SUPPLEMENTARY LIGHTING AND CO_2 ENRICHMENT FOR ACCELERATED GROWTH OF SELECTED WOODY ORNAMENTAL SEEDLINGS AND ROOTED CUTTINGS

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Daily 16-h (0400–2000 h) supplementary lighting with high-pressure sodium (HPS) lamps at 45 $\mu E \cdot m^{-2} \cdot sec^{-1}$ increased growth of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), white spruce (*Picea glauca* (Moench) Voss), crape-myrtle (*Lagerstroemia indica* L.), and seven cultivars of English holly (*Ilex aquifolium* L.). Enrichment of greenhouse atmosphere with CO_2 to 1000–1300 ppm increased growth of four cultivars of English holly. In comparing two different light sources in CO_2-enriched greenhouses, low-pressure sodium (LPS) lamps at 42 $\mu E \cdot m^{-2} \cdot sec^{-1}$ were found as effective as HPS in increasing growth of white spruce, crape-myrtle, and five cultivars of English holly, but not so effective in Douglas-fir and three cultivars of English holly.

Un éclairage quotidien supplémentaire de 16 h (4 à 20 h) au moyen de lampes à sodium haute pression (HPS) à 45 $\mu E \cdot m^{-2} \cdot sec^{-1}$ accélère la croissance du sapin de Douglas (*Pseudotsuga menziensii* (Mirb.) Franco), de l'épinette blanche (*Picea glauca* (Moench) Voss), de la lagerstrémie des Indes (*Lagerstroemia indica* L.) et de sept cultivars de houx commun (*Ilex aquifolia* L.). L'enrichissement de l'atmosphère de la serre au CO_2 jusqu'à 1000–1300 ppm accélère la croissance des quatre cultivars de houx commun. Dans la comparaison entre deux sources d'éclairage en serre à atmosphère enrichie, les lampes à sodium basse pression (LPS) à 42 $\mu E \cdot m^{-2}/sec^{-1}$ sont aussi efficaces que les PHS pour accélérer la croissance de l'épinette blanche, de la lagerstrémie et de cinq cultivars de houx commun, mais pas aussi efficaces envers le sapin de Douglas et trois cultivars de houx commun.

Depending upon the emission spectrum, supplementary lighting may have both photoperiodic and photosynthetic effects (Canham 1972). Photoperiodic lighting at low irradiation levels has been shown to delay dormancy and thereby increase growth of several forest tree species (Arnott 1979). Photosynthetic lighting, at a high irradiation level, has increased growth and improved quality of spray pompon chrysanthemums during the winter months (Carpenter 1976). Although earlier studies have used supplementary lighting on woody ornamentals (Cathey and Campbell 1979), the advantages and limitations have not been fully determined.

Enrichment of the greenhouse atmosphere with CO_2 has increased yield of cut roses (Mattson and Widmer 1971) and tomatoes (Hicklenton and Jolliffe 1978), and stimulated growth of crabapple (Krizek et al. 1971), Chinese holly (Laiche 1978) and black walnut (Tinus 1976). Additional information is required on the effects of CO_2 enrichment on other woody plants.

This study determined the influence of supplementary lighting, with or without CO_2 enrichment in the greenhouse, on

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growth acceleration of selected woody ornamental seedlings and rooted cuttings.

MATERIALS AND METHODS

Five similar greenhouse compartments were used to provide the following treatments: (1) daylight (DL) with added CO_2 (DL+CO_2); (2) DL without added CO_2 (DL−CO_2); (3) high-pressure sodium (HPS) light with added CO_2 (HPS+CO_2); (4) HPS without added CO_2 (HPS−CO_2); and (5) low-pressure sodium (LPS) light with added CO_2 (LPS+CO_2). LPS without added CO_2 (LPS−CO_2) was not tested. In treatments with supplementary lighting, daily 16-h lighting (0400–2000 h) was provided from early October to late May (1977–1979) by either two HPS lamps (400 W SON/T) placed 2.6 m apart and 2.1 m above the growing bench, or two LPS lamps (180 W SOX) placed 2.1 m apart and 1.3 m above the bench, providing 45 and 42 $\mu E \cdot m^{-2} \cdot sec^{-1}$, respectively, (the equivalent of 3800 and 4400 lx) at plant level. In treatments with CO_2 enrichment, the CO_2 concentration in the air during the lighting hours was maintained at 1000–1300 ppm, supplied from a CO_2 cylinder. Air temperatures of 16°C (dark) and 18–21°C (light) were thermostatically controlled in all treatments.

