/heat treatments may cause additional pruning costs or greater use of water while those treatments are being applied. Traditional production will require a whole extra year of maintenance, irrigation, and use of space that could be used for new stock.

During this experiment plants were propagated in Year 1 (autumn 2005), *Aucuba japonica* and *Osmanthus heterophyllus* were exposed to approximately 36 weeks of treatments. This was over Year 2 (spring and autumn treatments, 2006) and Year 3 (spring treatment, 2007). *Photinia fraseri* and *Camellia japonica* were exposed to approximately 31 weeks of treatments (the same periods as above, but a slightly shorter treatment in spring of Year 2). *Hydrangea macrophylla*, *Pittosponum tenuifolium*, *Choisya ternata* and *Cytisus scoparius* were only given the treatments in spring of Year 2, and then left in a polytunnel or cool glasshouse. This was because the project grower coordinators felt that they had reached sale size by September 2006. They therefore only had about 12 weeks of treatments.

In the supplementary light treatment (five SONTs per bench providing 20W per m^2 (i.e. 9000 lux), supplementary light was used from 8 am until 4 pm. This is 8 hours of lighting per day, yielding total lighting hours of approximately 2,016 hours (i.e. 8 h x 7 d x 36 wk) for *Aucuba japonica* and *Osmanthus heterophyllus*, 1,736 hours for *Photinia fraseri* and *Camellia japonica*, and 672 hours for *Hydrangea macrophylla*, *Pittosporum tenuifolium*, *Choisya ternata* and *Cytisus scoparius*. These numbers of hours of supplementary lighting, scaled up to a hectare, would cost about £37k for *Hydrangea macrophylla*, *Pittosporum tenuifolium*, *Choisya ternata* and *Cytisus scoparius*, about £110k for *Photinia fraseri* and *Camellia* *japonica*, and about £123k for *Aucuba japonica* and *Osmanthus heterophyllus*. Costs were calculated for each treatment based on appropriate energy cost data kindly supplied by John Adlam and could only be reduced if some of the supplementary lighting was provided during off-peak hours (before 7 am), or over fewer weeks.

In the day length extension light treatment (8 × 60 W tungsten spot lights per bench), lighting was provided to ensure 15.5 hours of day length. All plants in this treatment received approximately 223 hours of day length extension light in the spring of Year 2, except for *Photinia fraseri* and *Camellia japonica* which received about 100 hours of day length extension light at that time. *Aucuba japonica*, *Photinia fraseri*, *Osmanthus heterophyllus* and *Camellia japonica* received an additional 425 hours the following autumn and 291 hours in spring of Year 3. In total, then, *Hydrangea macrophylla*, *Pittosporum tenuifolium*, *Choisya* and *Cytisus scoparius* received about 223 hours of day length extension light, *Photinia fraseri* and *Camellia japonica* received about 816 hours, and *Aucuba japonica* and *Osmanthus heterophyllus* received about 939 hours. Of these hours, 87.5 were off-peak for *Hydrangea macrophylla*, *Pittosporum tenuifolium*, *Choisya* and *Cytisus scoparius*, 201 were off-peak for *Photinia fraseri* and *Camellia japonica*, and 210 were off-peak for *Aucuba japonica* and *Osmanthus heterophyllus*. The remaining peak hours are more expensive. In total, scaled up to a glasshouse of 1 hectare, this would mean total day length extension lighting costs of £1k for *Hydrangea macrophylla*, *Pittosporum tenuifolium*, *Choisya* and *Cytisus scoparius*, of £4k for *Photinia fraseri* and *Camellia japonica*, and £7.6k for *Aucuba japonica* and *Osmanthus heterophyllus*. These costs were calculated per treatment based on appropriate energy cost data provided by John Adlam. The costs entailed in using day length extension light are clearly far less than in using supplementary light. This relates both to fewer hours of lighting and the lower energy requirement. The capital investment in supplementary (SONT) light would also be much greater than for tungsten light.

The environments in the glasshouse had set points of either 5°C or 15°C. The costs per m^2 to heat a glasshouse to 5°C or to 15°C from outside temperatures below temperatures these using gas or oil were supplied by John Adlam. Multiplying these values by the number of hours when the outside temperature was below the relevant set point at East Malling Research provides the total cost of heating. For *Cytisus scoparius, Choisya ternata*, *Hydrangea macrophylla* and *Pittosporum tenuifolium* plants, heating the glasshouse to 5°C in spring 2006 would have cost £3.9k per hectare if gas was used and £4.9k if oil was used. Based on 25 pots per m^2, these costs are in the range of 1.5 p to 1.9 p per plant. If a hectare of glasshouse at East Malling Research was kept at >5°C for the entire 36 weeks in which *Aucuba japonica* and *Osmanthus heterophylla* plants were kept in the cool environment, heating would have cost more than £10k if gas was used or almost £13k if oil was used; to heat the to 15°C would have cost £87-111k for this length of time.

Hydrangea macrophylla, *Pittosporum tenuifolium*, *Choisya ternata* and *Cytisus scoparius* were considered to have reached sale quality and size in September 2006, even those that were kept in the cool glasshouse with only ambient lighting. Clearly, therefore, the costs of lighting would be unnecessary expenses. It would be interesting to determine the effects of merely keeping the plants in an unheated glasshouse, or of using the light treatments but in the absence of heat. Although energy costs are the obvious financial issue with the treatments used in this project, economic viability may in fact hinge on whether labour costs are affected by the treatments. For example Hodges *et al.* (2001) broke nursery costs down to a per dollar value produced and found that labour costs were the highest (this excludes management) – about $0.35/$ – and the next highest items were supplies and overheads. Facilities and equipment costs were relatively low – about $0.05/$. Other costs listed were management, depreciation and interest. The magnitude of labour costs relative to all other costs is repeated over and over again by growers in the UK.

Whether the additional costs are economic is dependent on the profit margin of increasing the throughput of plants. Unfortunately, despite various enquiries we have not managed to determine the profit obtained on each of the varieties used. This is because there appears to be little or no knowledge in the industry as to the profit associated with different species. The profit margin will depend on the cost of the liner for a given species/cultivar, and the price at which the plant can be sold, and in particular the cost of bringing it from liner to sale stage.

In this experiment, *Osmanthus heterophyllus* did not reach the required size when a year was taken out of production. It is essential to take an entire year, rather than part of a year, out of production, as otherwise key marketing dates will be missed. Therefore, in the case of *Osmanthus heterophyllus*, the use of heated glasshouse facilities or supplementary or extension lighting, is definitely not cost-effective.

It should also be noted that several species/cultivars were screened in the first year of the project, and many did not respond to heat or light treatments. Therefore, it is unlikely that any nursery would wish to use heated glasshouses or light treatments for their entire production. Heat or light could be used in perhaps one relatively small area of the nursery, for those plants which respond well to such treatments, and which are sufficiently valuable to justify the extra energy costs. Over a small area the costs indicated above would be much reduced and may be feasible.

