Project Title:	To develop proven protocol and methodology for reducing production times for woody species
Project Number:	HNS 124
Report:	Annual report, Year 1, June 2005
Previous reports:	None
Project leader:	Dr Neil Hipps, East Malling Research
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 RG6 6AH Chris Lane, Coblands Nurseries, Trench Road Tonbridge Kent TN11 9NG Neal Wright, Micropropagation Services (EM) Ltd, Kirk Ley Road, East Leake, Loughborough, Leics, 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

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 is the most promising treatment for consistently increasing plant size and reducing production times across a wide range of HNS species
- Day length extension light (tungsten) applied in autumn and/or spring has potential for improving plant size

Background and expected deliverables

The main aim of this project is to use the techniques for scheduling HNS species to attempt to remove a year from the production of a standard perennial plant. Specific objectives are:

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 photoperiodic extension and supplementary light.

Summary of the project and main conclusions

This year, 21 different HNS species (Table A) were screened to determine growth response in autumn and spring using the following environmental conditions.

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

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

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

5. Ambient light
6. Supplementary (SONT) light, 8hrs
7. Tungsten light to give day length extension, ≥ 15hrs
8. Supplementary (8 hrs) and day length extension light

The heating and supplementary lighting treatments were provided from 16 August until 26 November 2004. After this the lighting in the supplementary and day length extension treatments was switched off and the set point in the cool environment was adjusted to 5°C. The plants were moved to a jacketed, unlit 2°C cold store on 22-23 December 2004 and returned into the glasshouse on 9 February 2005. The treatments were repeated as above from 11 February until 27 April 2005. The species used and the main effects of the treatments are given in Table A.

The main results were:

- 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
- What was the effect of supplementary light and day length extension?

Number of species showing a positive growth response to modified environmental conditions applied in autumn and again in the following spring

Autumn response			Spring response		
Temperature	Day length extension light	Supplementary light	Temperature	Day length extension light	Supplementary light
7	8	4	19	12	1

Conclusions

- Early application of warmth in spring is the most promising treatment for consistently increasing plant size across a wide range of HNS species
- Day length extension light applied in autumn and/or spring has potential for improving plant size
- Supplementary light has very limited value and should only be considered for use in autumn

Financial benefits

This project has made good progress towards reducing 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; this will be determined during the next phases of the project.

Action points for growers

Growers wishing to	Autumn	Spring

reduce production times by increasing plant size within a shorter period of time should initially concentrate on using warmth in spring and or day length extension light in autumn and spring. Table A. The main effects of temperature, day length extension and supplementary light on the size of 21 different HNS species in autumn and spring. + indicates a positive effect, - indicates a negative effect on size, blank space indicates no effectSpecies	Temp.	Day len. exten. light	Suppl. light	Temp.	Day len. exten. Light	Suppl. light
Azalea japonica 'Santa maria'	+	+		+	+	
Berberis thunbergii 'Pink Queen'	+			+	+	
Camellia japonica 'Guilio Nuccio'				+		
Chaenomeles speciosa 'Madame Butterfly'				+		
Choisya ternate				+	+	
Clematis 'Jackmanii'		+		+		
Convolvulus cneorum	+	+		+	+	
Cytisus scoparius 'Burkwoodii'				+		
Hydrangea 'King George'				+	+	
Ilex aquifolium Argentea Marginata			+	+	+	
Lavendula angustifolia 'Hidcote'				+	+	
Mahonia japonica						
Osmanthus heterophyllus				+/-		

‘Goshiki’						
Philadelphus ‘Silver showers’	+			+	+	
Photina x fraseri ‘Red Robin’			+	+	+	
Pittosporum tenuifolium ‘Gold Star’			+	+	+	
Prunus incisa ‘Kojo-no-mai’		+	+			+
Rhododendron ‘Shamrock’	+	+		+	+	
Viburnum x bodnatense ‘Dawn’		+		+		
Viburnum tinus ‘French White’ EM27	+	+		+	+	
Weigela ‘Rubidor’	+	+		+		

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.

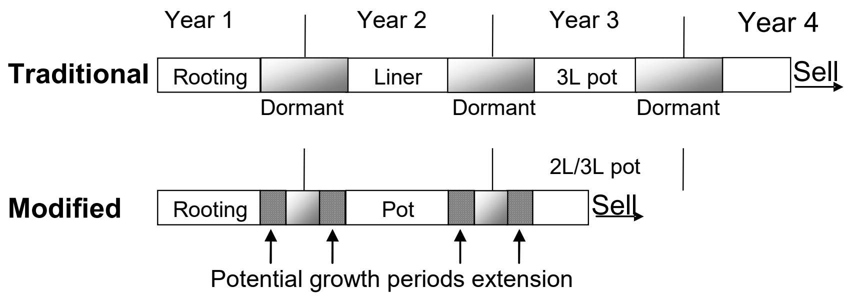
Manipulation of day length is commonly used by protected crop growers to schedule flowering out of season. Much previous scientific work has been directed at the fundamentals of flowering and scheduling of plants. The largest screening programme of flowering responses has been undertaken at Michigan 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 recent 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.

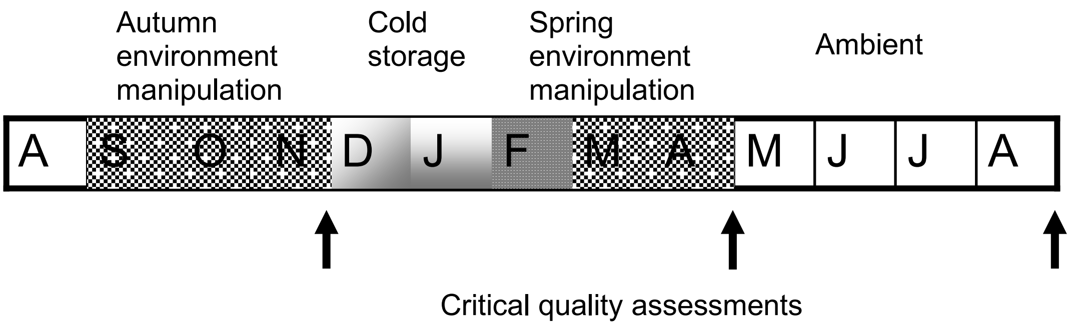
Therefore, important opportunity exists to shorten the production time of woody perennials using the scheduling techniques and facilities now available under cover. Currently, from a cutting being stuck to the sale of a finished plant in a 3 litre pot being sold can take up to 4 years (Figure A). This 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 versus modified schedule for producing HNS 3l plant taking 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 1 y rather than up to 3 y 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.

Materials and methods

The 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 x 3.2 m compartment was divided into two sections longitudinally (N-S direction) down the middle by the use 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 filament bulbs at 1 m spacing 2.1 m above the benches. These were subsequently replaced on 19 October 2004 with 60 W tungsten spot lights. Sunrise and sunset times for Maidstone (http://www.onelinewaether.com/v4/uk/sun/Maidstone.html) were used to calculate day length. Then the lights were put on 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 20,000mW/m^2 (i.e. 9000 lux). The heating and supplementary lighting treatments were provided from 16 August until 26 November 2004, when the lighting in the SD and LD treatments was switched off and the set point in the cool house was adjusted to 5°C. The plants were moved to a jacketed, unlit 2°C cold store on 22-23 December 2004 and returned into the glasshouse on 9 February 2005. Each plant was placed into exactly the same position it had occupied previously 10-12 February 2005. Some of the plants were pruned prior to replacing in the glasshouse chambers. The details of pruning are given in the results section. The set point in the warm house was set to 15°C on 11 February and the supplementary and day length extension lighting was switched on 12 February 2005.

Twenty-one different species (Table B) were chosen for the initial phase of the work following consultation and agreement with the grower co-ordinators. These included spring and winter flowering deciduous and evergreen hardy plant groups.

The plants were supplied by New Place Nurseries Ltd on 26 July in 9 cm containers except *Mahonia* 1 litre. They were potted on between 27 July and 3 August into 2 litre containers using a Richmoor Mix 1 substrate supplemented with Osmocote Plus Autumn 12 to 14 months at 3.0 kg/m^3, except Rhododendron and Azalea which used a more appropriate ericaceous substrate provided by New Place Nurseries Ltd.

Each bench allowed for 42 rows and four columns, so it was possible to place eight plants from each species onto each bench. 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 1,344 plants.

Statistical analysis

The experimental design was regarded as randomised block with heat, supplementary light and day length extension light as treatment factors. 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/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.

Table B. Species screened for response to different growing environment used for the first year July 2004 – May 2005

Evergreen	***Flowering***	**Deciduous**	***Flowering***
Azalea japonica 'Santa Maria'	*Spring*	Berberis thunbergii 'Pink Queen'	Foliage *Late spring/early summer*
Camellia japonica 'Guilio Nuccio'	*Spring*	Chaenomeles 'Madame Butterfly'	*Early/mid spring*
Choisya ternata	*Late spring*	Clematis	*Early summer - Autmun*
Convolvulus eneorum	*Summer*	Hydrangea 'King George'	*Summer*
Cytisus 'Burkwoodii'	*Summer*	Philadelphus 'Silver showers'	*Summer*
Mahonia japonica	*Spring*	Prunus incisa 'Kojo-no-mai'	*Early mid spring*
Osmanthus heterophyllus 'Goshiki'	*Late summer*	Viburnum bodnantense 'Dawn'	*Winter*
Photinia fraseri 'Red robin'	Foliage *Winter*	Weigela 'Rubidor'	*Spring*
Pittosporum tenuifolium 'Gold star' in full please	**Foliage** *(Spring flower)*		
Rhododendron 'Shamrock'	*Spring*		
Viburnum tinus 'French White' EM27	*Winter*		
Ilex aquifolium 'Argentea Marginata'	*(April/May) Autumn (berries)*		
Lavendula angustifolia 'Hidcote'	*Spring*		

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 11-13 August 2004 and heights, breadth (across two positions at right angles) and number of breaks were recorded on 17-22 December 2004 and again on 27 April - 4 May 2005.

Photographs

Representative plants for each species from each treatment were photographed on 27 July, 26 November, 2 December 2004 and 16 May 2005.

Environment

Temperature and total and photosynthetic active radiation was measured using the appropriate sensors and logged on 1 or 10 minute intervals either on a glasshouse computer or a Delta-T Devices ML2 logger in all of the chambers throughout the experiment.

Results and Discussion

Azalea japonica 'Santa Maria'

Key points

- Day length extension light applied in autumn and spring respectively increased plant size in autumn and spring respectively
- Warmth applied in autumn and spring increased plant size in autumn and spring respectively
- Supplementary light had no effect on growth, but increased the number of breaks in spring
- Spring flowering was brought forward by two weeks in the warm environment and persisted for a week less than in the cool environment

Azalea responded day length extension lighting by increasing the period of growth from early October until mid-November (Figure 1) i.e. when the lights and heating were switched off. This resulted in larger plants that were taller and wider in December than those in ambient lighting conditions (Table 2, Plate 1). Increasing temperature also increased plant size, but this was due to faster growth rather than extension of the growth period, since warmth had no effect on period of active growth (Figure 1). Supplementary lighting had no effect on growth in autumn.

Following cold storage, the plants were hedge trimmed to height 16cm. They started to grow approximately one month earlier in the warm environment and produced more new shoots (breaks) than those in the cool environment (Table 1). Day length extension light had no impact on the start of growth, although the plants were larger by May (Table 2, Plate 1). Supplementary light increased the number of shoots per plant in spring.

Flowering started two weeks earlier in spring, but lasted for a shorter period than in the cool environment (Table 1).

Table 1. The effect of different environmental conditions on flowering of Azalea. AL Ambient light, SL Supplementary light, DL day length extension light

Treatment	**Flowers open**	**Petal fall**
Cool house		
AL	6 April	27 April
SL	6 April	27 April
DL	6 April	27 April
SL + DL	6 April	27 April
Warm house		
AL	24 March	6 April
SL	24 March	6 April
DL	24 March	6 April
SL + DL	18 March	6 April

Figure 1. The effect of different environmental conditions on active plant growth of Azalea. Blue = cool house, red = warm house, AL=Ambient light, SL= Supplementary light, DL = day length extension light

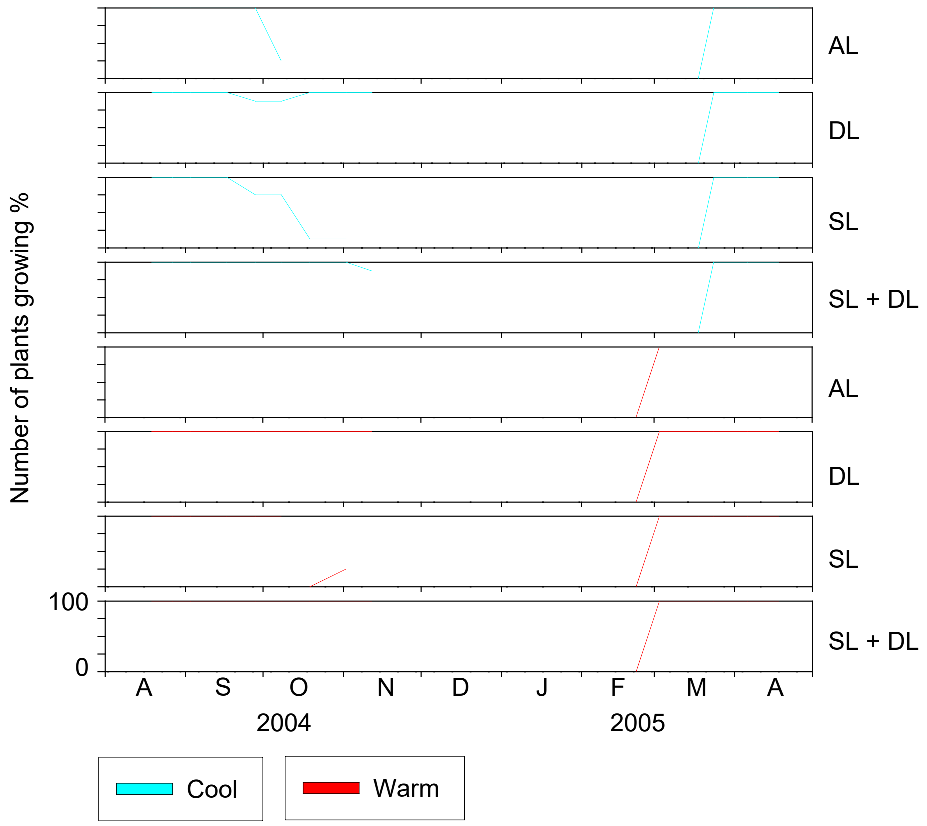
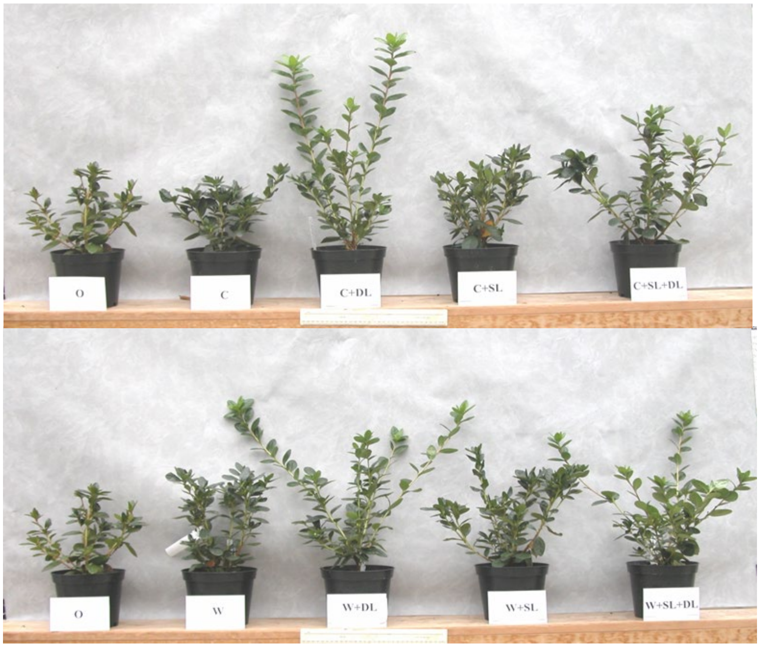


Table 2. The main effects of temperature, supplementary and day length extension light on plant size and number of new shoots (breaks) of Azalea following autumn and spring extended growth seasons. Probability * is statistically significant (<0.05), ** is highly significant (≤ 0.01) and *** is very highly significant (≤ 0.001)

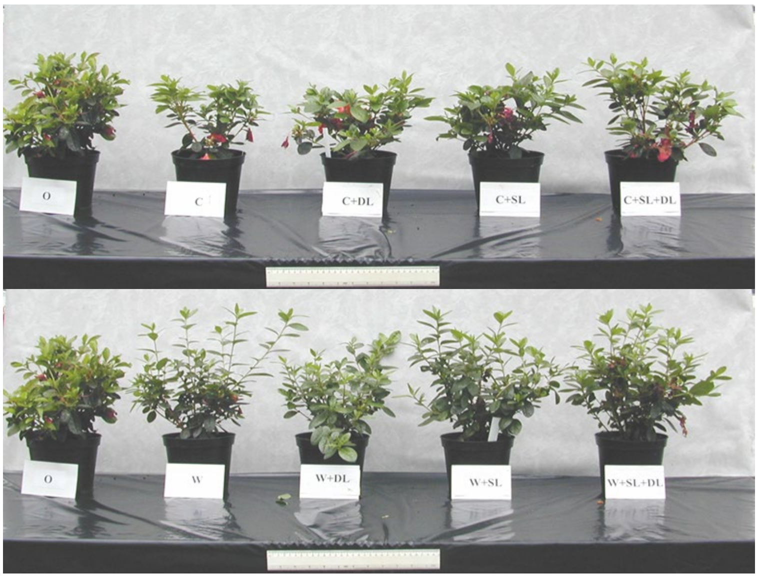
Main effect		Height (cm)		Width (cm)		No. new shoots per plant	
		Dec. 2004	May 2005	Dec. 2004	May 2005	Dec. 2004	May 2005
Temperature	Cool	27	18	28	29	12	15
	Warm	34	29	33	36	11	19
Probability		***	***	*	***	ns	**
Supplementary	-	29	23	29	31	11	15
light	+	31	24	32	34	12	19
Probability		0.143	0.437	0.123	0.058	0.476	0.028
Day length	-	24	23	26	30	11	18
extension light	+	37	24	35	35	12	16
Probability		***	ns	***	**	ns	ns
SED (8 d.f)		1.2	0.8	1.7	1.2	0.9	1.3
Interactions		None	Heat x DL	None	None	None	None

Plate 1. Examples of Azalea growth in December 2004 and May 2005 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)

December 2004



May 2005



Berberis thunbergii 'Pink Queen'

Key Points

- Warmth applied in autumn and spring increased shoot extension in autumn and spring respectively
- Supplementary light had no effect on growth
- Day length extension light increased growth in spring, but not in autumn

Berberis did not show a clear response to day length extension and/or supplementary light in autumn as seasonal growth activity was unaffected (Table 3, Plate 2). However, plants in the warm environment had an increased extension rate during active growth resulting in larger plants in December.

The plants were tipped back to smaller compact shape (about 14 cm) after coming out of cold store. Warmth only had a small effect in speeding up the commencement of growth (Figure 2), although it increased growth rate substantially as the plants were more than 100% larger compared to those in the cool environments by May (Table 3, Plate 2). The number of new shoots per plant was also increased by warmth. Supplementary light had no effect on growth, but day length light slightly increased plant size.

