Supplementary Lighting to Stock Plants and Cuttings of *Kalanchoe blossfeldiana* v. Poelln.

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Stock plants and cuttings of *Kalanchoe blossfeldiana* 'Goldstrike' and 'Charme' were subjected to different levels of supplementary lighting during cultivation in a greenhouse at low levels of natural light. The effects on yield and quality of cuttings, and on rooting and growth of the cuttings were studied. Based on increases in number of cuttings, fresh weight, dry weight, and dry matter content of the cuttings, a doubling of the supplementary light level to the stock plants from 73 to 146 μmol m^{-2} s^{-1} was beneficial. The formation of roots in the cuttings was delayed by a doubling of the supplementary light level to the stock plants, while growth increment of the cuttings was unaffected by this treatment. Increasing levels of supplementary lighting during propagation strongly promoted rooting, growth increment, and quality of the cuttings, irrespective of stock plant lighting. The growth performance of the cuttings was modified by natural light conditions during propagation. From a practical viewpoint, these results indicate that 30% to 50% more cuttings could be harvested from stock plants of *K. blossfeldiana* by a doubling of the currently used level of supplementary lighting during cultivation. Subsequent growth of the cuttings is mainly influenced by the level of supplementary lighting during propagation.

INTRODUCTION

The production of *Kalanchoe blossfeldiana* in Norway is scheduled on a year-round basis. Under low natural light conditions during late autumn and winter (Oct. to March), production of cuttings and subsequent rooting and growth of the plants rely on use of supplementary lighting. Many growers use high pressure sodium vapor (HPS) lamps to provide additional lighting of stock plants and rooted cuttings for 20 h day^{-1} with a photosynthetic photon flux (PPF) of 60 to 70 μmol m^{-2} s^{-1} at plant level. Previous studies have shown that pot plants can utilize much higher levels of supplementary lighting during winter, especially with respect to cutting yield of stock plants, rooting ability, and growth rate of cuttings (Moe, 1977; Borowski et al., 1981). The objective of the present experiment was therefore to determine if a doubling of the currently used level of supplementary lighting could increase productivity of *K. blossfeldiana* stock plants in northern latitudes during winter, and to study possible after-effects of stock plant lighting on subsequent rooting and growth of the cuttings. Interactions of different levels of supplementary lighting to stock plants and cuttings were also studied.

MATERIALS AND METHODS

Stock Plants. Rooted cuttings of *K. blossfeldiana* 'Goldstrike' and 'Charme' were obtained from a local grower and potted in fertilized peat in 12-cm pots on 13 Sept.

The plants were placed in a growth room maintained at 20C with 73 μmol m^{-2} s^{-1} supplementary lighting provided by HPS lamps for 20 h day^{-1}. On 6 Oct. the plants were pinched and placed in greenhouse compartments maintained at 22C with 73 or 146 μmol m^{-2} s^{-1} supplementary lighting provided by HPS lamps for 20 h day^{-1}. Number of plants per light level was 36. The plants were subjected to ebb-and-flood irrigation with a growers' standard nutrient solution (EC = 1.5 mS cm^{-1}) when considered necessary. Relative air humidity (RH) was not controlled, and varied between 40% and 80%. The PPF levels were measured during night at plant level by means of a Lambda LI-185B instrument with quantum sensor (400 to 700 nm).

Terminal cuttings were harvested weekly from 13 Oct. until 22 Feb. (19 weeks). Number of cuttings per plant and fresh weight of cuttings were recorded at each harvest. Fresh and dry weight of samples of 10 cuttings from each stockplant treatment were recorded at 10 harvests evenly distributed throughout the harvesting period. Dry matter content of the cuttings was determined after drying at 80C until constant weight.