Seedlings of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and white spruce (*Picea glauca* (Moench) Voss), newly rooted cuttings of crape-myrtle (*Lagerstroemia indica* L.) and eight cultivars of English holly (*Ilex aquifolium* L.) were planted on different dates (Table 1). The growing medium consisted of equal volumes of sphagnum peat moss and fir sawdust amended with 3.6 kg/m^3 dolomitic lime, 4.7 kg/m^3 superphosphate and 74 g/m^3 fritted trace elements. Plants were fertilized weekly by hand with 200 ppm of N using 20.0 N-8.8 P-16.6 K fertilizer. Height and width of plants were measured on dates described in Table 1.

Four of the treatments formed a 2 × 2 factorial experiment with two levels of irradiation (+ or − HPS) and two levels of CO_2 (+ or −CO_2) for analysis of variance. The fifth treatment (LPS+CO_2) was included in the statistical analysis by comparing it with the HPS+CO_2 treatment. A separate analysis was carried out for each cultivar and species.

RESULTS AND DISCUSSION

Ten of the 11 species and cultivars tested showed growth stimulation from HPS lighting, and four were stimulated by CO_2 enrichment (Table 2). The growth of English holly cv. Wilsonii was not affected by supplementary lighting and CO_2 enrichment and its data were not included in Table 2. There was no interaction between HPS lighting and CO_2 enrichment except for the width parameter of English holly cvs. Shortspra and Silvary. As a direct comparison, HPS+CO_2 was similar to LPS+CO_2 in increasing the growth in seven of the 11 species and cultivars while in the other four, HPS+CO_2 was more effective than LPS+CO_2.

Table 1. Plant species studied

Species	Propagation methods	Pot size (Litre)	Dates of transplanting	No. plants measured per treatment	Dates of measurements
Douglas-fir (*Pseudotsuga menziesii*)	Seeds	4.5	20 Sept. 1978	20	28 Feb. 1979
White spruce (*Picea glauca*)	Seeds	4.5	27 Jan. 1978	7	29 Nov. 1978
Crape-myrtle (*Lagerstroemia indica*)	Cuttings	1.6	16 Oct. 1978	8	28 Feb. 1979
English holly† (*Ilex aquifolium*)	Cuttings	4.5	20 Sept. 1978	3-6	18 May 1979

† All cuttings of eight English holly cultivars were cut back to 10 cm on 10 Oct. 1978.

Table 2. The effects of supplementary lighting with high- (HPS) and low- (LPS) pressure sodium lamps, with (+) and without (−) CO_2 enrichment, on the height and width of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), white spruce (*picea glauca* (Moench) Voss), crape-myrtle (*Lagerstroemia indica* L.) and seven cultivars of English holly (*Ilex aquifolium* L.)

Species and cultivars	Variable (cm)	CO_2	Lighting†			Source of variation			
			DL	HPS	LPS	HPS	CO_2	HPS×CO_2	HPS+CO_2 vs. LPS+CO_2
Pseudotsuga menziesii	Height	−	13.1	32.0	−				
		+	12.1	30.6	26.2	**	NS	NS	NS
	Width	−	9.3	27.0	−				
		+	7.0	29.0	22.5	**	NS	NS	**
Picea glauca	Height	−	15.9	25.1	−				
		+	18.3	27.4	26.6	**	NS	NS	NS
	Width	−	13.4	20.9	−				
		+	11.6	22.1	19.8	**	NS	NS	NS
Lagerstroemia indica	Height	−	8.9	15.9	−				
		+	7.9	17.1	17.6	**	NS	NS	NS
	Width	−	12.3	20.3	−				
		+	11.8	24.4	22.7	**	NS	NS	NS
Ilex aquifolium 'Golden Queen'	Height	−	29.3	60.3	−				
		+	34.5	86.7	65.8	**	*	NS	*
	Width	−	34.9	48.0	−				
		+	37.4	56.2	51.6	**	NS	NS	NS
I. aquifolium 'Shortspra'	Height	−	32.8	40.5	−				
		+	43.7	66.3	73.3	**	**	NS	NS
	Width	−	35.2	46.0	−				
		+	38.9	67.8	52.6	**	**	**	**
I. aquifolium 'Yellow Berried'	Height	−	73.8	86.0	−				
		+	68.3	83.0	77.5	*	NS	NS	NS
	Width	−	50.9	69.5	−				
		+	51.9	83.1	81.9	**	NS	NS	NS
I. aquifolium 'Pemberton'	Height	−	33.0	67.5	−				
		+	54.3	74.5	67.2	**	*	NS	NS
	Width	−	37.6	55.3	−				
		+	42.0	55.9	52.9	**	NS	NS	NS
I. aquifolium 'Brethour'	Height	−	42.0	76.3	−				
		+	49.8	83.0	59.0	**	NS	NS	*
	Width	−	37.3	64.4	−				
		+	40.8	60.3	46.9	**	NS	NS	*
I. aquifolium 'Silvary'	Height	−	42.5	74.0	−				
		+	62.3	71.0	56.0	**	NS	NS	NS
	Width	−	35.0	56.9	−				
		+	50.6	50.8	51.9	**	NS	**	NS
I. aquifolium 'J.C. van Tol'	Height	−	35.5	44.0	−				
		+	41.3	77.5	94.5	**	**	NS	NS
	Width	−	34.1	50.3	−				
		+	43.9	76.9	72.5	**	**	NS	NS