Experiment 5 - Effects of autumn *versus* spring warmth

***Azalea japonica* 'Santa Maria'**

(Figure 9, Plate 25, Table 9)

Key Points

- Application of warmth in spring was the most effective treatment as it increased plant size by approximately 90% compared to plants at ambient temperature in a polytunnel
- Autumn warmth increased plant size by approximately 5%
- Day length extension light and supplementary light were much less effective than early spring warmth for increasing plant size

All plants in the polytunnel ambient conditions continued to grow between September and October 2006, whereas some of those receiving the autumn warming treatment, in the absence of day length extension light, stopped growing during November. Subsequently all of the plants receiving warmth in February 2007 started growing within 2 weeks of the application of heat, whereas those in the polytunnel did not start growing until late March early April. One exception was those plants that had received warmth and supplementary light in the autumn which also started to grow in mid February. Plants that had received warmth in the autumn, only started to grow about one month later in the polytunnel than those which had received no warmth previously.

Application of warmth in the spring had a much larger effect on increasing plant size than application in autumn. By May those plants that had received warmth in the spring were on average 17 cm taller and 37 cm wider than those which had remained in the polytunnel. The plants that received the warming treatment only in the autumn were 4 cm taller and 6 cm wider than those that received no additional heat. Although, the combined treatment produced the largest plants, this was due predominantly to the effect of the spring warmth. Plants receiving warming in spring only had the highest visual quality.

The main effects of either of the supplementary or the day length extension light treatments were small and not significant.

Figure 9 The effect of autumn and spring warmth (set point >15ºC) *versus* ambient and different light conditions on % of *Azalea japonica* liners growing during extended autumn 2006 and spring 2007. Polytunnel no warmth or light treatments, AL ambient light, DL day length extension light, SL supplementary light, A- no autumn warmth, A+ autumn warmth, S- no spring warmth, S+ spring warmth

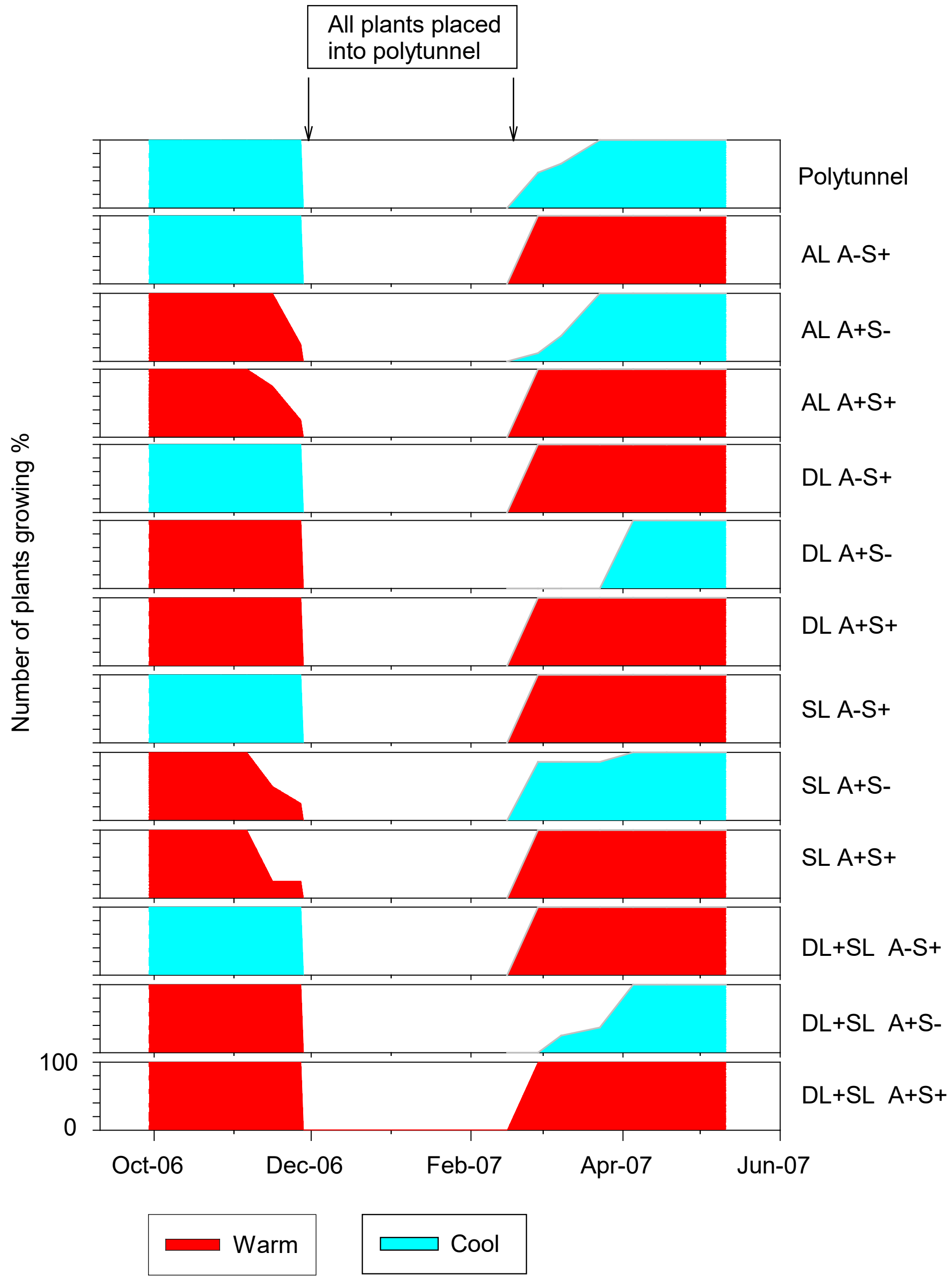
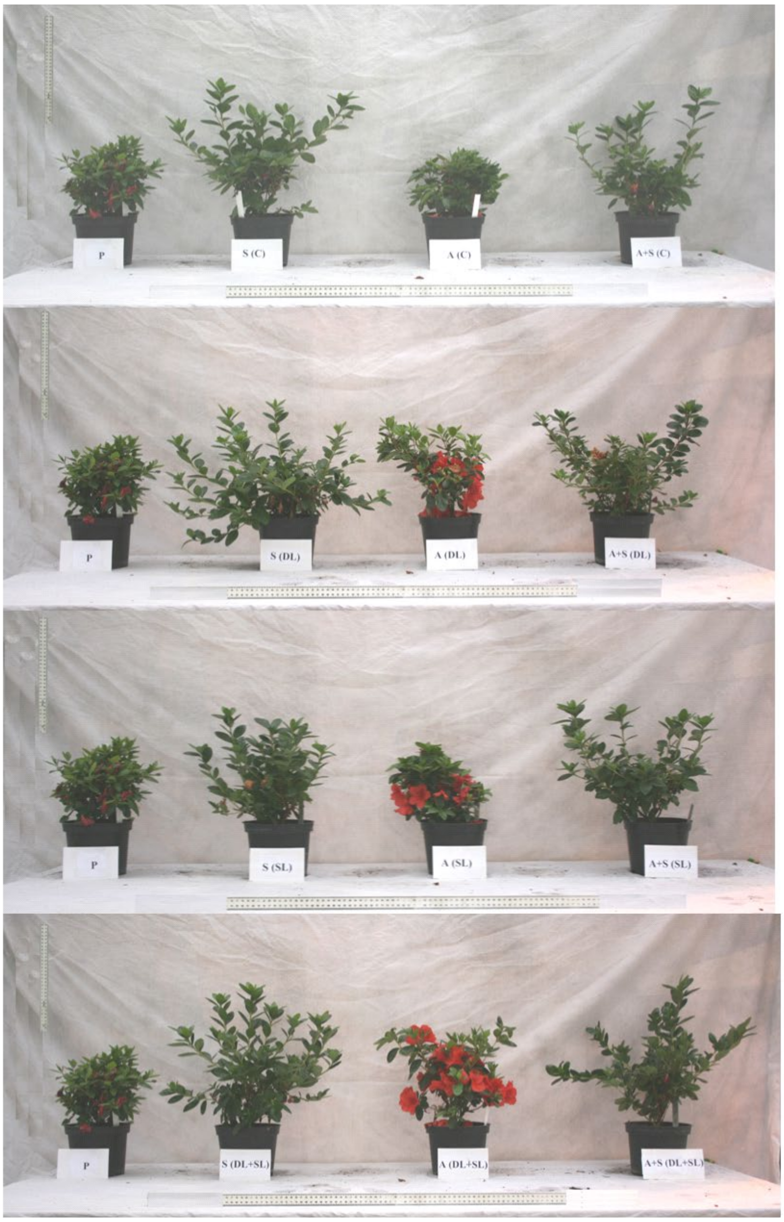