Figure 2. The effect of different environmental conditions on active plant growth of Berberis. Blue = cool house, red = warm house, AL Ambient light, SL Supplementary light, DL day length extension light

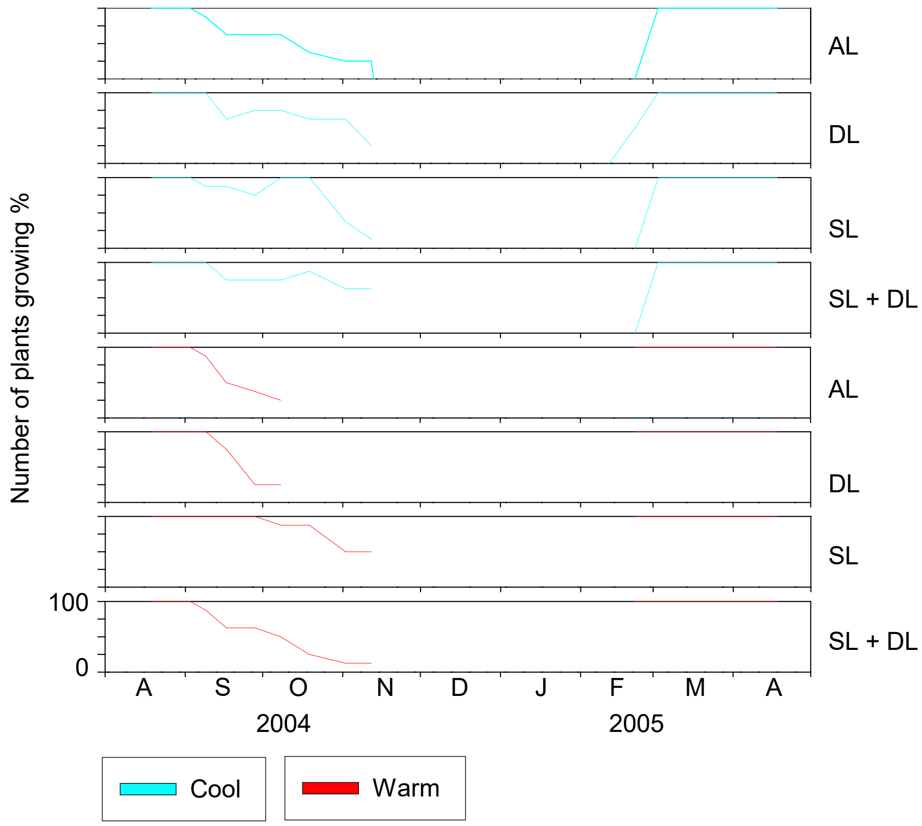


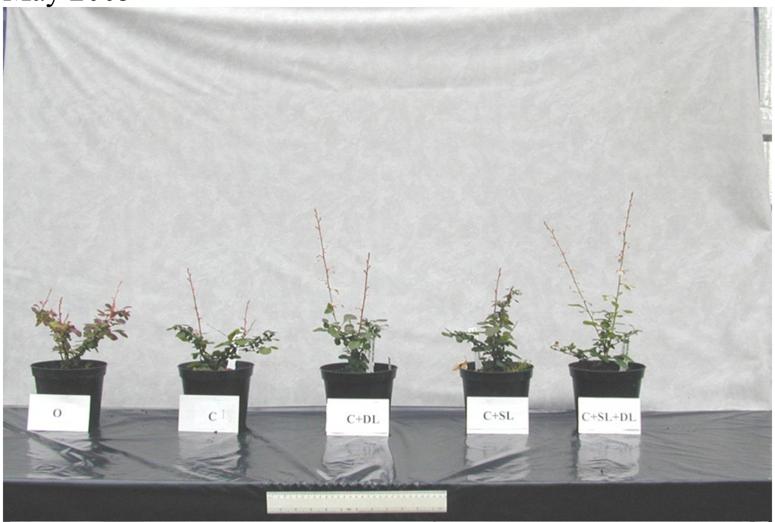
Table 3. The main effects of temperature, supplementary and day length extension light on plant size and number of new shoots (breaks) of Berberis following autumn and spring extended growth seasons. Probability * is statistically significant (<0.05), ** is highly significant (≤ 0.01) and *** is very highly significant (≤ 0.001)

Main effect		Height (cm)		Width (cm)		No. new shoots per plant	
		Dec 2004	May 2005	Dec 2004	May 2005	Dec 2004	May 2005
Temperature	Cool	27	19	30	19	5	1
	Warm	33	66	36	53	5	3
Probability		***	***	**	***	ns	**
Supplementary	-	30	43	33	35	5	2
light	+	29	43	33	37	5	2
Probability		*	ns	ns	ns	ns	ns
Day length	-	29	35	33	30	5	2
extension light	+	30	51	34	43	5	2
Probability		ns	**	*	***	ns	ns
SED (8 d.f)		0.9	3.7	1.6	2.7	0.2	0.4
Interactions		None	Heat x DL	None	Heat x DL	None	None

Plate 2. Examples of Berberis growth in December 2004 and May 2005 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)

December 2004

May 2005



Camellia japonica 'Guilio Nuccio'

Key points

- No response to supplementary and day length extension lighting in autumn and spring
- Growth was increased by warmth applied in spring only

Camellia showed no response to any of the environmental treatments in autumn (Table 4, Figure 3, Plate3).

The plants were tipped back to 24 cm and flower buds removed after cold storage. Plants in the warm environment started to grow approximately two weeks earlier than those in the cool environment in spring. Warmth increased growth rate, but had no effect on the number of breaks, so those in the warm environment were larger than those in the cool house by May. Supplementary lighting and day length extension lighting had no effect on growth (Plate 3, Table 4).

Figure 3. The effect of different environmental conditions on active plant growth of Camellia. Blue = cool house, red = warm house, AL Ambient light, SL Supplementary light, DL day length extension light

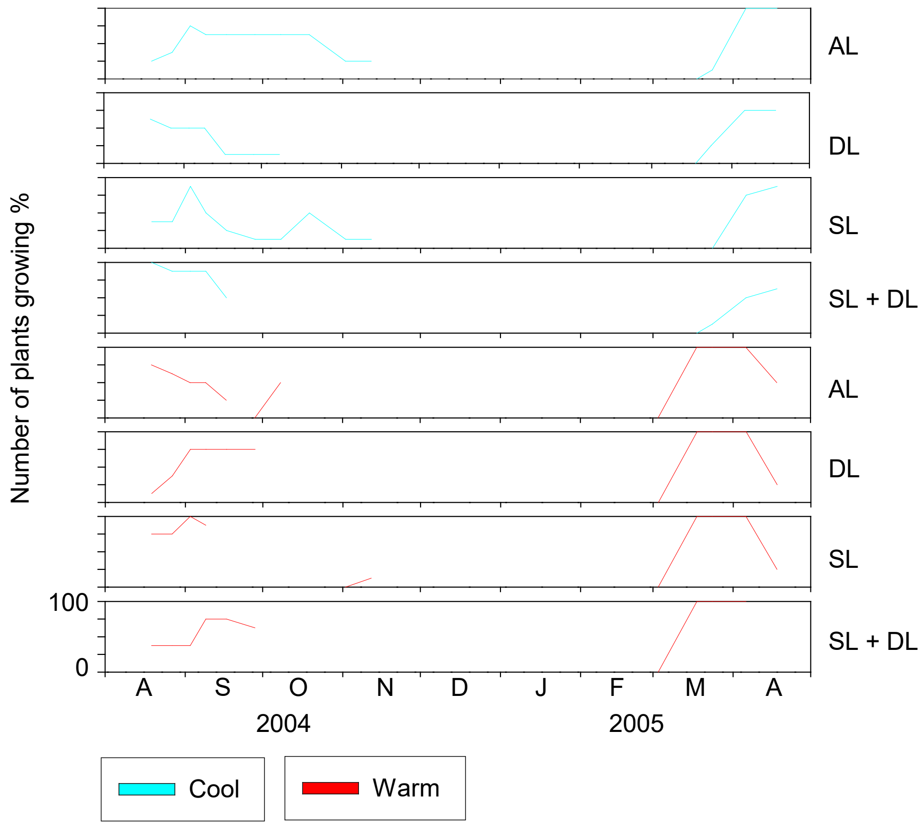


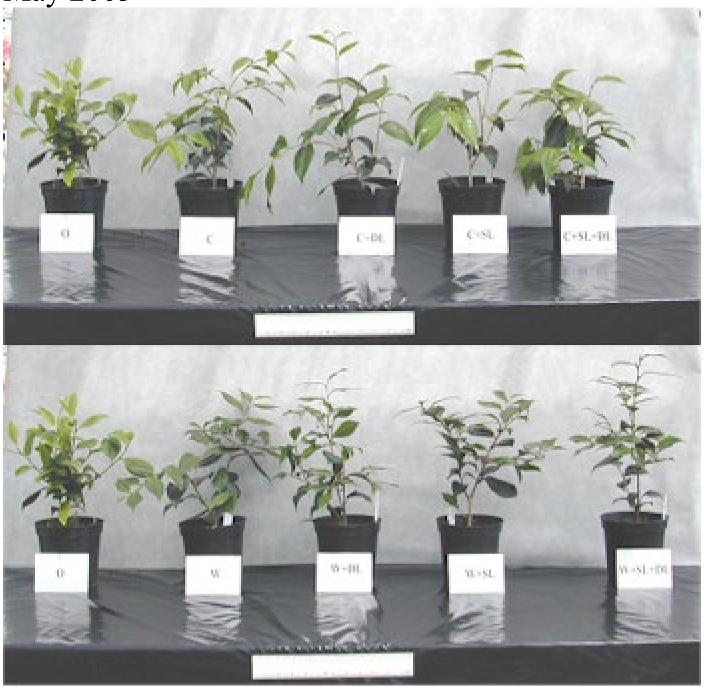
Table 4. The main effects of temperature, supplementary and day length extension light on plant size and number of new shoots (breaks) of Camellia following autumn and spring extended growth seasons. Probability * is statistically significant (<0.05), ** is highly significant (≤ 0.01) and *** is very highly significant (≤ 0.001).

Main effect		Height (cm)		Width (cm)		No. new shoots per plant	
		Dec. 2004	May 2005	Dec. 2004	May 2005	Dec. 2004	May 2005
Temperature	Cool	21	27	22	30	3	5
	Warm	22	33	22	39	2	6
Probability		ns	***	ns	***	ns	ns
Supplementary lighting	-	21	30	22	35	3	5
	+	23	31	22	33	3	6
Probability		ns	ns	ns	ns	ns	ns
Day length extension light	-	21	31	23	34	3	6
	+	23	29	22	34	2	6
Probability		ns	ns	ns	ns	**	ns
SED (8 d.f)		2.3	1.0	1.7	1.5	0.1	1.0
Interactions		None	None	None	None	None	None

Plate 3. Examples of Camellia growth in December 2004 and May 2005 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)

December 2004

May 2005



Chaenomeles speciosa 'Madame Butterfly' (Japanese quince)

Key points

- No response to supplementary and day length extension light in autumn and spring
- Growth was increased by warmth applied in spring only
- Number of breaks per plant was increased when warmth and supplementary lighting was applied together in spring

Chaenomeles showed no response to any of the different environmental treatments in autumn (Table 5, Figure 4).

The plants were tipped back to a smaller more compact shape after coming out of cold store. Warmth did not influence the start of growth in spring (Figure 4), although it increased substantially the rate of growth (width). Thus, the plants in the warm environments were larger than those in the cool environments by May. (Table 5, Plate 4). The number of new shoots per plant (breaks) was also increased by warmth and supplementary light. There was an interaction between these two factors, supplementary light only increased number of shoots per plant when grown in the warm environment. Supplementary light and day length extension lighting had no effect on plant size.

Figure 4. The effect of different environmental conditions on active plant growth of Chaenomeles. Blue = cool house, red = warm house, AL Ambient light, SL Supplementary light, DL day length extension light

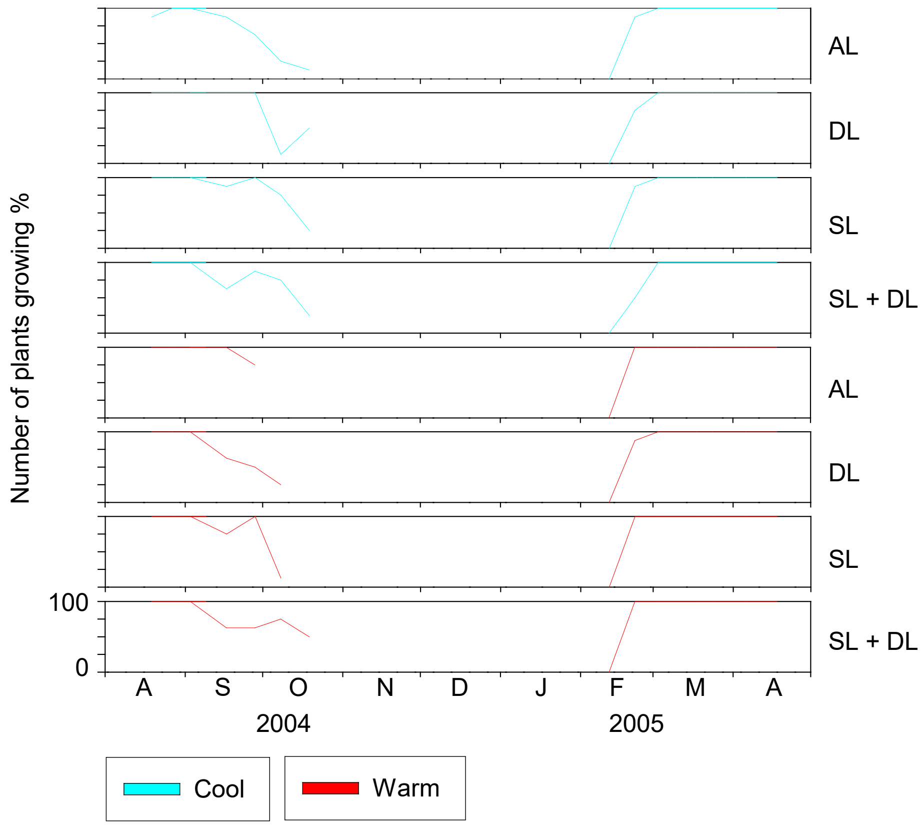


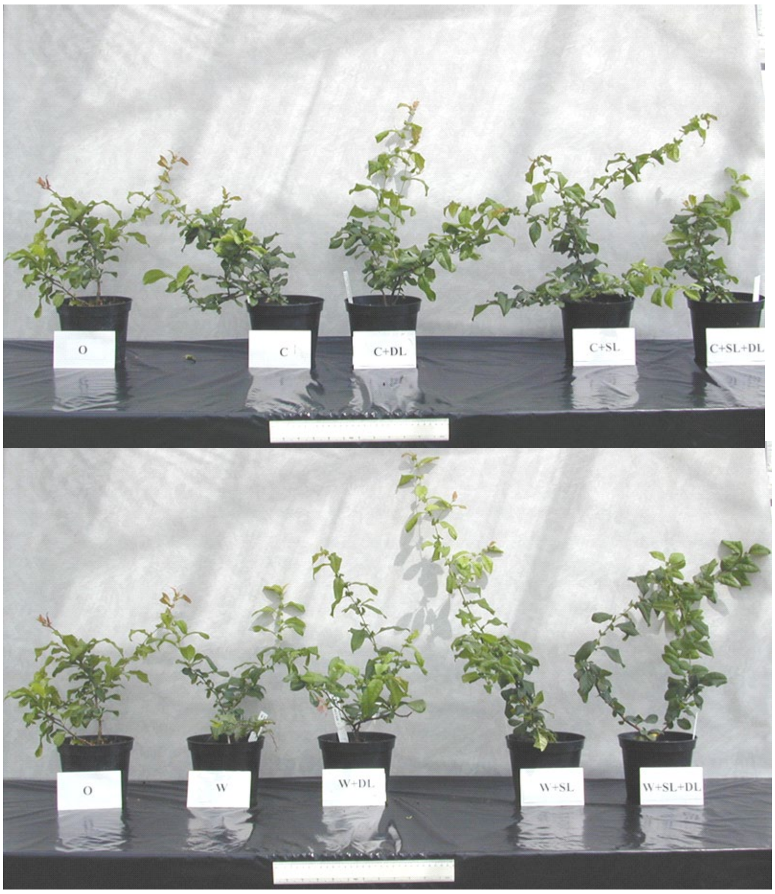
Table 5. The main effects of temperature, supplementary and day length extension light on plant size and number of new shoots (breaks) of Chaenomeles following autumn and spring extended growth seasons. Probability * is statistically significant (<0.05), ** is highly significant (≤ 0.01) and *** is very highly significant (≤ 0.001).

Main effect		Height (cm)		Width (cm)		No. new shoots per plant	
		Dec. 2004	May 2005	Dec. 2004	May 2005	Dec. 2004	May 2005
Temperature	Cool	42	30	37	34	4	2
	Warm	43	38	34	51	3	5
Probability		ns	ns	ns	***	ns	**
Supplementary light	-	42	32	35	39	4	3
	+	44	36	37	46	4	4
Probability		*	ns	ns	ns	ns	*
Day length extension light	-	43	36	35	40	4	4
	+	42	32	36	45	3	4
Probability		ns	ns	ns	ns	ns	ns
SED (8 d.f)		0.7	3.8	3.3	3.3	0.6	0.8
Interactions		All	None	None	None	None	Heat x SL

Plate 4. Examples of Chaenomeles growth in December 2004 and May 2005 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)

December 2004

May 2005



Choysia ternata (Mexican Orange Blossom)

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 increased growth in spring
- Supplementary lighting had no effect on growth

Choysia showed no growth responses to any of the different environmental treatments in autumn (Table 6, Figure 5).

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 (Figure 5). This resulted in larger plants in the warm environment by May (Table 6, Plate 5). Day length extension light caused a small increase in plant size. Supplementary lighting had no effect on growth. The number of new shoots per plant was unaffected by temperature, supplementary and/or day length extension light.

Figure 5. The effect of different environmental conditions on active plant growth of Choysia. Blue = cool house, red = warm house, AL Ambient light, SL Supplementary light, DL day length extension light

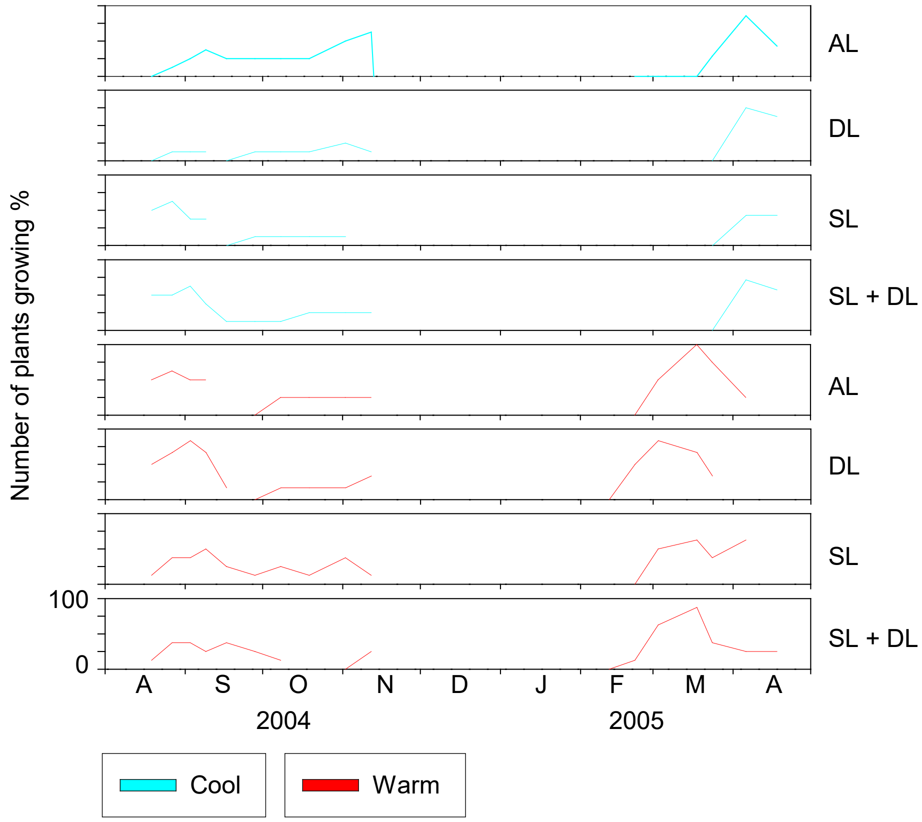
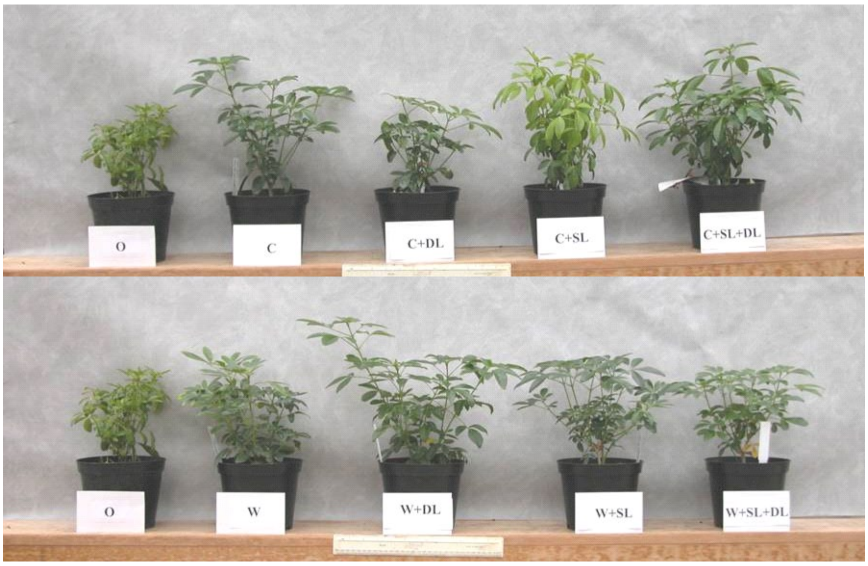


Table 6. The main effects of temperature, supplementary and day length extension light on plant size and number of new shoots (breaks) of Choysia following autumn and spring extended growth seasons. Probability * is statistically significant (<0.05), ** is highly significant (≤ 0.01) and *** is very highly significant (≤ 0.001).