Cuttings. Rooting and growth increments of cuttings from the two stock plant treatments were investigated on cuttings harvested 18 Nov., 1 Dec., and 11 Jan. At each harvest 10 cuttings from each treatment were randomly selected, weighed, and inserted in 5 cm × 5 cm plastic plugs containing perlite saturated with a growers' standard nutrient solution with an EC of 1.5 mS cm^{-1}. A second group of 10 cuttings was randomly selected, weighed, and inserted in 5 cm × 5 cm plastic plugs containing fertilized peat. The cuttings were placed in a greenhouse compartment maintained at 22C with 36, 73, or 146 μmol m^{-2} s^{-1} supplementary lighting provided by HPS lamps for 20 h day^{-1}. Relative humidity was not controlled, and the cuttings were covered with two layers of a white polyethylene sheet (Agryl) the first week after insertion in order to reduce transpiration. The cuttings were watered daily with the aforementioned nutrient solution.

After 14 days number of roots per cutting and length of the longest root were recorded on cuttings rooted in perlite. After 35 days number of lateral shoots and fresh and dry weight of the cuttings rooted and grown in peat were recorded. Percentage increase in fresh weight and dry weight was calculated, and dry matter content was determined as aforementioned. The three harvests were treated as replicates in a general linear models procedure analysis of variance of rooting and growth parameters. Details of light conditions during the experimental periods are shown in Table 1.

RESULTS

Stock Plant Production and Quality of Cuttings. Average cutting yield per plant per week increased from 3.1 to 4.6 (48%) in 'Goldstrike' and from 5.0 to 6.7 (34%) in 'Charme' when the supplementary light level increased from 73 to 146 μmol m^{-2} s^{-1} (Table 2). The mean fresh weight of the cuttings increased from 3.2 to 3.5 g (9%) in 'Goldstrike' and from 2.6 to 2.9 g (12%) in 'Charme' by doubling the supplementary light level. A doubling of the supplementary light level increased mean dry matter content of the cuttings from 6.1 to 7.2% (18%) in 'Goldstrike' and from 5.4 to 6.7% (24%) in 'Charme'. Mean dry weight per cutting at the weekly cutting harvest increased from 60.5 to 115.9 mg (92%) in 'Goldstrike' and from 70.2 to 130.2 mg (85%) in 'Charme'

Table 1. Light integrals in mol m^{-2} day^{-1} at plant level during experiments with supplementary lighting of *Kalanchoe blossfeldiana* stock plants and cuttings.

Production stage		Period	Natural light	Supplementary light 36	Supplementary light 73	Supplementary light 146
				Light integrals from natural + supplementary light		
Stock plant cultivation:		06.10.-22.02.[Z]	1.9	-	7.2	12.4
Cuttings:						
Rooting	1	18.11.-01.12.	0.9	3.5	6.2	11.4
	2	01.12.-14.12.	0.8	3.4	6.1	11.3
	3	11.01.-24.01.	1.0	3.6	6.3	11.5
Growth	*1*	*18.11.-22.12.*	*0.9*	*3.5*	6.2	*11.4*
	2	01.12.-04.01.	0.9	3.5	6.2	11.4
	3	11.01.-14.02.	2.2	4.8	7.5	12.7

[Z]06.10-22.02 = 6 October to 22 February

Table 2. Effects of doubling the supplementary light level to stock plants of *Kalanchoe blossfeldiana* 'Goldstrike' and 'Charme' on cutting yield, fresh weight, dry matter content, and dry weight of cuttings harvested for a period of 19 weeks. Values for cutting parameters represent means ± SE (n = 10).

Supplemental light level ($\mu mol\ m^{-2}\ s^{-1}$)	Mean number of cuttings harvested per plant per week	Mean fresh weight of cuttings (g)	Mean dry matter content of cuttings (%)	Mean dry weight of weekly cutting harvest (mg)
'Goldstrike'				
73	3.1	3.2±0.2	6.1±0.3	60.5±4.0
146	4.6	3.5±0.3	7.2±0.5	115.9±10.6
'Charme'				
73	5.0	2.6±0.2	5.4±0.5	70.2±5.9
146	6.7	2.9±0.3	6.7±0.7	130.2±14.9

After-effects on Cuttings. Number of roots per cutting after 14 days was unaffected by the level of supplementary light provided to stock plants of 'Goldstrike', while in 'Charme' it decreased when the supplementary light level to the stock plants increased from 73 to 146 µmol m^{-2} s^{-1} (Table 3). In both cultivars length of the longest root decreased by a doubling of the supplementary light level. No after-effects of supplementary light to the stock plants or interactions of stock plant and light treatment of cuttings on growth increment of cuttings were detected.

