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Influence of Photoperiod and Light Quality on Lateral Branching and Flowering of Selected Vegetatively-propagated Plants[1]

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Abstract. **Alternanthra amoena Voss, *Coleus* X *hybridus* Voss., *Hedra helix* L., *Pelargonium* X *hortorum* Bailey, *Peperomia obtusifolia* L., *Pilea cadierei* Gagnep. & Guillaum, *Pilea* 'Moon Valley' and *Pilea involucrata* 'Panamegia' Sims were grown under normal photoperiods (ND), short photoperiods (SD) and several night lighting regimes using red, incandescent, or far red light. Lateral branching and cutting production was promoted on *P.* 'Moon Valley' under SD while flowering was inhibited. *P.* 'Moon Valley' and *P. involucrata* flowered under long days. The remaining plant species produced more cuttings under ND or the night lighting treatments when compared to SD. Cycling *P.* 'Moon Valley' and *P. involucrata* between SD and day continuation red lighting treatments every 20 days significantly increased cutting production on plants compared to plants grown continuously under SD or ND.**

Lateral branching in many plant species is influenced by light quality (4, 8, 12). Red light promotes lateral branching (4) while far-red light inhibits it (10, 12). Branching can also be influenced by photoperiod (3, 5).

The number of cuttings produced by a stock plant is limited to the number of lateral buds released from apical dominance and which continue to develop. Assuming environmental factors are optimal and not limiting, cutting production then can be increased by increasing the total number of these lateral shoots and/or by decreasing the time necessary for these lateral buds to begin active growth once the terminal bud is removed (4, 5).

Since both light quality and photoperiod are known to influence lateral branching, we wished to determine their effect on lateral branching and cutting production in several vegetatively propagated plant species used in commerce.

Materials and Methods

Experiment I. Terminal cuttings from *Alternanthra amoena, Coleus* X *hybridus, Hedera helix, Pelargonium* X *hortorum,*

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Peperomia obtusifolia, Pilea cadierei, and *P.* 'Moon Valley' plants which had been grown under normal day (ND) on the 45°N latitude (14) were rooted under mist in 10 cm pots filled with a mixture of 1 soil:1 peat:1 sand (by volume). Plants were placed under light treatments (Table 1) on the dates indicated in Table 2. *Alternanthra, Coleus,* and *Pelargonium* were grown in a glass greenhouse at 18°C day/16.5° night temperature regime. *Peperomia* and the 2 *Pilea* species were grown at 24°/20° under 66% saran.

Plants were irradiated with red (R) or incandescent (I) light. Cool White fluorescent (CWF) lamps (20W) were wrapped with 2 layers of red cellophane to obtain the R light (2.9 μ Wcm^{-2}, 650-700 nm; 0.6 μ Wcm^{-2}, 700-750 nm) and the I light was obtained from a 100 W bulb (303 μ Wcm^{-2}, 650-700 nm; 395 μ Wcm^{-2}, 700-750 nm).

Experiment II. Terminal cuttings of *Pilea involucrata* 'Panamegia', *P.* 'Moon Valley' and *H. helix* were taken from stock plants grown under ND and rooted under intermittent mist in 10 cm plastic pots filled with a mixture of 1 soil:1 peat:1 perlite (by volume). After rooting, plants were grown at a constant 21°C temperature regime under ND for 25 days and then placed into the respective treatments (Tables 1, 2). Plants were alternated between SD and ND or SD and the respective light treatments every 10, 20, or 30 days, e.g. 10 days SD, 10 days ND, 10 days SD, etc. Control plants were included under each treatment.

In Experiment II the R and FR light qualities were provided from experimental fluorescent tubes (Table 4) which were suspended 70 cm above the plants. Irradiance levels were 4.79 μ Wcm^{-2}, 650-700 nm; 0.94 μ Wcm^{-2}, 700-750 nm for the R light and 1.77 μ Wcm^{-2}, 650-700 nm; 8.38 μ Wcm^{-2}, 700-750 nm for the FR light.

With Experiment I and II all treatments (Table 1) were separated by black plastic partitions during irradiation; compartments were open topped. SD plants were covered with 4 mil black plastic.

