Project Title:	To develop proven protocol and methodology for reducing production times for woody species
Project Number:	HNS 124
Report:	Annual report, Year 2, July 2006
Previous reports:	Annual report, Year 1, June 2005
Project leader:	Dr Neil Hipps, East Malling Research
Key worker:	Mike Davies
Location:	East Malling Research Kent ME19 6BJ Tel: 01732 523728 Fax: 01732 849067
Project Co-ordinators:	John Hedger, New Place Nurseries Ltd, London Road, Pulborough, West Sussex, RH20 1AT Ross Cameron, Reading University, Whiteknights, PO Box 217, Reading, Berkshire, RG6 6AH Chris Lane, Witchhazel Nurseries, The Granary, Callaways Lane, Newington, Kent, ME9 7LU Neal Wright, Micropropagation Services (EM) Ltd, Kirk Ley Road, East Leake, Loughborough, Leicestershire, LE12 6PE
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, Camellia japonica, Choisya ternata, Cytisus scoparius, Hydrangea macrophylla, Osmanthus heterophyllus, Pittosporum tenuifolium, Photinia × fraseri, Viburnum tinus*, cold storage

Disclaimer

The results and conclusions in this report are based on an investigation conducted over one year. 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.

CONTENTS

Page no.

Grower Summary

Headline

- Early application of warmth in spring generally has the largest effect on increasing plant size of both liners and rooted cuttings and has real potential as a tool for reducing production times for HNS.

Background and expected deliverables

The main aim of this project is 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. Specific objectives are:

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 have been 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 year of the project that established the responses of growing temperatures, supplementary lighting and other parameters on a range of HNS species, we are now looking to apply these techniques to a range of different species as cuttings (Table A), potentially allowing improved growth much earlier in production cycle. This experiment started in February 2006 and will be completed in May 2007.

In addition, for some of the species used last year, it was considered that more pruning of the liners in autumn may have improved plant quality and structure. Therefore, it was decided to repeat last years experiment on a limited number of species (Table A) to determine if the combination of more frequent pruning and the different environmental conditions could improve the quality.

In another specific experiment on *Hydragea* and *Photinia* liners, the impact of winter chilling on plant growth and quality in spring was determined. The former species was chosen because of the positive impact of some of the different environmental treatments on flowering last year and the latter species to provide a contrast with an evergreen.

Summary of the project and main conclusions

The experiments used the following environmental conditions:

Cool environment (heat set point 5^{o}C, vent 8^{o}C, fan vent 10^{o}C)

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

Warm environment (heat set point 15^{o}C, vent 18^{o}C, fan vent 20^{o}C)

5. Ambient light
6. Supplementary (SONT) light during natural daylight hours, 8 h
7. Tungsten 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

Improving liner quality

The liner experiment included *Choisya, Hydrangea, Photinia* and *Viburnum*. The heating and supplementary and day length extension light treatments were provided from 5 September until 30 November 2005, when the lights in the supplementary and day length extension light treatments were switched off and the set point in the warm house was adjusted to 5ºC. The plants were moved to a jacketed, unlit 2ºC cold store on 19 December 2005 and returned into the glasshouse on 2 February 2005. The set point in the warm house was set to 15ºC on 3 February 2006 when the supplementary and day length extension lighting were switched on. The lights and supplementary heating were switched off on 2 May 2006.

Full production cycle using rooted cuttings

Rooted cuttings of *Aucuba, Choisya, Cytisus, Hydrangea, Osmanthus*, and *Pittosporum* were placed into the different experimental environments on 17 February 2006. Rooted cuttings of *Photinia* and *Camellia* were placed into the experimental environments on 16 March 2006. Conditions were maintained as for the liner experiment described above.

Winter chilling

Hydrangea and *Photinia* liners were kept in the cool ambient light environment from 5 September until 19 December 2005. Control plants of each species were left in this environment (i.e. they were not allowed to experience temperatures below 5ºC) whilst the other were placed into the jacketed, unlit 2ºC cold store on the same day. Plants of each species were removed from the coldstore on 3 January and 18 January 2006 and placed back into the cool ambient light environment. On 2 February 2006, the remaining plants were removed from the cold store. It was therefore possible to determine the effects of 0, 15, 30 and 45 days of cold storage at 2ºC. Plants of each species from each cold storage period were then placed into the warm extended day length and the cool extended day length environments respectively on 3 February and remained there until 2 May 2006.

The main results for improving the liner quality and rooted cuttings experiments are summarised in Tables A and B.

Table A. The main effects of temperature, day length extension and supplementary light treatments on the size of liners in autumn and spring

Species	Autumn 2005			Spring 2006		
	Temp at 15⁰C	Day length extension lighting	Supple-mentary lighting	Temp at 15⁰C	Day length extension Light	Supple-mentary lighting
Choisya ternata				+		+
Hydrangea macrophylla 'King George'		+		+ *	+	
Photina x fraseri 'Red Robin'	-			- *		*
Viburnum tinus 'French White' EM27	+	+		+ *	+	*

Table B. The main effects of temperature, day length extension and supplementary light treatments applied potted in winter 2006 on the size of rooted cuttings spring 2006

Aucuba japonica 'Goldstrike'	+	+	+
Camellia japonica 'Guilio Nuccio'			
Choisya ternata	+		
Cytisus scoparius 'Burkwoodii'	+	+	+
Hydrangea macrophylla 'King George'	+	+	
Osmanthus heterophyllus 'Goshiki'	+		
Photina x fraseri 'Red Robin'	+		
Pittosporum tenuifolium 'Goldstar'	+	+	

Key to Tables A and B

+ indicates a positive effect, i.e. increased size
- indicates a negative effect on size
* indicates increase in visual quality (only assessed for liners)
blank space indicates no effect on size or quality)

It is also worth noting that:

- Flowering of Hydrangea was at least a month earlier in these plants in the warm environments in spring, and plant quality tended to increase with increased periods of chilling.

- Supplementary light in spring increased the number of new shoots of *Photinia* liners.

- Warmth advanced the start of growth in spring of *Aucuba, Choisya, Osmanthus* and *Pittosporum*.

- Different periods of winter chilling had no impact on the growth of *Hydrangea* and *Photinia*.

In conclusion

- Early application of warmth in spring generally has the largest effect on increasing plant size of both liners and rooted cuttings and has real potential as a tool for reducing production times for HNS.

- The combination of judicious pruning in autumn and enhanced environmental treatments can significantly improve plant visual quality of liners in spring.

- Day length extension light applied in autumn and/or spring could be used by growers for improving plant size.

- Supplementary light has limited value for advancing the start of growth and improving plant size, but might be used for improving visual quality.

Financial benefits

This project continues to make good progress towards reducing plant production times in HNS. The extent of the financial benefits will depend on which treatments are required over the full production cycle and whether it is possible to move a year from production; work on this aspect of the project is ongoing.

Action points for growers

Growers who wish to reduce the period of plant production whilst increasing plant size and improving visual quality, should initially concentrate on using warmth on rooted cuttings and liners as early in spring as possible.

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, 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 the normal period of daylight are referred to as photoperiodic effects. For perennial plants these responses mainly concern bud dormancy plants and production of flowers and seeds.

Generally, long days 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 the low temperatures of winter combined with long days. Sometimes, long days promote bud break even without low temperatures, e.g. birch.

Short days lead to the changes associated with autumn, i.e. leaf abscission, reduced stem elongation, reduced chlorophyll production, increased formation of other pigments, dormancy and development of frost hardiness.

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 of autumn, typically the response is strongly modified by temperature. However, different ecotypes of the same species may have different responses to day length and most studies of photoperiodism have concentrated on only the flowering effects.

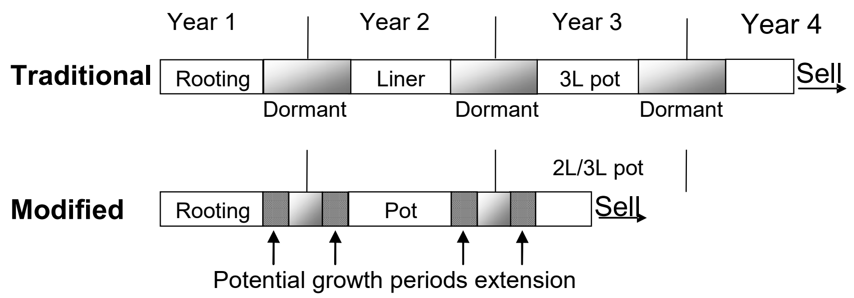
Manipulation of day length is commonly used by protected crop growers to schedule flowering out of season. Much previous scientific work has been directed at the fundamentals of flowering and scheduling of plants. The largest screening programme of flowering responses has been undertaken at Michigan State University, but the techniques have not been adopted in the UK. This led to the 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 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.

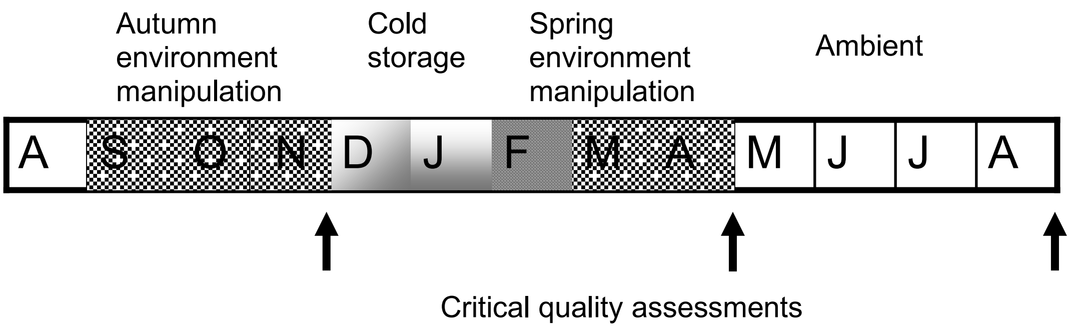
Therefore, important opportunity exists to shorten the production time of woody perennials using the scheduling techniques and facilities now available under cover. Currently, from a cutting being stuck to the sale of a finished plant in a 3 litre pot being sold can take up to 4 years (Figure A). This uses space on a nursery 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 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. However, the plant must be ready for sale one year earlier, as a saleable plant 6 months early will miss the key marketing dates. 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 application for growing season extension



The commercial objective of this project is 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, Experiment 1 screened 21 different species of hardy nursery stock (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 warmth in autumn also responded to warmth in spring. Day length extension light applied in autumn increased plant size for eight species and in spring for twelve species. 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.

Experiments for 2005-2006 growing season

For some of the species used last year it was considered that more pruning of the liners in autumn may have improved plant quality and structure. Therefore, it was decided to repeat last year's experiment on a limited number of species (Table B) to determine if the combination of more frequent pruning and the different environmental conditions could improve the quality of plants by late spring (Experiment 2 in Materials and Methods).

Following the general success of the first year's experiment, in consultation with the grower coordinators, the project proceeded to its second phase of attempting a full production cycle. This involved applying the different environmental conditions to a range of different species as cuttings rather than liners (Table C), potentially allowing improved growth much earlier in production (Experiment 3 in Materials and Methods). This experiment started in February

2006 and will be completed in May 2007, i.e. a full (shortened) production cycle will be examined.

The impact of winter chilling on plant growth and quality in spring was determined specifically in another experiment (Experiment 4 in Materials and Methods) on *Hydrangea* and *Photinia.* Production of hydrangea normally requires propagation in spring or summer, so bud formation takes place in late summer or early autumn, followed by a period of winter chilling (cold storage) for satisfactory flower development.

Short day plants will only develop flowers (obligate) – or develop flowers more readily (facultative) when the daily light period is less than a critical value (See HNS 103 for a review of the controls of flowering in plants). *Hydrangea macrophylla* is a short day plant and it produces inflorescences primordia more effectively under 8 - 10 h than under long days >16 h photoperiod (Bailey & Weiler, 1984, Guo *et al.*, 1995). *Hydrangea* also requires short days to become dormant (Lopes & Weiler, 1973). Plants under long days (16-24 h illumination) maintain vegetative growth and produced longer shoots than those under 8-10 h photoperiod (Bailey & Weiler, 1984, Guo *et al.*, 1995).

Temperature also effects bud formation as there can be an interaction between day length and growth temperature. Post (1942) found that *Hydrangea* did not form flower buds at temperatures > 20ºC. Later, experiments on the effect of temperature on bud formation in *Hydrangea* have shown that 15-18ºC were optimal for most cultivars. At 27ºC, no flower initiation occurs after six weeks, although eventually buds formed on some plants at this temperature. Short days hastened flower bud differentiation (formation) at high temperature. At 15-18ºC, the plants were nearly day neutral. This implies that short day treatments are unimportant if temperatures are favourable to flower bud formation (Litlere & Strømme, 1975). However, these authors qualify this statement by stating that good light conditions are required as a prerequisite for rapid growth and bud development. Other workers have also found that high temperatures reduce flowering (Yeh & Chiang, 2003). Nevertheless, Bailey & Weiler (1984) found that plants containing inflorescence primordia within their apical buds developed more rapidly at 24ºC than at 18ºC or 13ºC.

In a further refinement of the influence of temperature, it has been found that split night temperature specifically influenced flowering. Maintaining 17ºC from 17:00-21:00 hours followed by a 9-12ºC minimum accelerated development over a 9-12ºC minimum constant night temperature (Shanks, 1987).

Winter chilling (vernalisation) is another important factor that is known to effect plant growth and subsequent flowering. However, very little information is available on the amount of chilling (temperature and period) that is actually required for a range of HNS species including *Hydrangea*. Therefore, with the agreement of the grower coordinators, two species were chosen to determine the impact of different periods of winter chilling. *Hydrangea* was chosen because of the joint interest of the impact of winter chilling on it growth and quality including flower formation. Furthermore, the different environmental treatments influenced flowering last year and there may have been an unmeasured interaction with that year's winter chilling treatment. *Photinia* was chosen to provide a complete contrast as an evergreen foliage species for which no background information on the impact of environmental conditions is available.

The null hypothesis was that winter chilling below 5ºC has no effect on subsequent plant growth.