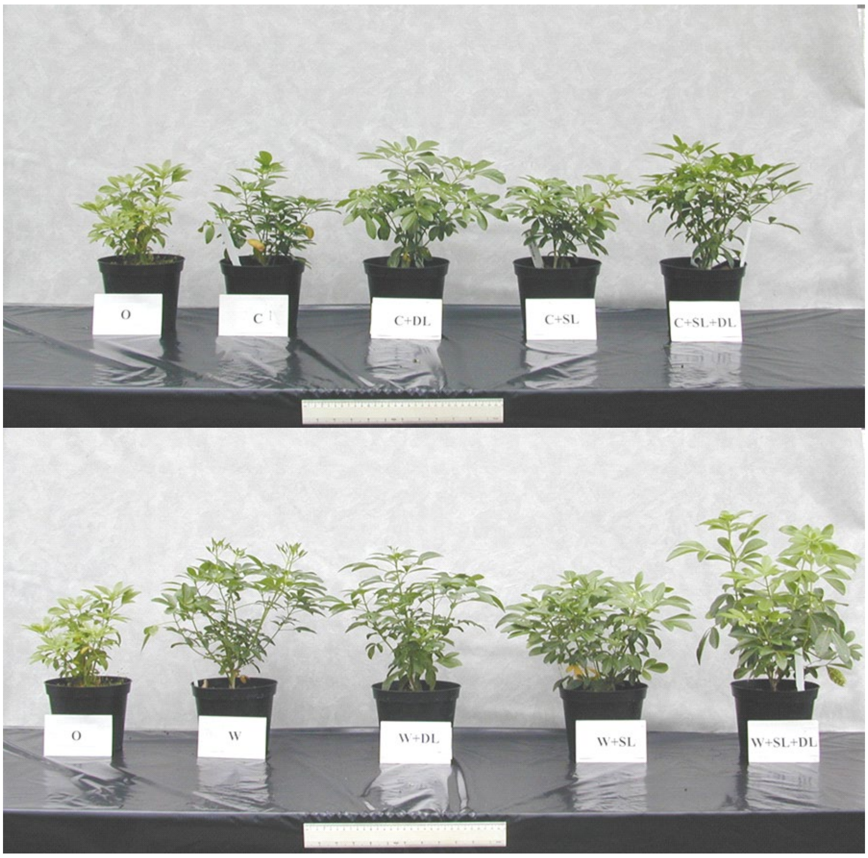
Main effect		Height (cm)		Width (cm)		No. new shoots per plant	
		Dec. 2004	May 2005	Dec. 2004	May 2005	Dec. 2004	May 2005
Temperature	Cool	19	20	23	26	7	7
	Warm	19	26	25	35	7	8
Probability		ns	**	ns	**	ns	ns
Supplementary light	-	20	23	25	32	7	8
	+	18	23	23	29	7	7
Probability		ns	ns	ns	ns	ns	ns
Day length extension light	-	18	21	23	29	7	9
	+	20	25	24	32	7	7
Probability		ns	ns	ns	ns	ns	ns
SED (8 d.f.)		1.4	1.8	1.6	2.2	0.4	1.1
Interactions		Heat x SL	None	None	None	None	None

Plate 5. Examples of Choysia growth in December 2004 and May 2005 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, SL supplementary light. (Ruler = 30 cms)

December 2004



May 2005



Clematis jackmanii

Key points

- No growth response to warmth or supplementary light applied in autumn, but plant size (height) was increased by day length extension light
- Number of plants flowering was increased by a combination of supplementary and day length light in the cool environment in autumn, whereas in the warm environment day length extension light alone was most effective
- Plant size was increased by warmth applied in spring
- Supplementary and day length extension light had no effect on plant size in spring

Growth continued for a longer in autumn in the warm environment. Supplementary and day length extension light had inconsistent effects in this respect, but the latter increased shoot length (Table 8, Figure 6, Plate 6).

In the cool environment the combination of supplementary and day length extension light substantially increased flowering, whereas, individually, the effects of these treatments was negligible. Day length extension lighting alone increased the number of plants that came into flower in the warm environment. (Table 7).

The plants were pruned back to 5-10 cm after coming out of cold store. Growth commenced in late February irrespective of environmental conditions. Warmth increased final shoot length of plants by 65% compared to those in the cool environment (Table 8). This clearly indicates that the rate of growth is increased by application of heat in spring. Neither, supplementary nor day length extension light had any effects on plant size (Plate 6).

Table 7. The effect of different environmental conditions on flowering of Clematis. AL ambient light, SL supplementary light, DL day length extension light

Treatment	**Date first flower open within treatment**	**% of plants that flowered before going into cold store**
Cool house		
AL	8 October	38
SL	19 October	13
DL	None	0
SL + DL	8 October	75
Warm house		
AL	19 October	13
SL	2 November	13
DL	28 September	75
SL + DL	28 September	63

Figure 6. The effect of different environmental conditions on active plant growth of Clematis. Blue = cool house, red = warm house, AL Ambient light, SL Supplementary light, DL day length extension light

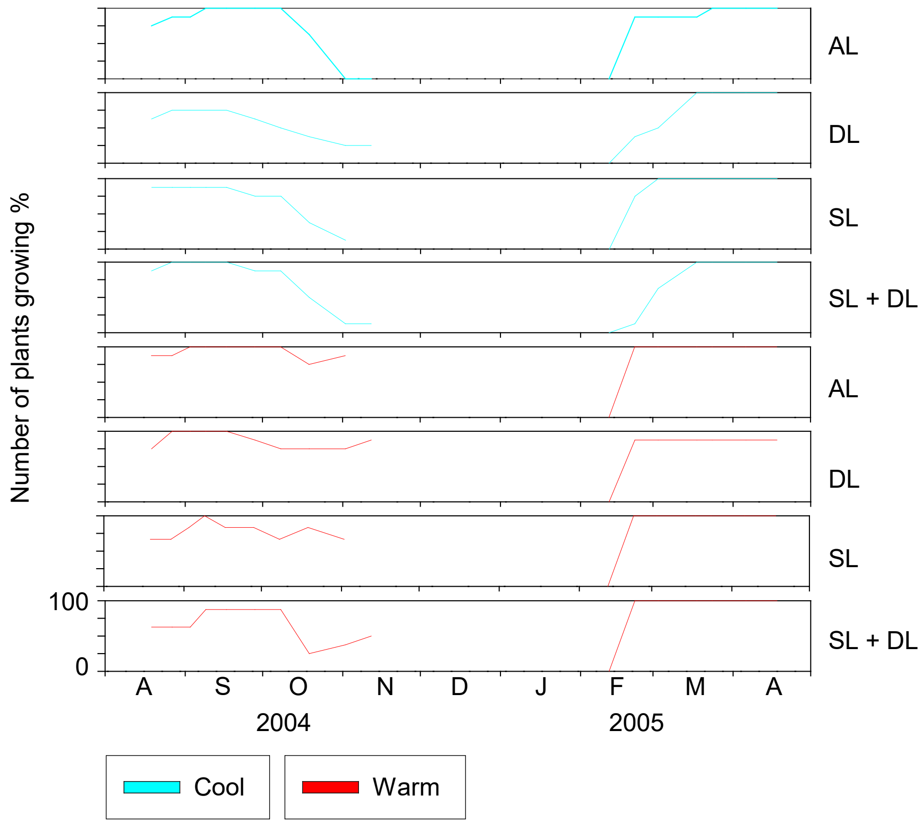


Table 8. The main effects of temperature, supplementary and day length extension light on plant size and number of new shoots (breaks) of Clematis following autumn and spring extended growth seasons. Probability * is statistically significant (<0.05), ** is highly significant (≤ 0.01) and *** is very highly significant (≤ 0.001).

Main effect		Height (cm)		No. new shoots per plant	
		Dec. 2004	May 2005	Dec. 2004	May 2005
Temperature	Cool	135	143	1	3
	Warm	130	222	1	2
Probability		ns	**	ns	ns
Supplementary light	-	141	175	1	2
	+	124	190	1	2
Probability		ns	ns	ns	ns
Day length extension light	-	117	195	1	3
	+	148	170	1	2
Probability		*	ns	ns	*
SED (8 d.f)		10.6	16.9	0.2	0.4
Interactions		None	None	None	None

Plate 6. Examples of Clematis growth in December 2004 and May 2005 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)

December 2004

May 2005

Convolvulus cneorum

Key points

- Growing continued longer in autumn and started earlier in spring in the warm environment
- Day length extension light increased plant size only in the warm environment in spring
- Number of shoots per plant was increased by heat applied in spring, (particularly in combination with supplementary lighting)

In autumn, plants grew for approximately one month longer in the warm environment than those in the cool environment resulting in larger sizes (Figure 7, Table 9). Supplementary and day length extension light reduced growth activity when applied individually in the cool environments, but this did not influence plant size. Neither light treatment had an effect on growth activity in the warm environment.

The plants were hedge trimmed to approximately 18 cm after coming out of cold store. Growth commenced by the end of February for plants in the warm environment, a full month ahead of those in the cool environment. Plant size was increased by 50% by warmth (Table 9). Day length extension light increased plant size, but this effect only occurred in the warm environment. Supplementary light did not have any effect on plant size. The number of new shoots per plant was increased by warmth and supplementary light. However, supplementary light did not increase the number of shoots per plant in the cool environment.

Figure 7. The effect of different environmental conditions on active plant growth of Convolvulus. Blue = cool house, red = warm house, AL Ambient light, SL Supplementary light, DL day length extension light

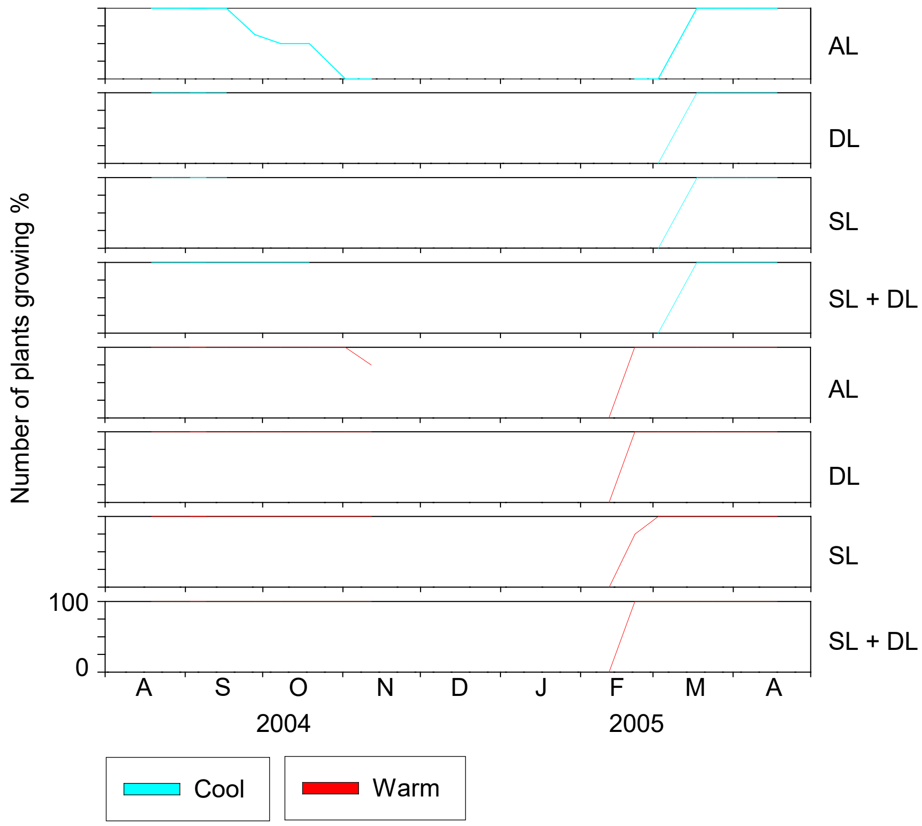


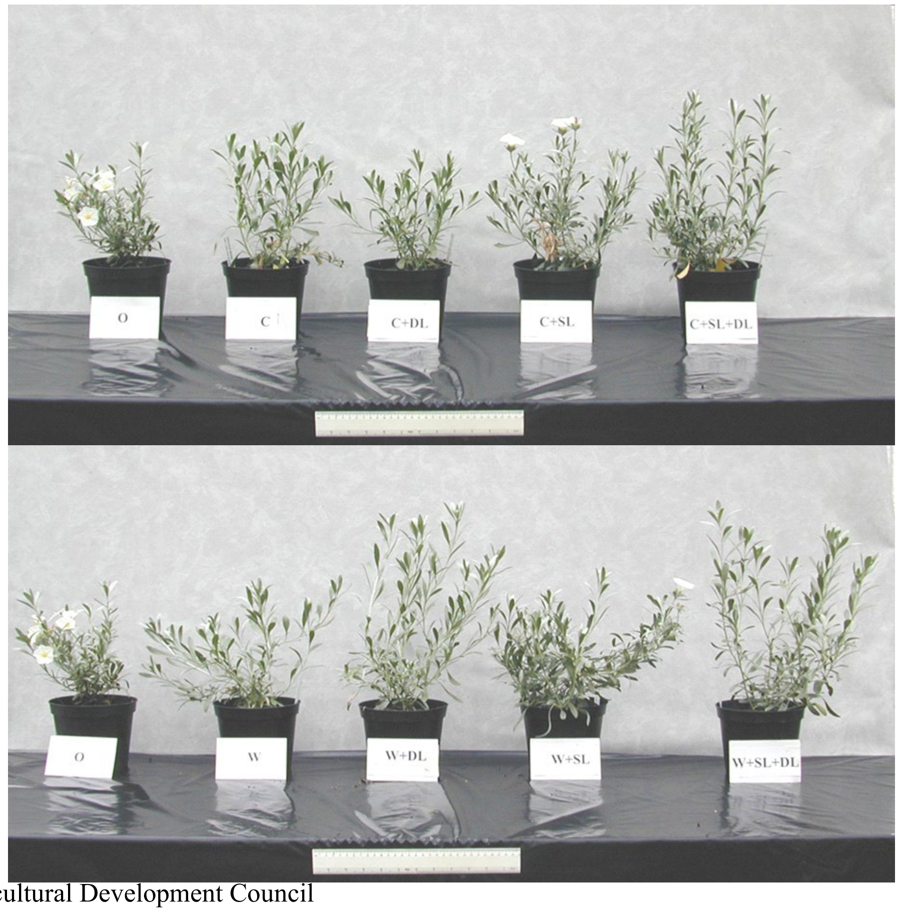
Table 9. The main effects of temperature, supplementary and day length extension light on plant size and number of new shoots (breaks) of Convolvulus following autumn and spring extended growth seasons. Probability * is statistically significant (<0.05), ** is highly significant (≤ 0.01) and *** is very highly significant (≤ 0.001).

Main effect		Height (cm)		Width (cm)		No. new shoots per plant	
		Dec. 2004	May 2005	Dec. 2004	May 2005	Dec. 2004	May 2005
Temperature	Cool	25	22	29	22	6	9
	Warm	33	31	33	33	6	13
Probability		*	***	ns	**	ns	**
Supplementary	-	29	27	30	26	6	10
light	+	29	26	31	28	7	12
Probability		ns	ns	ns	ns	*	*
Day length	-	26	23	31	27	6	11
extension light	+	32	29	31	27	6	11
Probability		ns	***	ns	ns	ns	ns
SED (8 d.f)		2.5	0.8	2.3	2.2	0.4	1.1
Interactions		None	(Heat x DL) (SL x DL)	None	None	None	Heat x SL

Plate 7. Examples of Convolvulus growth in December 2004 and May 2005 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)

December 2004

May 2005



Cytisus scoparius 'Burkwoodii' (Broom)

Key points

- No growth response to any of the different environmental conditions applied in autumn
- Growth started more quickly in the warm environment in spring
- Plant size and number of new shoots per plant was increased by heat applied in spring.
- Supplementary and/or day length extension light had no effect on growth in spring

Cytisus showed no response to any of the environmental conditions in autumn (Table 10, Figure 8, Plate 8).

The plants were hedge trimmed to approximately 22 cm after coming out of cold store. Growth commenced before the end of February for plants in the warm environments, approximately one month ahead of those in the cool environments (Figure 8). Warmth increased plant size and the number of new shoots per plant by 100% (Table 10, Plate 8). Supplementary and day length extension light had no effect on growth. The number of new shoots was increased by application of heat; increasing the number of new shoots by 100% of the cool environment. Neither light treatment affected shoot number.

Figure 8. The effect of different environmental conditions on active plant growth of Cytisus. Blue = cool house, red = warm house, AL Ambient light, SL Supplementary light, DL day length extension light

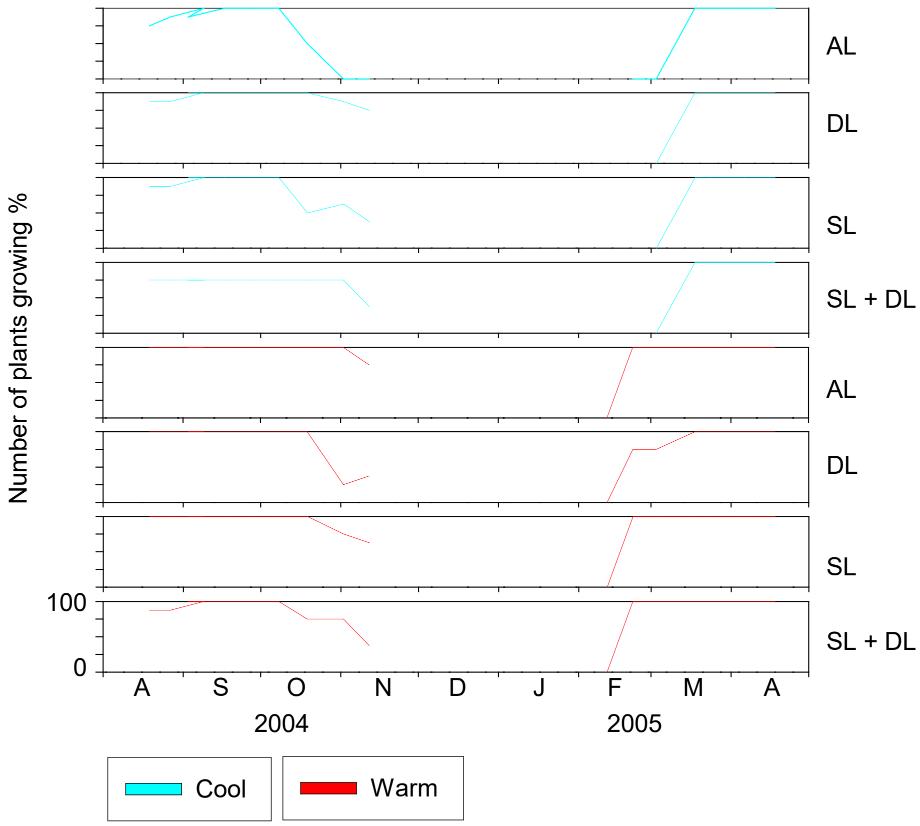


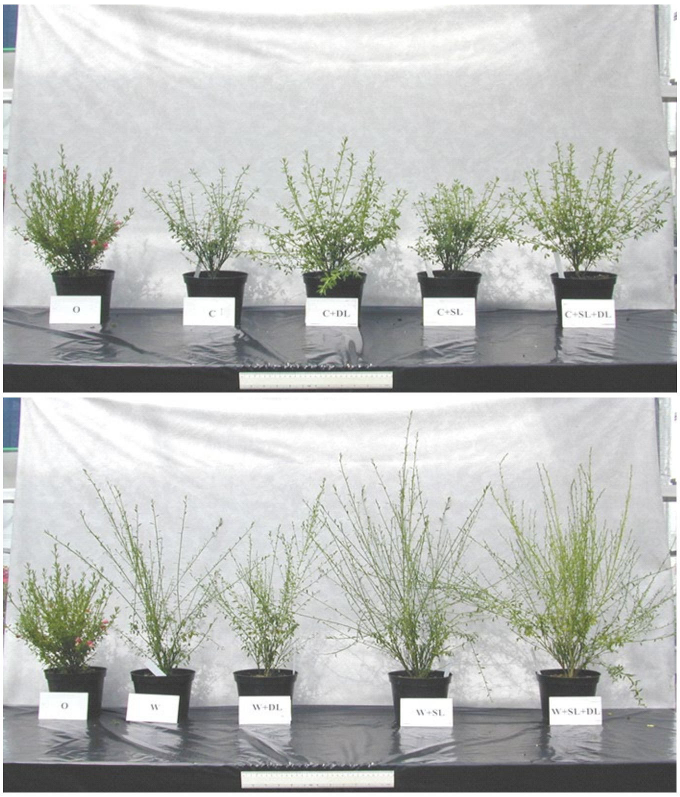
Table 10. The main effects of temperature, supplementary and day length extension light on plant size and number of new shoots (breaks) of Cytisus following autumn and spring extended growth seasons. Probability * is statistically significant (<0.05), ** is highly significant (≤ 0.01) and *** is very highly significant (≤ 0.001).

Main effect		Height (cm)		Width (cm)		No. new shoots per plant	
		Dec. 2004	May 2005	Dec. 2004	May 2005	Dec. 2004	May 05
Temperature	Cool	49	23	35	24	14	30
	Warm	49	44	40	41	14	60
Probability		ns	***	ns	**	ns	ns
Supplementary	-	49	34	38	33	13	41
light	+	50	33	37	33	15	19
Probability		ns	ns	ns	ns	ns	ns
Day length	-	48	32	35	30	12	36
extension light	+	51	35	40	35	16	54
Probability		ns	ns	ns	ns	ns	ns
SED (8 d.f)		6.9	3.6	5.8	4.3	2.2	14.0
Interactions		None	None	None	None	None	None

Plate 8. Examples of Cytisus growth in December 2004 and May 2005 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, SL supplementary light. (Ruler = 30 cm)

December 2004

May 2005



Hydrangea macrophylla 'King George'

Key points

- No growth response to any of the different environmental treatments 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.