Plate 25 Examples of *Azalea japonica* liners size in May 2007 showing the effects of autumn and spring warmth (set point >15°C) *versus* plants at ambient in a polytunnel and different light conditions. (Horizontal ruler length = 70 cm, vertical ruler = 30 cm)

Polytunnel | Spring warmth | Autumn warmth | Spring and autumn warmth



Ambient light

Day length extension light

Supplementary light

Day length extension and supplementary light

Table 9, a, b, c, d The effect of autumn and spring warmth (set point >15°C) *versus* ambient and different light conditions on the plant height, width numbers of new shoots and quality of *Azalea japonica* liners in May 2007

a) Height (cm)

	Warmth				Mean
	None	Spring only	Autumn only	Autumn + spring	
Ambient light	21	39	22	40	**33**
Day length extension light		39	27	42	**36**
Supplementary light		36	21	38	**32**
Day length extension and supplementary light		37	29	44	**36**
Mean	**21**	**38**	**25**	**41**	
Light Probability SED 110 d.f.	**ns 1.1**	For comparing main effects (bold type)			
Warmth Probability SED 110 d.f.	***** 1.0**				

Probability * is statistically significant (<0.05), ** is highly significant (< 0.01) and *** is very highly significant (< 0.001), ns is not statistically significant

b) Width (cm)

	Warmth				Mean
	None	Spring	Autumn	Autumn + spring	
Ambient light	51	85	53	88	**75**
Day length extension light		88	58	89	**78**
Supplementary light		88	53	86	**76**
Day length extension and supplementary light		91	63	100	**84**
Mean	**51**	**88**	**57**	**91**	
Light Probability SED 110 d.f.	**ns 2.6**	For comparing main effects (bold type)			
Warmth Probability SED 110 d.f.	***** 2.3**				

Probability * is statistically significant (<0.05), ** is highly significant (< 0.01) and *** is very highly significant (< 0.001), ns is not statistically significant

c) Number of new shoots per plant

	Warmth				Mean
	None	Spring	Autumn	Autumn + spring	
Ambient light	29	24	33	23	**26**
Day length extension light		24	20	24	**23**
Supplementary light		30	26	26	**27**
Day length extension and supplementary light		24	20	24	**25**
Mean	**29**	**26**	**25**	**25**	
Light **Probability** **SED 110 d.f.**	**ns** **1.8**	For comparing main effects (bold type)			
Warmth **Probability** **SED 110 d.f.**	**ns** **1.5**				

Probability * is statistically significant (<0.05), ** is highly significant (< 0.01) and *** is very highly significant (< 0.001), ns is not statistically significant

d) Quality (1=low, 3 = high)

	Warmth				Mean
	None	Spring	Autumn	Autumn + Spring	
Ambient lighting	1.9	2.3	2.3	1.8	**2.1**
Day length extension light		2.5	2.0	1.4	**2.0**
Supplementary light		2.5	2.5	2.4	**2.5**
Day length extension and supplementary light		2.6	1.8	1.3	**1.9**
Mean	**1.9**	**2.5**	**2.1**	**1.7**	
Light **Probability** **SED 110 d.f.**	**n.s** **0.24**	For comparing main effects (bold type)			
Warmth **Probability** **SED 110 d.f.**	****** **0.20**				

Probability * is statistically significant (<0.05), ** is highly significant (< 0.01) and *** is very highly significant (< 0.001), ns is not statistically significant

Convolvulus cneorum

(Figure 10, Plate 26, Table 10)

Key Points

- Application of warmth in spring was the most effective treatment at increasing plant size. Plants were 50-70% larger than those kept at ambient temperature in a polytunnel
- Autumn warmth only increased plant size by approximately 20-35%
- Day length extension light and supplementary light were less effective than early spring warmth for increasing plant size

Plants in the ambient conditions of the polytunnel ceased growing during mid November whereas those receiving the autumn warmth treatment continued to grow until the warmth was switched off. Likewise, when the spring warmth treatment was applied the plants responded very quickly compared to the plants remaining in the polytunnel. The latter condition delayed the start of growth by approximately 2 weeks. The light treatments did not influence the end of growth in the autumn or the start of growth in the spring.

The application of spring warmth had a large effect on plant size by May 2007. Compared to plants left in the polytunnel, these plants were on average 12 cm taller, 42 cm wider and had produced 9 more shoots per plant. Autumn application of warmth had a smaller effect on increasing growth as the plants were only 5 cm taller, 21 cm wider and produced one more shoot per plant than those in the polytunnel. Thus, the larger plants produced as a result of the autumn and spring applications of warmth were due predominantly to the effect of the spring warmth. However, autumn application of warmth reduced plant quality compared to spring or no application.

For the plants grown in the glasshouse, the light treatments also influenced growth, but the effects were much smaller than those achieved from the spring application of warmth. Day length extension light was more effective than supplementary light. Neither light treatment significantly affected plant quality.