Table C. Species screened for response to different growing environment and winter chilling used. Species used in the liner quality (L) experiment, cuttings experiment (C), and winter chilling (Ch)

	Evergreen	***Display***		**Deciduous**	***Display***
C	*Aucuba japonica* 'Goldstrike'	Foliage (spring flower)	C,L,Ch	Hydrangea 'King George'	Summer flower
C	*Camellia japonica* 'Guilio Nuccio'	Spring flower			
C,L	*Choisya ternata*	Late spring flower			
C	*Cytisus* 'Burkwoodii'	Summer flower			
	Osmanthus heterophyllus 'Goshiki'	Late summer flower			
C,L,Ch	*Photinia fraseri* 'Red robin'	Winter foliage			
C	*Pittosporum tenuifolium* 'Gold star'	Foliage (spring flower)			
L	*Viburnum tinus* 'French White' EM27	Winter 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 lighting (AL)
2. Supplementary (SONT) lighting, 8hrs (SL)
3. Photoperiod (tungsten) lighting to give day lengthening, ≥ 15hrs (DL)
4. Supplementary (8 hrs) and photoperiod lighting (SL + DL)

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

5. Ambient lighting (AL)
6. Supplementary (SONT) lighting, 8hrs (SL)
7. Photoperiod (tungsten) lighting to give day lengthening, ≥ 15hrs (DL)
8. Supplementary (8 hrs) and photoperiod lighting (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. The lights were put on using a time switch to extend the day to 15.5 h continuously from pre-dawn. 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 2 – Improving liner quality

Four species (Table A) were chosen for the pruning experiment following consultation and agreement with the grower co-ordinators. The plants were supplied by New Place Nurseries Ltd, in the week commencing 7 August 2005, in 9 cm containers. They were potted on before 18 August into 2 litre containers using a Richmoor Mix 1 substrate supplemented with Osmocote Plus Autumn 12 to 14 months at 3.0 kg per m^3.

The plants were arranged in two blocks in N–S direction, thus each block contained four pots of each species arranged E-W. The experiment used a total of 256 plants.

The heating and supplementary lighting treatments were provided from 5 September until 30 November 2005, when the lighting in the SD and LD treatments was switched off and the set point in the cool house was adjusted to 5ºC. The plants were moved to a jacketed, unlit 2ºC cold store on 19 December 2005 and returned into the glasshouse on 2 February 2005. Each plant was placed into exactly the same position it had occupied previously. The set point in the warm house was set to 15ºC on 3 February 2006 and the supplementary and day length extension lighting was switched on 3 February 2006. The lighting and heating were switched off on 2 May 2006.

The plants were pruned on up to three occasions (Table D). On 22 September 2005, all plants were severely pruned, i.e. generally taken back to near their previous cuts. On 19 October 2005, most of the *Photina* and *Viburnum* and some of the *Choisya* were given a light prune. This was repeated on 28 February 2006.

Table D. Dates of pruning of liners and quantities cut (% of total number of plants pruned)

Choisya Environment		22/9/05	19/10/05	28/2/06
Cool	Ambient	100	13	0
	Day length extension light	100	63	13
	Supplementary light	100	25	0
	Day length extension light + Supplementary light	100	63	43
Warm	Ambient	100	38	13
	Day length extension light	100	13	13
	Supplementary light	100	13	13
	Day length extension light + Supplementary light	100	50	25
Hydrangea				
Cool	Ambient	100	0	0
	Day length extension light	100	0	0
	Supplementary light	100	0	0
	Day length extension light + Supplementary light	100	0	0
Warm	Ambient	100	0	0
	Day length extension light	100	0	0
	Supplementary light	100	0	0
	Day length extension light + Supplementary light	100	0	0
Photinia				
Cool	Ambient	100	3	25
	Day length extension light	100	88	88
	Supplementary light	100	100	100
	Day length extension light + Supplementary light	100	100	88
Warm	Ambient	100	75	88
	Day length extension light	100	100	88
	Supplementary light	100	100	100
	Day length extension light + Supplementary light	100	100	100
Viburnum				
Cool	Ambient	100	25	63
	Day length extension light	100	75	100
	Supplementary light	100	100	63
	Day length extension light + Supplementary light	100	75	88
Warm	Ambient	100	13	100
	Day length extension light	100	88	88
	Supplementary light	100	100	100
	Day length extension light + Supplementary light	100	75	100

Experiment 3 - Full production cycle

Eight species (Table C) 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 last year.

Rooted cuttings of *Aucuba, Choisya, Cytisus, Hydrangea, Osmanthus*, and *Pittosporum* were supplied by New Place Nurseries Ltd, on 15 February 2006, in 9 cm containers. They were potted on into 2 litre containers using compost supplied by New Place Nurseries on the 16 February 2006 and placed into the experimental environments on 17 February 2006. Rooted cuttings of *Photinia* and *Camellia* were collected from New Place Nurseries on 14 March 2006 and potted on into 2l pots on the 15 March 2006 and placed into the experimental environments on 16 March 2006. 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 glasshouse in ambient light.

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. The experiment used a total of 672 plants.

Experiment 4 - Winter chilling

The *Hydrangea* and *Photinia* liners were supplied and potted as for the plants in Experiment 2. Forty-eight plants of each species were placed into the cool ambient light environment (C, AL Treatment 1). They were laid out in 12 rows of four plants for each species. Sixteen plants of each species were left in cool ambient light environment (i.e. they were not allowed to experience temperatures below 5ºC whilst the other 32 plants were placed into the jacketed, unlit 2ºC cold store on 19 December 2005. Sixteen plants of each species were removed from the coldstore on 3 January and 18 January, and placed back into the cool ambient light environment. On 2 February 2006, the remaining 16 plants were removed from the cold store. Thus, it was possible to determine the effects of 0, 15, 30 and 45 days of cold storage at 2ºC. Eight plants of each species from each cold storage period (i.e. a total of 32 plants) were placed into the warm extended day length (W DL) and the cool extended day length (C DL) environments respectively.

Statistical analysis

The experimental design was regarded as randomised block with heat, supplementary light and day length extension light as treatment factors in Experiments 2 and 3. The treatments formed a 2^3 factorial set for temperature (warm, cool) by day length light (normal, extended to 15h) by light (normal, supplementary 8h per 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 two 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.

The experimental design for Experiment 4 was regarded as randomised block with heat and time in cold store as treatment factors. Within each glasshouse (heat factor) there were two blocks for each species with four rows in each block. Each cold storage treatment randomly occurred once in every row. Probabilities given in the text and tables are those associated with the F-tests of treatment effects from the ANOVA.

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 8-12 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 height of each plant was measured after pruning on 22 September 2005 and heights, breadth (across two positions at right angles) and number of new shoots (>1cm) were recorded on 14 December 2005 and again on 19 April 2006.

Plant quality

The quality of the liners in experiment 3 was determined using a visual assessment system. The details of this are given in Appendix 1.

Photographs

Representative plants for each species from each treatment were photographed on 18 August (i.e. on arrival), 22 September (i.e. after pruning), 5 December 2005 and 20 April 2006.

Environment

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

RESULTS

Experiment 2 - improving liner quality

***Choisya ternata* (Mexican Orange Blossom)**
(Figure 1, Table 1, Plate 1)

Key points

- No growth response to different environmental conditions applied in autumn
- Plant size was increased by warmth applied in spring
- Day length extension light had no effect on growth
- Supplementary lighting increased growth in spring only
- Environment had no effect on plant quality

Choisya showed no growth responses to any of the different environmental treatments in autumn, although the plants grew for slightly longer in the cool environment.

In spring, growth started approximately one month earlier in the warm environment, and the plants completed a whole growth episode before those in the cool environment had started to grow. This resulted in larger plants in the warm environment by May with breadths of whole plant 50% greater than those in the cool environment. The latter effects were consistent with those found in last years experiment. Day length extension light had no effect on plant size, but supplementary lighting caused a small (< 3 cm) increase in width and increased number of new shoots. This was the reverse of what occurred last year, when supplementary lighting had no effect. The number of new shoots per plant was unaffected by temperature and/or day length extension light.

Figure 1. The effect of different environmental conditions on % of *Choisya* liners growing during extended autumn and spring growth seasons. AL Ambient light, SL Supplementary light, DL day length extension light

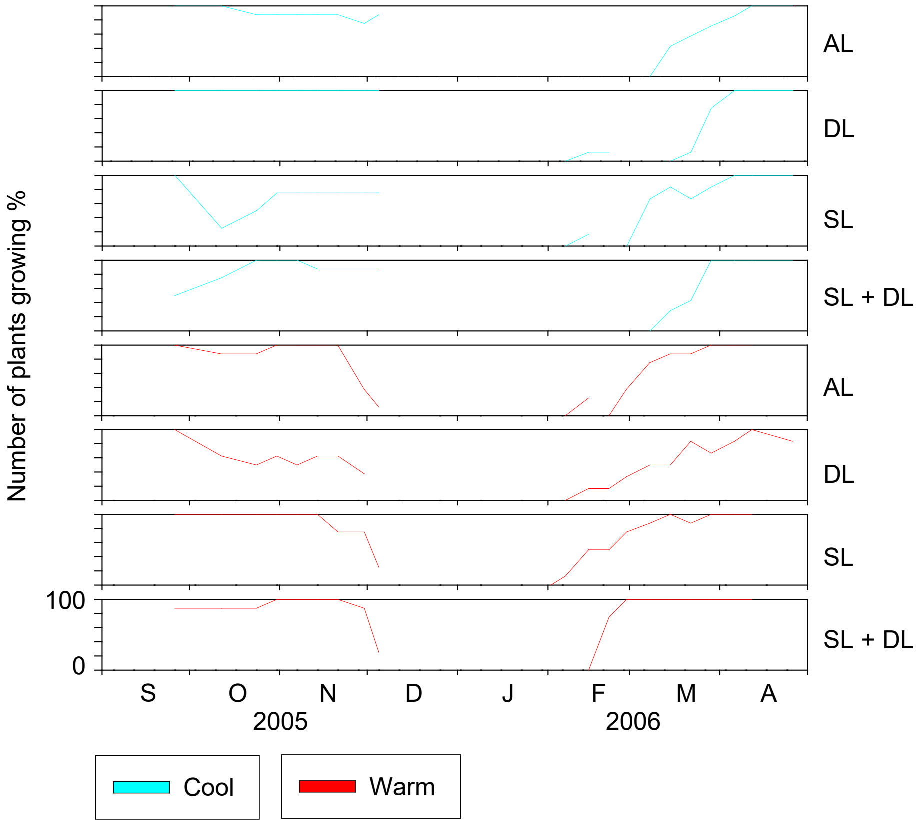


Table 1. The main effects of temperature, supplementary and day length extension light on plant size and number of new shoots (breaks) of Choisya liners following autumn and spring extended growth seasons. Probability * is statistically significant (<0.05), ** is highly significant (< 0.01) and *** is very highly significant (< 0.001), ns is not statistically significant

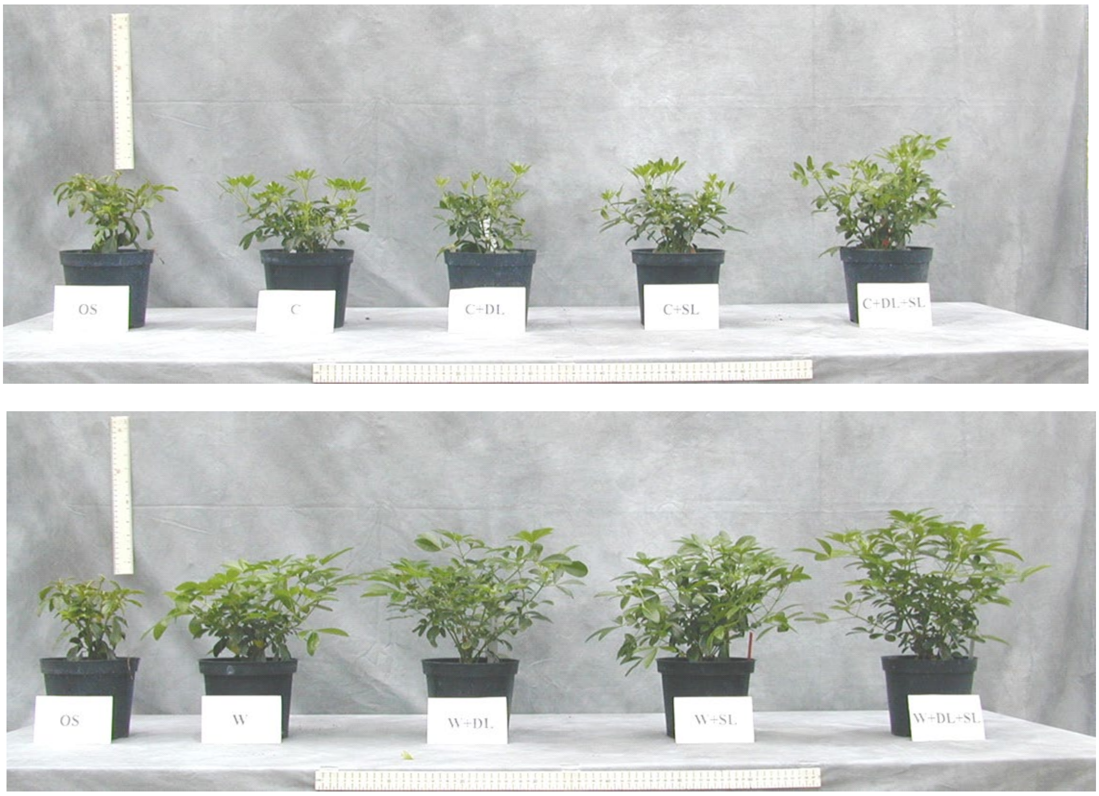
Main effect		**Height (cm)**		**Width (cm)**		**No. new shoots per plant**		**Quality**
		Dec. 2005	**April 2006**	**Dec. 2005**	**April 2006**	**Dec. 2005**	**April 2006**	**April 2006**
Temperature	Cool	15	18	21	21	15	11	1.8
	Warm	16	21	22	32	15	13	2.3
Probability		ns	ns	ns	***	ns	ns	ns
Supplementary	-	15	19	20	25	14	10	1.8
light	+	15	20	22	28	17	14	2.3
Probability		ns	ns	ns	*	ns	*	ns
Day length	-	15	20	21	27	15	13	2.2
extension light	+	16	20	22	25	16	11	1.9
Probability		ns	ns	ns	ns	ns	ns	ns
SED* (8 d.f.)		0.5	1.2	1.4	1.1	1.6	1.7	0.79
Interactions		None	None	None	None	Temp x DL	None	None

*SED for comparison between main effects

Plate 1. Representative examples of *Choisya* liners growth in December 2005 and April 2006 following the autumn and spring extended growth seasons respectively. C cool house, W warm house, OS plants kept outside, no second letter = ambient light, DL day length extension light, SL supplementary light. (Rulers = 30 cm, except April 2006 horizontal ruler = 70cm)

December 2005

April 2006



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

(Figure 2, Table 2, Plate 2)

Key points

- Small increase in size caused by day length extension light and small increase in number of shoots caused by warm environment in autumn.
- Plant size was increased by day length lighting applied in spring.
- Flowering was at least a month earlier for plants in the warm environments.
- Plants grown in the warm environment were of a saleable quality by the end of April.