Cutting Treatment. Increasing the level of supplementary lighting from 36 to 73 µmol m^{-2} s^{-1} and further up to 146 µmol m^{-2} s^{-1} significantly increased number of roots per cutting and length of the longest root in 'Goldstrike' (Table 4). In 'Charme' number of roots per cutting and length of the longest root increased when the supplementary light level increased from 73 to 146 µmol m^{-2} s^{-1}.

Increasing the level of supplementary lighting from 36 to 73 µmol m^{-2} s^{-1} and further up to 146 µmol m^{-2} s^{-1} significantly increased fresh and dry weight increment, dry matter content, and number of lateral shoots per cutting in both cultivars after 35 days (Table 5).

In both cultivars fresh weight increase and number of lateral shoots after a growth period of 35 days were greater in cuttings from the third harvest compared with cuttings from the two first harvests (Table 6). A similar pattern was observed for dry weight increment in cuttings from 'Goldstrike'. In 'Charme', dry weight increment of the cuttings differed between all harvests. Lower dry matter content of cuttings from the third harvest compared with cuttings from the two first harvests was measured in both cultivars.

DISCUSSION

The production of cuttings by stock plants of *K. blossfeldiana* 'Goldstrike' and 'Charme' cultivated under low natural light conditions was strongly enhanced when the supplementary light level was increased from 73 to 146 µmol m^{-2} s^{-1} (Table 2). The magnitude of this response was in agreement with results from previous experiments which showed increasing yield of cuttings from stock plants of the same cultivars of *K. blossfeldiana* at supplementary light levels up to 183 µmol m^{-2} s^{-1} during autumn and winter (Willumsen and Rogstad, 1995). Increase in cutting yield due to supplementary lighting has also been reported for stock plants of other cultivars of *K. blossfeldiana* at increasing, but much lower levels of supplementary lighting (Nielsen et al., 1984; Andersson and Amsen, 1985). A higher yield of cuttings of approximately equal size and fresh weight per cutting obtained by weekly harvests, indicate that a main effect of the doubling of the supplementary light level in the present experiment could be attributed to a faster growth rate and/or better lateral branching of the stock plants as earlier found in *Begonia* (Bertram et al., 1989) and *Campanula* (Moe, 1977) at increasing levels of supplementary lighting.

In addition to increasing cutting yield, the doubling of the supplementary light level also improved dry matter content of the cuttings (Table 2). This is a common response of stock plants subjected to supplementary lighting, and is often used as an index of cutting quality (Molitor and von Hentig, 1987). Further, the increase in dry weight per cutting was nearly proportional to the increase of supplementary light level (Table 2). This response is in agreement with the findings of Mortensen (1983) which did not indicate any signs of light saturation of photosynthesis and dry matter accumulation in *K. blossfeldiana* plants at total PPFs below 350 µmol m^{-2} s^{-1}.

Table 3. Main effects of doubling the supplementary light level to stock plants of *Kalanchoe blossfeldiana* on rooting of the cuttings after 14 days. Values represent means of 3 supplementary light levels to the cuttings.

Supplemental light level ($\mu mol\ m^{-2}\ s^{-1}$)	'Goldstrike' Number of roots per cutting	'Goldstrike' Longest root (mm)	'Charme' Number of roots per cutting	'Charme' Longest root (mm)
73	48.5	17.1	18.3	6.4
146	47.8	14.5	12.6	5.1
Significance	ns	$P<0.01$	$P<0.001$	$P<0.01$

Table 4. Main effects of supplementary lighting to cuttings of *Kalanchoe blossfeldiana* on rooting of cuttings after 14 days. Values represent means of 2 supplementary light levels to the stock plants. Mean separation in columns by Duncan's multiple range test, $P\leq0.05$.