Figure 10 The effect of autumn and spring warmth (set point >15ºC) *versus* ambient and different light conditions on % of *Convolvulus cneorum* liners growing during extended autumn 2006 and spring 2007. Polytunnel no warmth or light treatments, AL ambient light, DL day length extension light, SL supplementary light. A- no autumn warmth, A+ autumn warmth, S- no spring warmth, S+ spring warmth

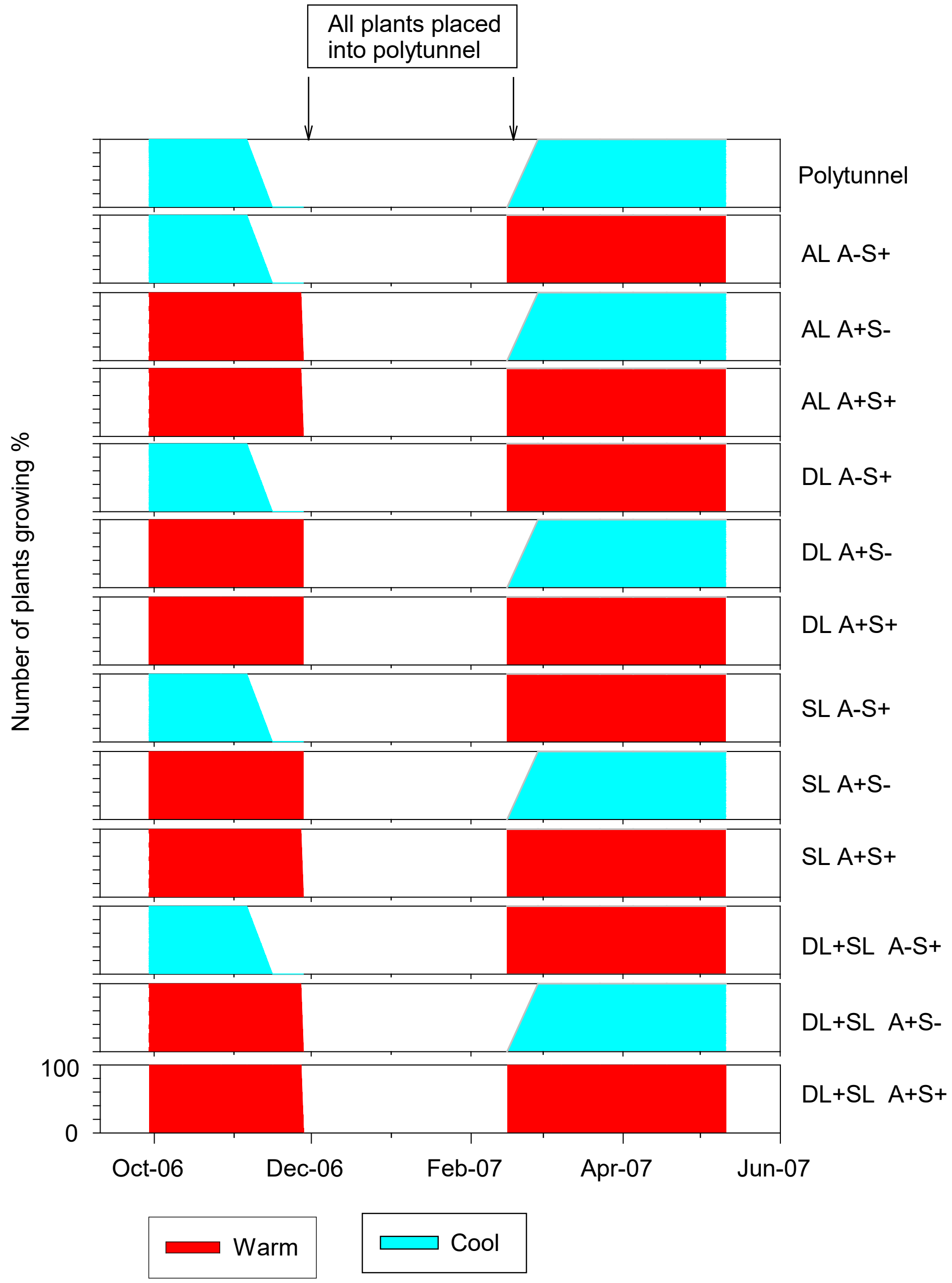


Plate 26 Examples of *Convolvulus cneorum* liners size in May 2007 showing the effects of autumn and spring warmth (set point >15°C) *versus* plants at ambient in a polytunnel and different light conditions. (Horizontal ruler length = 30 cm, vertical ruler = 70 cm)

Polytunnel | Spring warmth | Autumm warmth | Spring and autumn warmth

Ambient light

Day length extension light

Supplementary light

Day length extension and supplementary light

Table 10 a, b, c, d The effect of autumn and spring warmth (set point >15ºC) *versus* ambient and different light conditions on the height, width, number of shoots per plant and quality of *Convolvulus cneorum* liners in May 2007

a) Height (cm)

	Warmth				**Mean**
	None	Spring	Autumn	Autumn + spring	
Ambient light	24	37	27	37	**33**
Day length extension light		40	26	40	**36**
Supplementary light		29	30	28	**29**
Day length extension and supplementary light		37	32	37	**35**
Mean	**24**	**36**	**29**	**35**	
Light Probability SED 110 d.f.	****** **0.9**	For comparing main effects (bold type)			
Warmth Probability SED 110 d.f.	******* **0.8**				

Probability * is statistically significant (<0.05), ** is highly significant (< 0.01) and *** is very highly significant (< 0.001), ns is not statistically significant

b) Width (cm)

	Warmth				**Mean**
	None	Spring	Autumn	Autumn + spring	
Ambient light	59	97	79	106	**94**
Day length extension light		109	82	119	**103**
Supplementary light		99	78	102	**93**
Day length extension and supplementary light		100	80	106	**96**
Mean	**59**	**101**	**80**	**108**	
Light Probability SED 110 d.f.	**ns** **2.8**	For comparing main effects (bold type)			
Warmth Probability SED 110 d.f.	******* **2.4**				

Probability * is statistically significant (<0.05), ** is highly significant (< 0.01) and *** is very highly significant (< 0.001), ns is not statistically significant

c) Number of shoots per plant

	Warmth				**Mean**
	None	Spring	Autumn	Autumn + spring	
Ambient light	22	29	28	42	**33**
Day length extension light		31	20	24	**25**
Supplementary light		34	22	37	**31**
Day length extension and supplementary light		30	21	38	**30**
Mean	**22**	**31**	**23**	**34**	
Light Probability SED 110 d.f.	**** 1.5**	For comparing main effects (bold type)			
Warmth Probability SED 110 d.f.	***** 1.3**				

Probability * is statistically significant (<0.05), ** is highly significant (< 0.01) and *** is very highly significant (< 0.001), ns is not statistically significant

c) Quality (1 = low, 3 =high)

	Warmth				**Mean**
	None	Spring	Autumn	Autumn + Spring	
Ambient light	2.5	2.4	2.6	2.6	**2.5**
Day length extension light		2.8	1.4	1.5	**1.9**
Supplementary light		2.9	2.7	2.0	**2.5**
Day length extension and supplementary light		2.8	1.7	2.0	**2.2**
Mean	**2.5**	**2.7**	**2.1**	**2.0**	
Light Probability SED 110 d.f.	**ns 0.19**	For comparing main effects (bold type)			
Warmth Probability SED 110 d.f.	***** 0.16**				

Probability * is statistically significant (<0.05), ** is highly significant (< 0.01) and *** is very highly significant (< 0.001), ns is not statistically significant

Viburnum tinus

(Figure 11, Plates 27, Table 11)

Key Points

- Application of warmth in spring had the largest positive effect on plant size
- Day length extension light and supplementary light were less effective than early spring warmth for increasing plant size

All of the environmental treatments had either no or a negligible effect on growth activity during autumn or spring.