Hydrangea showed no growth response to any of the different environmental treatments in autumn (Figure 9, Table 11, Plate 9).

After coming out of cold store shoot growth started by the end of February irrespective of temperature. Plant size was increased by day length extension light. The width of the plants was greater in the warm than in the cool environments. Supplementary light had no effect on growth. The number of new shoots per plant was unaffected by temperature, supplementary and/or day length extension light.

Flowering time was strongly influenced by the environmental treatments. Plants in the warm environments flowered by the end April/early May, whereas those in the cool environments were still not in flower by mid-June. Day length extension light advanced flowering slightly in the warm environment. It is also worth noting that all the plants that went into cold store produced flower buds, whereas those that were left in the polytunnel did not. This suggests that chilling is an essential component of flower bud formation in Hydrangea (Plate 9).

Figure 8. The effect of different environmental conditions on active plant growth of Hydrangea. Blue = cool house, red = warm house, AL Ambient light, SL Supplementary light, DL day length extension light

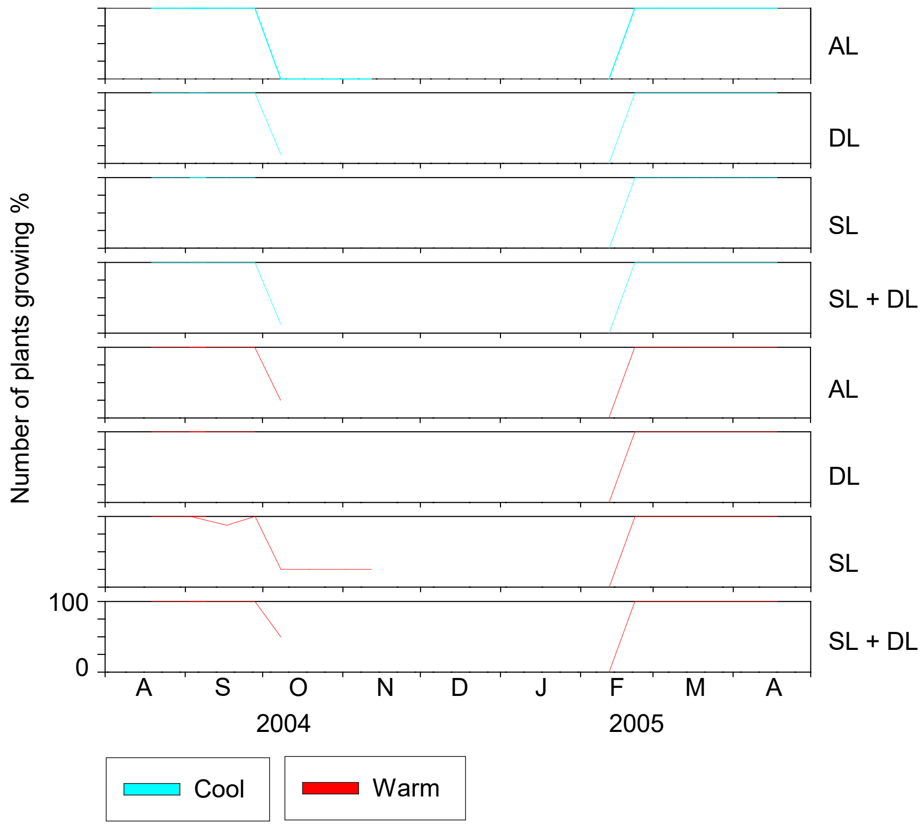


Table 11. The main effects of temperature, supplementary and day length extension light on plant size and number of new shoots (breaks) of Hydrangea following autumn and spring extended growth seasons. Probability * is statistically significant (<0.05), ** is highly significant (≤ 0.01) and *** is very highly significant (≤ 0.001).

Main effect		Height (cm)		Width (cm)		No. new shoots per plant	
		Dec. 2004	May 2005	Dec. 2004	May 2005	Dec. 2004	May 2005
Temperature	Cool	14	39	33	46	6	8
	Warm	15	39	35	54	5	8
Probability		ns	ns	ns	**	ns	ns
Supplementary	-	14	40	35	52	5	7
light	+	14	38	33	48	6	8
Probability		0.605	0.315	0.061	0.141	0.299	0.273
Day length	-	14	36	34	47	5	8
extension light	+	14	42	34	53	5	7
Probability		ns	**	ns	*	ns	ns
SED (8 d.f)		0.6	1.5	1.1	2.2	0.2	0.5
Interactions		None	None	None	None	None	None

Plate 9. Examples of Hydrangea growth in December 2004 and May 2005 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)

December 2004

May 2005

Ilex aquifolium 'Argentea Marginata' (Holly)

Key points

- No growth response to the heat and day length extension light treatments in autumn, but a small increase in size caused by supplementary light
- In the warm environments growth commenced earlier in spring than in the cool environments
- Day length extension light and warmth increased plant size in spring, the latter also increased number of shoots per plant

Ilex showed no growth response to the heat and day length extension light treatments in autumn, but a small increase in size caused by supplementary light (Figure 10, Table12, Plate, 10).

After coming out of cold store plants in the warm environments started growing in early March, i.e. a full month ahead of those in the cool environments (Figure 10). Warmth and day length extension light increased plant size, the former also increased the number of new shoots per plant. Supplementary lighting had no effect on growth (Table 12).

Figure 10. The effect of different environmental conditions on active plant growth of Ilex. Blue = cool house, red = warm house, AL Ambient light, SL Supplementary light, DL day length extension light

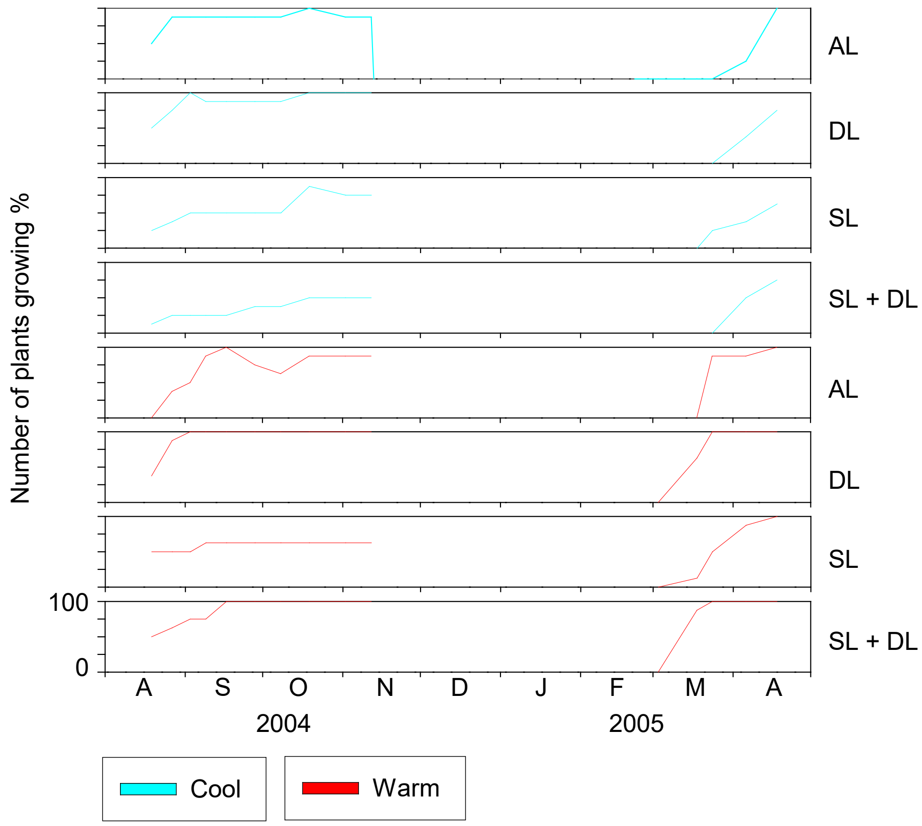


Table 12. The main effects of temperature, supplementary and day length extension light on plant size and number of new shoots (breaks) of Ilex following autumn and spring extended growth seasons. Probability * is statistically significant (<0.05), ** is highly significant (≤ 0.01) and *** is very highly significant (≤ 0.001).

Main effect		Height (cm)		Width (cm)		No. new shoots per plant	
		Dec. 2004	May 2005	Dec. 2004	May 2005	Dec. 2004	May 2005
Temperature	Cool	34	37	25	28	8	6
	Warm	32	41	24	40	7	9
Probability		ns	*	ns	***	ns	**
Supplementary light	-	34	39	25	35	8	8
	+	32	38	23	33	7	6
Probability		ns	ns	*	ns	ns	ns
Day length extension light	-	33	38	24	31	7	8
	+	32	39	25	37	7	6
Probability		ns	ns	ns	***	ns	ns
SED (8 d.f)		1.6	1.5	0.7	1.1	0.7	0.9
Interactions		None	None	None	Heat xDL	None	None

Plate 10. Examples of Ilex growth in December 2004 and May 2005 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)

December 2004

May 2005

Lavendula angustifolia 'Hidcote' (Lavender)

Key points

- Growth continued longer in autumn and commenced earlier in spring in the warm environment
- Plant size (spread only) was increased by warmth applied in spring
- In spring, flowering commenced one month earlier in the warm environment
- Supplementary and day length extension light applied in autumn and spring had no effect on plant size

Lavendula grew for a longer period in the autumn in the warm environments (Figure 11). However, this response did not have a significant effect on plant size and number of new shoots per plant. Supplementary and/or day length extension lighting had no effect on growth (Table 13, Plate 11).

The plants were hedge trimmed to approximately 18 cm after coming out of cold store. Growth commenced by late February for plants in the warm environments, 2-3 weeks ahead of those in the cool environments. Warmth doubled plant width but had no effect on number of new shoots per plant (Table 13). Supplementary light had no effect on growth, but day length extension light increased plant width.

Plants in the warm environments started flowering at the end April until early May, whereas those in the cool environments did not start flowering until early June.

Figure 11. The effect of different environmental conditions on active plant growth of Lavendula. Blue = cool house, red = warm house, AL Ambient light, SL Supplementary light, DL day length extension light

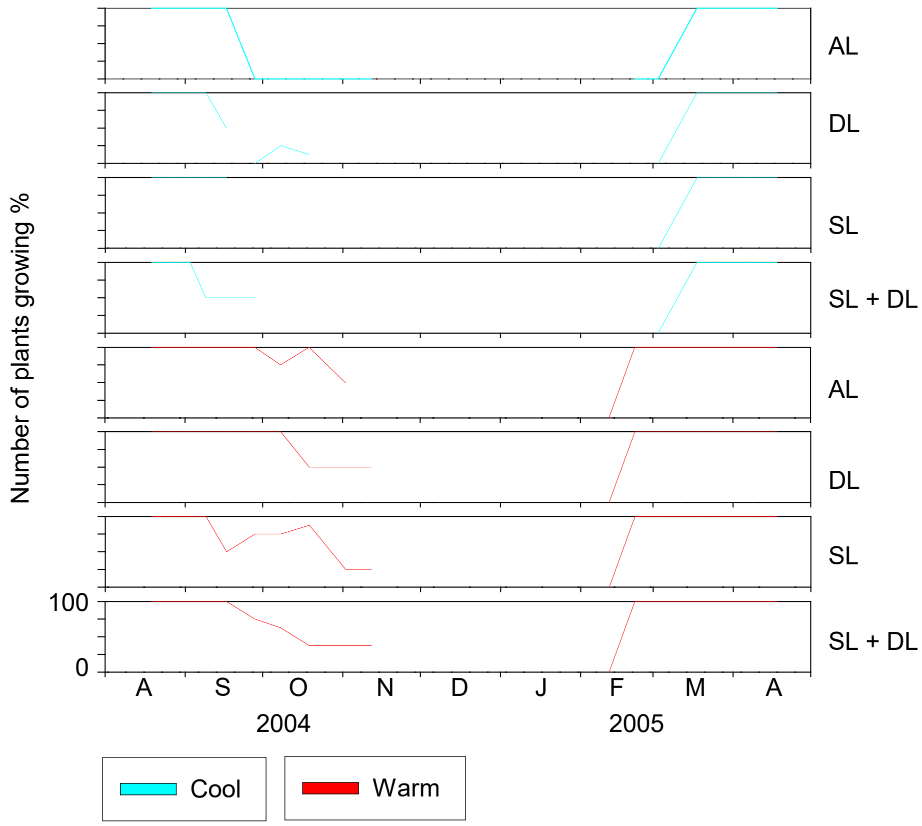
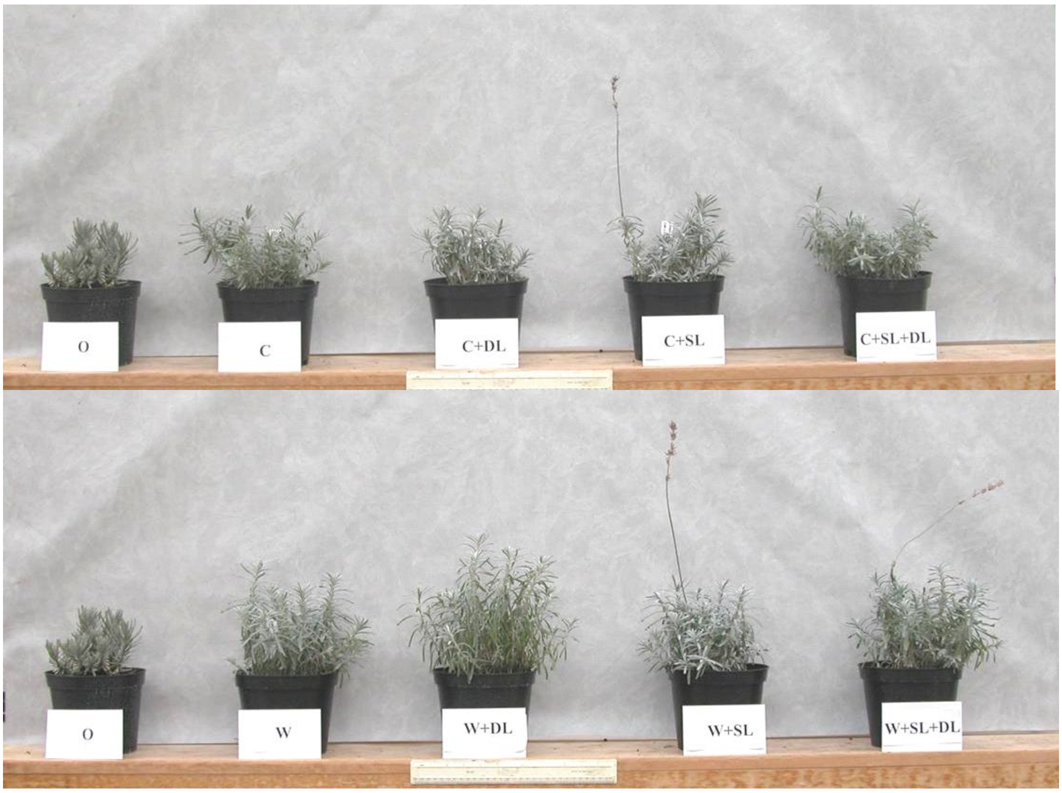


Table 13. The main effects of temperature, supplementary and day length extension light on plant size and number of new shoots (breaks) of Lavendula following autumn and spring extended growth seasons. Probability * is statistically significant (<0.05), ** is highly significant (≤ 0.01) and *** is very highly significant (≤ 0.001).

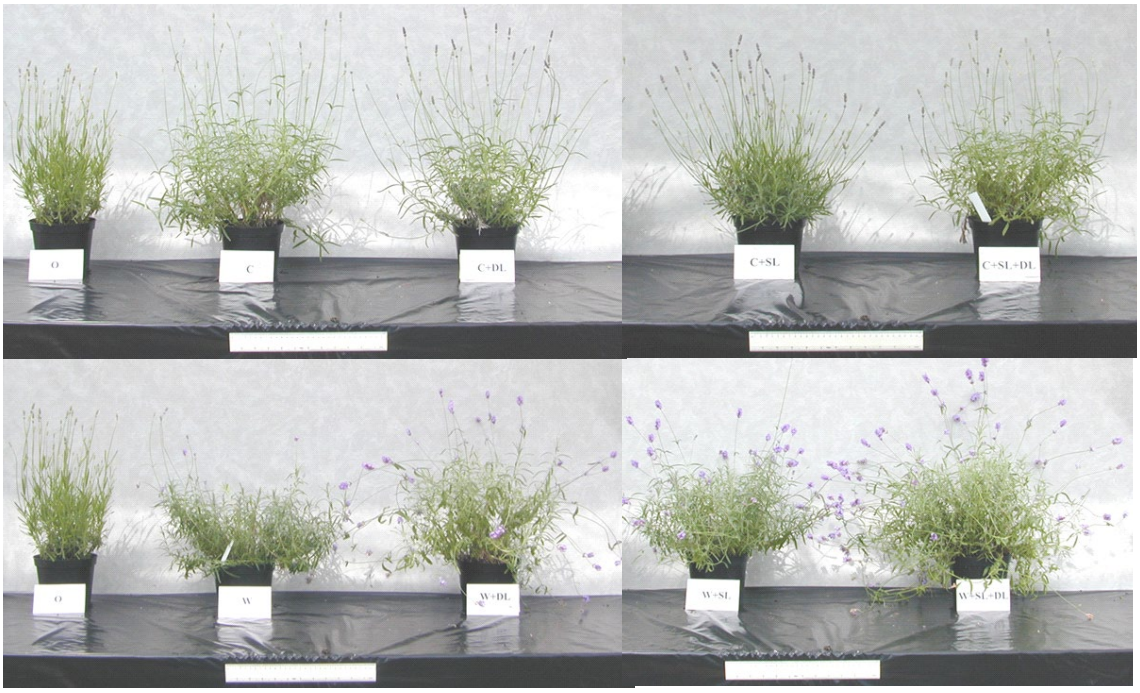
Main effect		Height (cm)		Width (cm)		No. new shoots per plant	
		Dec. 04	May 05	Dec. 04	May 05	Dec. 04	May 05
Temperature	Warm	20	26	24	70	17	66
	Cool	16	22	21	34	18	56
Probability		ns	ns	ns	***	ns	ns
Supplementary	-	19	25	22	54	16	62
lighting	+	16	23	22	50	19	60
Probability		ns	ns	ns	ns	ns	ns
Day length	-	17	23	22	47	18	59
extension light	+	19	25	23	57	18	63
Probability		ns	ns	ns	ns	ns	ns
SED (8 d.f)		2.2	1.7	1.4	4.4	1.3	6.1
Interactions		None	None	None	None	None	None

Plate 11. Examples of Lavendula growth in December 2004 and May 2005 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, SL supplementary light. (Ruler = 30 cm)

December 2004



May 2005



Mahonia japonica

Key points

- Growth commenced earlier in spring for plants in the warm environments, but plant size was note affected
- Growth was not affected by supplementary and or/day length extension light in autumn and spring respectively
- Flowering finished approximately one week earlier for plants in the warm environments compared to those in the cool environments

Mahonia showed no response to any of the environmental treatments in autumn and in fact showed no signs of growth (Figure 12, Table 15, Plate 12).

Following cold storage, growth commenced earlier for plants in the warm environments. Mahonia has short bursts of episodic growth; plants in the warm environments went through their first episode earlier than those in the cool environments. However, this did not affect the final plant size (Figure 12, Table 15, Plate 12). Supplementary and/or day length extension lighting had no effect on growth. The start of flowering was not affected by any of the treatments, although those plants in the warm environments generally finished flowering a week earlier than those in the cool environments (Table 14).