Supplemental light level ($\mu mol\ m^{-2}\ s^{-1}$)	'Goldstrike' Number of roots per cutting	'Goldstrike' Longest root (mm)	'Charme' Number of roots per cutting	'Charme' Longest root (mm)
36	40.1c	13.9c	14.1b	5.0b
73	46.4b	15.1b	14.8b	5.6b
146	58.1a	17.4a	18.6a	6.8a

Except for number of roots per cutting in 'Goldstrike', a doubling of the supplementary light level to the stock plants decreased root formation and appearance of the roots after 14 days, irrespective of supplementary light levels supplied to the cuttings (Table 3). These results demonstrate that root formation in cuttings of *K. blossfeldiana* is influenced by the light conditions during the growth of the stock plants, and that an optimal response with respect to rooting performance of the cuttings, is achieved at low or moderate levels of total PPF as observed in most other plant species (Hansen, 1987). The present results also show that increasing level of supplementary lighting provided during rooting strongly promotes rooting performance, irrespective of supplementary light level provided to the stock plants (Table 4). A similar response to increasing levels of supplementary lighting was obtained with respect to growth increments on a fresh and dry weight basis, and on quality of the rooted cuttings with respect to dry matter content and number of lateral shoots after 35 days (Table 5). The strong enhancement of fresh and dry weight gain and improved lateral branching in cuttings propagated after the third harvest compared with the two first harvests (Table 6) most probably is a result of increased total PPF during late February and March. A similar deviation in rooting pattern between harvests as a result of increasing natural light levels was reported in *Begonia* by Bertram et al. (1989). The fact that no beneficial after-effects of a doubling of the supplementary light level to the stock plants on growth increment of the cuttings were observed, further suggests that subsequent rooting and growth of the cuttings is less influenced by stock plant lighting when propagation takes place under supplementary lighting. It has, however, to be kept in mind that the cuttings in the present experiment were shaded during the first week of rooting. This treatment may have influenced root initiation. However, the generalized response curves of irradiance to stock plants and cuttings on rooting proposed by Moe and Andersen (1988), which suggest lower light levels to cuttings than to stock plants during propagation, does not seem to be valid for *K. blossfeldiana*.

Table 5. Main effects of supplementary lighting to cuttings of *Kalanchoe blossfeldiana* 'Goldstrike' and 'Charme' on growth of cuttings after 35 days. Values represent means of 2 supplementary light levels to the stock plants.

Supplemental light level ($\mu mol\ m^{-2}\ s^{-1}$)	Fresh weight increase (%)	Dry weight increase (%)	Dry matter content (%)	Number of lateral shoots per cutting
		'Goldstrike'		
36	208	201	6.4	4.4
73	228	249	6.9	5.2
146	319	397	7.6	6.2
Significance	P<0.001	P<0.001	P<0.001	P<0.001
		'Charme'		
36	175	184	5.6	4.6
73	221	279	6.9	5.2
146	245	379	7.6	7.0
Significance	P<0.001	P<0.001	P<0.001	P<0.001

Table 6. Main effects of harvest date of *Kalanchoe blossfeldiana* 'Goldstrike' on growth of cuttings after 35 days. Values represent means of two supplementary light levels to the stock plants, and three supplementary light levels to cuttings. Mean separation in columns by Duncan's multiple range test, $P \leq 0.05$.

Harvest date	Fresh weight increase (%)	Dry weight increase (%)	Dry matter content (%)	Number of lateral shoots per cutting
'Goldstrike'				
18.11.	183b	240b	7.8a	4.8b
01.12.	180b	227b	7.6a	4.7b
11.01.	393a	373a	5.5b	6.3a
'Charme'				
18.11.	159b	218c	7.8a	4.0b
01.12.	154b	278b	7.6a	4.2b
11.01.	340a	346a	5.5b	7.9a

In conclusion, the present observations suggest a maximal response of photosynthesis and growth of the stock plants by doubling the currently used supplementary light level, and make it clear that a supplementary light level of 146 $\mu mol\ m^{-2}\ s^{-1}$ will improve both quality and growth of cuttings harvested from *K. blossfeldiana* stock plants during late autumn and winter in northern latitudes.

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