The spring warmth treatment had a larger effect on increasing plant size than the autumn treatment. By May the plants receiving warmth in spring were 10 cm taller, 17 cm wider and had 3 more shoots per plant than those in the polytunnel. Plants that received warmth only in the autumn were slightly (4 cm) taller, than those in the polytunnel, but in other respects were similar. Plant quality was lowest for the plants that received autumn and spring and warmth, but did not differ between polytunnel and plants that received warmth in spring only.

Both of the light treatments increased plant size, but the effects were small and had no influence on plant quality.

Figure 11 The effect of autumn and spring warmth (set point >15ºC) *versus* ambient and different light conditions on % of *Viburnum tinus* liners growing during extended autumn 2006 and spring 2007. Polytunnel no warmth or light treatments, AL ambient light, DL day length extension light, SL supplementary light, A- no autumn warmth, A+ autumn warmth, S- no spring warmth, S+ spring warmth

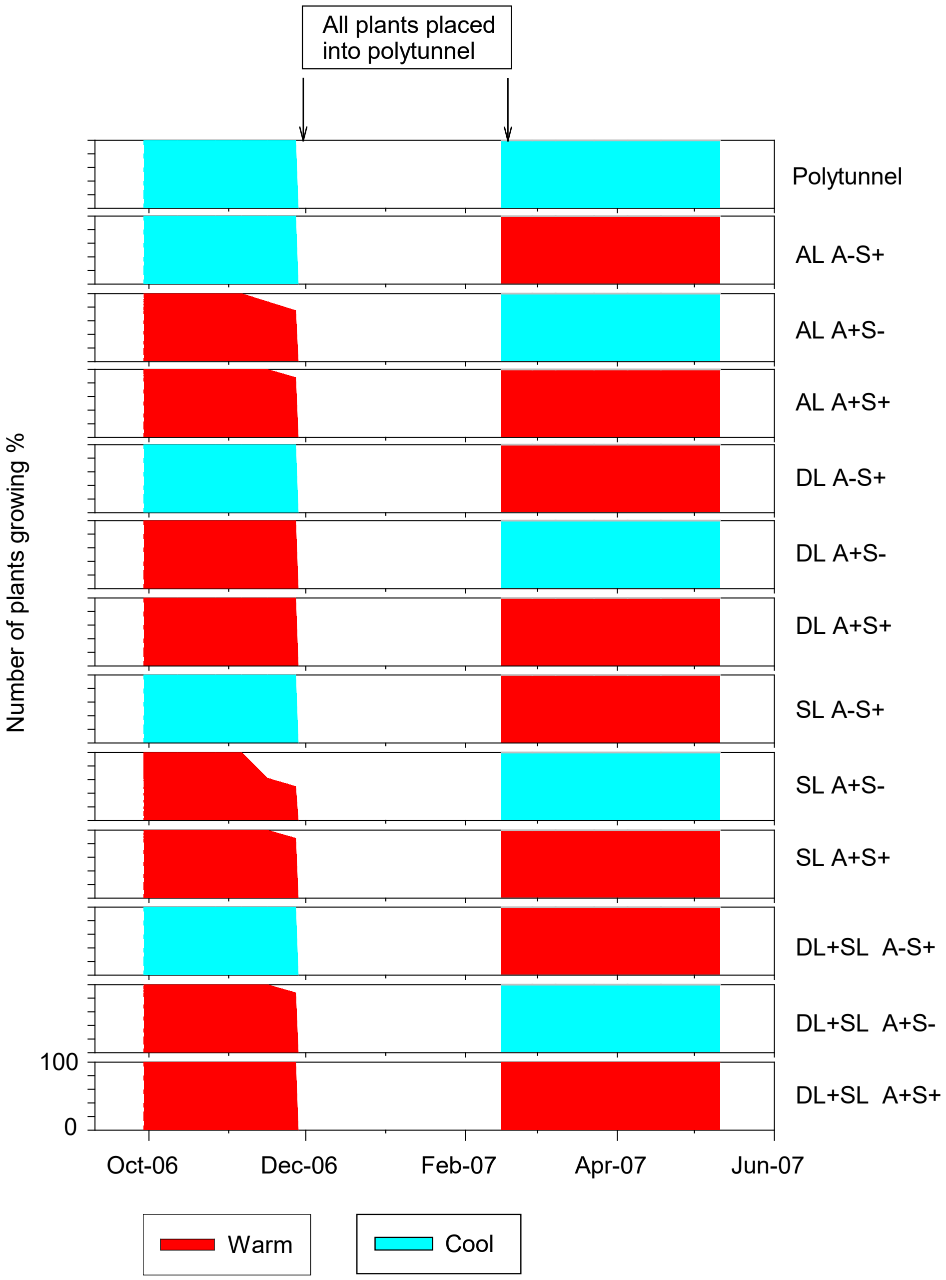


Plate 27 Examples of *Viburnum tinus* liners size in May 2007 showing the effects of autumn and spring warmth (set point >15°C) *versus* plants at ambient in a polytunnel and different light conditions. (Horizontal ruler length = 70 cm, vertical ruler = 30 cm)

Polytunnel | Spring warmth | Autumm warmth | Spring and autumn warmth

Ambient light

Day length extension light

Supplementary light

Day length extension and supplementary light

Table 11 a, b, c, d The effect of autumn and spring warmth (set point >15ºC) *versus* ambient and different light conditions on the growth and quality of *Viburnum tinus* liners in May 2007

a) Height (cm)

	Warmth				**Mean**
	None	Spring	Autumn	Autumn + spring	
Ambient light	34	44	38	46	**43**
Day length extension light		39	38	43	**40**
Supplementary light		42	37	51	**44**
Day length extension and supplementary light		50	41	49	**46**
Mean	**34**	**44**	**38**	**47**	
Light Probability SED 110 d.f.	*** 1.5**	For comparing main effects (bold type)			
Warmth Probability SED 110 d.f.	***** 1.3**				

Probability * is statistically significant (<0.05), ** is highly significant (< 0.01) and *** is very highly significant (< 0.001), ns is not statistically significant

b) Width (cm)