†DL = daylight; HPS = high-pressure sodium; LPS = low-pressure sodium.
*,** Significant at $P = 0.05$ and $P = 0.01$, respectively; NS=nonsignificant at the $P = 0.05$ level.

HPS Lighting

HPS increased the height and width of Douglas-fir, white spruce, crape-myrtle, English holly cvs. Golden Queen, Shortspra, Yellow Berried, Pemberton, Brethour, Silvary and J. C. van Tol (Table 2). Douglas-fir seedlings produced no new shoots under DL, whereas under HPS they continued to grow and produced an average of 6.7 new shoots per plant and an average of 13.8 cm extension per new shoot in 5 mo. The increase in growth of white spruce was evident throughout the whole experiment. However, after 10 mo all white spruce seedlings were dormant even under HPS. They resumed growth following a 6-wk cold treatment at 5°C. A further increase in growth caused by HPS was observed 6 mo later when the spring flush of growth was completed in May 1979. The increase in growth of English holly cv. Brethour, for example, became evident soon after HPS lighting began. In 2 mo Brethour under DL produced 2.5 new shoots per plant and averaged 7.9 cm extension per new shoot as compared to 3.8 new shoots averaging 12.4 cm under HPS. The observed increase in growth of Douglas-fir, white spruce, and English holly was probably due in part to the 16-h photoperiod. HPS has been observed effective in producing long-day effects on amabilis fir, mountain hemlock, and white and Engelmann spruce seedlings (Arnott 1979). Long days have delayed and broken the dormancy of Douglas-fir (Roberts et al. 1974) and white spruce (Arnott 1979), and increased growth of Chinese (Wright 1976) and Japanese hollies (Cathey and Campbell 1975). In addition to long day effects, the irradiation level of HPS used in our study exceeded the requirements for photoperiodic lighting and was in the range for photosynthetic lighting. Some of the increased growth was likely also due to increased photosynthetically active radiation (PAR) provided by HPS lighting. In a preliminary study (unpubl. obs.) HPS lighting resulted in greater fresh weight of English holly CVS. Brethour and Shortspra than long day control (night interruption with incandescent light). This was in agreement with the results obtained by Cathey and Campbell (1979) who found HPS lighting accelerated growth more than long-day control and concluded that long day alone was inadequate to maintain optimal photosynthesis (growth) of most plants tested in the winter months. Similarily, increase in PAR has resulted in increased number of axillary shoots and fresh weight of seed-propagated geranium in the winter (Erickson et al. 1980). The results obtained in this study confirmed and extended the range of woody species in which the winter growth had been observed to be increased by high intensity supplementary lighting (Cathey and Campbell 1979).

HPS in Comparison with LPS

Both HPS and LPS lamps are highly effective in producing PAR in the region of 400–700 nm (Cathey and Campbell 1980). The effects of HPS+CO_2 and LPS+CO_2 on increased growth were similar in white spruce, crape-myrtle, English holly cvs. Yellow Berried, Pemberton, Silvary, Wilsonii and J. C. van Tol (Table 2). The plants of crape-myrtle grown under HPS+CO_2 or LPS+CO_2 were twice the height and width of those grown under DL. With CO_2, the HPS- and LPS- lighted plants bloomed earlier than control plants. The increased growth in crape-myrtle was probably due to HPS or LPS lighting more than CO_2 enrichment because CO_2 did not increase the growth either with or without HPS. The results were in general agreement with the results of Cathey and Campbell (1979) who demonstrated HPS and LPS were effective in increasing winter growth of most plants they tested. They concluded that total irradiation (energy) was more important than light quality for the growth and flowering of several herbaceous plants. However, the spectral emission of the two light sources differ; HPS has a relative wide peak at 589 nm while LPS is almost monochromatic at 589 nm. HPS produces more far-red and near infrared radiation (700–850 nm) than LPS (Cathey and Campbell 1980) and this may be the cause of greater growth of Douglas-fir, English holly cvs, Golden Queen, Shortspra and Brethour under HPS+CO_2 than under LPS+CO_2 (Table 2). Krizek and Ormrod (1980) reported that increasing the levels of far-red and infrared radiation stimulated the growth of lettuce and marigold in controlled-environment chambers where equal levels of PAR were provided.