In both experiments *Pilea* cuttings were harvested when there were 4 mature nodes on a cutting. *Hedera* cuttings were taken when there were 4 fully expanded leaves on a cutting. In all cases 2 nodes remained on the stock plants for future lateral branching. The number of commercially acceptable cuttings, flowering of stock plants, and at the conclusion of the experiment the number of all potential cuttings present or actively growing lateral buds were determined.

Culture was according to standard commercial practices and nutritional applications were based on weekly soil tests. For each species, there were 5 plants per treatment in a randomized complete block design with 2 blocks. Species were randomized within a treatment.

Table 1. Lighting treatments applied to plants during the experiments.

Treatment used during Expt.		Treatment	Description
I	II		
Yes	Yes	Normal day (ND)	Natural photoperiod conditions at 45°N latitude (14)
Yes	Yes	Short day (SD)	8 hr light (0800-1600); 16 hr dark
Yes	Yes	Day continuation (DC)	Lamps started 30 min prior to sunset and continued for 4 hr. Time adjusted every 15 days
Yes	Yes	Night interruption (NI)	Irradiated 2200 to 0200
Yes	No	Pre-dawn (PD)	Lamps started 3 hr 30 min prior to sunrise and continued 30 min after sunrise (total 4 hr). Time adjusted every 15 days
Yes	No	Day continuation and Pre-dawn (DC + PD)	Combination of DC and PD above (sum of 8 hr)

Results

Experiment I

Alternanthra amoena. Significantly more cuttings were produced under ND and the various light treatments than under SD (Table 3). No significant differences were observed among the light treatments except between the PD-I and DC-CWF treatments. The increase in number of cuttings produced under both ND and the light treatments was expected since these treatments were under longer irradiation spans than the SD treatment (Table 1).

Although data for each block are not presented in Table 3, significant differences existed between blocks. One block of plants was near the water cooled pad end of the house while the other was near the fans. A temperature differential of about 5°C existed between blocks when the cooling system was operating. Growth in the cooler block was slower and plants exhibited differences in leaf morphology (increased sulcation). Cutting production was reduced at the cooler temperatures by 29%.

Table 2. Treatment periods, normal daylengths during experimental treatments, and number of cutting flushes for each species in Experiment I and II.

Experiment	Species	Treatment period	Normal daylength (hr:min)[z]	No. of flushes
I	*Alternanthra amoena*	Aug. 23 to Dec. 23	13:43 to 8:46	4
	Coleus X hybridus	Dec. 1 to Mar. 22	9:02 to 12.15	8
	Hedera helix	Aug. 23 to Mar. 25	13:43 to 12:25	4
	Pelargonium X hortorum	Dec. 1 to May 5	9:02 to 14:26	5
	Peperomia obtusifolia	Aug. 23 to May 20	13:43 to 15:02	5
	Pilea cadierei	Aug. 23 to May 20	13:43 to 12:08	3
	Pilea 'Moon Valley'	Aug. 23 to May 11	13:43 to 14:41	4
II	*Hedera helix*	Nov. 5 to June 9	9:59 to 15:33	3
	Pilea 'Moon Valley'	Nov. 5 to June 9	9:59 to 15:33	4
	Pilea involucrata 'Panamegia'	Nov. 5 to June 9	9:59 to 15:33	5

[z]Shortest day of the year at 45°N latitude is 8 hr 46 min (14). St. Paul Campus of the University of Minnesota is on the 45°N parallel.

Table 3. Influence of light quality and time of lighting on cutting production and fresh weight per cutting.