Hydrangea showed a small positive response in height (1 cm) and width (2 cm) to day length extension lighting and a small increase in number of new shoots in the warm environment in autumn. No growth responses to any of the other environmental treatments were observed during this period.

After coming out of cold store, plant activity started at the beginning of February in the cool and warm environments. Plant height was reduced (8%) and width was significantly increased (17%), the number of new shoots was increased in the warm compared to the cool environment. Plant quality was significantly better in the warm environment, predominantly due to improved shape, structure and flower bud formation.

The phenology of plants in the cool house was generally later than those in the warm house. Leaves of plants in this environment were not fully expanded at the end of April, resulting in less leaf area and more structural gaps. The leaves were a lighter green colour due to immaturity. However, later in the year as these plants develop their quality improved to similar levels to those plants in the warm environment.

Plant height and width were increased (16% and 20% respectively) by day length extension light, but the number of shoots per plant was unaffected. However, this resulted in a more 'leggy' plant (see Plate 2), which reduces its quality. Supplementary light had no effect on plant size, but increased the number of shoots per plant. Neither types of lighting influenced plant quality.

Figure 2. The effect of different environmental conditions on % of Hydrangea liners growing during extended autumn and spring growth seasons. AL Ambient light, SL Supplementary light, DL day length extension light

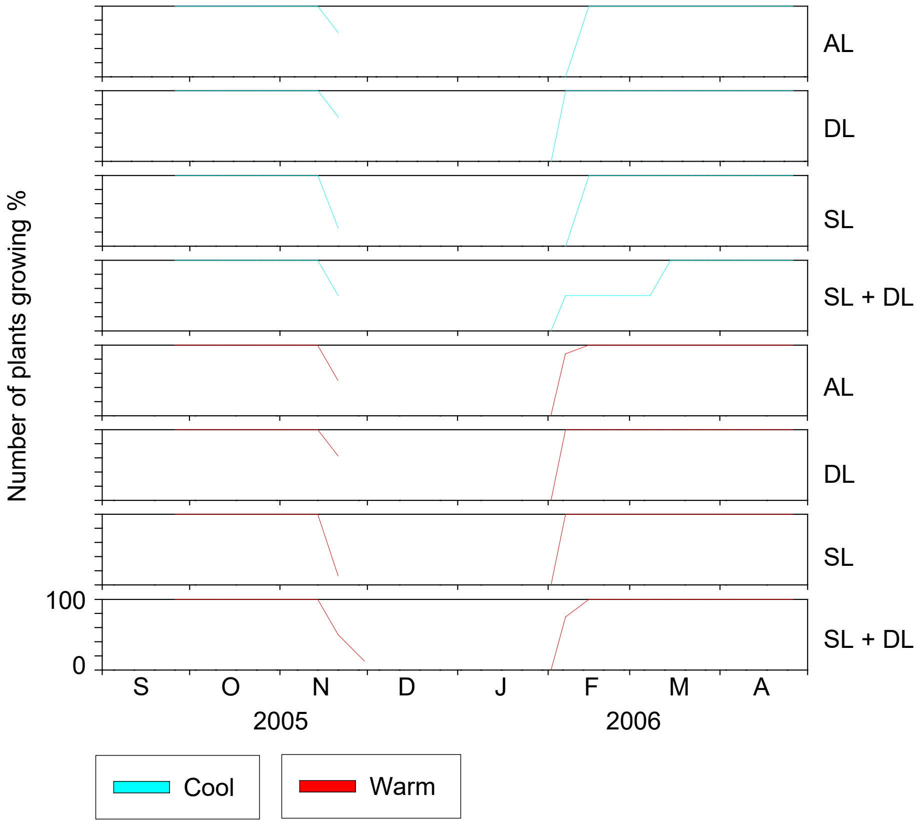


Table 2. The main effects of temperature, supplementary and day length extension light on plant size and number of new shoots (breaks) of Hydrangea liners following autumn and spring extended growth seasons. Probability * is statistically significant (<0.05), ** is highly significant (< 0.01) and *** is very highly significant (< 0.001), ns is not statistically significant

Main effect		**Height (cm)**		**Width (cm)**		**No. new shoots per plant**		**Quality**
		Dec. 2005	**April 2006**	**Dec. 2005**	**April 2006**	**Dec. 2005**	**April 2006**	**April 2006**
Temperature	Cool	14	28	23	37	10	13	2.5
	Warm	15	25	23	44	12	11	3.3
Probability		ns	*	ns	**	*	**	**
Supplementary	-	14	26	23	39	10	11	2.7
light	+	15	27	23	42	11	14	3.0
Probability		ns	ns	ns	ns	ns	**	ns
Day length	-	14	25	22	37	11	12	3.0
extension light	+	15	28	24	44	11	12	2.7
Probability		*	**	*	***	ns	ns	ns
SED* (8 d.f.)		0.4	1.0	0.9	1.3	0.6	0.6	0.17
Interactions		None	None	None	None	Temp x DL	None	None

*SED for comparison between main effects

Plate 2. Representative examples of *Hydrangea* liners growth in December 2005 and April 2006 following the autumn and spring extended growth seasons respectively. C cool house, W warm house, O plants kept outside, no second letter = ambient light, DL day length extension light, SL supplementary light. (Rulers = 30 cm, except April 2006 horizontal ruler = 70cm)

December 2005

April 2006

***Photinia fraseri* 'Red Robin'**

(Figure 3, Table 3, Plate 3)

Key points

- Plants receiving warmth during autumn and spring were smaller than those in the cool treatment in December and April respectively
- Day length extension and supplementary light had no effect on plant size in autumn
- Day length extension and supplementary light had no effect on plant size in spring
- Plant quality was improved by warmth and supplementary lighting
- Supplementary light in spring increased number of new shoots

Plants in the cool environment had a greater width (4 cm) than those in the cool environment in December 2005. Plants in the cool and warm environments not receiving supplementary lighting showed little growth activity after the end of November 2005, whereas more of those receiving supplementary lighting continued to grow in early December 2005. Number of shoots per plant were unaffected by any of the treatments.

After coming out of cold store, none of the environmental treatments influenced the start of growth, but warmth decreased plant size and increased number of shoots. Day length extension light had no effect on plant growth. Supplementary light increased the number of shoots per plant.

Temperature and supplementary lighting increased plant quality. In both cases, this was due to better shape and structure. Day length extension lighting had no effect on plant quality.

Figure 3. The effect of different environmental conditions on % of *Photinia* liners growing during extended autumn and spring growth periods. AL Ambient light, SL Supplementary light, DL day length extension light

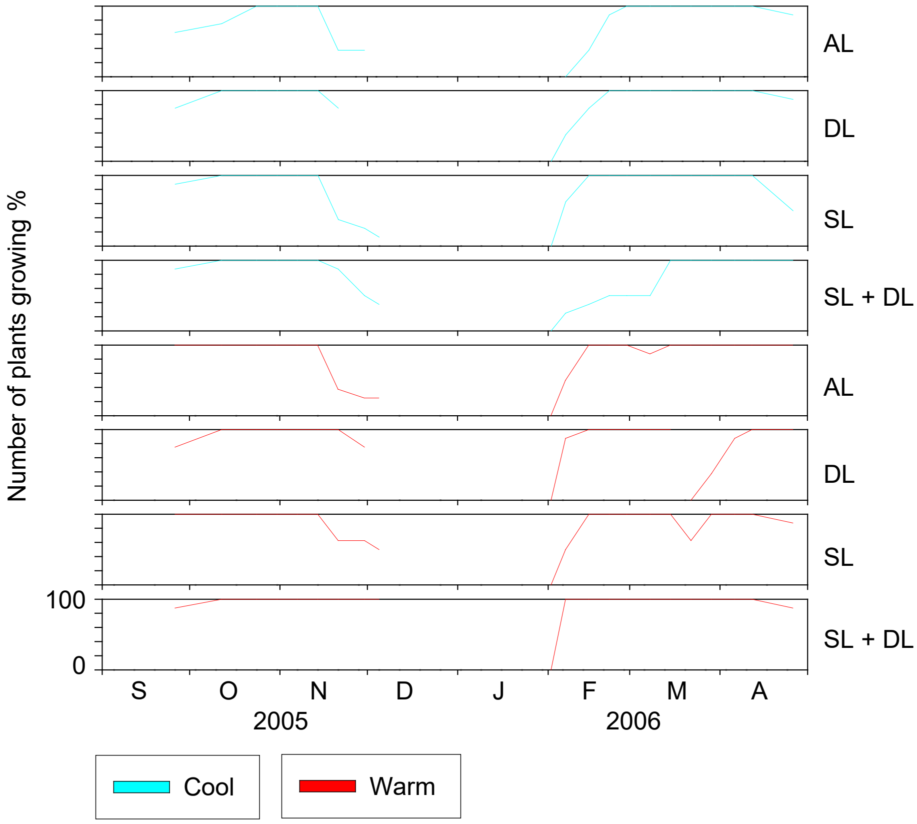


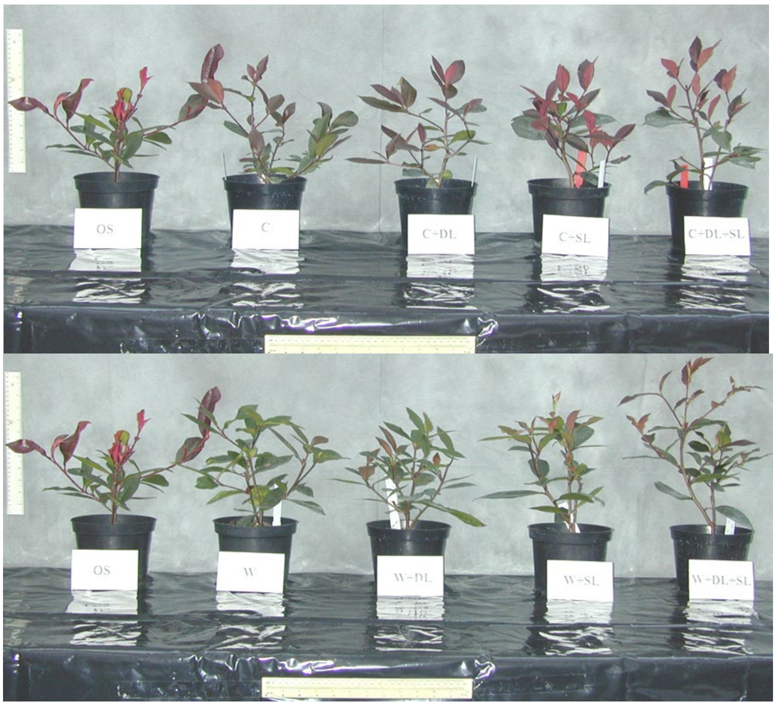
Table 3. The main effects of temperature, supplementary and day length extension light on plant size and number of new shoots (breaks) of *Photinia* liners following autumn and spring extended growth seasons. Probability * is statistically significant (<0.05), ** is highly significant (< 0.01) and *** is very highly significant (< 0.001), ns is not statistically significant

Main effect		**Height (cm)**		**Width (cm)**		**No. new shoots per plant**		**Quality**
		Dec. 2005	**April 2006**	**Dec. 2005**	**April 2006**	**Dec. 2005**	**April 2006**	**April 2006**
Temperature	Cool	30	36	32	43	7	9	1.9
	Warm	29	36	29	38	7	11	2.4
Probability		ns	ns	*	*	ns	ns	*
Supplementary	-	30	35	31	40	7	9	1.7
light	+	30	37	30	41	8	11	2.6
Probability		ns	ns	ns	ns	ns	*	***
Day length	-	30	35	31	40	7	11	2.3
extension light	+	30	37	30	41	7	9	2.0
Probability		ns	ns	ns	ns	ns	ns	ns
SED* (8 d.f.)		0.5	1.3	1.3	1.9	0.6	0.7	0.17
Interactions		SL x DL	None	None	None	Temp x DL	None	None