Table 14. The effect of different environmental conditions on flowering of Mahonia. AL Ambient light, SL Supplementary light, DL day length extension light

Treatment	**Flowers open**	**Petal fall**
Cool house		
AL	23 February	24 March
SL	23 February	24 March
DL	23 February	24 March
SL + DL	23 February	24 March
Warm house		
AL	23 February	18 March
SL	23 February	18 March
DL	23 February	18 March
SL + DL	23 February	24 March

Figure 12. The effect of different environmental conditions on active plant growth of Mahonia. Blue = cool house, red = warm house, AL Ambient light, SL Supplementary light, DL day length extension light

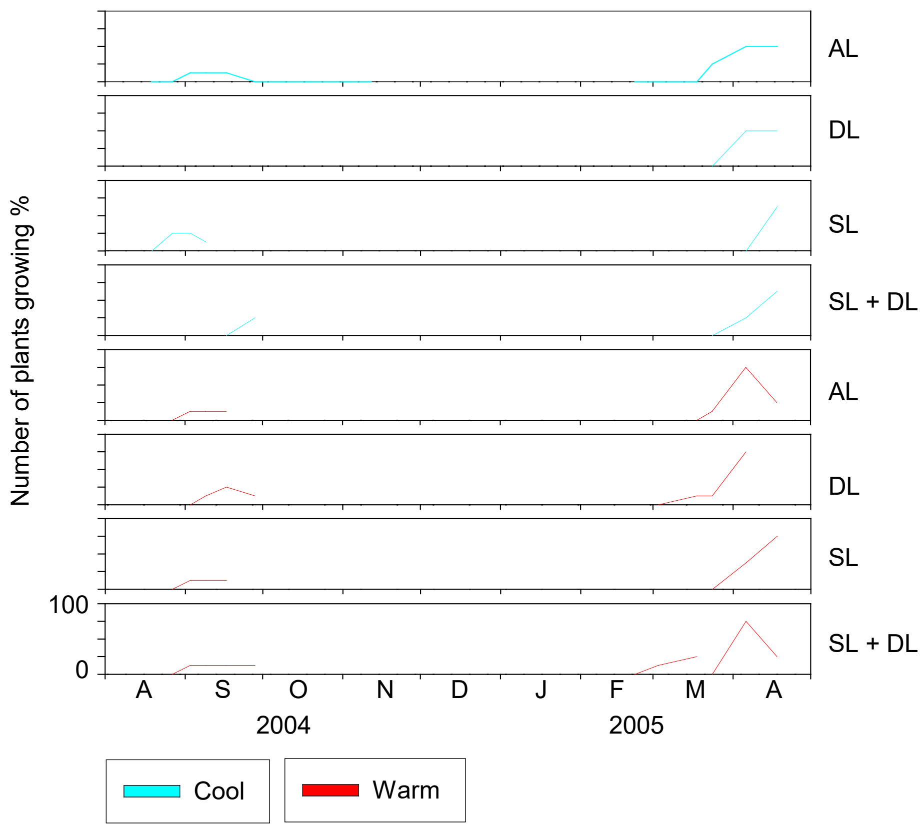


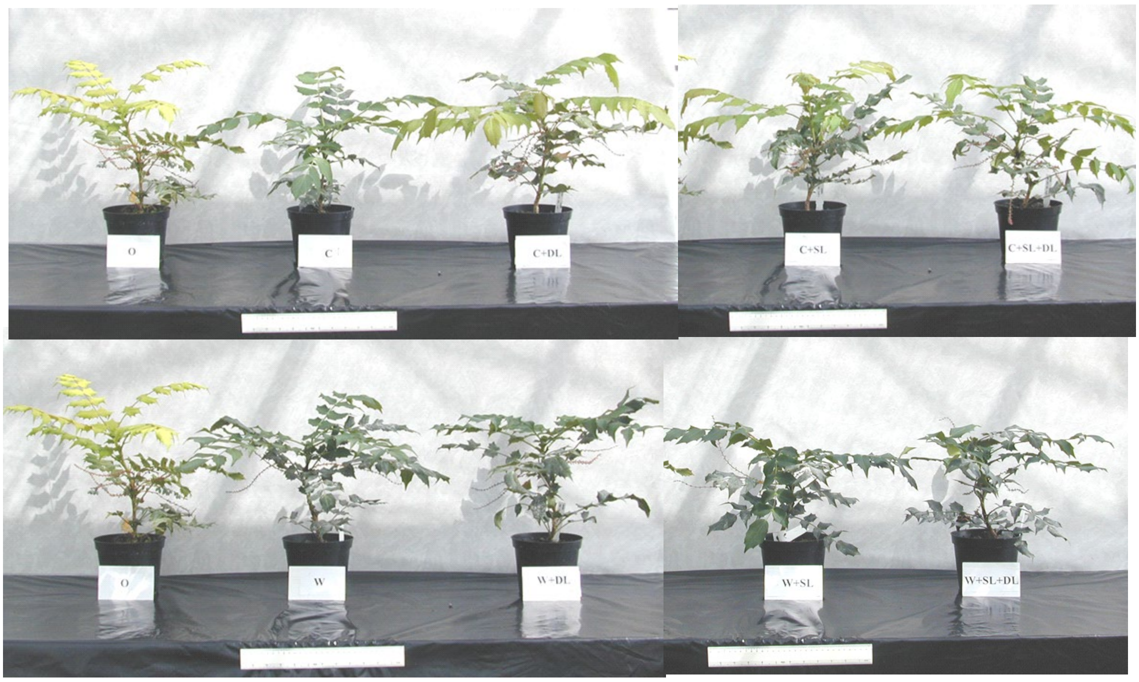
Table 15. The main effects of temperature, supplementary and day length extension light on plant size. of Mahonia following autumn and spring extended growth seasons. Probability * is statistically significant (<0.05), ** is highly significant (≤ 0.01) and *** is very highly significant (≤ 0.001).

Main effect		Height (cm)		Width (cm)	
		Dec. 2004	May 2005	Dec. 2004	May 2005
Temperature	Cool	19	30	46	58
	Warm	19	28	49	61
Probability		ns	ns	ns	ns
Supplementary	-	19	29	46	62
light	+	19	28	49	57
Probability		ns	ns	ns	ns
Day length	-	21	28	48	58
extension light	+	17	29	46	61
Probability		ns	ns	ns	ns
SED (8 d.f)		2.1	2.8	2.9	2.7
Interactions		None	None	None	None

Plate 12. Examples of Mahonia growth in December 2004 and May 2005 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)

December 2004

May 2005



Osmanthus heterophyllus 'Goshiki' (Holly olive)

Key points

- No growth response to any of the different heat or light treatments in autumn
- Growth commenced earlier in the spring and plant size was increased in the warm environments
- In the absence of day length extension light, plants in the warm environment were smaller than those receiving the other treatments
- The number of shoots per plant was less for those grown in warm than in cool environments

Osmanthus showed little or no response to any of the environmental treatments in autumn (Figure 13, Table 16, Plate 13).

Osmanthus has episodic growth. After coming out of cold store, growth commenced between the middle and end of February for plants in warm environments and these plants had completed one growth episode by mid-March. Plants in the cool houses did not start growing until between the middle and end of March and were still going through their first episodic growth phase at the end of April. Plants grown in the warm environment without day length extension light were smaller than those in the other treatments. Warmth slightly increased the spread of the plants, but reduced the number of new shoots per plant. Supplementary and/or day length extension light did not affect number of shoots per plant.

Figure 13. The effect of different environmental conditions on active plant growth of Osmanthus. Blue = cool house, red = warm house, AL Ambient light, SL Supplementary light, DL day length extension light

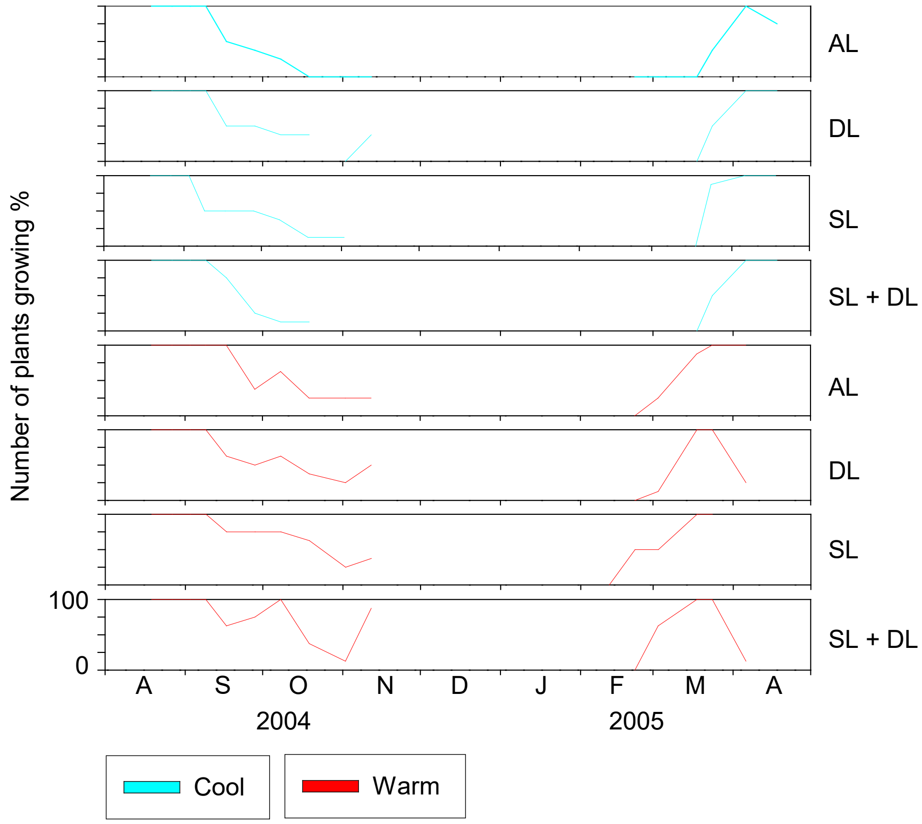


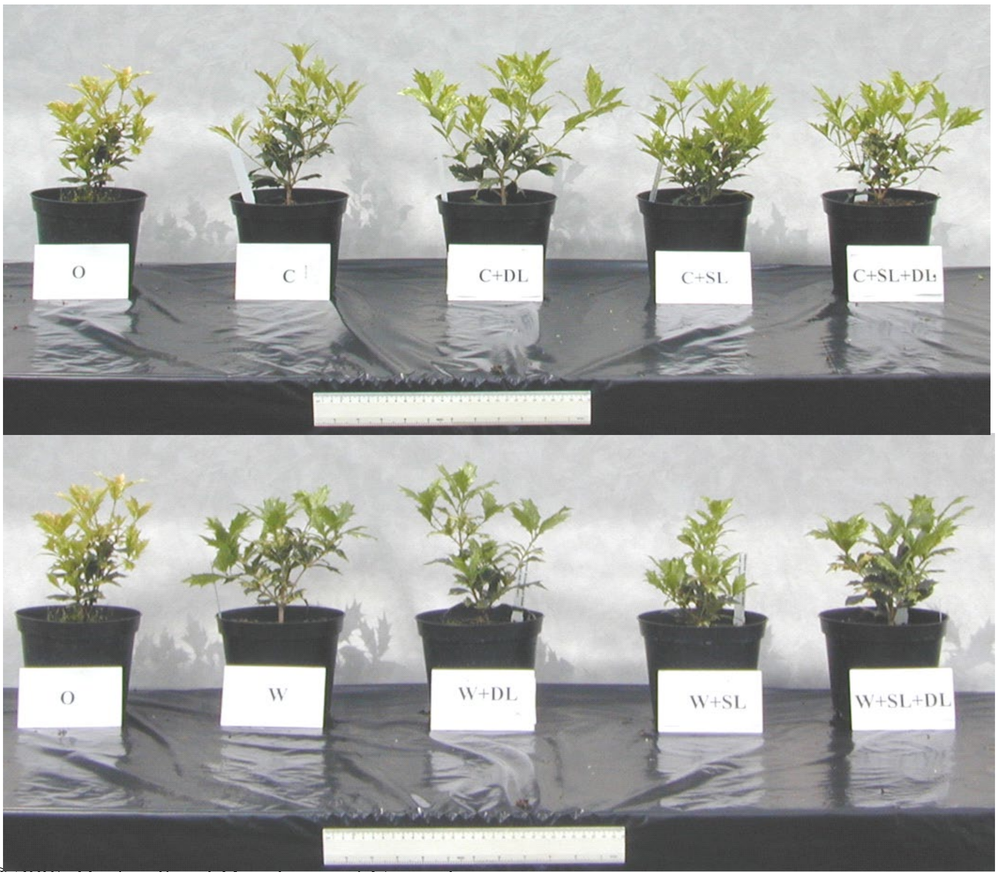
Table 16. The main effects of temperature, supplementary and day length extension light on plant size and number of new shoots (breaks) of Osmanthus following autumn and spring extended growth seasons. Probability * is statistically significant (<0.05), ** is highly significant (≤ 0.01) and *** is very highly significant (≤ 0.001).

Main effect		Height (cm)		Width (cm)		No. new shoots per plant	
		Dec. 2004	May 2005	Dec. 2004	May 2005	Dec. 2004	May 2005
Temperature	Cool	11	18	14	17	8	14
	Warm	11	16	15	20	6	11
Probability		ns	*	*	*	**	**
Supplementary	-	11	17	14	19	7	12
light	+	11	16	14	18	7	13
Probability		*	*	*	*	*	*
Day length	-	11	17	14	18	7	13
extension light	+	11	17	14	19	7	13
Probability		*	*	*	*	*	*
SED (8 d.f)		0.5	0.6	0.4	0.9	0.4	0.8
Interactions		None	Heat xDL	None	None	None	None

Plate 13 Examples of Osmanthus growth in December 2004 and May 2005 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)

December 2004

May 2005



Philadelphus 'Silver Showers' (Mock orange)

Key points

- Plants continued growing for longer in the warm environment in autumn, but supplementary and day length extension light had no effects
- Plant size was increased by heat applied in spring and autumn respectively
- Day length extension lighting increased plant size in spring, particularly in the warm environment
- Supplementary lighting had no effect on growth in autumn and spring

The growth of Philadelphus in the cool environments stopped by mid-November; but in the warm environments continued until the treatments were switched off (Figure 14). Plant size was increased by warmth and day length extension light, but supplementary light had no effect (Table 17, Plate 14). Only supplementary light increased the number of shoots per plant.

The plants were hedge trimmed to approximately 17 cm height after coming out of cold store. Growth commenced by the end of February for plants in all environments (Figure 14). However, by the end of April plants in warm environments were nearly double the size of those in cool environments indicating the greater rate of growth of these plants (Table 17, Plate 14). Day length extension light also increased growth of plants that were in the warm environments, but had no effect on those in the cool environments. Supplementary light did not have any effect on growth. The number of new shoots per plant was increased in the warm environments compared to the cool environments. Supplementary lighting and day length extension lighting had no effect on number of shoots per plant.

Figure 14. The effect of different environmental conditions on active plant growth of Philadelphus. Blue = cool house, red = warm house, AL Ambient light, SL Supplementary light, DL day length extension light.

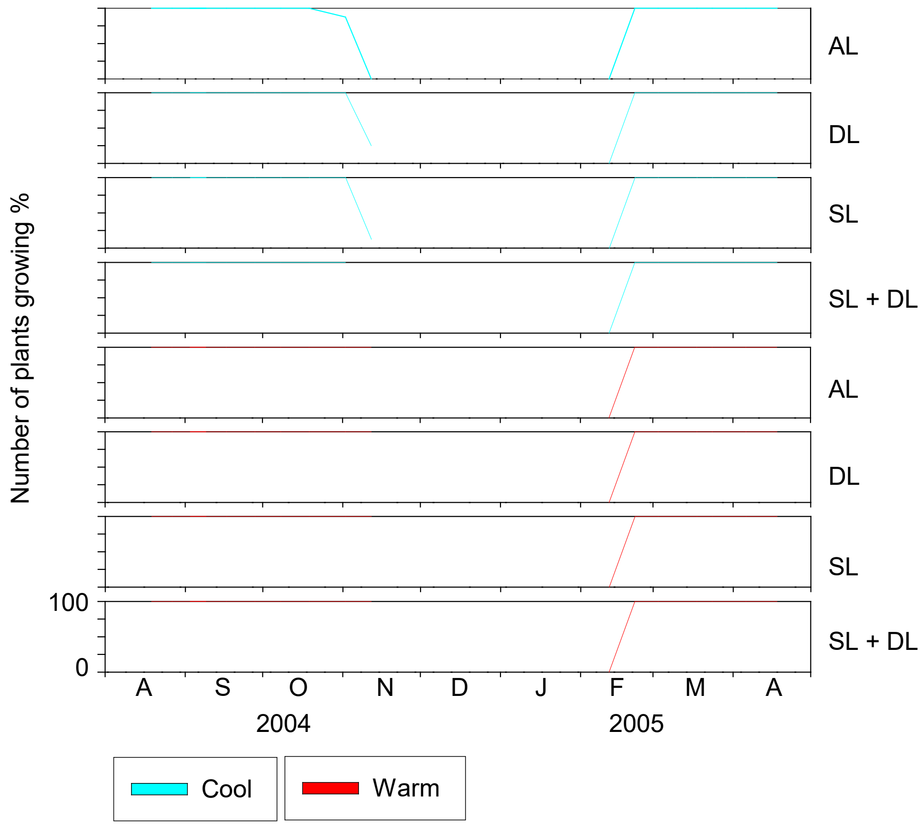
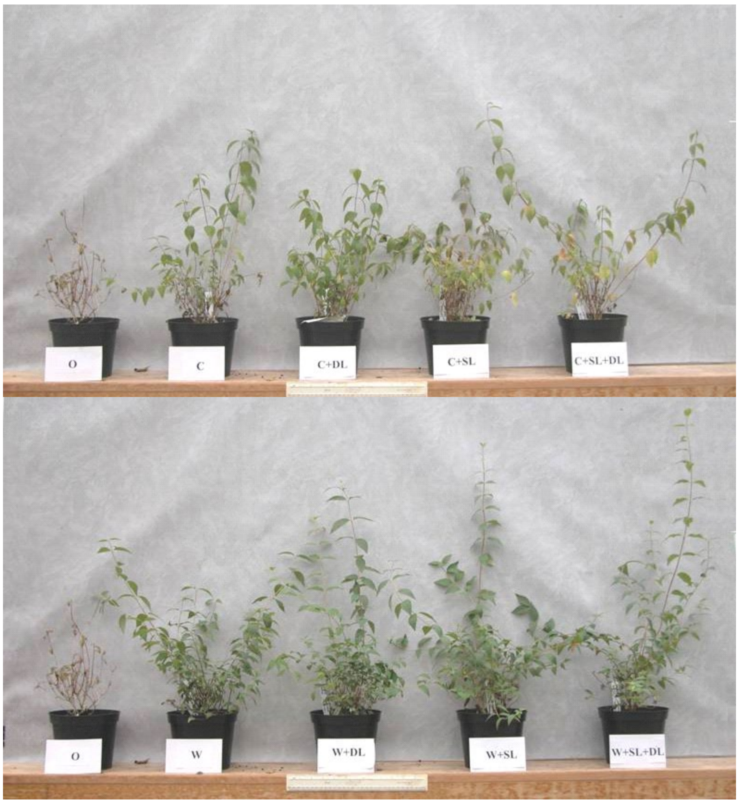


Table 17. The main effects of temperature, lighting and day length extension light on plant size and number of new shoots (breaks) of Philadelphus following autumn and spring extended growth seasons. Probability * is statistically significant (<0.05), ** is highly significant (≤ 0.01) and *** is very highly significant (≤ 0.001).

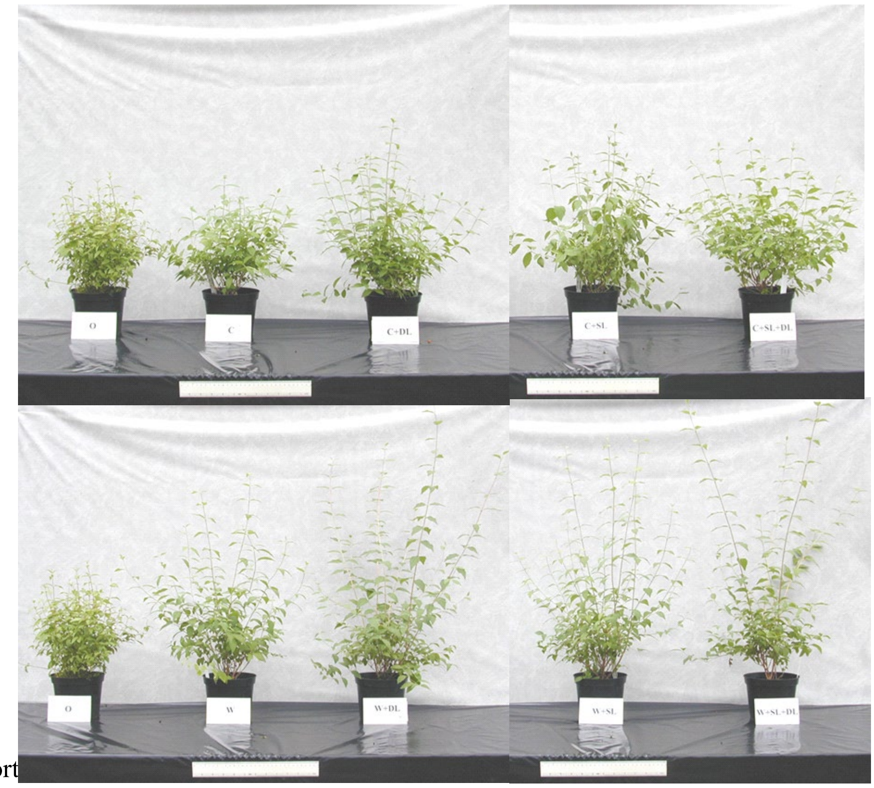
Main effect		Height (cm)		Width (cm)		No. new shoots per plant	
		Dec. 2004	May 2005	Dec. 2004	May 2005	Dec. 2004	May 2005
Temperature	Cool	43	34	28	35	13	44
	Warm	57	61	43	56	13	36
Probability		***	***	**	***	ns	*
Supplementary light	-	51	47	36	46	12	37
	+	49	49	35	44	15	43
Probability		*	*	ns	ns	**	ns
Day length extension light	-	50	44	33	42	14	423
	+	50	51	37	49	13	37
Probability		ns	**	ns	ns	ns	ns
SED (8 d.f)		2.5	1.8	3.1	1.9	0.7	3.7
Interactions		None	Heat x DL	None	Heat x DL	None	None

Plate 14. Examples of Philadelphus growth in December 2004 and May 2005 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)

December 2004



May 2005



Photinia fraseri 'Red Robin'

Key points

- Supplementary light used in a cool environment maintained plant growth for longer resulting in larger plants in autumn
- Day length extension light and warmth had no effect on growth in autumn
- Day length extension light and warmth increased plant size in spring
- Supplementary light had no effect on plant growth in spring

More plants receiving supplementary light in the cool environment continued to grow for longer than those receiving any other treatment in autumn (Figure 15) and this resulted in an increase in size (Table 18, Plate 15). Day length extension light and temperature had no effect on growth.