	Warmth				**Mean**
	None	Spring	Autumn	Autumn + spring	
Ambient light	92	101	85	103	**75**
Day length extension light		106	87	112	**78**
Supplementary light		117	87	112	**76**
Day length extension and supplementary light		113	99	115	**84**
Mean	**92**	**109**	**91**	**109**	
Light Probability SED 110 d.f.	**ns 3.2**	For comparing main effects (bold type)			
Warmth Probability SED 110 d.f.	***** 2.8**				

Probability * is statistically significant (<0.05), ** is highly significant (< 0.01) and *** is very highly significant (< 0.001), ns is not statistically significant

c) Number of shoots per plant

	Warmth				Mean
	None	Spring	Autumn	Autumn + spring	
Ambient light	22	22	19	20	**20**
Extension light		24	20	17	**20**
Supplementary light		27	24	25	**25**
Day length extension and supplementary light		27	20	23	**23**
Mean	**22**	**25**	**21**	**21**	
Light Probability SED 110 d.f.	**ns 1.5**	For comparing main effects (bold type)			
Warmth Probability SED 110 d.f.	**** 1.3**				

Probability * is statistically significant (<0.05), ** is highly significant (< 0.01) and *** is very highly significant (< 0.001), ns is not statistically significant

d) Quality (1 =low, 3 = high)

	Warmth				Mean
	None	Spring	Autumn	Autumn + Spring	
Ambient light	2.5	2.3	2.0	1.9	**2.0**
Day length extension light		2.3	2.4	2.0	**2.3**
Supplementary light		2.7	2.3	1.7	**2.3**
Day length extension and supplementary light		2.8	2.8	2.4	**2.5**
Mean	**2.5**	**2.5**	**2.3**	**2.0**	
Light Probability SED 110 d.f.	**ns 1.5**	For comparing main effects (bold type)			
Warmth Probability SED 110 d.f.	**** 0.20**				

Probability * is statistically significant (<0.05), ** is highly significant (< 0.01) and *** is very highly significant (< 0.001), ns is not statistically significant

Conclusions

This project has clearly demonstrated that by modifying the temperature of the growing environment it is possible to take a year out of the production cycle for woody HNS species and that a wide geographical range of species have potential to respond.

In the screening experiment carried out in Year 1, twice as many species responded to the spring warming treatment as the autumn warming treatment despite the fact that the latter was carried out for 28 less days. When the effects of autumn *versus* spring warming were compared directly, it was clear that spring warming was more beneficial to plant growth. This was probably due in part to the nature of the experiment. In spring the differential temperature between the glasshouse environments and outside temperatures was greater. Mean monthly temperatures outside the glasshouse in September, October and November 2006 were 18, 14, and 9ºC respectively and in the warm environment were 20, 17 and 16ºC respectively. Mean monthly temperatures outside the glasshouse in February, March and April 2007 were 7, 8 and 13ºC respectively and in the warm environment they were 16, 17 and 18ºC respectively.

In fact, raising temperature from February until May to above 5°C may be sufficient for accelerating growth. Clear evidence for this is that plants propagated in autumn 2005 and maintained in a glasshouse with a set point 5ºC were substantially larger in December 2006 than those of a similar age grown over the same period grown under unheated glass from a commercial nursery. These differences could have varied with respect to weather conditions, however minimum air temperatures during the experiment were close to the seasonal norms (see Appendix).

Furthermore, in the full production cycle experiment much of the difference in growth caused by raising the temperature from 5˚C to 15˚C between February and May was not evident after the plants had been in the unheated glasshouse until September. This was due to a combination of compensatory (catching up) growth and the pruning treatments. Other factors including pot size, watering regime and availability of nutrients will also influence growth. We used 2 l pots to ensure that sufficient volume of substrate and nutrients were available for the plant during its production and hand watered to optimise water availability. So it is unlikely that these confounded the effects of our environmental treatments.

Our screening method raised the glasshouse set point from 5°C to 15°C and this proved a useful method for determining the influence of temperature on growth. It would probably be uneconomic to maintain this temperature for long periods of time in HNS production. However, when growers are testing their own species, our comparisons with the unheated commercial nursery suggest that raising temperatures above 5°C may be enough to force growth in early spring. This could be used as a more economic and practical screen to test species not included in this project.

No common genetic or geographical factor has been related to the species that have not responded to either day length extension or warmth treatments. Therefore, when using species not included in the experiments reported here it will be necessary to carry out small scale on site trials to evaluate their potential to respond beneficially.

The large additional cost in installing and using supplementary (SONT) during normal daylight hours and the general lack of response of a high proportion of species means that this treatment appears ineffective and is likely to be uneconomic. However, the lack of response to the supplementary light treatment in the EMR experiments may have been because the enhancement of photosynthetically active radiation (PAR) was insufficient to stimulate growth (Appendix). A greater enhancement of PAR may have been beneficial, but would have added further to the cost of this already expensive treatment.

The use of supplementary lighting in an unheated environment was not considered in this project and may be beneficial for some species. Nevertheless, there is a risk that although growth activity will be maintained, the rate of growth at low temperature will be too low to maintain plant size and improve quality.

Clearly, the greater number of plants that any enhanced growth methods can influence will reduce the cost per plant. This points towards trying to enhance growth as early as possible in the production cycle.

Accelerating the initial growth of cuttings during the rooting phase following propagation also was not considered during this project and could be highly beneficial to reducing the production cycle. A technique such as ‘carbohydrate loading’ could be a very cost effective method of accelerating growth, particularly if it does not have a high energy demand.

To enable the benefits of reducing production times to be economically evaluated more is needed to be known about the costs of production of individual woody species. This would then allow rational decisions to be made as to which species are worth the extra investment involved in accelerating their growth.

Technology Transfer

HDC News Article in press.

Technical Road shows for Hardy Nursery Stock Growers:

Lancashire – 21 August 2007
West Midlands – 22 August 2007
East Anglia – 29 August 2007
Kent – 30 August 2007

References

Bailey D.A. & Weiler T.C. (1984). Stimulation of inflorescence expansion in florist hydrangea, *Hydrangea macrophylla* cultivar Merritt's supreme. *Journal American Society for Horticultural Science*, **109**:785-791

Bailey D.A. & Weiler T.C. (1984). Control of floral initiation in florists *Hydrangea macrophylla*. *Journal American Society for Horticultural Science* **109**:785-791

Michigan State University (1966). Firing up Perennials. Formulas for success from Michigan State University. *Greenhouse Grower,* Special Series

Guo Z., Goi M., Tanaka M. & Fukai S. (1995). Effects of temperature and photoperiod on the bud formation of Hydrangea. *Kagawa Daigaku Nogakubu Gakujuysu Hokoku*, **47**:23-31

HDC HNS 65 – Development of scheduling techniques for containerised roses for successional spring and summer sales, 1999

HDC HNS 65a – Roses: predictive model development and testing for flowering in containerised crops, 1999

HDC HNS 69 – Ornamental shrubs: developing the concept of the 'designer liner', 1999

HDC HNS 103 – Hardy herbaceous perennials: A review of techniques for manipulating growth and flowering, 2000

HDC HNS 103a – Hardy herbaceous perennials: Validation of a screening protocol for factors that manipulate flowering, Final Report 2002

Hodges, Satterthwaite & Haydu (2001) Business Analysis of Ornamental Plant Nurseries in Florida (1998) University of Florida p. 13

Litlere B. & Strømme E. (1975). The influence of temperature, day length and light intensity on flowering in Hydrangea macrophylla (thumb.) Ser. Acta Horticulturae, 51:285-298.