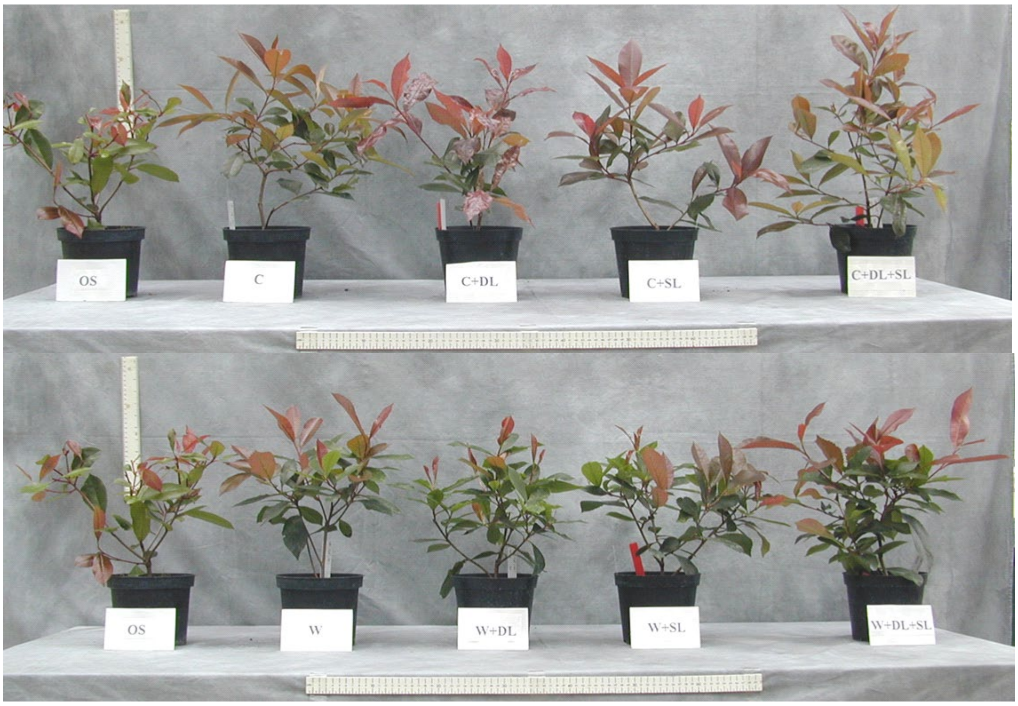
*SED for comparison between main effects

Plate 3. Representative examples of *Photinia* liners growth in December 2005 and April 2006 following the autumn and spring extended growth seasons respectively. C = cool house, W= warm house, O plants kept outside, no second letter = ambient light, DL day length extension light, SL supplementary light. (Ruler = 30 cm; April 2006 horizontal ruler = 70cm)

December 2005



April 2006



***Viburnum tinus* 'French White' EM27 (Laurustinus)**

(Figure 4, Table 4, Plate 4)

Key points

- Plant size was increased by warmth applied in autumn and spring respectively
- Supplementary light had no effect on plant size in autumn or spring, but overall plant quality was slightly improved
- Day length extension light increased plant size in autumn and spring respectively
- Warmth improved plant quality

In the absence of supplementary lighting, growth ceased earliest (around late November) in the warm environment; plants in the cool environment continued growing until mid December. Nevertheless, plants in the warm environment had an average width (4 cm) greater than those in the cool environment by December. Plants in the warm environment grew at a faster rate than those in the cool environments, reaching the termination point at the end of a growth episode earlier. Day length extension light increased plant height (2 cm) and width (4 cm). Supplementary lighting had no effect on plant size. None of the autumn treatments affected the number of shoots per plant.

After coming out of cold store, growth started approximately one month earlier in the warm than in the cool environment. Thus, nearly all the plants were growing in the warm environment by 22 February, whereas in cool environment it took until 22 March 2006 for this to occur. Warmth greatly increased plant width (13 cm) and height (2 cm) in spring, but had no effect on the number of shoots per plant.

Supplementary lighting had a small effect on plant size in the spring and no effect on the number of shoots per plant. Day length extension lighting had a small effect on increasing plant size, but also did not affect the number of shoots per plant.

Plant quality was improved by warmth and supplementary lighting. In both cases this was due better shape, more even structure and spring growth.

Figure 4. The effect of different environmental conditions on % of *Viburnum* liners growing during extended autumn and spring growth seasons. AL Ambient light, SL Supplementary light, DL day length extension light

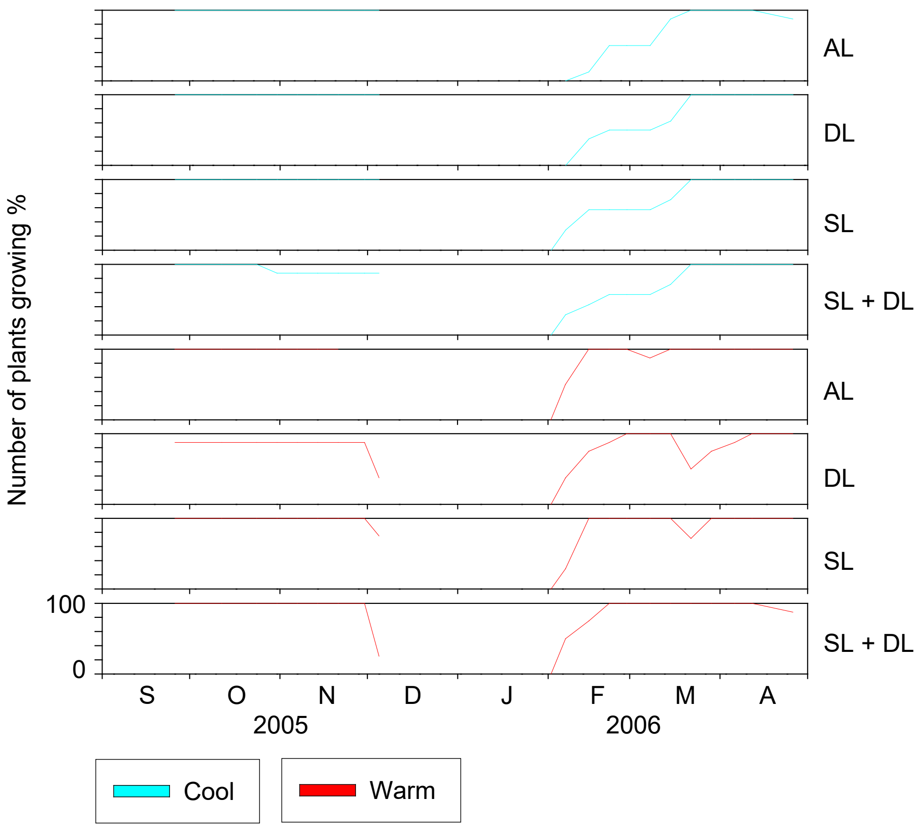


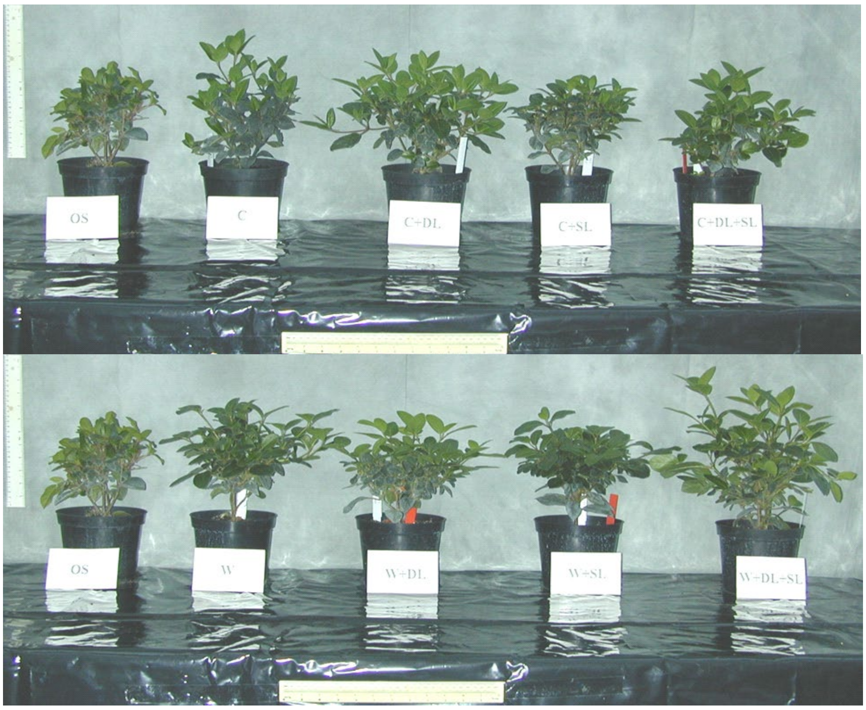
Table 4. The main effects of temperature, supplementary and day length extension light on plant size and number of new shoots (breaks) of *Viburnum* liners following autumn and spring extended growth seasons. Probability * is statistically significant (<0.05), ** is highly significant (< 0.01) and *** is very highly significant (< 0.001), ns is not statistically significant

Main effect		**Height (cm)**		**Width (cm)**		**No. new shoots per plant**		**Quality**
		Dec. 2005	**April 2006**	**Dec. 2005**	**April 2006**	**Dec. 2005**	**April 2006**	**April 2006**
Temperature	Cool	23	27	29	31	27	26	2.3
	Warm	24	29	32	44	28	28	2.7
Probability		ns	*	**	***	ns	ns	*
Supplementary light	-	24	27	31	36	27	26	2.4
	+	24	29	30	39	29	28	2.7
Probability		ns	ns	ns	ns	ns	ns	*
Day length extension light	-	23	27	29	36	27	26	2.5
	+	25	29	32	38	28	27	2.6
Probability		ns	*	**	ns	ns	ns	ns
SED* (8 d.f.)		0.8	0.8	0.9	1.3	1.5	1.3	0.11
Interactions		None	Temp x SL x DL	None	None	Temp x DL	None	None

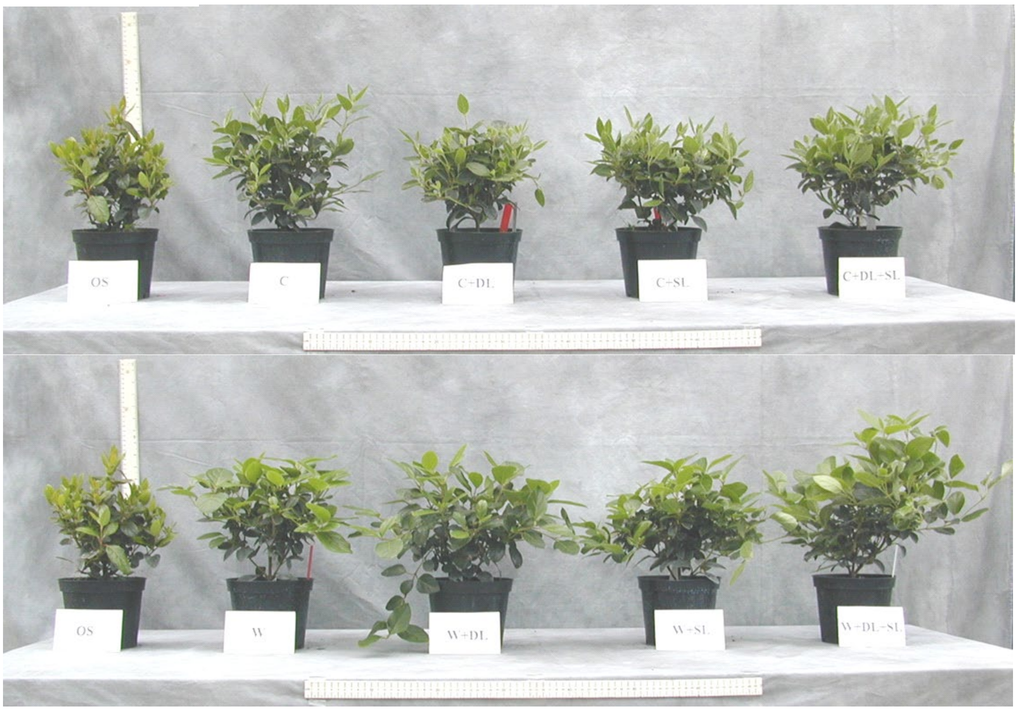
*SED for comparison between main effects

Plate 4. Representative examples of *Viburnum* liners growth in December 2005 and April 2006 following the autumn and spring extended growth seasons respectively. C cool house, W warm house, O plants kept outside, no second letter = ambient light, DL day length extension light, SL supplementary light. (Rulers = 30 cm; except April 2006, horizontal ruler = 70cm)

December 2005



April 2006



Experiment 3 – Full production cycle

***Aucuba japonica* 'Goldstrike'**

(Figure 5, Table 5, Plate 5)

Key points

- Plant size was substantially increased by warmth applied in spring
- Supplementary light had a small effect on increasing plant width
- Day length extension light caused a small increase in plant size
- Warmth brought forward the start of growth by at least 1 month

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 plants were much larger (80% taller) and had more shoots by late April. Plants in the warm environments had broken bud and sent out new shoots by the end of April (Plate 5), whereas the majority of those in the cool environment had only just broken bud. Supplementary and day length extension lighting also increase plant size, but not to the same extent as increased temperature.