CO_2 Enrichment

Enrichment with CO_2 in the greenhouse atmosphere increased the growth of English holly CVS. Golden Queen, Shortspra, Pemberton and J. C. van Tol (Table 2). This was similar to the results observed in Chinese holly (Laiche 1978). However, CO_2 enrichment did not promote the growth of the other seven species and cultivars tested. This may have been due to the low concentration used in this study, since a higher concentration of 3000 ppm increased the growth of tea crabapple seedlings (Zimmerman et al. 1970).

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ARNOTT, J. T. 1979. Effect of light intensity during extended photoperiod on growth of amabilis fir, mountain hemlock, and white and Engelmann spruce seedlings. Can. J. For. Res. **9**: 82–89.

CANHAM, A. E. 1972. Light and the plant propagator. Proc. Int. Plant Prop. Soc. **22**: 246–254.

CARPENTER, W. J. 1976. Photosynthetic supplementary lighting of spray pompon, *Chrysanthemum morifolium* Ramat. J. Am. Soc. Hortic. Sci. **101**: 155–158.

CATHEY, H. M. and CAMPBELL, L. E. 1975. Effectiveness of five vision-lighting sources on photo-regulation of 22 species of ornamental plants. J. Am. Soc. Hortic. Sci. **100**: 65–71.

CATHEY, H. M. and CAMPBELL, L. E. 1979. Relative efficiency of high- and low-pressure sodium and incandescent filament lamps used to supplement natural winter light in greenhouses. J. Am. Soc. Hortic. Sci. **104**: 812–825.

CATHEY, H. M. and CAMPBELL, L. E. 1980. Light and lighting systems for horticultural plants. Hortic. Rev. **2**: 491–539.

ERICKSON, V. L., ARMITAGE, A., CARLSON, W. H. and MIRANDA, R. M. 1980. The effect of cumulative photosynthetically active radiation on the growth and flowering of the seedling geranium, *Pelargonium* × *hortorum* Bailey. HortScience **15**: 815–817.

HICKLENTON, P. R. and JOLLIFFE, P. A. 1978. Effects of greenhouse CO_2 enrichment on the yield and photosynthetic physiology of tomato plants. Can. J. Plant Sci.**58**: 801–817.

KRIZEK, D. T. and ORMROD, D. P. 1980. Growth response of 'Grand Rapid' lettuce and 'First Lady' marigold to increased far-red and infrared radiation under controlled environments. J. Am. Soc. Hortic. Sci. **105**: 936–939.

KRIZEK, D. T., ZIMMERMAN, R. H., KLUETER, H. H. and BAILEY, W. A. 1971. Growth of crabapple seedlings in controlled environments: Effect of CO_2 levels, and time and duration of CO_2 treatment. J. Am. Soc. Hortic. Sci. **96**: 285–288.

LAICHE, A. J. 1978. Effects of refrigeration, CO_2 and photoperiod on the initial and subsequent growth of rooted cuttings of *Ilex cornuta* Lindl. et Paxt. cv. Burfordii. Plant Prop. **24**: 8–10.

MATTSON, R. H. and WIDMER, R. E. 1971. Year round effects of carbon dioxide supplemented atmospheres on greenhouse rose (*Rosa hybrida*) production. J. Am. Soc. Hortic. Sci. **96**: 487–488.

ROBERTS, A. N., TOMASOVIC, B. J. and FUCHIGAMI, L. H. 1974. Intensity of bud dormancy in Douglas-fir and its relation to scale removal and rooting ability. Physiol. Plant. **31**: 211–216.

TINUS, R. W. 1976. Photoperiod and atmospheric CO_2 level interact to control black walnut (*Juglans nigra* L.) seedling growth. Plant Physiol. **57** (Suppl.): 106 (Abstr.).

WRIGHT, R. D. 1976. Temperature and photoperiod on the growth of *Ilex cornuta* Lindl. et Paxt. HortScience **11**: 44–46.

ZIMMERMAN, R. H., KRIZEK, D. T., BAILEY, W. A. and KLUETER, H. H. 1970. Growth of crabapple seedlings in controlled environments: Influence of seedling age and CO_2 content of the atmosphere. J. Am. Soc. Hortic. Sci. **95**: 323–325.