Lopez L.C. & Weiler T.C. (1973). Photoperiodic control of growth and flowering of *Hydrangea macrophylla* Ser. *HortScience* **8**:257

Morita M., Iwamoto S & Higuchi H. (1980). Interrelated effect between thermoperiodism and photperiodism on growth and development of ornamental woody plants 5. Modification of photoperiodic response to temperature treatment. *Journal Japanese Society for Horticultural Science* **48**:488-494

Post K. (1942). Effects of day length and temperature on growth and flowering of some florist crops. *Cornell University Agricultural Experimental Station Bulletin*, **787**:1-70

Salisbury F.B. & Ross C.W. (1992). Plant physiology. Wadsworth Publishing Company, Belmont ,California

Shanks J.B. (1987). Development of ornamental crops under split night temperatures. *Journal of American Society for Horticultural Science* **112**:651-657

Yeh D.M. & Chiang H.H. (2003). Effects of temperature on flower formation of *Hydrangea macrophylla* 'Leuchfeuer', *Journal Chinese Society for Horticultural Science* **49**:211-220

APPENDIX – PLANT VISUAL QUALITY ASSESSMENT GUIDE

Aucuba japonica

Parameters: shape, structure, colour

Category 3

1. Round shape (when looked at from above)
2. Even structure, i.e. looked at from the side there are only a few gaps through the plant, and the stems are of similar height
3. Colour of leaves is dark glossy green with yellow speckling

Category 2

One of the shape, structure, colour parameters described in Category 3 is not met, e.g. any of the following:

1. Shape not completely circular
2. Structure uneven, with many gaps in the foliage
3. Colour of leaves is light green or with poor variegation

Category 1

At least two parameters described in Category 3 are not met

Category 1

Category 2

Category 3

Azalea japonica

Parameters: shape, structure, colour

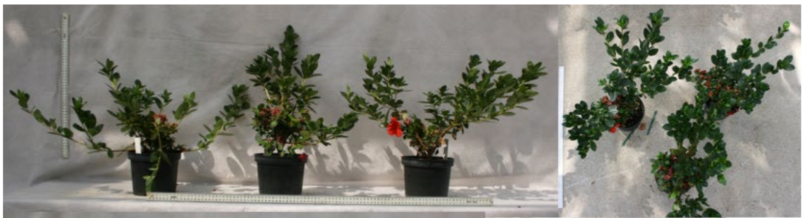
Category 1
At least two parameters described in Category 3 are not met

Category 2
One of the shape, structure, colour parameters described in Category 3 is not met, e.g. any of the following:

4. Shape not completely circular
5. Structure uneven, with many gaps in the foliage
6. Colour of leaves is light green

Category 3

4. Round shape (when looked at from above)
5. Even structure, i.e. looked at from the side there are only a few gaps through the plant, and the stems are of similar height
6. Colour of leaves is dark glossy green



Category 1

Category 2

Category 3

Camellia japonica

Parameters: shape, structure

Category 1
Both parameters described in Category 3 are not met

Category 2
One of the shape, structure, in Category 3 is not met, e.g. any of the following:

1. Shape not completely circular and not covering the pot
2. Structure uneven, poorly defined structure

Category 3

3. Round shape (covering the pot when looked at from above)
4. Even structure, i.e. looked at from the side there is good plant structure

Category 1

Category 2

Category 3

Choisya ternata

Parameters: shape, structure, leaf colour

Category 1
At least two parameters described in Category 3 are not met

Category 2
One of parameters described in Category 3 is not met, e.g. any of the following:

1. Shape not completely circular, some foliage gaps exposing the surface of the pot
2. Structure uneven, branch length irregular across the plant
3. Light green leaves

Category 3
1. Round shape (covering the pot when looked at from above – no obvious foliage gaps and wayward branches in the most recent flush of growth)
2. Even structure, i.e. looked at from the side there is no foliage gaps or very few through the plant, and the stems are of similar height
3. Dark green leaves

Category 1

Category 2

Category 3

Convolvulus cneorum

Parameters: shape, structure

Category 1
Both parameters described in Category 3 are not met

Category 2
One of the shape, structure, colour, flower bud parameters in Category 3 is not met, e.g. any of the following:

1. Shape not completely circular, some foliage gaps exposing surface of the pot
2. Structure uneven, branch length irregular across the plant

Category 3

3. Round shape (covering the pot when looked at from above)
4. Even structure, i.e. looked at from the side there are no foliage gaps or very few through the plant, and the branches are similar lengths

Category 1

Category 2

Category 3

Cytisus scoparius

Parameters: shape, structure, flower buds/flowers

Category 1
At least two parameters described in Category 3 are not met

Category 2
One of the shape, structure, colour, flower bud parameters in Category 3 is not met, e.g. any of the following:

1. Shape not completely circular, some foliage gaps exposing surface of the pot
2. Structure uneven, branch length irregular across the plant
3. Few flowers or flower buts

Category 3

4. Round shape (covering the pot when looked at from above)
5. Even structure, i.e. the branches are similar lengths
6. Large profusion of flowers or flower buds

Category 1

Category 2

Category 3

Hydrangea macrophylla

Parameters: shape, structure, leaf colour, flower bud

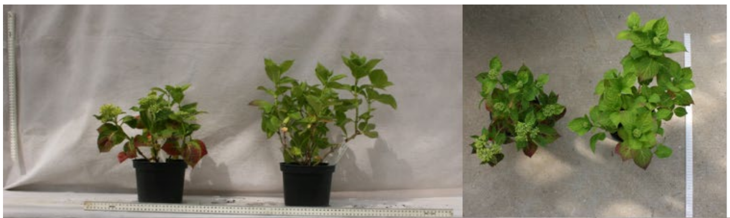
Category 1
At least two parameters described in Category 4 are not met

Category 2
One of the shape, structure, colour, flower bud parameters in Category 3 is not met, e.g. any of the following:

1. Shape not completely circular, some foliage gaps exposing surface of the pot
2. Structure uneven, branch length irregular across the plant
3. Four or less visible flower buds

Category 3

4. Round shape (covering the pot when looked at from above)
5. Even structure, i.e. looked at from the side there are no foliage gaps or very few through the plant, and the branches are similar lengths
6. Five or more visible flower buds