Figure 5. The effect of different environmental conditions on % of *Aucuba* rooted cuttings growing during an extended spring growth season. AL Ambient light, SL Supplementary light, DL day length extension light

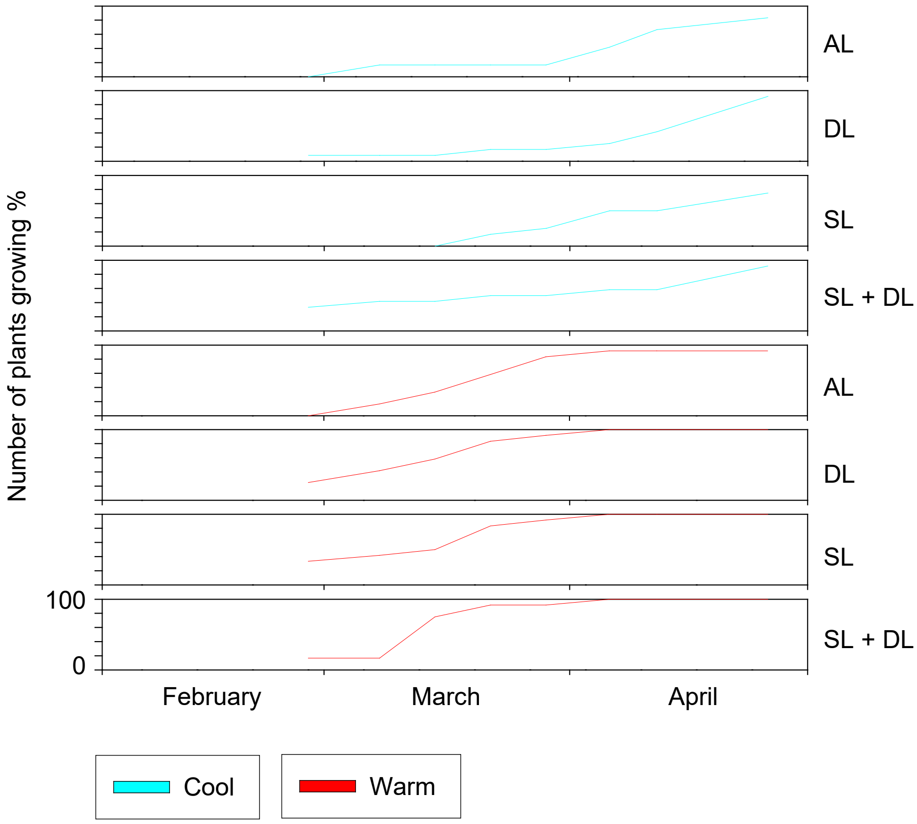
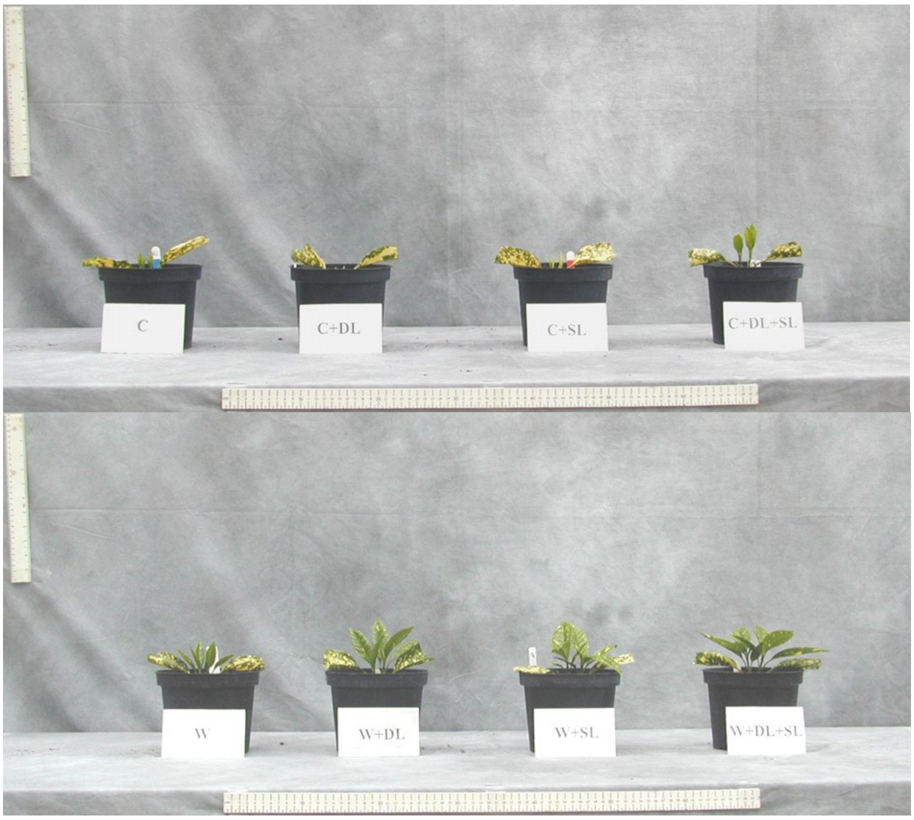


Table 5. The main effects of temperature, supplementary and day length extension light on plant size and number of new shoots (breaks) of *Acuba* rooted cuttings following spring extended growth season. Probability * is statistically significant (<0.05), ** is highly significant (< 0.01) and *** is very highly significant (< 0.001), ns is not statistically significant

Main effect		**Height (cm)**	**Width (cm)**	**No. new shoots per plant**
			April 2006	
Temperature	Cool	5	13	1
	Warm	10	16	2
Probability		***	***	***
Supplementary light	-	7	14	1
	+	8	15	1
Probability		ns	*	ns
Day length extension light	-	7	14	1
	+	8	15	1
Probability		*	*	ns
SED* (22 d.f.)		0.4	0.5	0.2
Interactions		Temp x SL x DL	Temp x DL	None

*SED for comparison between main effects

Plate 5. Representative examples of *Aucuba* rooted cuttings growth in April 2006 following the 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)



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

(Figure 6, Table 6, Plate 6)

Key points

- None of the environmental treatments had an effect on plant size
- None of the environmental treatments had an effect on the start of growth

The plants in all the different treatments started to grow at approximately the same time in the cool and warm environments. 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 occurred.

Figure 6. The effect of different environmental conditions on % of *Camellia* rooted cuttings growing during an extended spring growth season. AL Ambient light, SL Supplementary light, DL day length extension light

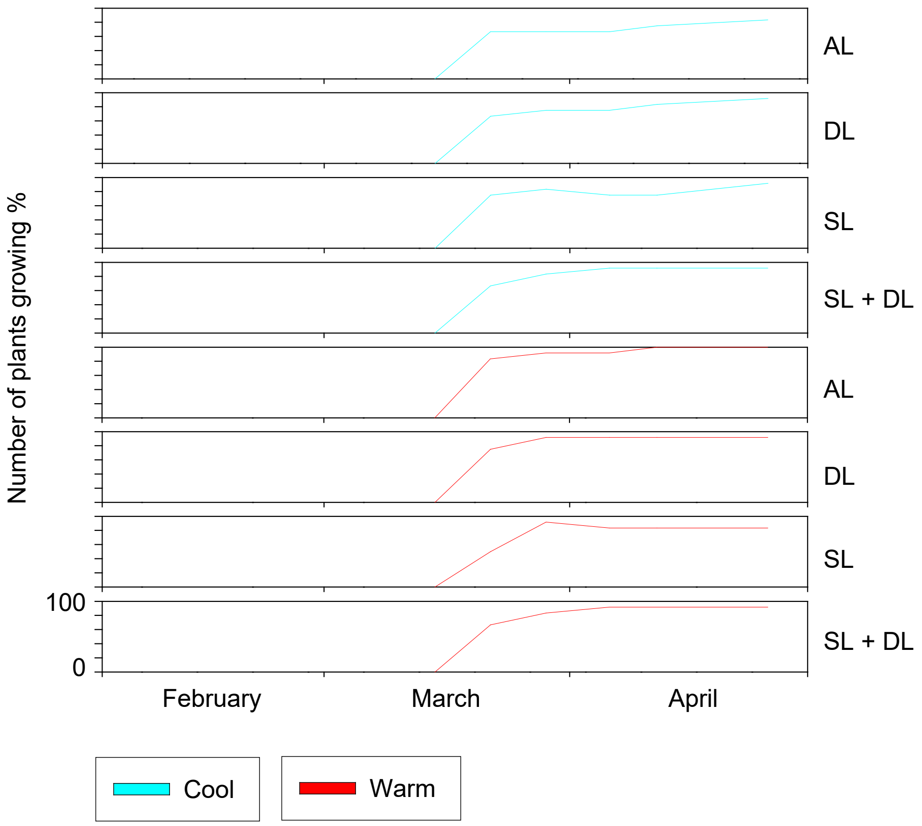
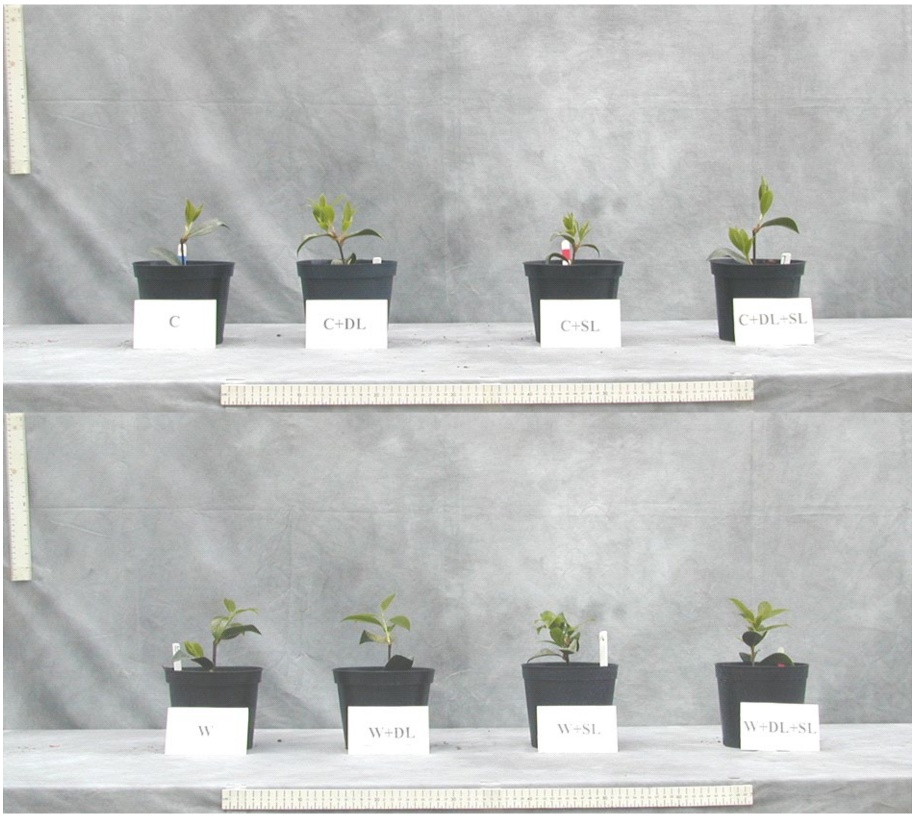


Table 6. The main effects of temperature, supplementary and day length extension light on plant size and number of new shoots (breaks) of *Camellia* rooted cuttings following spring extended growth season. Probability * is statistically significant (<0.05), ** is highly significant (< 0.01) and *** is very highly significant (< 0.001), ns is not statistically significant

Main effect		Height (cm)	Width (cm)	No. new shoots per plant
		April 2006		
Temperature	Cool	11	12	2
	Warm	12	12	2
Probability		ns	ns	ns
	-	12	12	2
Supplementary light	+	12	12	2
Probability		ns	ns	ns
Day length extension	-	12	12	2
light	+	12	12	2
Probability		ns	ns	ns
SED* (22 d.f.)		0.6	0.4	0.2
Interactions		None	None	None

*SED for comparison between main effects

Plate 6. Representative examples of *Camellia* rooted cuttings growth in April 2006 following the 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)



***Choisya ternata* (Mexican Orange Blossom)**

(Figure 7, Table 7, Plate 7)

Key points

- Warmth substantially increased the size of plants
- Warmth brought forward the start of growth.

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

Figure 7. The effect of different environmental conditions on % of *Choisya* rooted cuttings growing during an extended spring growth season. AL Ambient light, SL Supplementary light, DL day length extension light

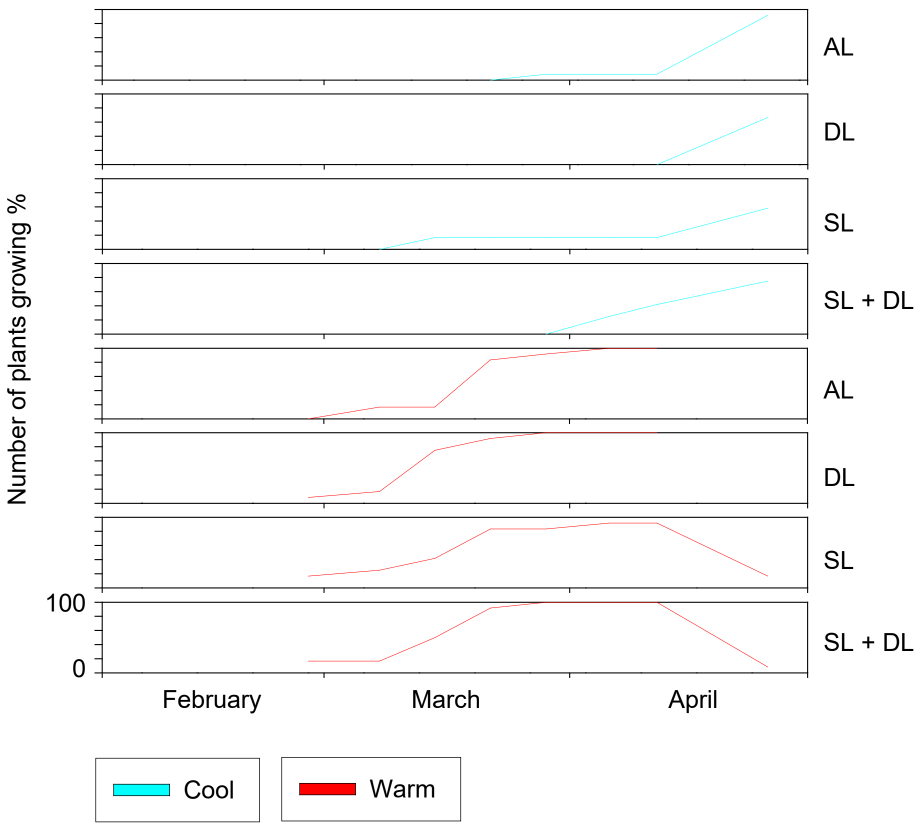


Table 7. The main effects of temperature, supplementary and day length extension light on plant size and number of new shoots (breaks) of *Choisya* rooted cuttings following spring extended growth season. Probability * is statistically significant (<0.05), ** is highly significant (< 0.01) and *** is very highly significant (< 0.001), ns is not statistically significant.

Main effect		**Height (cm)**	**Width (cm)**	**No. new shoots per plant**
		April 2006		
Temperature	Cool	6	11	0
	Warm	14	20	4
Probability		***	***	***
Supplementary	-	10	16	2
light	+	10	15	2
Probability		ns	ns	ns
Day length	-	10	16	2
extension light	+	10	15	2
Probability		ns	ns	ns
SED* (22 d.f.)		0.5	0.7	0.2
Interactions		None	SL x DL	None

*SED for comparison between main effects

Plate 7. Representative examples of *Choisya* rooted cuttings growth in April 2006 following the 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)

***Cytisus scoparius* ‘Burkwoodii’ (Broom)**

(Figure 8, Table 8, Plate 8)

Key points

- Warmth substantially increased plant size
- Warmth brought forward the start of growth
- Supplementary and day length extension light had a small effect on increasing plant size

The plants in the warm environment started to grow almost as soon as they were placed into the chamber, whereas those in the cool environment did not show any growth activity until approximately one month later. As a result, the plants had double the height and width of 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. *Cytisus* was also responsive to changes in the light environment. Supplementary light 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 heat.