Species	SD	ND	Photoperiod treatments[z] DC CWF[x]	DC I	NI CWF	NI I	PD CWF	PD I	DC+PD CWF	DC+PD I	HSD[y]
					No. of cuttings						
Alternanthra amoena	11.3	14.7	15.8	15.2	16.5	16.6	17.3	19.3	15.5	17.5	3.1
Coleus X hybridus	31.5	38.8	33.8	39.6	36.8	33.0	37.6	36.7	33.9	38.8	4.1
Hedera helix	9.6	11.6	12.7	13.8	11.5	10.8	12.1	12.0	11.2	14.4	2.0
Pelargonium X hortorum	8.1	10.4	7.7	8.8	8.2	9.2	8.3	8.8	9.2	8.3	1.1
Peperomia obtusifolia	6.7	8.2	9.0	9.2	7.6	6.7	8.4	9.8	8.4	9.0	1.5
Pilea cadierei	3.3	5.4	4.2	4.7	5.0	3.9	3.8	5.6	4.5	3.1	[w]
Pilea 'Moon Valley'	8.1	5.8	5.4	3.2	2.4	2.1	3.2	2.6	1.3	2.3	2.9
					Fresh wt/cutting (g)						
Alternanthra amoena	3.81	3.44	3.22	3.41	3.47	3.27	3.35	3.07	3.54	3.14	0.31
Coleus X hybridus	3.72	3.49	3.60	3.15	3.44	3.32	3.45	3.43	3.57	3.12	0.28
Hedera helix	2.56	2.83	2.64	2.68	3.06	3.81	2.72	2.91	2.34	2.45	.6
Pelargonium X hortorum	16.23	14.35	20.27	17.54	17.30	15.33	16.14	16.12	15.17	18.13	2.49
Peperomia obtusifolia	1.27	1.03	.98	1.02	.99	1.18	1.04	.94	1.00	.99	.15
Pilea cadierei	5.89	5.08	5.41	5.33	5.92	5.31	5.49	4.94	5.74	6.98	[w]
Pilea 'Moon Valley'	9.39	8.15	10.41	6.37	2.40	9.35	2.83	6.10	0	7.08	4.84

[z]SD = short days (1600 to 0800 dark); ND = normal days (see Table I); DC = day continuation begins 30 min prior to sunset and continues for 4 hr; NI = night interruption (2200-0200 hr); PD = pre-dawn begins 3.5 hr prior to sunrise and continues for 30 min after sunrise; DC+PD – Day continuation and pre-dawn = combination of both previously described treatments. All clocks adjusted bi-monthly.

[y]Differences between 2 means must be greater than amount indicated in column to be different at P = 5%.

[x]CWF = Cool White fluorescent tubes wrapped with 2 layers of red cellophane (2.9 μ Wcm^{-2} 650-700 nm, 0.6 μ Wcm^{-2} 700-750 nm), I = incandescent bulb (303 μ Wcm^{-2} 650-700 nm, 395 μ Wcm^{-2} 700-750 nm).

[w]HSD not presented due to unequal sample size.

Although the number of cuttings were significantly less under SD, the fresh weight per cutting (FW) was significantly greater than all light treatments except DC + PD – CWF. Thus, SD may be influencing FW accumulation in cuttings.

Coleus X hybridus. Coleus plants grown under SD produced fewer cuttings than the other treatments (Table 3). Plants maintained under the DC–I and DC + PD – I light treatments produced significantly more cuttings than the R irradiated counterparts. However, FW of the I-irradiated cuttings was significantly less than the CWF irradiated or SD cuttings.

Hedera helix. Plants grown under DC, PD, and DC + PD light treatments produced significantly more cuttings than plants grown under SD (Table 3). The inverse relationship between low cutting production and high FW is again observed on cuttings from NI treated plants.

Pelargonium X hortorum. Normal day plants produced significantly more cuttings than SD or any light treatment (Table 3). The greatest FW was observed in the DC–CWF treatment, which also had the lowest number of cuttings, while the lowest FW was observed under ND treatment which had the grestest number of cuttings.

Peperomia obtusifolia. The same trends for number of cuttings observed with *H. helix* were also observed here (Table 3). Plants irradiated with the DC, PD, or DC + PD treatments produced more cuttings than SD. The lighted treatments were not different from the ND treatment. The FW was greater for the SD treated cuttings than for the light treatments or ND. This is the same type of response observed with *A. amoena* and *C. blumei.* Differences between light treatments and ND were non-significant except for NI–I.

Pilea cadierei. No differences in number of cuttings of FW were observed between treatments (Table 3).

Pilea 'Moon Valley'. Except for DC–CWF, all light treatments resulted in significantly fewer cuttings than SD and significantly fewer cuttings than ND (Table 3). Time of lighting influenced FW; cuttings which were irradiated with NI, PD or DC + PD weighed less than SD or DC treated cuttings.