After coming out of cold store the long extension shoots were tipped back to approximately 22 cm. None of the environmental treatments influenced the start of growth (Figure 15), but warmth and day length extension light increased plant size (Table 18). Supplementary light had no effect on plant growth

Figure 15. The effect of different environmental conditions on active plant growth of Photinia. Blue = cool house, red = warm house, AL Ambient light, SL Supplementary light, DL day length extension light

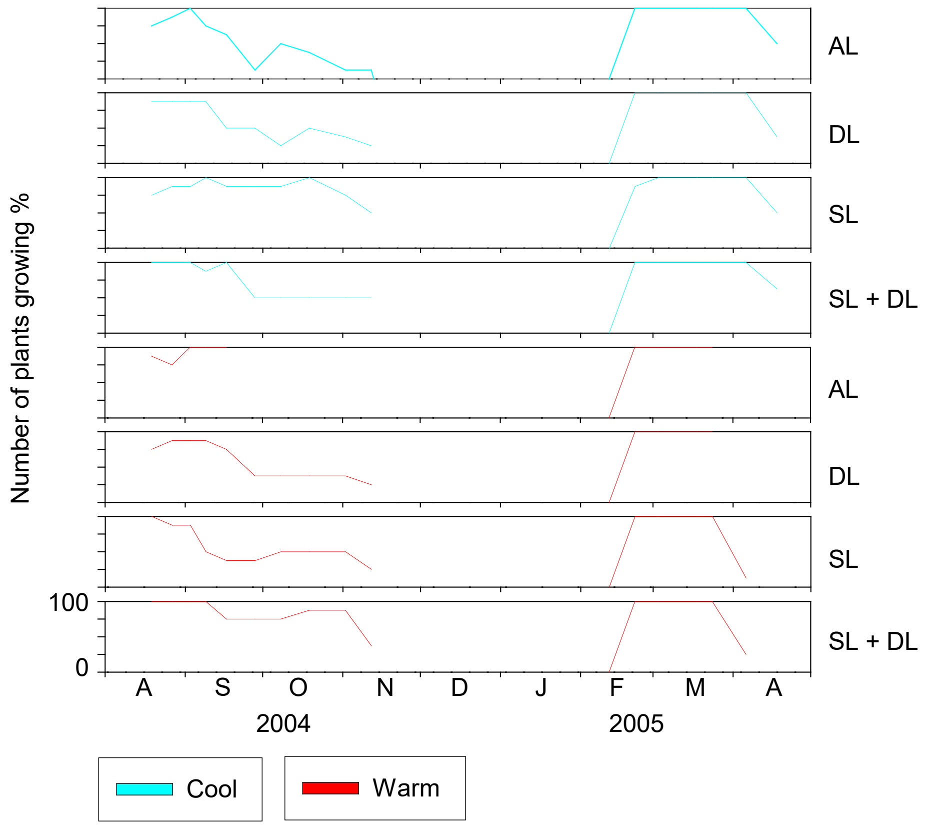
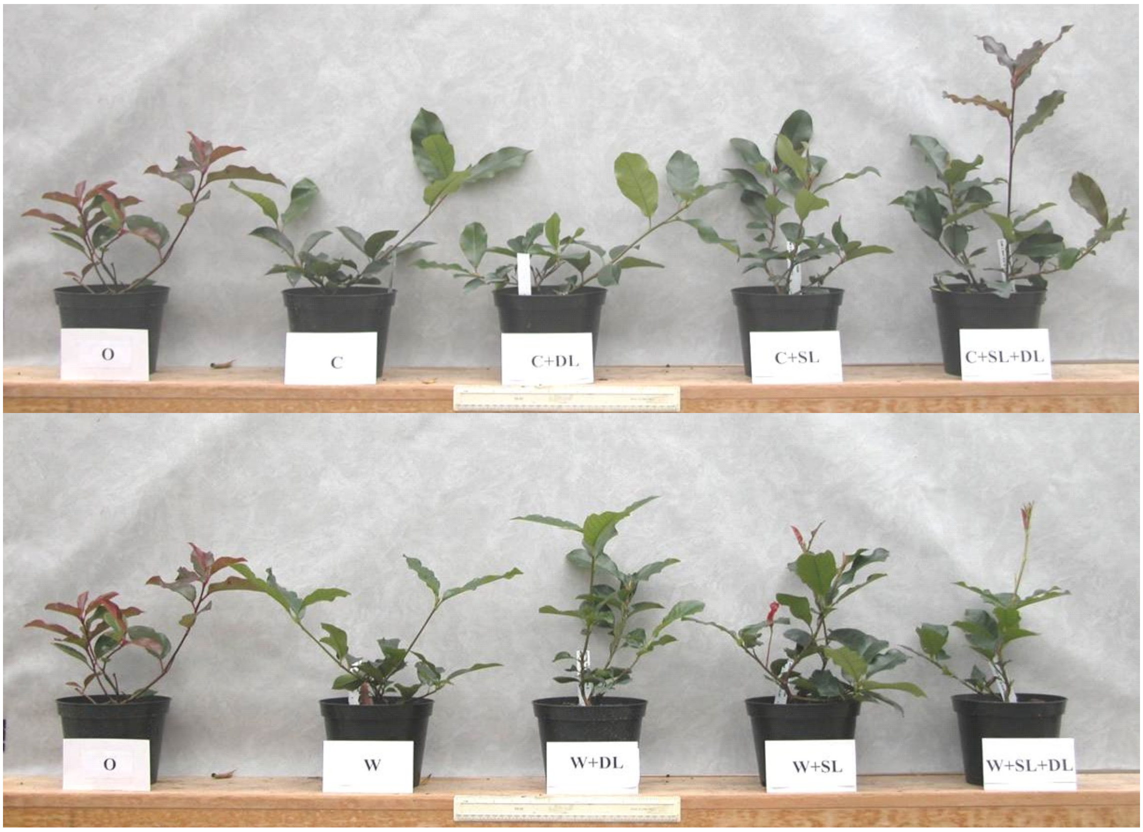


Table 18. The main effects of temperature, lighting and day length extension light on plant size and number of new shoots (breaks) of Photinia following autumn and spring extended growth seasons. Probability * is statistically significant (<0.05), ** is highly significant (≤ 0.01) and *** is very highly significant (≤ 0.001).

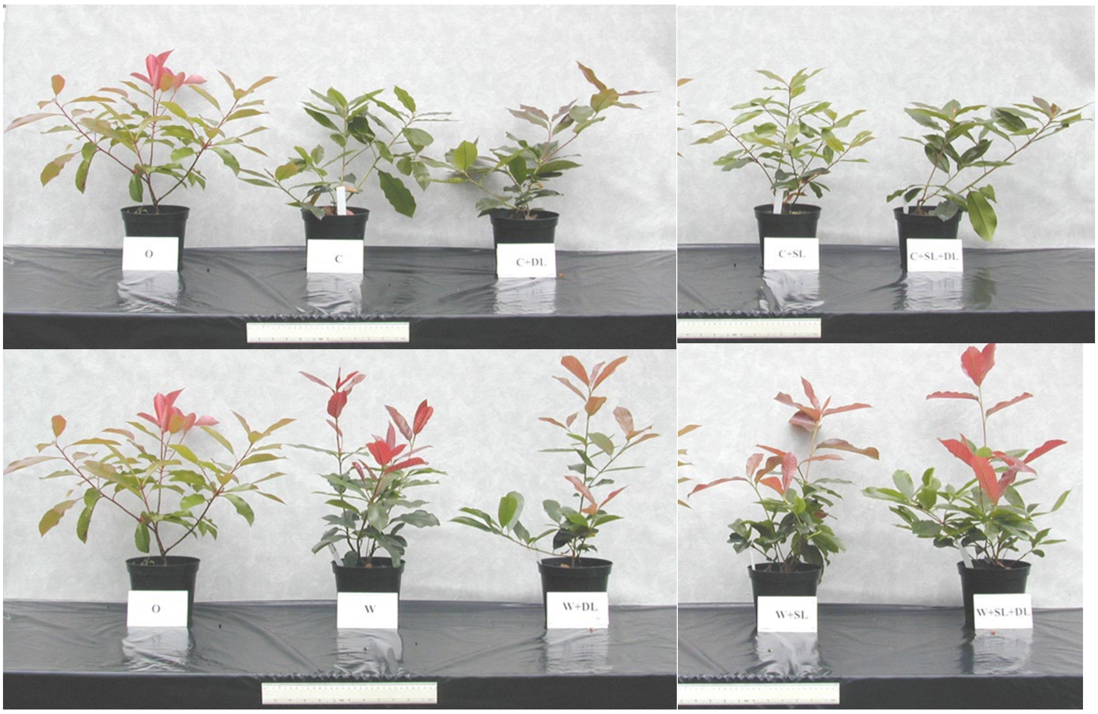
Main effect		Height (cm)		Width (cm)		No. new shoots per plant	
		Dec. 2004	May 2005	Dec. 2004	May 2005	Dec. 2004	May 2005
Temperature	Cool	19	29	28	47	4	7
	Warm	21	37	28	41	4	6
Probability		ns	*	ns	*	ns	ns
Supplementary	-	17	31	28	46	4	6
light	+	24	35	28	43	4	7
Probability		*	ns	ns	ns	ns	*
Day length	-	18	29	27	42	4	7
extension light	+	22	36	28	47	3	7
Probability		ns	ns	ns	*	ns	ns
SED (8 d.f)		2.2	3.2	1.0	1.9	0.4	0.6
Interactions		None	None	None	None	None	None

Plate 15. Examples of Photinia growth in December 2004 and May 2005 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, SL supplementary light. (Ruler = 30 cm)

December 2004



May 2005



Pittosporum tenuifolium 'Gold Star'

Key points

- Temperature and day length extension light had no impact on growth activity and plant size in autumn
- Supplementary light in autumn increased plant size and number of shoots per plant
- Growth started earlier in spring when warmth was applied and this was associated with increased plant size compared to the cool environment
- Plant size was particularly increased by day length extension light applied in the warm environment in spring
- Plant size was increased with a combination of supplementary and day length extension light applied together in spring

Pittosporum completed two episodes of growth in the autumn, but showed no response to temperature and day length extension light treatments. Supplementary light increased plant width (Table 19, Figure 16, Plate 16).

The plants were trimmed slightly after coming out of cold store. Plants in warm environments started to grow by mid-March and completed their first episode by mid April, those in cool houses did not start growing until early April (Figure 16). The plants in warm environments were larger than those in the cool environments (Table 19). Day length extension light increased plant size (width) in the warm environment, but had no effect in the cool environment (Plate 16). Supplementary in combination with day length extension light caused an increase in plant size (width). The number of shoots per plant was increased by supplementary light when in combination with day length extension light, however, supplementary light without day length extension light had the opposite effect.

Figure 16. The effect of different environmental conditions on active plant growth of Pittospornum. Blue = cool house, red = warm house, AL Ambient light, SL Supplementary light, DL day length extension light

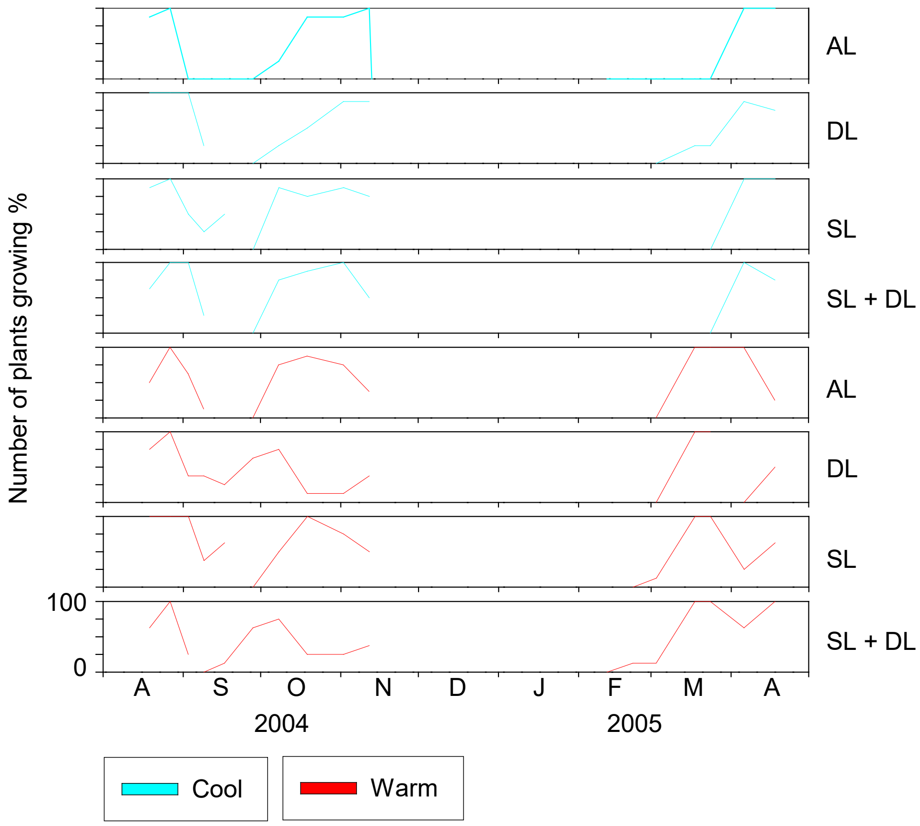
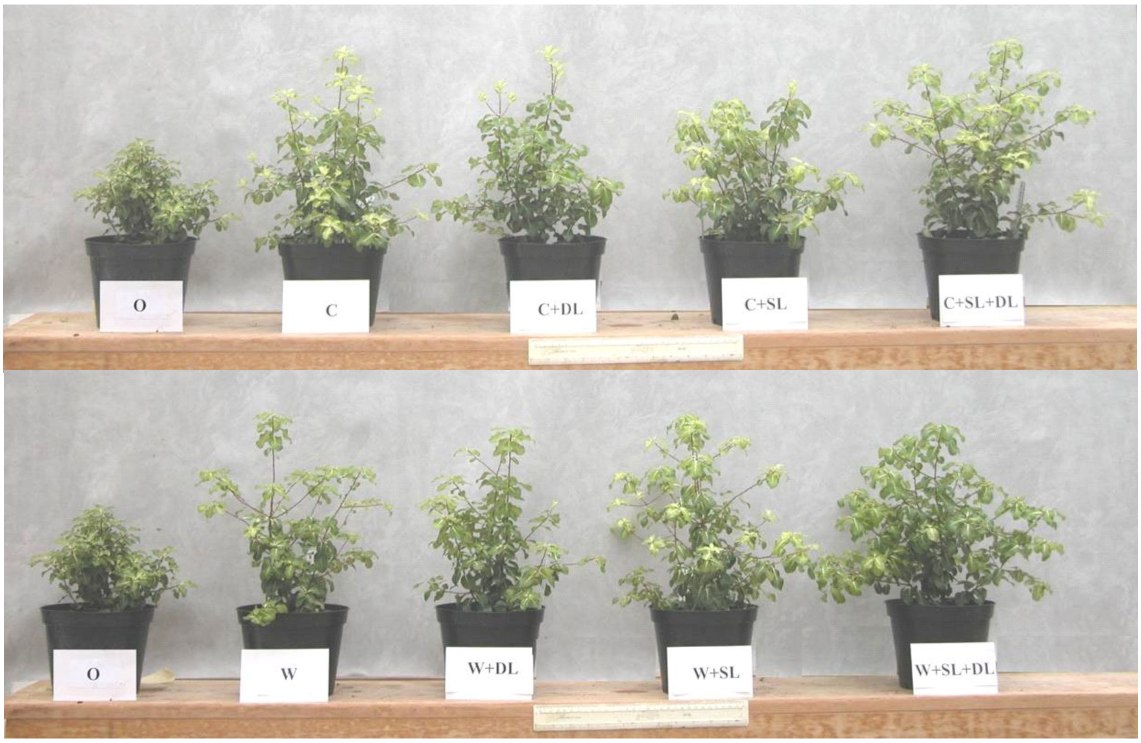


Table 19. The main effects of temperature, lighting and day length extension light on plant size and number of new shoots (breaks) of Pittospornum following autumn and spring extended growth seasons. Probability * is statistically significant (<0.05), ** is highly significant (≤ 0.01) and *** is very highly significant (≤ 0.001).

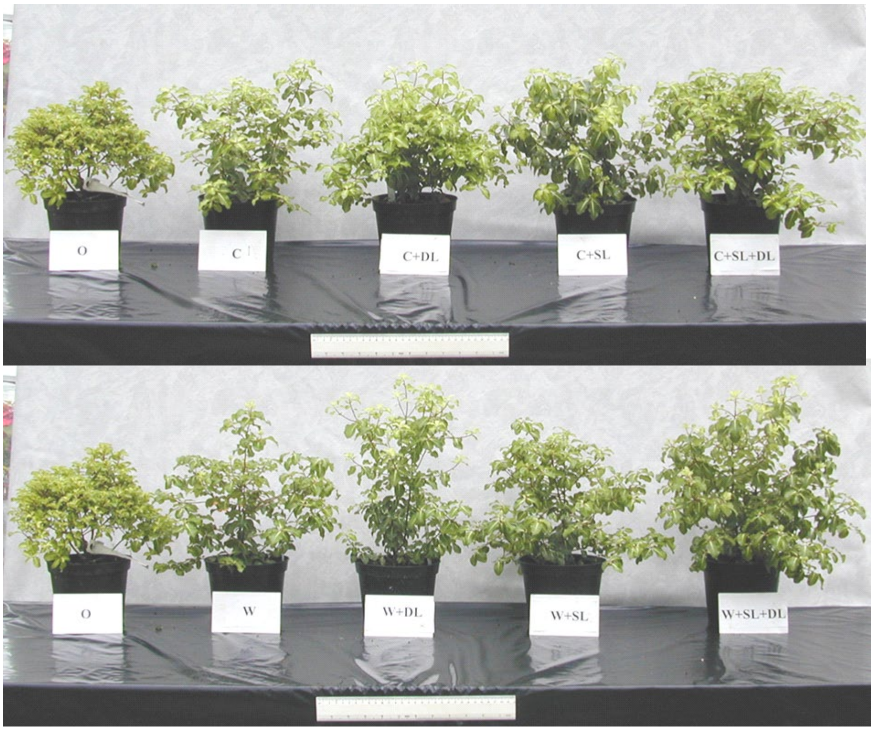
Main effect		Height (cm)		Width (cm)		No. new shoots per plant	
		Dec. 2004	May 2005	Dec. 2004	May 2005	Dec. 2004	May 2005
Temperature	Cool	27	26	30	35	26	61
	Warm	27	31	29	39	24	54
Probability		ns	***	ns	**	ns	ns
Supplementary	-	27	29	27	37	22	59
light	+	27	29	31	37	28	56
Probability		ns	ns	***	ns	**	ns
Day length	-	27	28	29	35	24	52
extension light	+	27	29	29	39	26	63
Probability		ns	ns	ns	**	ns	*
SED (8 d.f)		0.9	1.1	0.7	1.1	1.5	4.5
Interactions		None	None	None	(Heat x SL) (SL x DL)	None	DL x SL

Plate 20. Examples of Pittosporum growth in December 2004 and May 2005 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, SL supplementary light. (Ruler = 30 cm)

December 2004



May 2005



Prunus incisa 'Kojo-no-mai' (Fuji cherry)

Key points

- Plant size was increased by supplementary and day length extension light respectively applied in spring and autumn respectively
- Spring growth commenced approximately one month earlier in the warm environment
- Flowering started approximately 3 weeks earlier in warm compared to the cool environment in spring
- Plant size was unaffected by temperature in spring

Prunus stopped growing by mid September in all environments and there was no effect of warmth on plant size although the leaves remained on longer (Plate 17). Day length extension and supplementary light increased plant height slightly. The number of shoots per plant was unaffected by any of the environmental treatments (Table 21, Figure 17).

The plants were tipped back to approximately 17 cm after coming out of cold store. Growth started by the end of February for plants in the warm environments, a full month ahead of those in the cool environments (Figure 17). However, there was no difference in plant size by May (Table 21). Supplementary light increased plant size. The number of shoots per plant was unaffected by any of the environmental treatments

Flowering in the warm environments occurred between 23 February and 18 March, a month ahead of plants in the cool environments which flowered between 18 March and 6 April (Table 20).