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

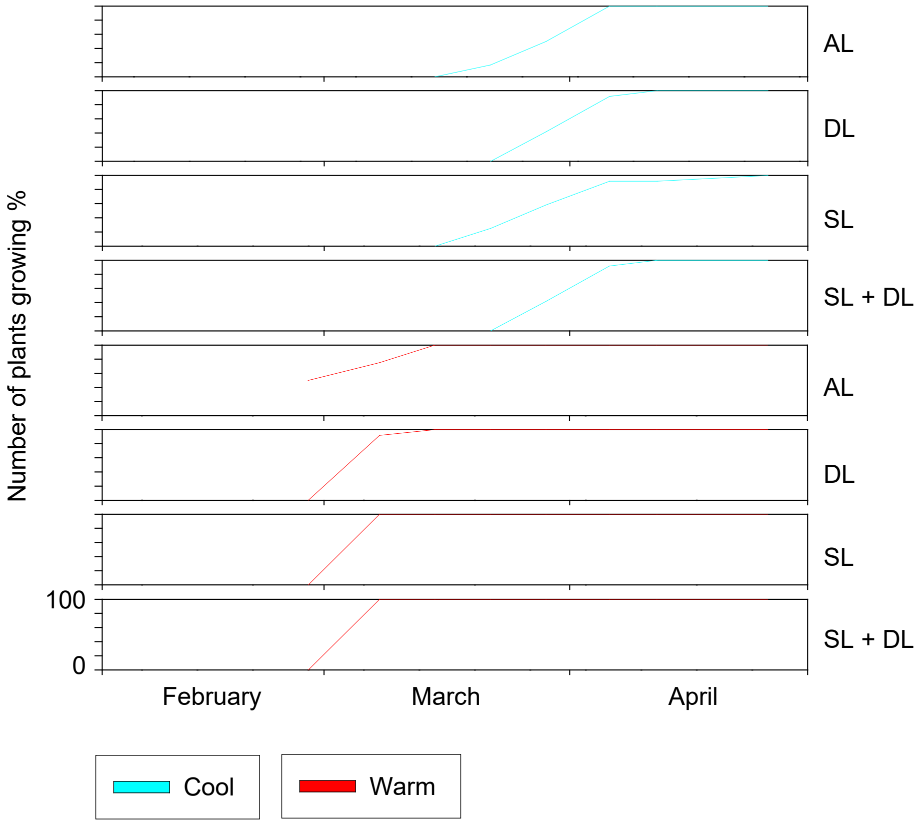


Table 8. The main effects of temperature, supplementary and day length extension light on plant size and number of new shoots (breaks) of *Cytisus* rooted cuttings following spring extended growth season. Probability * is statistically significant (<0.05), ** is highly significant (< 0.01) and *** is very highly significant (< 0.001), ns is not statistically significant.

Main effect		**Height (cm)**	**Width (cm)**	**No. new shoots per plant**
			April 2006	
Temperature	Cool	7	5	0
	Warm	13	12	8
Probability		***	***	***
Supplementary light	-	10	7	3
	+	10	9	5
Probability		ns	***	***
Day length extension light	-	9	7	4
	+	11	9	4
Probability		**	**	ns
SED* (22 d.f.)		0.5	0.4	0.4
Interactions		Temp x DL	Temp x SL x DL	Temp x SL

*SED for comparison between main effects

Plate 8. Representative examples of *Cytisus* rooted cuttings growth in April 2006 following the 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)

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

(Figure 9, Table 9, Plate 9)

Key points

- Warmth substantially increased plant size
- Day length extension light had a small effect on increasing plant size
- None of the environmental treatments had an effect on the start of growth

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 width and height by 1 cm.

Figure 9. The effect of different environmental conditions on % of *Hydrangea* rooted cuttings growing during an extended spring growth season. AL Ambient light, SL Supplementary light, DL day length extension light

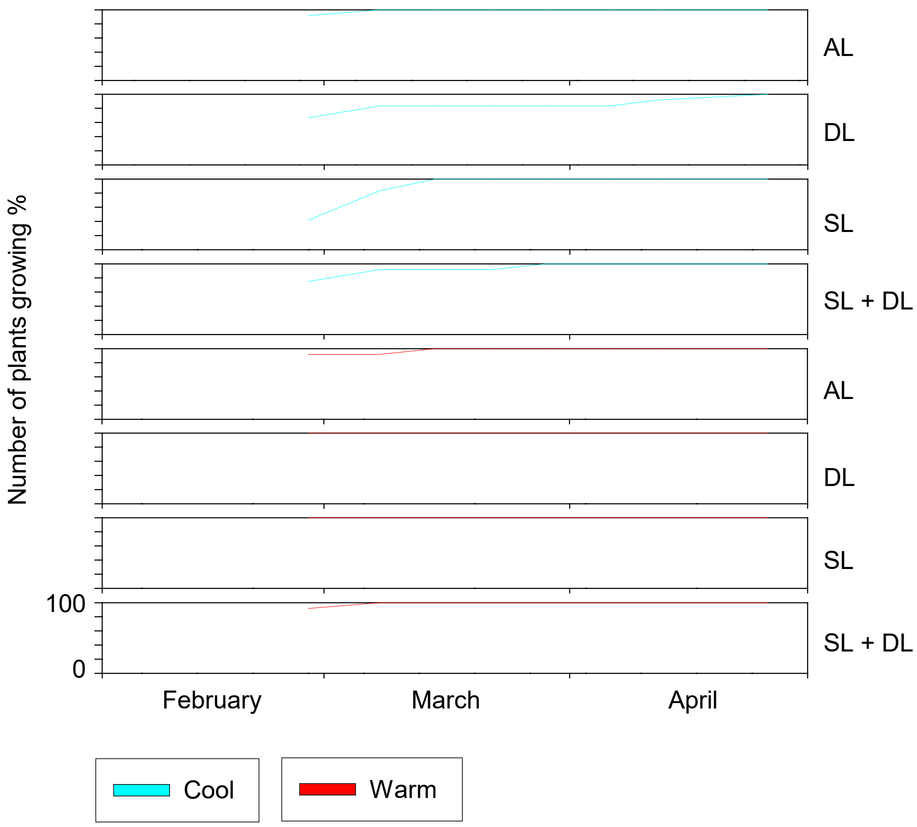
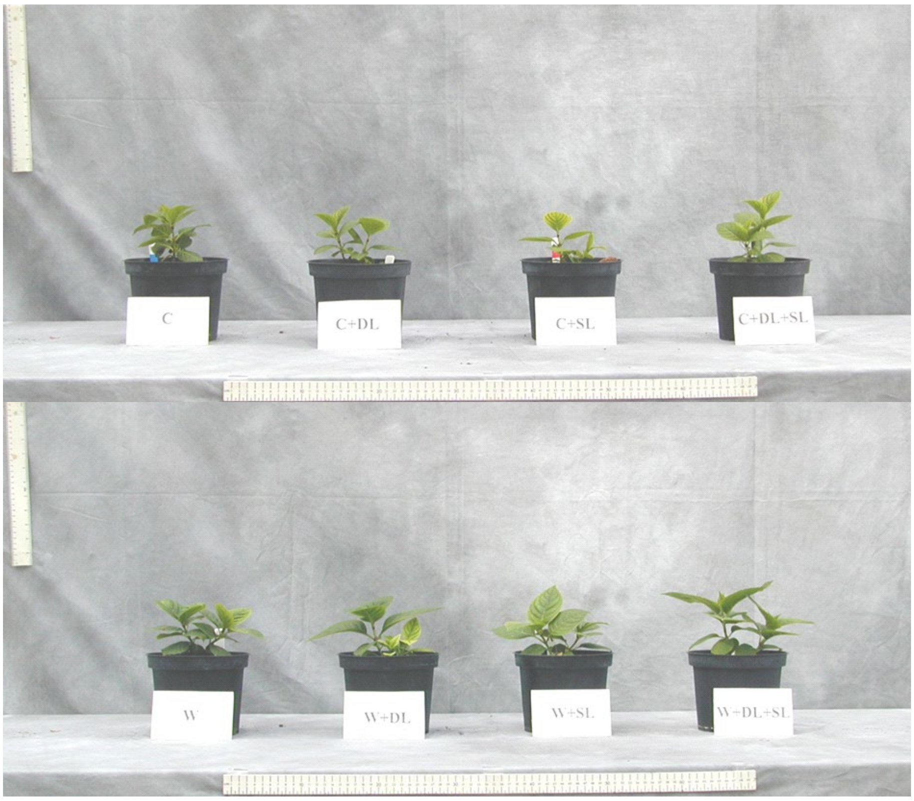


Table 9. The main effects of temperature, supplementary and day length extension light on plant size and number of new shoots (breaks) of *Hydrangea* rooted cuttings following spring extended growth season. Probability * is statistically significant (<0.05), ** is highly significant (< 0.01) and *** is very highly significant (< 0.001), ns is not statistically significant

Main effect		Height (cm)	Width (cm)	No. new shoots per plant
		April 2006		
Temperature	Cool	10	13	2
	Warm	11	18	2
Probability		**	***	ns
Supplementary	-	10	16	2
light	+	11	15	2
Probability		ns	ns	0.210
Day length	-	10	15	2
extension light	+	11	16	2
Probability		**	*	ns
SED* (22 d.f.)		0.5	0.8	0.2
Interactions		Temp x DL Temp x DL x SL	Temp x DL x SL	SL x DL

*SED for comparison between main effects

Plate 9. Representative examples of *Hydrangea* rooted cuttings growth in April 2006 following the 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)



***Osmanthus heterophyllus* 'Goshiki'**

(Figure 10, Table 10, Plate 10)

Key points

- Warmth substantially increased plant size and increased the number of new shoots per plant
- Warmth brought forward the start of growth
- Supplementary and day length extension light had no effect on plant size or the time that growth started

The *Osmanthus* plants were placed into the different environments in mid February, 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 4 cm taller and 2 cm wider than those in the cool environment at the end of April. In addition, the former plants had several new shoots growing whereas the latter had none. Supplementary and day length extension light had no effect on plant growth and size.

Figure 10. The effect of different environmental conditions on % of *Osmanthus* rooted cuttings growing during an extended spring growth period.. L Ambient light, SL supplementary light, DL day length extension light

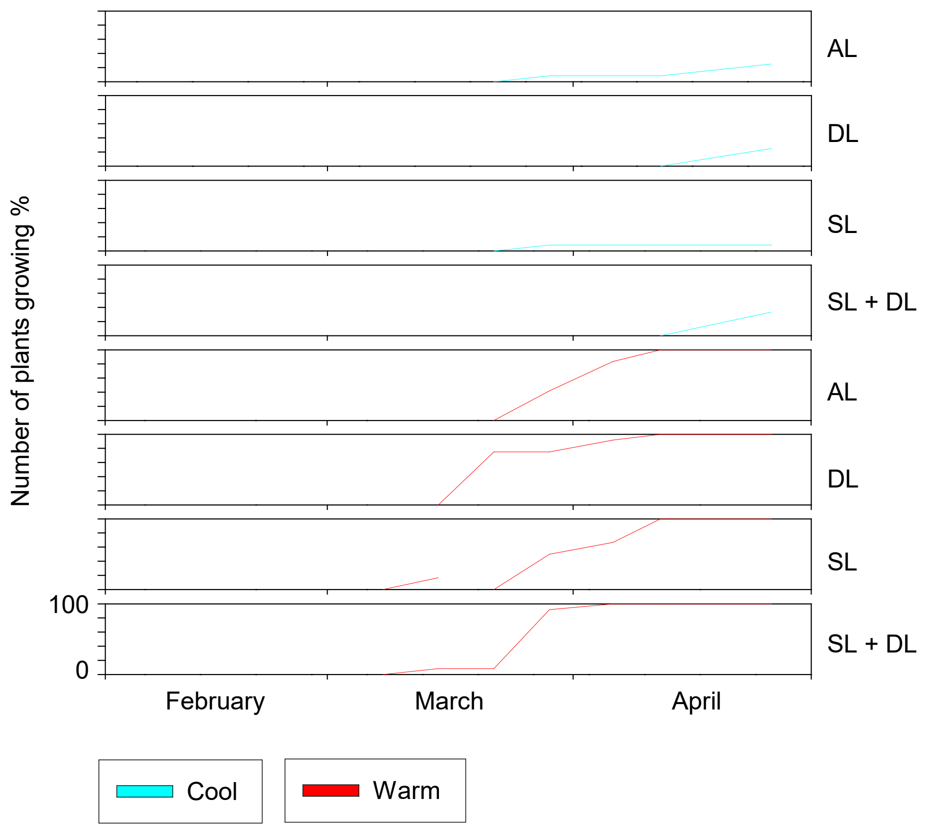
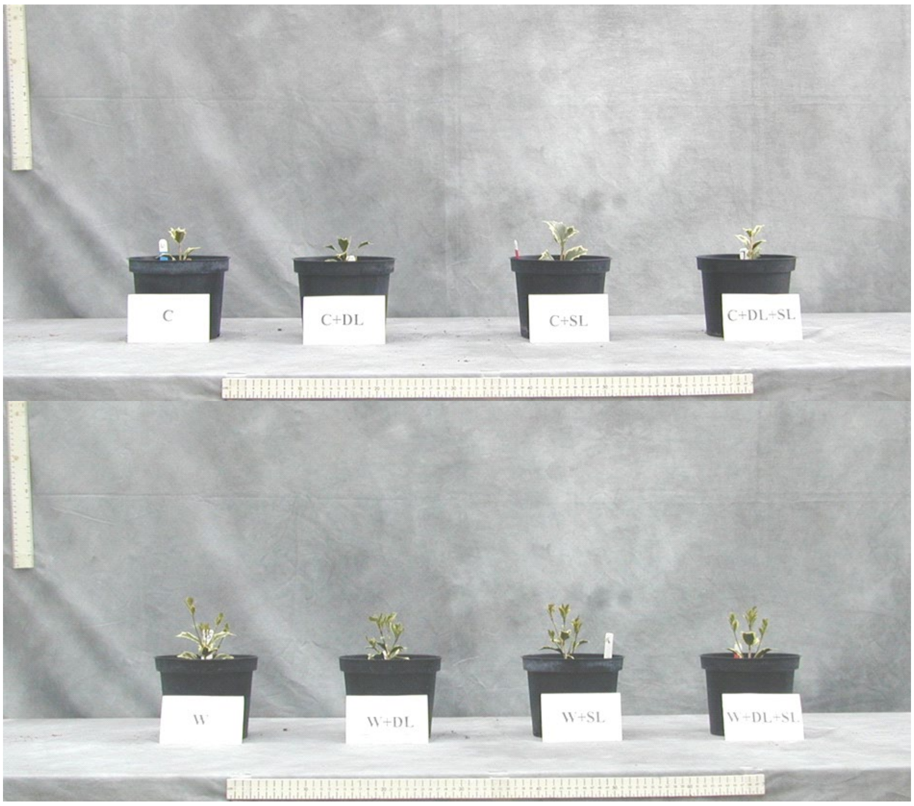