Experiment II

Hedera helix. Lighting treatment did not influence the number of cuttings except when grown under the NI–FR treatment (Table 4). Only when plants were moved every 30 days between SD and the respective light treatments were differences observed. Plants cycled every 10 or 20 days were similar to SD treated plants.

Pilea 'Moon Valley'. Plants continuously irradiated by NI or DC–FR treatments produced fewer cuttings than SD or ND (Table 4). These results are similar to results in Experiment I (Table 3). Cutting production increased when plants were moved every 10 days between SD and NI when compared to plants under the various continuous NI treatments. Twenty-day cycles were required with the various DC light treatments before increases in cutting production were obtained when compared to the continuous or 10 day cycle of DC–R or DC–FR. Increases occurred in the ND cycles only after 30 days of SD had been given and then moved back to ND. In all irradiation treatments, the maximum number of cuttings were produced under the 20-day SD light cycles with a decrease in cutting production under the 30-day SD light cycles. Thus with 'Moon Valley' the optimum number of SD prior to a light treatment to promote lateral bud activity was 20 days. This suggests the maximum number of cuttings were obtained when plants were maintained at this critical number of long day cycles.

Additional support for 20-day cycles comes from the flowering data (Table 4). Plants maintained continuously under light treatments produced many flower clusters. *Pilea* 'Moon Valley' can be considered a long day plant for flowering. When plants are cycled between SD and light treatments every 10, 20 or 30 days a good correlation (P = 1%) with number of flower

Table 4. Influence of photoperiod, light quality, and short day-photoperiod rotations on *Hedera helix*, *Pilea* 'Moon Valley' and *Pilea involucrata* 'Panamegia' cutting production and flowering.

	Photoperiod treatments[z]																				
						Day continuation								Night interruption							
			ND			Red[y]				Far red[y]				Red				Far red			
Species	SD	0[w]	10	20	30	0	10	20	30	-0	10	20	30	0	10	20	30	0	10	20	30	HSD[w]
										No. of cuttings											
Hedera helix	8.9	8.9	8.4	7.3	11.5	9.5	8.8	9.4	10.9	9.6	6.7	9.9	11.9	7.6	10.3	7.9	9.1	11.0	7.8	7.9	11.6	1.6
Pilea 'Moon Valley'	10.9	9.5	8.5	11.0	12.6	8.6	8.0	13.1	9.7	5.7	6.6	11.2	9.8	3.2	8.3	9.6	8.8	5.4	8.8	10.7	9.6	2.5
Pilea involucrata 'Panamegia'	39.9	52.5	35.8	62.6	33.5	61.2	41.8	74.1	37.8	42.6	33.1	59.1	29.8	46.1	35.8	61.4	38.8	43.0	28.9	44.5	31.7	13.4
										Flower production											
Pilea 'Moon Valley'	0	7.7	0	1.1	4.2	8.8	0	0.7	1.4	9.2	0	3.8	3.5	8.0	0	0.2	2.2	11.5	0	0.6	2.9	3.8
Pilea involucrata 'Panamegia'	–[v]	+	–	+	+	+	–	+	+	+	–	+	+	+	–	+	+	+	–	+	+	

[z]SD = short days (1600 to 0800 shade); ND = normal day (Oct. 21) to July 6. Daylength varied from 10 hr 43 min to 8 hr 47 min to 16 hr 38 min to 15 hr 29 mn); DC = day continuation (lamps started 30 min prior to sunset and continued for 4 hr. Time adjusted every 15 days.); NI = night interruption (Irradiated 2200 to 0200). (14)

[y]Red (4.79 μ Wcm^{-2} 650-700 nm, 0.94 μ Wcm^{-2} 700-750 nm); far red (1.77 μ Wcm^{-2} 650-700 nm, 8.38 μ Wcm^{-2} 700-750 nm). Experimental fluorescent tubes furnished by GTE Sylvania, 60 Boston Street, Salem, MA 01970.

[x]No. of days rotated between SD and respective photoperiod treatments.

[w]Differences between 2 means must be greater than amount indicated in column to be different at P = 5%.

[v]No flowers present (–), numerous flowers present (+).

clusters produced was observed. Thus, the more time under a long day light treatment, the greater the number of flowers.