Table 20. The effect of different environmental conditions on flowering of Prunus. AL Ambient light, SL Supplementary light, DL day length extension light

Treatment	**Flowers open**	**Petal fall**
Cool house		
AL	18 March	6 April
SL	18 March	6 April
DL	18 March	6 April
SL + DL	18 March	6 April
Warm house		
AL	23 February	18 March
SL	23 February	18 March
DL	23 February	18 March
SL + DL	23 February	18 March

Figure 17. The effect of different environmental conditions on active plant growth of Prunus. Blue = cool house, red = warm house, AL Ambient light, SL Supplementary light, DL day length extension light

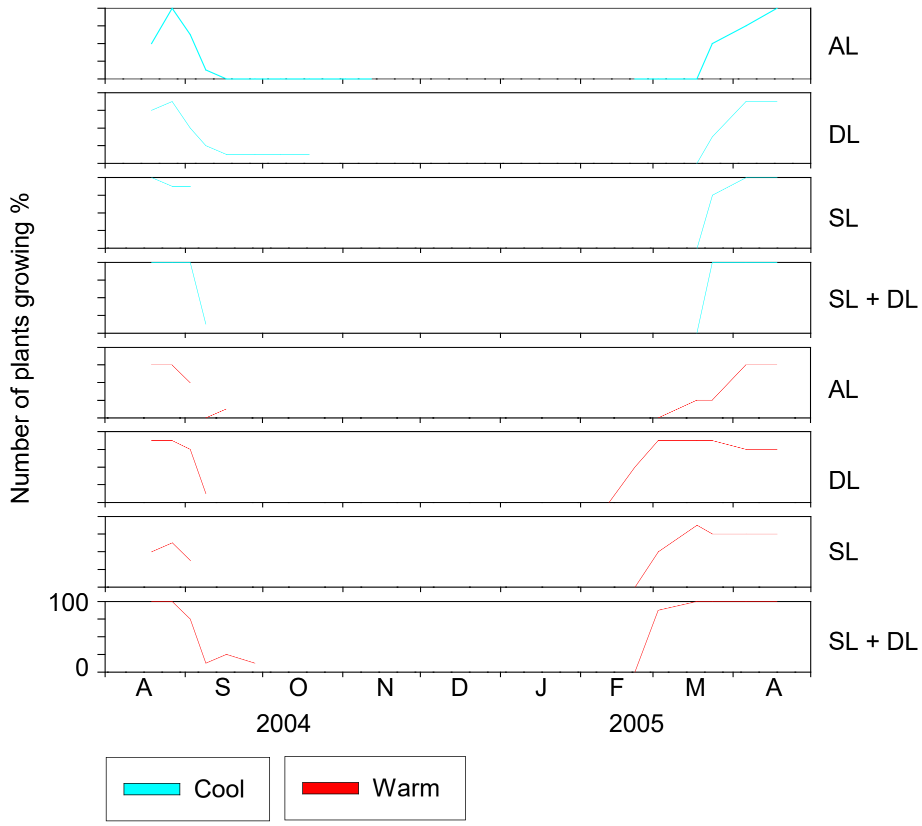


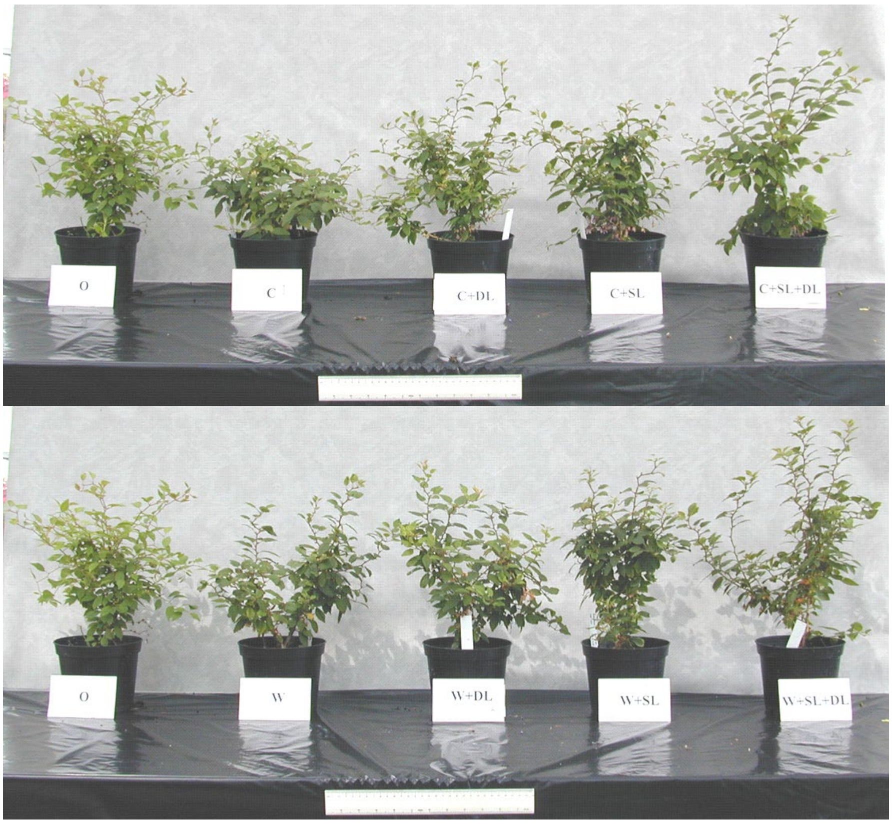
Table 21. The main effects of temperature, lighting and day length extension light on plant size and number of new shoots (breaks) of Prunus following autumn and spring extended growth seasons. Probability * is statistically significant (<0.05), ** is highly significant (≤ 0.01) and *** is very highly significant (≤ 0.001).

Main effect		Height (cm)		Width (cm)		No. new shoots per plant	
		Dec. 2004	May 2005	Dec. 2004	May 2005	Dec. 2004	May 2005
Temperature	Cool	27	28	22	28	7	13
	Warm	27	31	22	28	6	13
Probability		ns	ns	ns	ns	ns	ns
Supplementary	-	25	27	22	27	6	13
light	+	29	32	22	29	6	13
Probability		*	*	ns	ns	ns	ns
Day length	-	26	27	22	26	6	15
extension light	+	28	31	22	30	6	11
Probability		*	ns	ns	ns	ns	ns
SED (8 d.f)		1.1	1.8	1.3	2.4	0.6	2.5
Interactions		None	None	None	None	None	None

Plate 17. Examples of Prunus growth in December 2004 and May 2005 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)

December 2004

May 2005



Rhododendron ‘Shamrock’

Key points

- Plant size was increased by day length extension light applied in autumn and spring respectively. This effect was increased further in the warm environment
- Plant size was increased by warmth in autumn and spring respectively
- Day length extension light increased the growing period in autumn

Plants that received day length extension light continued to grow until November and this was associated with increased size, whereas those not receiving this light stopped growing by early September (Figure 18, Table 23, Plate18). Warmth also slightly increased plant size, but number of shoots per plant was unaffected by any treatment.

Following cold storage the combination of warm environment, supplementary and day length extension light treatments caused leaf scorching in spring. Ultimately, many of the plants died (Table 22), thus this combination of treatments is not recommended for Rhododendron! Day length extension light and warmth increased plant size (Table 23, Plate 18). Number of shoots per plant was unaffected by any of the environmental treatments.

The environmental conditions in the glasshouse chambers influenced flowering in spring because no flowering occurred in the warm environments and flowering in the cool environments was low. However, the plants kept outside and over wintered in the unheated polytunnel flowered fully.

Table 22. The effect of different environmental conditions on flowering (numbers in brackets are % of plants that survived that flowered) and number of plants that had died by end April of Rhododendron. AL Ambient light, SL Supplementary light, DL day length extension light

Treatment	Flowers open	Petal fall	Number of dead plants (%)
Cool house			
AL	24 March (38 %)	18 April	0
SL	24 March (38 %)	18 April	0
DL	24 March (38 %)	18 April	0
SL + DL	24 March (38 %)	18 April	0
Warm house			
AL	None		13
SL	None		25
DL	None		50
SL + DL	None		88

Figure 18. The effect of different environmental conditions on active plant growth of Rhododendron. Blue = cool house, red = warm house, AL Ambient light, SL Supplementary light, DL day length extension light

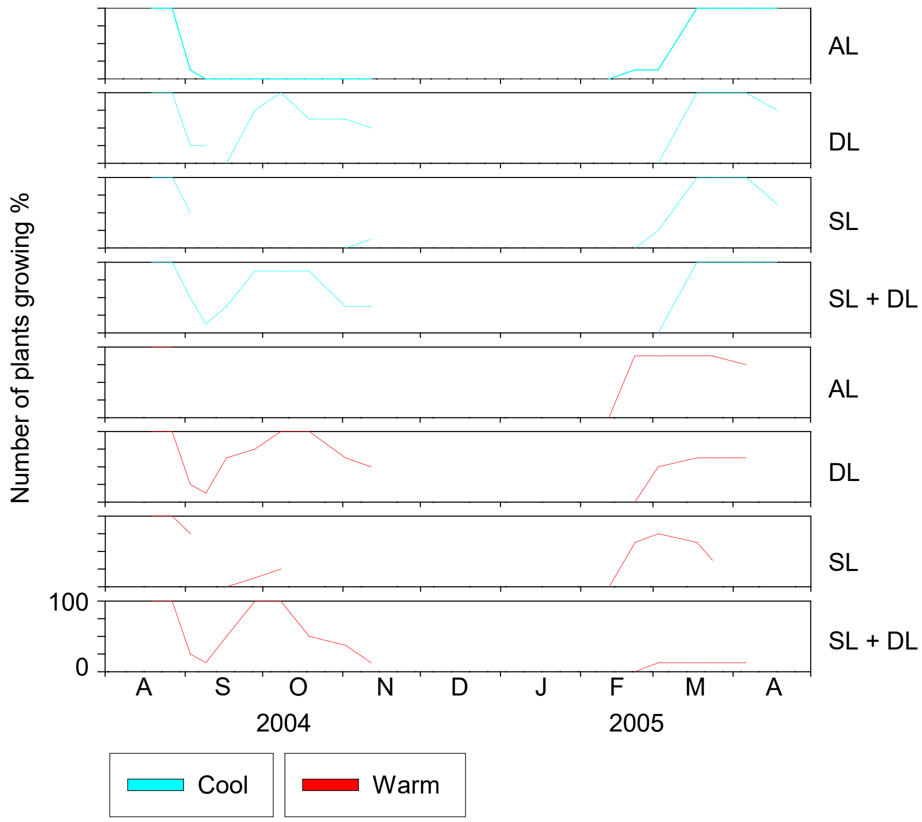
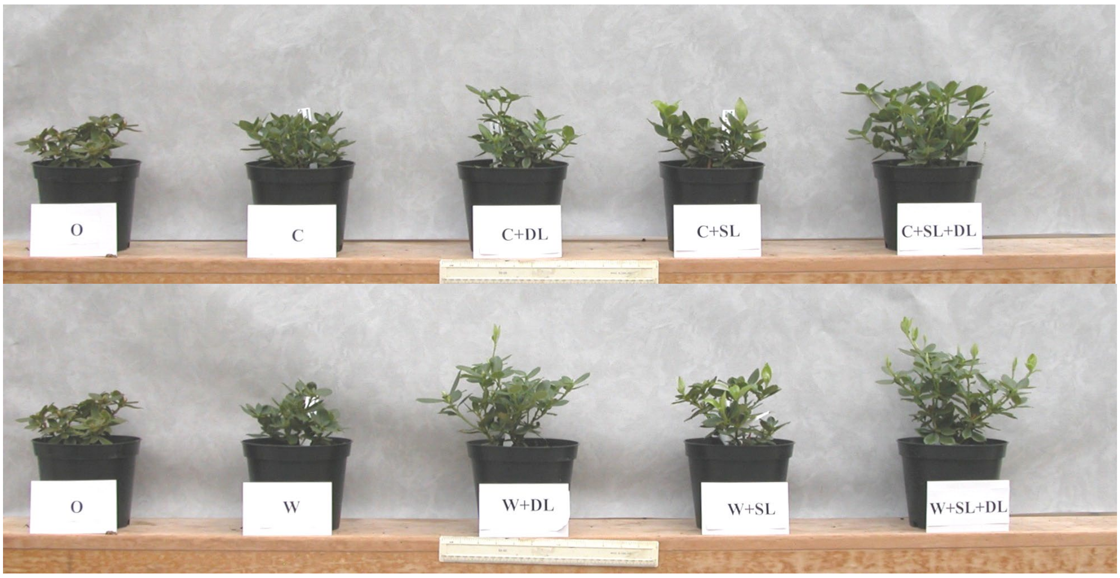


Table 23. The main effects of temperature, lighting and day length extension light on plant size and number of new shoots (breaks) of Rhododendron following autumn and spring extended growth seasons. Probability * is statistically significant (<0.05), ** is highly significant (≤ 0.01) and *** is very highly significant (≤ 0.001).

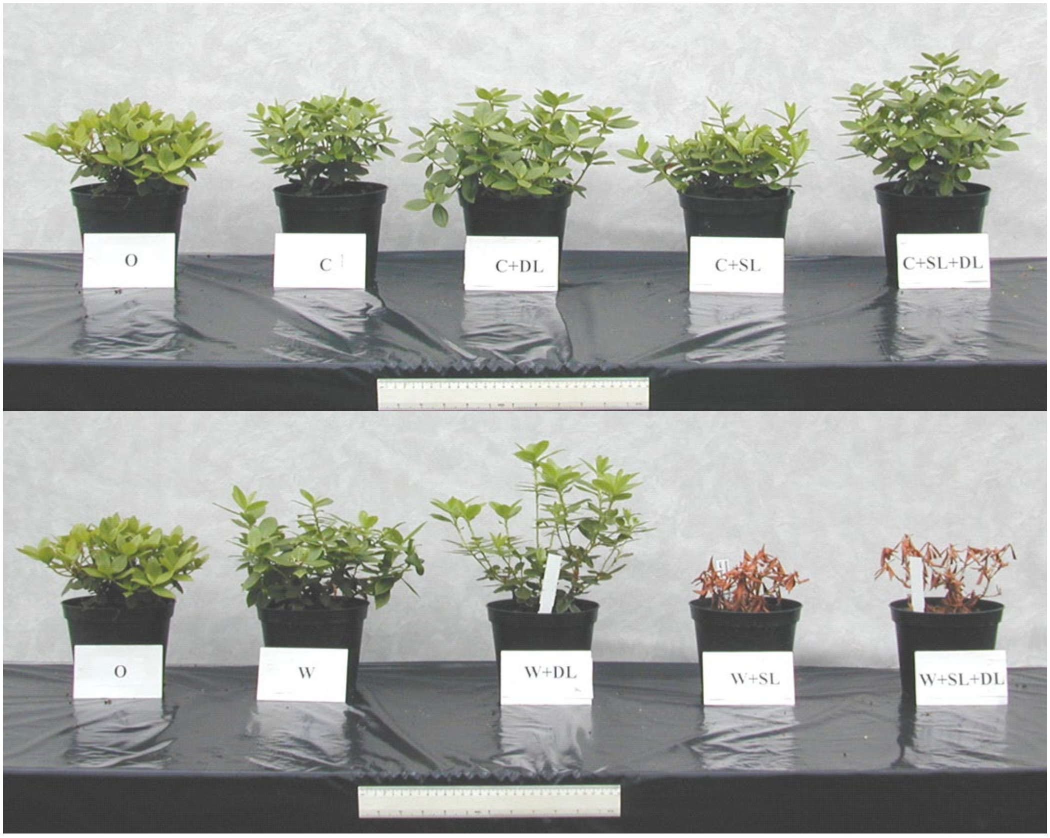
Main effect		Height (cm)		Width (cm)		No. new shoots per plant	
		Dec. 2004	May 2005	Dec. 2004	May 2005	Dec. 2004	May 2005
Temperature	Cool	10	17	19	27	15	28
	Warm	12	19	20	32	12	24
Probability		*	*	ns	**	ns	ns
Supplementary	-	10	18	19	29	13	22
light	+	11	18	21	29	14	31
Probability		ns	ns	ns	ns	ns	*
Day length	-	8	15	18	25	13	25
extension light	+	13	21	22	34	15	27
Probability		***	***	**	***	ns	ns
SED (8 d.f)		0.5	0.9	0.9	1.2	1.7	3.2
Interactions		Heat x DL	Heat x DL	None	Heat x DL	None	None

Plate 18. Examples of Rhododendron growth in December 2004 and May 2005 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)

December 2004



May 2005



Viburnum bodnantense 'Dawn' (Arrowood)

Key points

- Day length extension light increased plant size in autumn
- Plant size was increased by warmth applied in spring only
- Number of breaks decreased when warmth was applied in spring.

Only day length extension light influenced growth in autumn. It extended the growth period by approximately one month resulting in larger plants (Figure 19, Table 24, Plate 19).

The plants were pruned to above the third or fourth bud from the base after coming out of cold store. Warmth did not influence the start of growth, but the rate of growth was increased as the plants were larger in the warm than in the cool environment by the end of April (Figure 19, Table 24, Plate 19). The number of new shoots per plant was decreased by warmth. Supplementary and day length extension light had no effect on plant size or number of new shoots in spring.

Figure 19. The effect of different environmental conditions on active plant growth of Viburnum bodnantense. Blue = cool house, red = warm house, AL Ambient light, SL Supplementary light, DL day length extension light

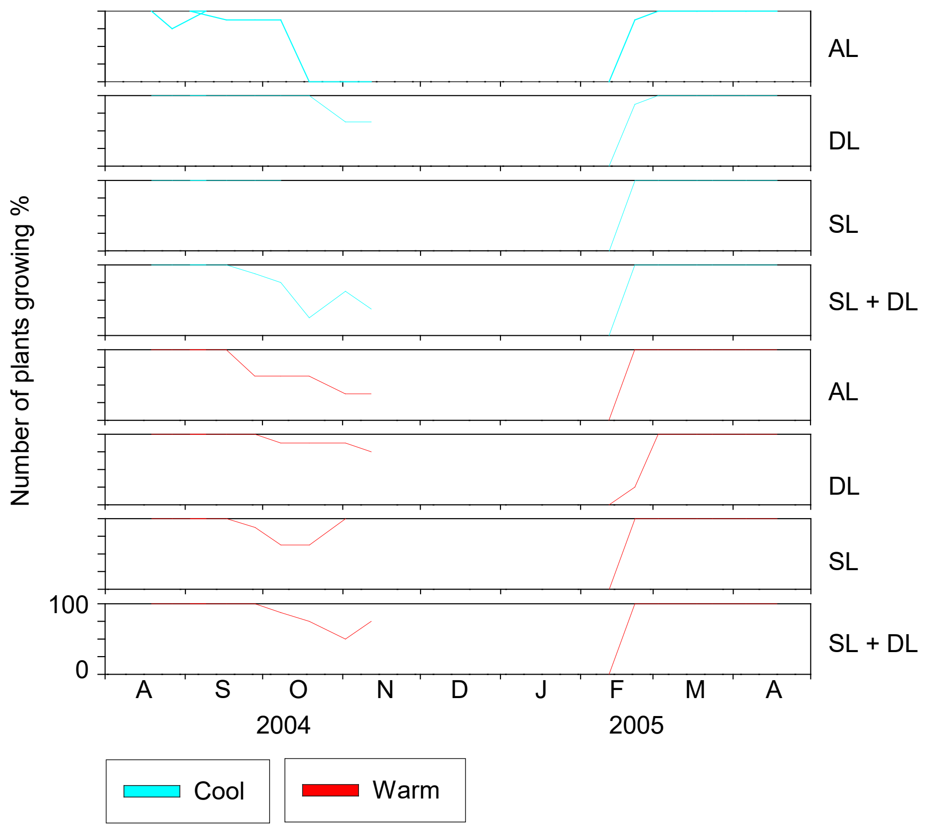


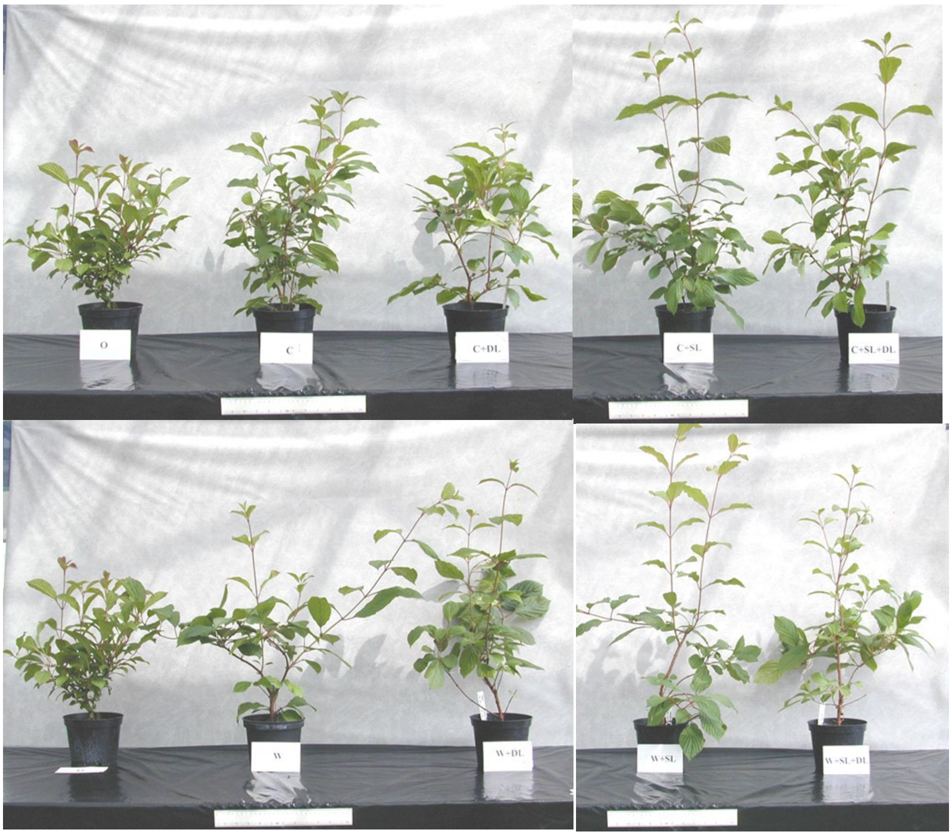
Table 24. The main effects of temperature, lighting and day length extension light on plant size and number of new shoots (breaks) of Viburnum bodnantense following autumn and spring extended growth seasons. Probability * is statistically significant (<0.05), ** is highly significant (≤ 0.01) and *** is very highly significant (≤ 0.001).