Table 10. The main effects of temperature, supplementary and day length extension light on plant size and number of new shoots (breaks) of *Osmanthus* rooted cuttings following spring extended growth season. Probability * is statistically significant (<0.05), ** is highly significant (< 0.01) and *** is very highly significant (< 0.001), ns is not statistically significant

Main effect		**Height (cm)**	**Width (cm)**	**No. new shoots per plant**
			April 2006	
Temperature	Cool	6	7	0
	Warm	10	9	4
Probability		***	***	***
Supplementary light	-	8	8	2
	+	8	8	2
Probability		ns	ns	ns
Day length extension light	-	8	8	2
	+	8	8	2
Probability		ns	*	ns
SED* (22 d.f.)		0.3	0.2	0.22
Interactions		None	SL x DL	None

*SED for comparison between main effects

Plate 10. Representative examples of *Osmanthus* rooted cuttings growth in April 2006 following the 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)



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

(Figure 11, Table 11, Plate 11)

Key points

- None of the environmental treatments influenced the start of growth
- Warmth increased plant size

None of the environmental treatments influenced the growth activity of the plants. 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 taller (3 cm) and wider (1 cm) by late April. Changes in light intensity and day length had no influence on growth.

Figure 11. The effect of different environmental conditions on % of *Photinia* rooted cuttings growing during an extended spring growth season. AL Ambient light, SL Supplementary light, DL day length extension light

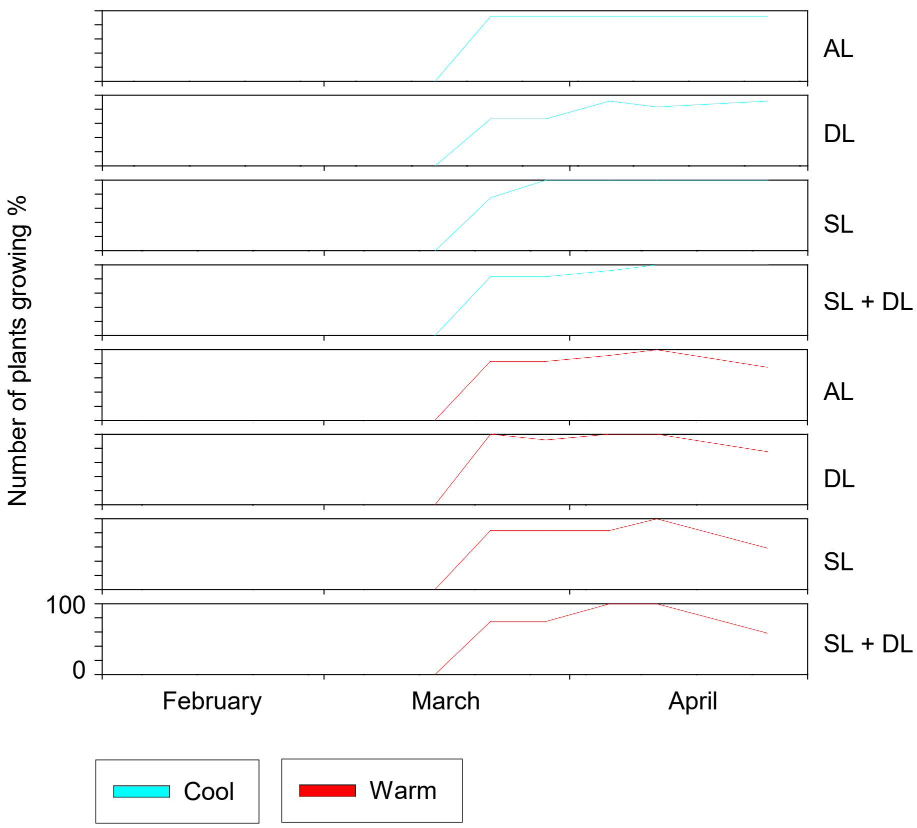
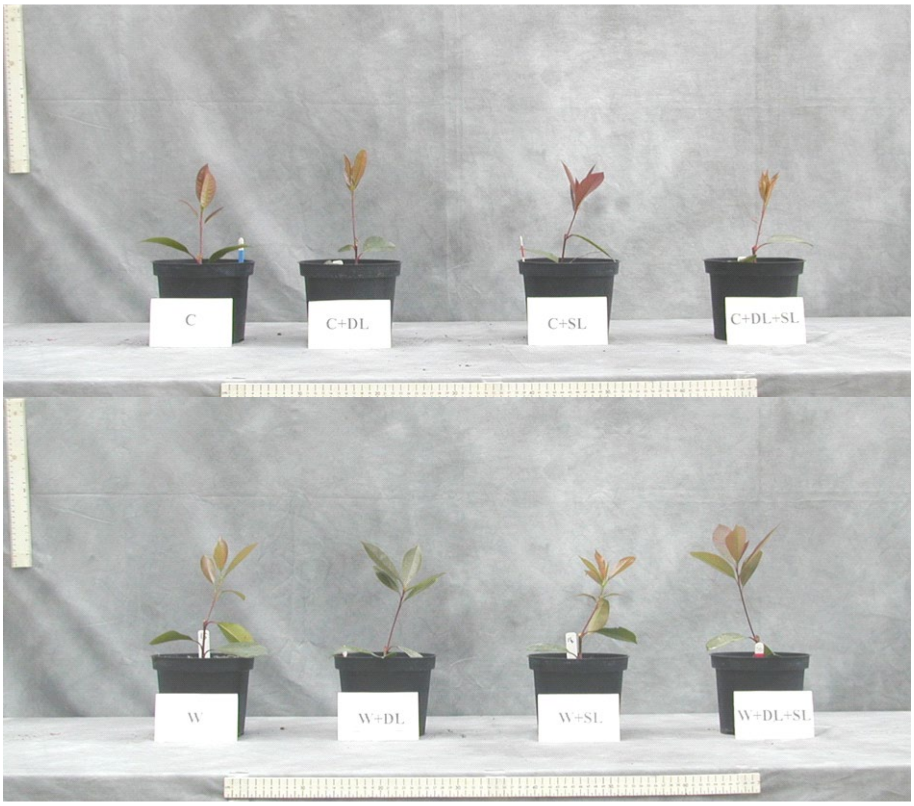


Table 11. The main effects of temperature, supplementary and day length extension light on plant size and number of new shoots (breaks) of *Photinia* rooted cuttings following spring extended growth season. Probability * is statistically significant (<0.05), ** is highly significant (< 0.01) and *** is very highly significant (< 0.001), ns is not statistically significant

Main effect		**Height (cm)**	**Width (cm)**	**No. new shoots per plant**
			April 2006	
Temperature	Cool	16	17	1
	Warm	19	18	1
Probability		*	*	ns
Supplementary light	-	17	18	1
	+	17	17	1
Probability		ns	ns	ns
Day length extension light	-	17	18	1
	+	18	17	1
Probability		ns	ns	ns
SED* (22 d.f.)		0.8	0.7	0.1
Interactions		Temp x SL	None	None

*SED for comparison between main effects

Plate 11. Examples of *Photinia* rooted cuttings growth in April 2006 following the 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)



***Pittosporum tenuifolium* ‘Goldstar’**

(Figure12, Table 12, Plate 12)

Key points

- Warmth substantially increased the size of plants
- Warmth brought forward the start of growth
- Neither supplementary nor day length extension light influenced growth activity or plant size

Initially the plants were slow to start growing with no growth 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 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.

Figure 12. The effect of different environmental conditions on % of *Pittosporum* rooted cuttings growing during an extended spring growth season. AL Ambient light, SL Supplementary light, DL day length extension light

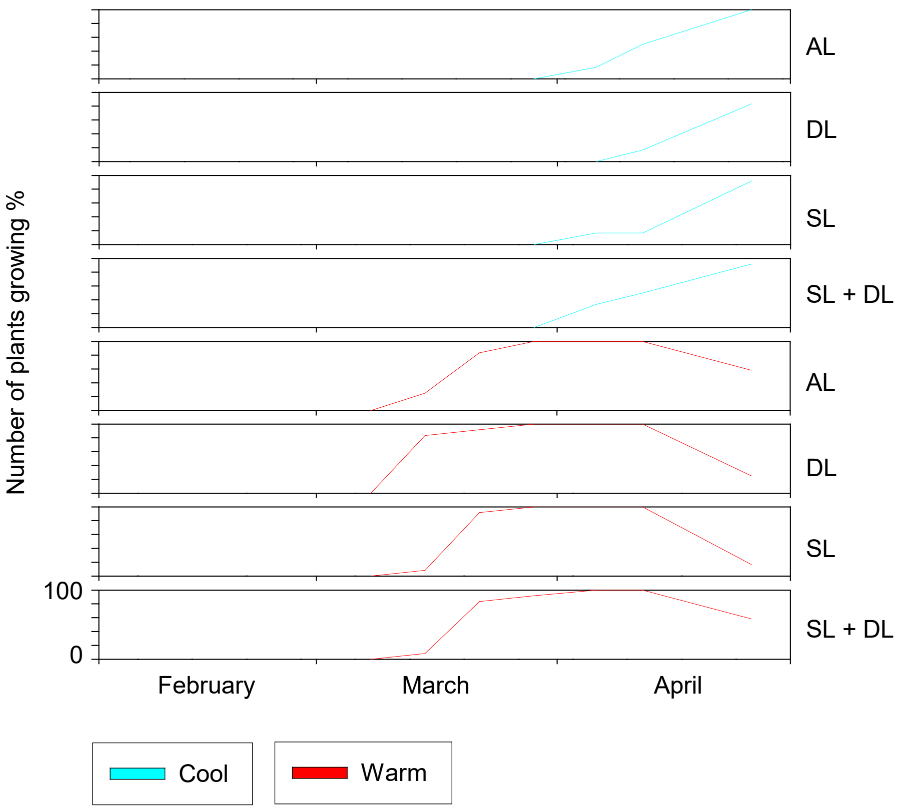
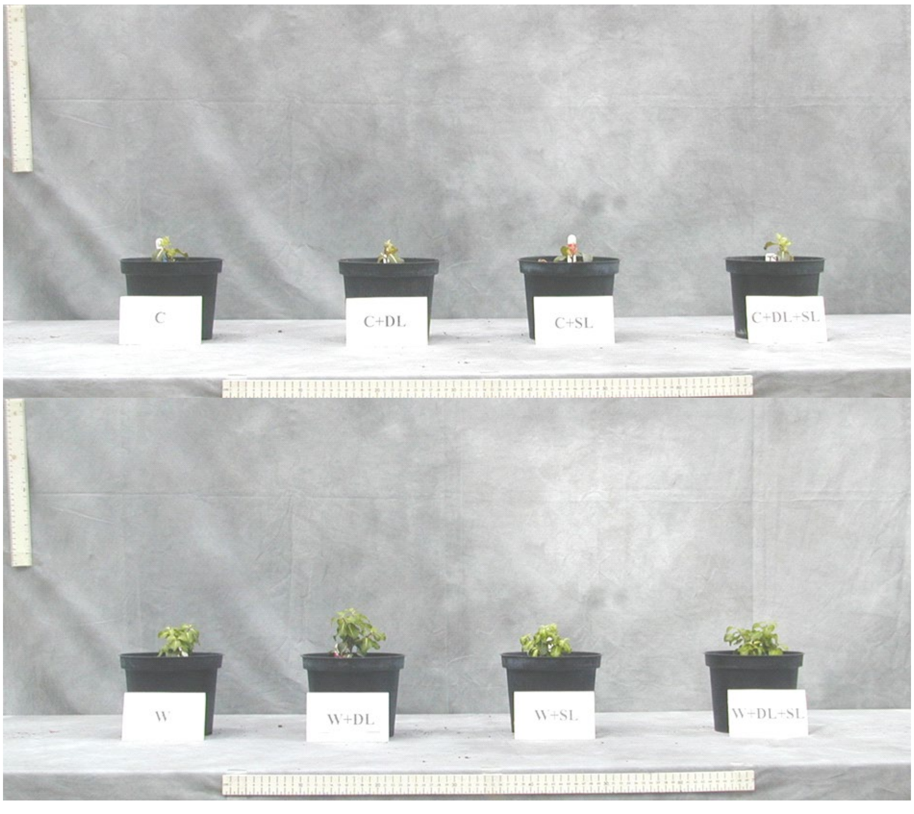


Table 12. The main effects of temperature, supplementary and day length extension light on plant size and number of new shoots (breaks) of *Pittosporum* rooted cuttings following spring extended growth season. Probability * is statistically significant (<0.05), ** is highly significant (< 0.01) and *** is very highly significant (< 0.001), ns is not statistically significant

Main effect		**Height (cm)**	**Width (cm)**	**No. new shoots per plant**
			April 2006	
Temperature	Cool	5	7	1
	Warm	7	9	5
Probability		***	***	***
Supplementary	-	6	8	3
light	+	6	8	3
Probability		ns	ns	ns
Day length	-	6	8	3
extension light	+	7	8	3
Probability		*	ns	ns
SED* (22 d.f.)		0.1	0.3	0.3
Interactions		SL x DL	None	SL x DL

*SED for comparison between main effects

Plate 12. Examples of *Pittosporum* rooted cuttings growth in April 2006 following the 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)



Experiment 3 - Winter chilling

(Figures 13, 14, Tables 13, 14, Plate 13, 14)

Key points

- Different periods of winter chilling had no impact on the growth of Hydrangea and Photinia
- Hydrangea had a trend of improved plant quality with increased period of chilling, but the effect was not statistically significant

The plants were placed into the warm environment with day length extension light following winter chilling because this was the environment that maximised growth in last year's experiment. Consistently with last year's experiment, the warm environment increased plant growth compared to the cool environment

None of the winter chilling treatments had an affect on growth on either species, although there was some evidence that increased cold storage period (winter chilling) improved plant quality in Hydrangea.