Pilea involucrata 'Panamegia'. When cutting production is compared to SD, the continuous DC–R treated plants produced a greater number of cuttings, while plants under the other continuous light treatments were similar to SD (Table 4). A greater number of cuttings were produced when plants were cycled every 20 days between SD and the photoperiod treatments, compared to SD or the non-cycled controls. The same trend was observed in *P.* 'Moon Valley'.

The flowering response for *Pilea involucrata* 'Panamegia' was similar to *P.* 'Moon Valley' data in that SD or 10 day cycles of SD and lighting inhibited flowering while 20 or 30 days of a light treatment were adequate to promote flowering of this long day plant.

Discussion

Historically, photoperiod and light quality work has been concerned primarily with the flowering response while overlooking the effect of photoperiod and light quality on lateral branching (2, 15). A few laboratories have been concerned with light quality and branching (4, 8, 10, 12). These data demonstrate the influence of photoperiod and light quality on lateral branching in understory and open habitat plant species.

A branching response to a high R to FR light ratio (normal sunlight) would be advantageous to plant species which grow in open habitats with little leaf canopy shading and consequently little leaf filtering out of the red light. However, under a high FR to R ration light regime (6, 8) lateral branching probably would be of little value to the plant whereas diversion of metabolites into stem elongation might be advantageous so that the stem would elongate into full sunlight (5, 7). However, plants normally growing in native understory environment may not respond to changes in the R to FR light ratio because diversion of metabolites into stem elongation would not increase the probability of that stem receiving more light.

The majority of the species used in these experiments came from typically understory environments (4, 13; P. A. Hyypio, personal communication); thus we would not expect to observe differences due to light quality. The differences that were observed fall into 3 responses: a response to end of day length (twilight), a difference in cutting FW in response of time of irradiance, and in Experiment II, a photoperiod cycling response between SD and the various light treatments. A dusk or dawn twilight effect (6, 8) is observed in *P. obtusifolia*, and womewhat in *H. helix*, where plants irradiated as a DC, PD, or DC + PD respond similar to ND, whereas NI responds similar to SD. This suggests that the lateral branching mechanism can be stimulated by light at twilight periods but not in the middle of the night. This is entirely different from other published work that showed that the DC and NI (4), or a DC (11) were most effective in promoting lateral branching. This discrepancy can be explained by the plant materials used. When DC or NI treatments were most effective, it appears that open habitat plants (chrysanthemum or tomato) were used, whereas in this experiment understory plants were used. The results presented here add further support to Holmes and Smith's (6) hypothesis that daily shifts in light quality during the twilight period could be involved in photoperiodic timing.

Several workers (1, 9) have reported on differences in FW in response to time of irradiance. Work by Heins et al. (5) observed increased lateral branching of *Dianthus caroyphyllus* under SD treatments and decreased branching under NI. The same results are observed in *P.* 'Moon Valley'. In *D. caryophyllus*, carnation, Heins et al. (5) found that SD promoted lateral branching by inhibiting flowering. In these experiments on *P.* 'Moon Valley', a similar response is observed (Table 4). *A. amoena, C. blumei, H. helix*, and *P. obtusifolia* exhibited the opposite response to SD (Table 3). Light treatments promoted lateral branching and SD inhibited branching. This response could either be photoperiodic or photosynthetic. In addition, these plants remained vegetative and did not flower. It is interesting to note that some treatments with low SD cutting production also have significantly higher FW per cutting produced under the SD treatments. However, if one were to total the

FW data of cuttings from all the plant species grown under SD the FW was less than from plants under the light treatments (Table 3).

The growth response to the alternation of SD and photoperiod treatments on a 10, 20 or 30 day basis as observed in Experiment II can be compared to work on the number of cycles needed to induce flowering under SD (Table 4). This was observed in *Glycine max* (15). We propose that there exists a critical number of light cycles (CNLC) for both flower promotion and lateral branching. In the case of *Pilea* it appears that the CNLC for branching is shorter than the CNLC for flower induction. The CNLC necessary for branching can easily be overlooked, since most CNLC studies to date have dealt with flowering (15). Also for many species used in these experiments (i.e. *Pilea,* Table 4) the photoperiod that promotes flowering is the opposite of that which promotes vegetative or lateral growth. Thus, additional work needs to be done to determine that CNLC needed for branching in many horticulturally important species.

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