Main effect		Height (cm)		Width (cm)		No. new shoots per plant	
		Dec. 2004	May 2005	Dec. 2004	May 2005	Dec. 2004	May 2005
Temperature	Cool	66	50	47	44	3	12
	Warm	77	62	53	60	4	7
Probability		ns	**	ns	***	ns	***
Supplementary	-	70	57	50	52	4	9
light	+	73	55	50	52	3	10
Probability		ns	ns	ns	ns	ns	ns
Day length	-	61	60	44	52	4	10
extension light	+	82	52	56	52	4	8
Probability		**	*	*	ns	ns	ns
SED (8 d.f)		6.3	3.6	3.4	2.0	0.3	1.0
Interactions		None	None	None	None	None	None

Plate 19. Examples of Viburnum bodnantense growth in December 2004 and May 2005 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)

December 2004

May 2005



Viburnum tinus 'French White' EM27 (Laurustinus)

Key points

- Plant size was increased by warmth and day length extension respectively applied in autumn and spring respectively
- Plant size was increased by the combination of warmth and day length extension light in spring more than for the individual effects separately
- Supplementary light had no effect on growth in autumn or spring

The growth of Viburnum tinus stopped by the end of October in ambient light in the cool environment. Plants receiving supplementary light continued to grow for a week longer and those receiving day length extension light continued until the treatments were switched off. Warmth also maintained growth until mid November irrespective of light treatments (Figure 20). Day length extension light caused a small increase in plant size, but supplementary light had no effect (Plate 20). Warmth also increased plant size (Table 25). The number of shoot per plant was unaffected by any treatment.

The plants were pruned lightly after coming out of cold store. Most plants started to grow by the end of February irrespective of their environmental conditions (Figure 20). Warmth and day length extension lighting respectively increased plant size (Table 25, Plate 20). The combination of warm environment and day length extension also caused a positive interaction on plant size, i.e. the combined effect was larger than the individual effects separately. Supplementary lighting did not affect plant growth.

Figure 20. The effect of different environmental conditions on active plant growth of Viburnum tinus. Blue = cool house, red = warm house, AL Ambient light, SL Supplementary light, DL day length extension light

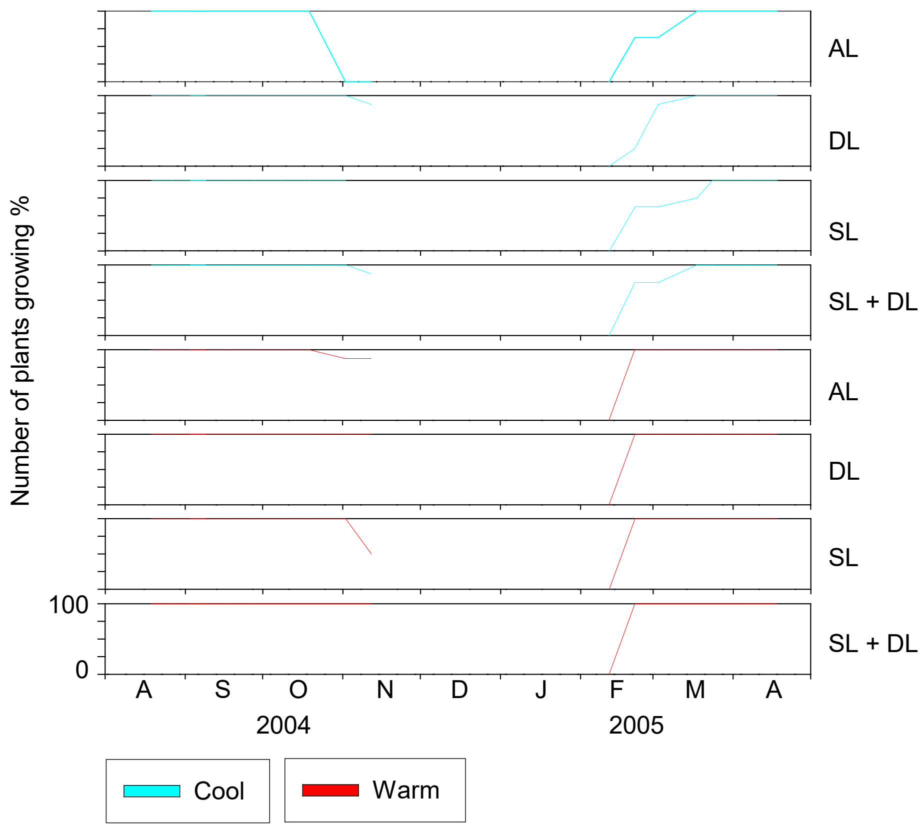
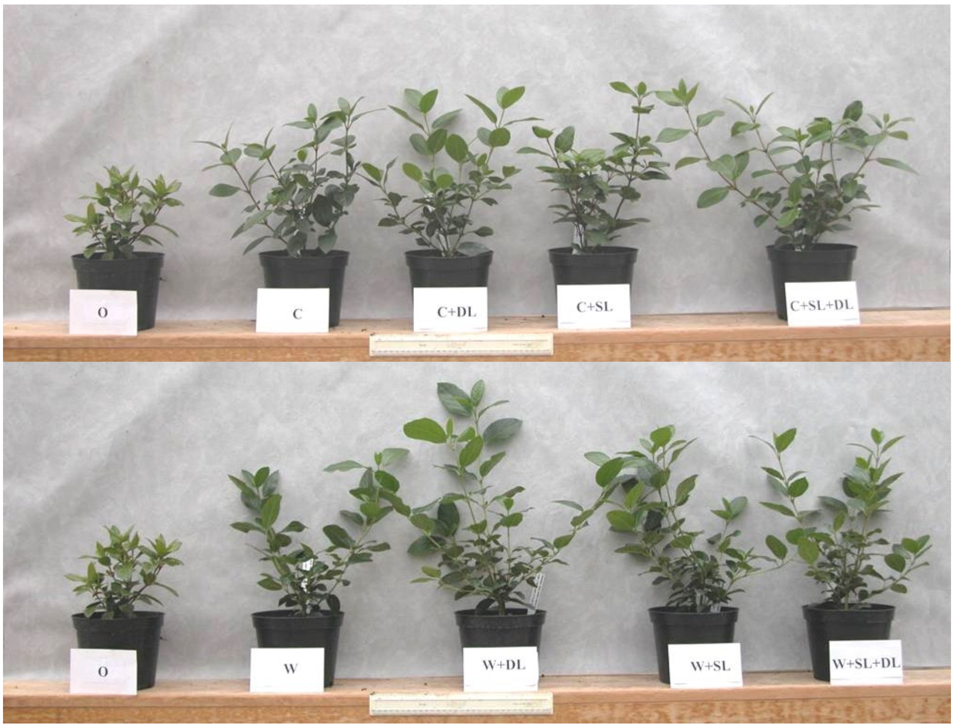


Table 25. The main effects of temperature, lighting and day length extension light on plant size and number of new shoots (breaks) of Viburnum tinus following autumn and spring extended growth seasons Probability * is statistically significant (<0.05), ** is highly significant (≤ 0.01) and *** is very highly significant (≤ 0.001).

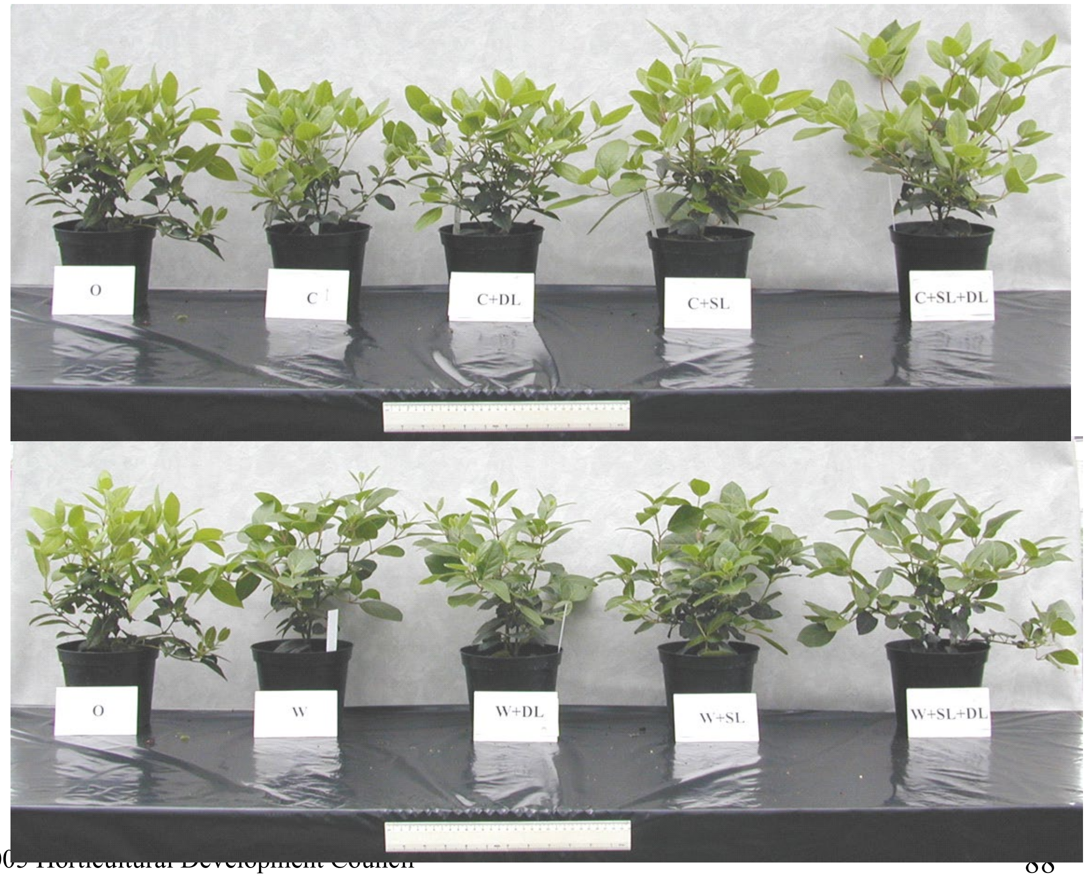
Main effect		Height (cm)		Width (cm)		No. new shoots per plant	
		Dec. 2004	May 2005	Dec. 2004	May 2005	Dec. 2004	May 2005
Temperature	Cool	28	25	30	33	7	18
	Warm	34	28	38	43	7	17
Probability		**	*	***	***	*	ns
Supplementary	-	31	26	34	38	7	16
light	+	31	27	34	39	7	18
Probability		ns	ns	ns	ns	**	*
Day length	-	29	24	32	36	8	18
extension light	+	32	29	36	40	8	17
Probability		ns	**	*	***	*	ns
SED (8 d.f)		1.6	1.2	1.3	0.8	0.2	0.7
Interactions		None	Heat x DL	None	Heat x DL	None	None

Plate 20. Examples of Viburnum tinus growth in December 2004 and May 2005 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)

December 2004



May 2005



Weigela 'Rubidor'

Key points

- Growth was increased by warmth applied in spring and autumn respectively
- Supplementary lighting had no effect on growth
- Day length extension lighting in cool environments only, increased growth.
- Warmth reduced the number of shoots per plant in spring.

Day length extension light extended the growing period in the cool environments from mid October until mid November (Figure 21). This resulted in increased plant size (Table 26). All the plants continued to grow until mid November in the warm environments and this also resulted in larger plants than those in the cool environments. Supplementary light had no effect on the duration of growth and plant size (Figure 21, Table 26, Plate 21).

The plants were hedge pruned to 20 cm after coming out of cold store. Plants in the warm environments quickly started growing (by 23 February), whereas those in the cool environments didn't start growing until mid March (Figure 21). Plants in the warm environments were larger than those in the cool environments by May. (Table 26, Plate 21). Warmth decreased the number of new shoots per plant. Supplementary and day length extension light had no effects on plant size.

Figure 21. The effect of different environmental conditions on active plant growth of Weigela . Blue = cool house, red = warm house, AL Ambient light, SL Supplementary light, DL day length extension light

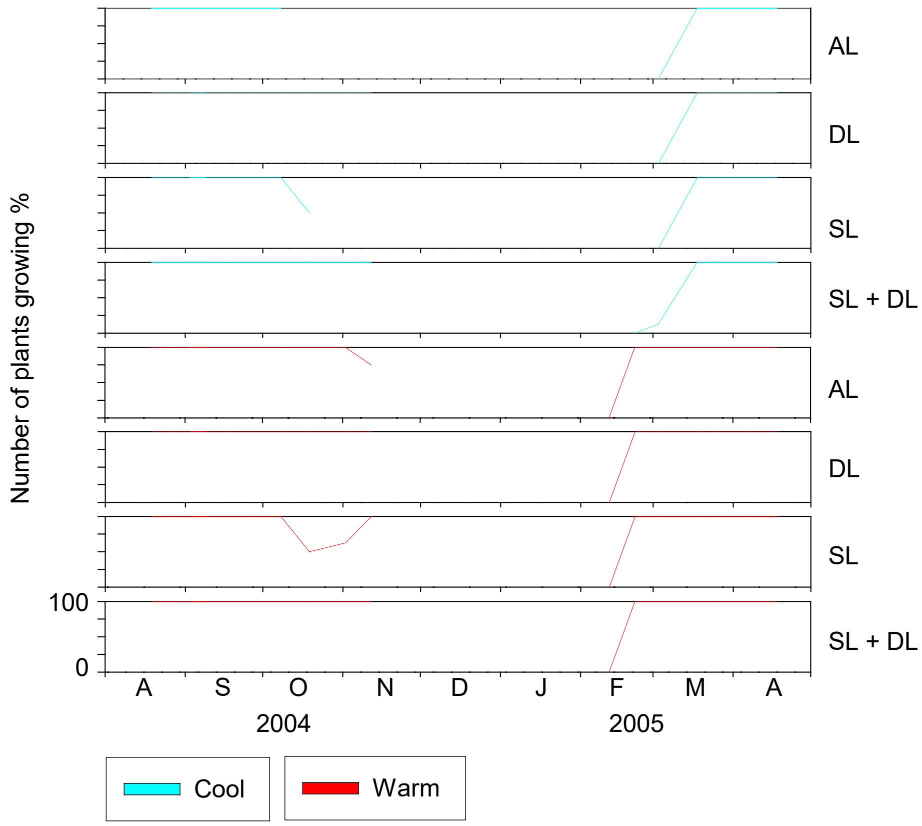


Table 26. The main effects of temperature, lighting and day length extension light on plant size and number of new shoots (breaks) of Weigela following autumn and spring extended growth seasons. Probability * is statistically significant (<0.05), ** is highly significant (≤ 0.01) and *** is very highly significant (≤ 0.001).

Main effect		Height (cm)		Width (cm)		No. new shoots per plant	
		Dec. 2004	May 05	Dec. 04	May 05	Dec. 04	May 05
Temperature	Cool	48	42	53	43	9	19
	Warm	53	52	62	51	8	14
Probability		ns	*	*	*	ns	**
Supplementary light	-	51	45	60	47	8	16
	+	50	49	55	47	8	17
Probability		ns	ns	ns	ns	ns	ns
Day length extension light	-	43	48	53	44	8	18
	+	58	46	62	50	8	15
Probability		***	ns	*	ns	ns	ns
SED (8 d.f)		3.0	3.8	3.4	2.4	0.7	1.3
Interactions		Heat x DL	None	Heat x DL	None	None	None

Plate 21. Examples of Weigela growth in December 2004 and May 2005 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

December 2004

May 2005

Conclusions

Typically temperate zone plants are influenced by the short days of autumn and therefore might be expected to show a positive response to day length extension either in the autumn or spring when ambient UK day light periods are short. Thus, it is not surprising most of the species that are native to Europe and North America were responsive to day length extension particularly in the spring (Table 27). The response to day length was more variable to plants native of Asia (five out of nine species responded positively to day length extension in autumn and only three responded in spring). However, for many of these, the exact distributions are difficult to determine and may cover wide latitude (Table 27) and thus different photoperiodic zones. It is also well known that photoperiodic response can vary within a species and even cultivars. So firm predictions of plant response to day length based on their distribution is always likely to be inexact.

The lack of response to supplementary lighting by most species was either due to light intensity not being a factor limiting growth or that the supplementary lighting was insufficient to influence growth. Improving the supplementary lighting intensity could be achieved by moving the lights nearer to the plants, but safety issues such as avoiding water and excessive heat make this impractical in many situations. Increasing the quantity of bulbs per unit area would have large cost implications.

The most reliable method of scheduling growth was raising temperature in Spring after the plants came out of cold store. This is not surprising since most plant biochemical and physiological processes are influenced by temperature and for example root growth will not occur unless temperatures exceed 5^{O}C.

- Early application of warmth in spring is the most promising treatment for consistently increasing plant size within a particular year across a wide range of HNS species
- Day length extension light applied in autumn and/or spring has potential for improving plant size

- Supplementary light has very limited value and should only be considered for use in autumn

Table 27. The main effects of temperature, day length extension and supplementary light treatments on the size of 21 different HNS species in autumn or spring. + indicates a positive effect, - indicates a negative effect on size, blank space indicates no effect. (D) = Deciduous, (E) = Evergreen.

Species	Native	Spring Temperature	Autumn day length. extension light	Spring day length extension light
		Asia		
Berberis thunbergii 'Pink Queen'* (D)	Asia (Temperate) Japan	+	+	+
Camellia japonica 'Guilio Nuccio'* (E)	Asia (Temperate) Japan, Korea	+		
Chaenomeles speciosa* 'Madame Butterfly' (D)	Asia (Temperate) China Asia (Tropical) Myanamar	+		
Mahonia japonica (E)	Japan			
Osmanthus heterophyllus 'Goshiki'* (E)	Japan, Taiwan	+/-		
Prunus incisa 'Kojo-no-mai' (D)	? Japan		+	
Rhododendron 'Shamrock' (E)	Southeast Asia, Australia, North America, Europe	+	+	+
Azalea japonica 'Santa maria' (E)	As for Rhododendron	+	+	+
Weigela 'Rubidor' (D)	Asia (Temperate) Japan, Korea, and Northern China	+	+	
		Europe		
Lavendul a angustifolia 'Hidcote'* (E)	Europe	+		+
*Convolvulus cneorum** (E)	Europe Mediterranean	+	+	+
Cytisus scoparius 'Burkwoodii'* (E)	Africa, Europe	+		
Ilex aquifolium Argentea Marginata* (E)	Africa Western Asia Europe	+		+

Viburnum tinus 'French White' EM27* (E)	Africa, Western Asia, Europe	+	+	+
		North America		
*Choisya ternate** (E)	Northern & Central Mexico	+		+
Hydrangea 'King George' (D)	North & South America Eastern Asia	+		+
Philadelphus 'Silver showers' (D)	? North America	+		+
		Australasia		
Pittosporum tenuifolium 'Gold Star' * (E)	New Zealand (North & South Islands)	+		+
		Unknown or cultivated only		
Clematis 'Jackmanii' (D)	Cultivated C. lanuginosa (China) x C. viticella (Europe)	+	+	
Photina x fraseri 'Red Robin'* (E)	Cultivated only	+		+
Viburnum x bodnatense 'Dawn'* (D)	Cultivated only	+	+	

- Distribution sourced from USDA, ARS National Genetic Resource Program, Germplasm Resources Information Network – (GRIN) [Online Database]. http://www.ars-grin.gov/cgi-bin/npgs/html/taxgenform.pl

Technology Transfer

There has been no technology transfer yet in this project, although the experiment was visited by HDC council on 13 October 2004. Demonstrations in the 2005/6 season are under discussion with the HDC Technical Manager.

Bibliography

Plant physiology. Salisbury FB and Ross CW. Wadsworth Publishing Company, Belmont California. 1992.

HDC HNS 65 Development of scheduling techniques for cotainerised 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

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