However, all of the plants including those kept in cold store were growing by the time of the first measurement of growth activity on 7 February 2006. It was evident that plants held in the cool (5°C) ambient environment for the entire time or after removal from cold storage at 15 and 30 days had not remained dormant during their time in this environment. Therefore, to directly measure the impact of different winter chilling periods it may be better to arrange the cold storage so that the plants are put into cold storage at different dates, but all are removed on the same date.

Figure 13. The effect of different cold storage periods at 2⁰C on active plant growth of *Hydrangea* liners subsequently placed into a cool environment (blue) or warm environment (red). Period of chilling is given on right y axis

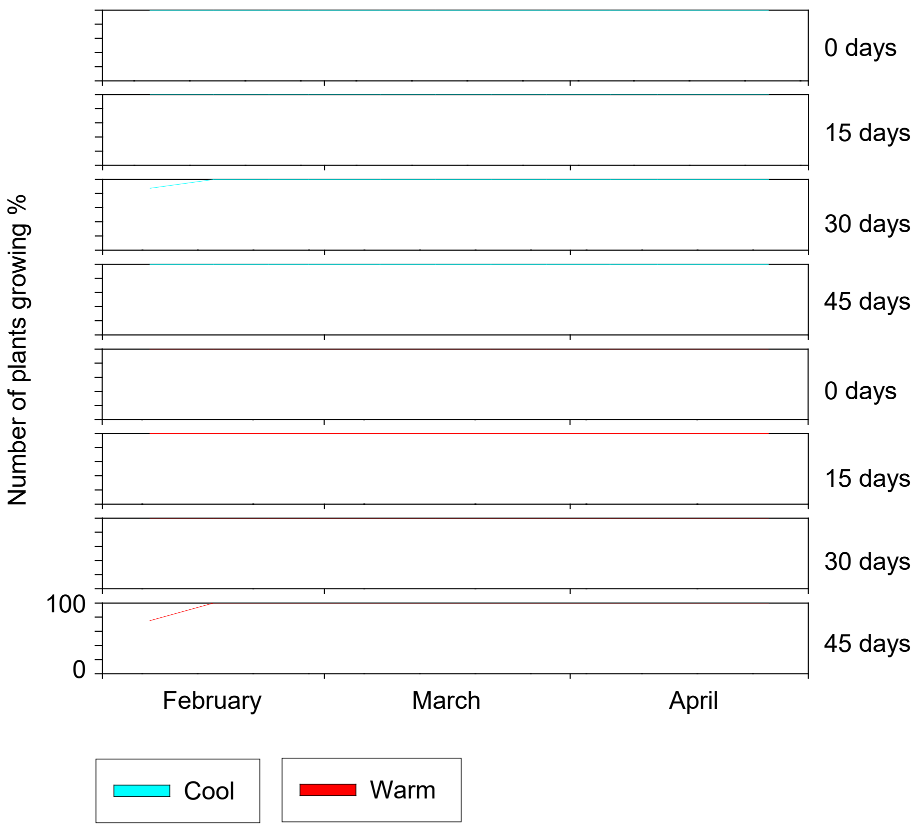


Table 13. The main effects different cold storage periods at 2^0C on plant size, number of new shoots (breaks) and plant quality of *Hydrangea* liners. Probability * is statistically significant (<0.05), ** is highly significant (< 0.01) and *** is very highly significant (< 0.001), ns is not statistically significant

Main effect		Height (cm)	Width (cm)	No. new shoots per plant	No. of flower buds	Quality
Temperature	Cool	29	60	12	3	2.1
	Warm	31	71	10	3	2.5
Probability		ns	ns	*	ns	ns
SED (2 d.f.)		1.2	4.6	0.4	0.3	0.26
Cold storage period (CSP)	*Days at 2^0C*					
	0	32	64	11	2	1.9
	15	30	65	11	3	2.4
	30	30	67	11	3	2.3
	45	28	66	11	3	2.7
Probability		ns	ns	ns	ns	ns
SED (42 d.f.)		1.5	2.7	0.7	0.8	0.21
Interactions		None	None	None	None	Temp x CSP

Plate 13. Representative examples of *Hydrangea* liners growth in April 2006 following different periods of cold storage. C = cool house, W = warm house after cold storage. 0, 15, 30, 45 = days at 2^0C during cold storage. (Ruler = 30 cm; horizontal ruler = 70cm)

Figure 14. The effect of different cold storage periods at 2^{0}C on active plant growth of *Photinia* liners subsequently placed into a cool environment (blue) or warm environment (red). Period of chilling is given on right y axis

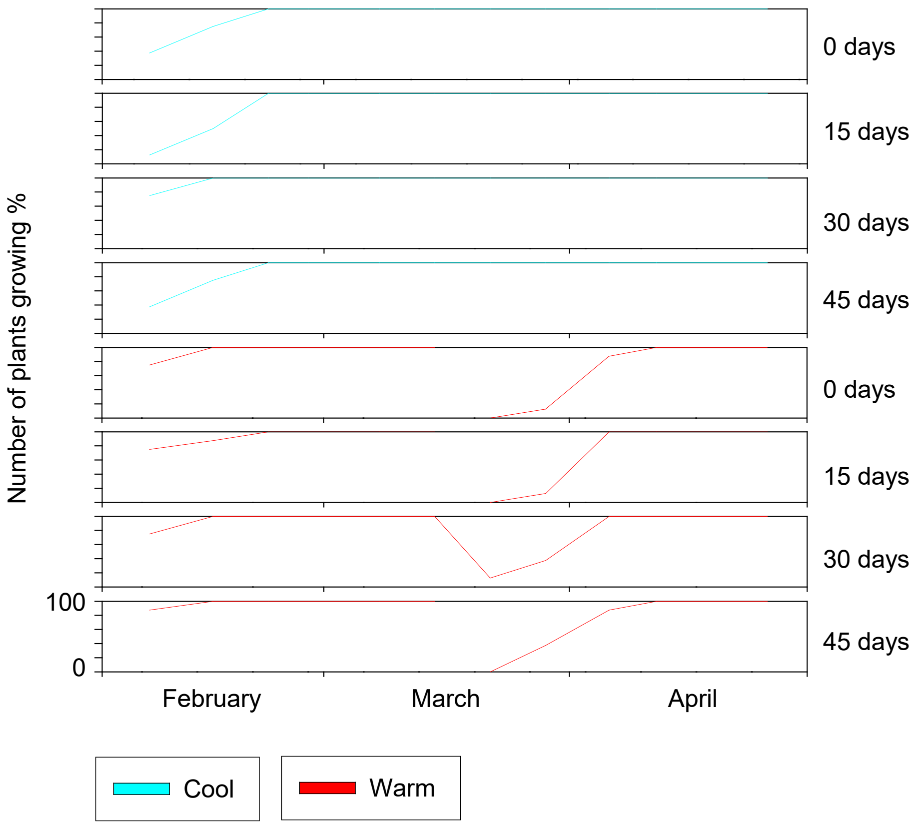
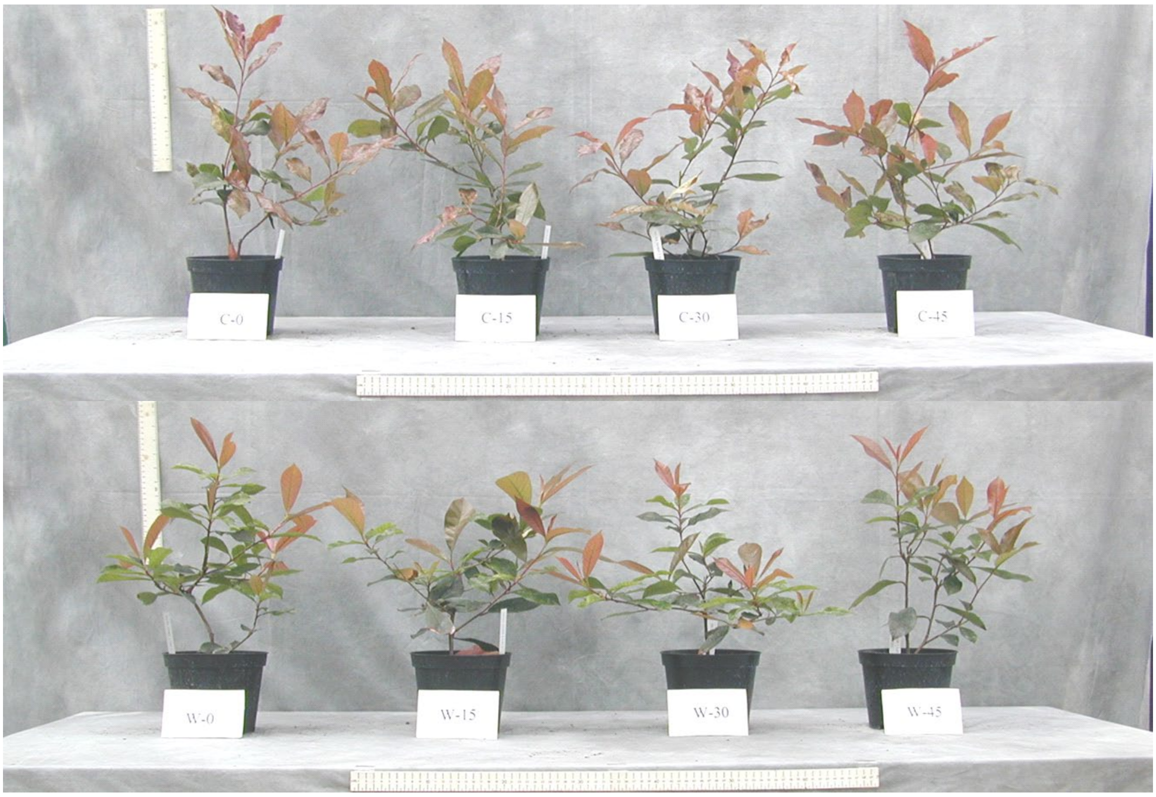


Table 14. The main effects of different cold storage periods at 2^{0}C on plant size, number of new shoots (breaks) and plant quality of *Photinia* liners. Probability * is statistically significant (<0.05), ** is highly significant (< 0.01) and *** is very highly significant (< 0.001), ns is not statistically significant

Main effect		**Height (cm)**	**Width (cm)**	**No. new shoots per plant**	**Quality**
Temperature	Cool	38	65	8	2
	Warm	40	62	7	2
Probability		n.s	n.s	n.s	n.s
SED (2 d.f)		1.3	2.5	0.5	0.1
Cold storage period (CSP)	*Days at 2^{0}C*				
	0	40	69	7	2
	15	41	64	8	2
	30	39	63	7	2
	45	36	59	8	2
Probability		n.s	n.s	n.s	n.s
SED (42 d.f)		2.1	3.7	0.6	0.3
Interactions		None	None	None	None

Plate 14. Representative examples of *Photinia* liners growth in April 2006 following different periods of cold storage. C = cool house, W = warm house after cold storage. 0, 15, 30, 45 = days at 2^0C during cold storage. (Ruler = 30 cm; horizontal ruler = 70cm)



Conclusions

- Early application of warmth in spring generally has the largest effect on increasing plant size of both liners and rooted cuttings and has real potential as a tool for reducing production times for HNS
- The combination of judicious pruning in autumn and enhanced environmental treatments can significantly improve visual quality of plant liners in spring
- Day length extension light applied in autumn and/or spring has potential for improving plant size
- Supplementary light has limited value for bringing forward the start of growth and improving plant size, but may be useful for improving visual quality.

Technology Transfer

Report of first year results in HDC News

Hipps NA, March 2006 Speeding up nursery stock. *HDC News* No 121 pp 28-30.

Bibliography

Bailey D.A. and 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. and 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. and 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.

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

Morita M., Iwamoto S and 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. and 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. and Chiang H.H. (2003). Effects of temperature on flower formation of *Hydrangea macrophylla* ‘Leuchfeuer’, Journal Chinese Society for Horticultural Science. 49:211-220.

APPENDIX 1 – PARAMETERS FOR VISUAL ASSESSMENT OF PLANT QUALITY

Choisya

Parameters: Shape, structure, leaf colour

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 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 1

At least two parameters described in Category 3 are not met

(Note – plants which have little new growth on them will score poorly for quality)

Category 1

Category 2

Category 3

Hydrangea

Parameters: Shape, structure, leaf colour, flower bud

Category 4

1. Round shape (covering the pot when looked at from above)
2. 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
3. Dark green leaves
4. Flower buds opening

Category 3

One of the shape, structure, colour, flower bud parameters in Category 4 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. Light green leaves
4. Flower buds closed

Category 2

At least two parameters described in Category 4 are not met

Category 1

At least three parameters described in Category 4 are not met

Category 1

Category 2

Category 3

Category 4

Photinia

Parameters: Shape, structure, new shoot growth

Category 3

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

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. Colour of leaves is light green or poorly mottled.

Category 1

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

Category 1

Category 2

Category 3

Viburnum tinus

Parameters: Shape, structure, new shoot growth

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 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 1

At least two parameters described in Category 3 are not met

Category 1

Category 2

Category 3