Category 1

Category 2

Category 3

Osmanthus heterophyllus

Parameters: shape, structure

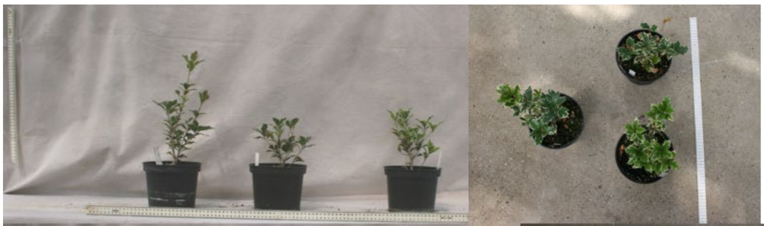
Category 1
Both parameters described in Category 3 are not met

Category 2
One of the shape, structure, colour parameters described in Category 3 is not met, e.g. any of the following:

1. Shape not completely circular
2. Structure uneven, with many gaps in the foliage

Category 3

3. Round shape and foliage covering most of the pot (when looked at from above)
4. Even structure, i.e. looked at from the side there are only a few gaps through the plant, and the stems are of similar height



Category 1

Category 2

Category 3

Photinia fraseri

Parameters: shape, structure, leaf colour

Category 1
Both parameters described in Category 3 are not met

Category 2
One of the shape, structure, colour parameters described in Category 3 is not met, e.g. any of the following:

1. Shape not completely circular, some gaps exposing surface of pot
2. Structure uneven, branch length irregular across the plant

Category 3

3. Round shape (covering the pot when looked at from above)
4. Even structure, i.e. looked at from the side there are only a few through the plant, and the stems are of similar height

Category 1

Category 2

Category 3

Pittosporum tenuifolium

Parameters: shape, structure, leaf finish

Category 1
Both parameters described in Category 3 are not met

Category 2
One of the shape, structure, colour parameters described in Category 3 is not met, e.g. any of the following:

1. Shape not completely circular, some gaps exposing surface of pot
2. Structure uneven, branch length irregular across the plant
3. Leaves marked with spots, spoiling leaf finish

Category 3

4. Round shape (covering the pot when looked at from above)
5. Even structure, i.e. looked at from the side there are no gaps through the plant, and the stems are of similar height
6. Leaves unblemished

Category 1

Category 2

Category 3

Viburnum tinus

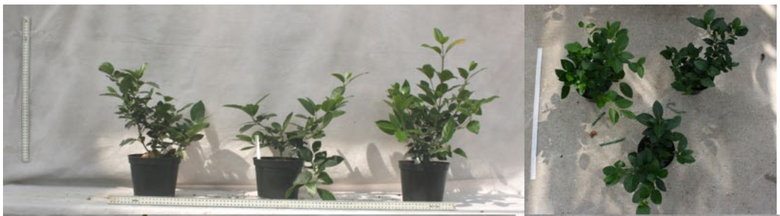
Parameters: shape, structure, new shoot growth

Category 1
At least two parameters described in Category 3 are not met

Category 2
One of the parameters in Category 3 is not met, e.g. any of the following:

1. Shape not completely circular, some gaps exposing surface of pot
2. Structure uneven, branch length irregular across the plant
3. Not much spring growth, with leaves not fully expanded

Category 3
1. Round shape (covering the pot when looked at from above)
2. Even structure, i.e. looked at from the side there is no foliage gaps or very few through. the plant, and the stems are of similar height
3. Plenty of new growth with fully expanded leaves (leaves fresh and glossy)

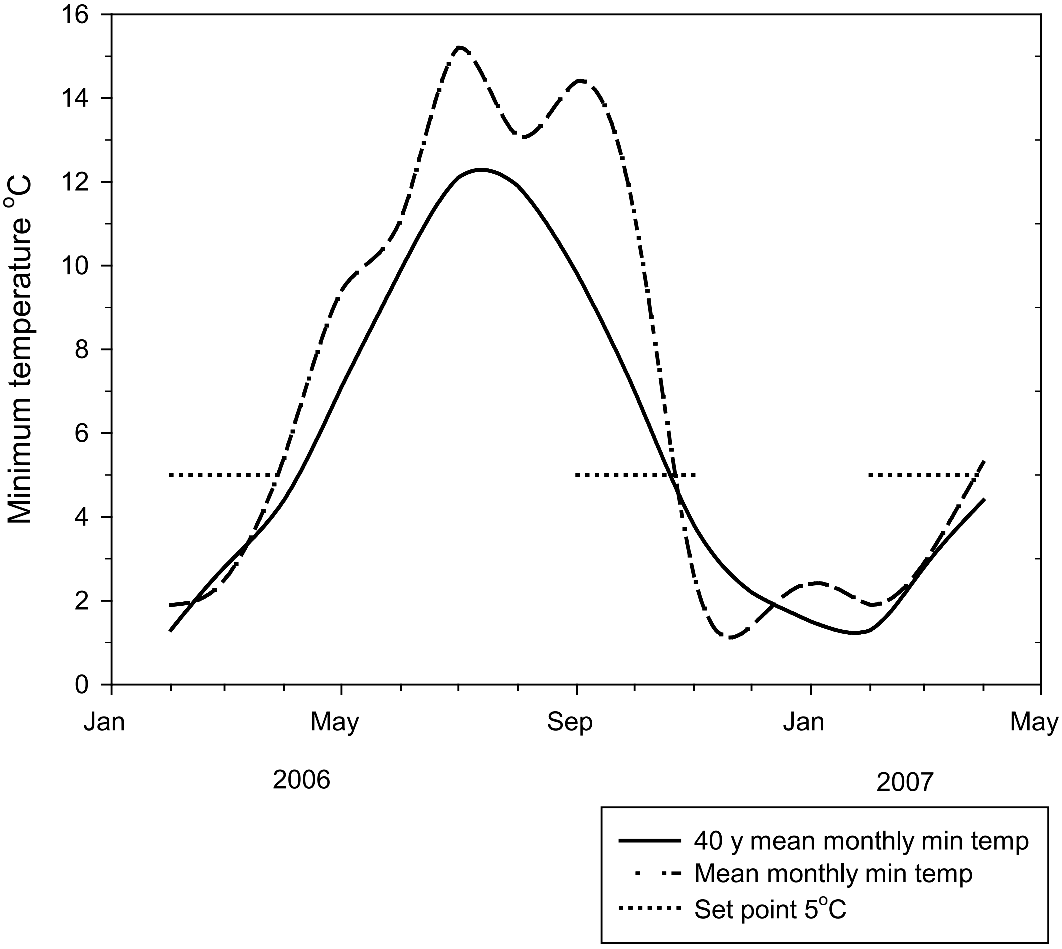


Category 1

Category 2

Category 3

APPENDIX – MEAN MONTHLY OUTSIDE MINIMUM TEMPERATURE AT EAST MALLING RESEARCH COMPARED TO THE SET POINT IN THE COOL (GLASSHOUSE) ENVIRONMENT



CALCULATED IRRADIANCE SUM AVERAGES INSIDE THE GREENHOUSE AND THE EFFECT OF SONT LIGHTS SWITCHED ON FOR 8 HOURS DURING DAYLIGHT HOURS.