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Effects of Photoperiod and Daily Light Integral on Rooting, Subsequent Growth, Flowering and Yield of Flowering Stems in *Gypsophila paniculata* L. 'Perfecta'.

Die Wirkungen von Photoperiode und Tageslichtsumme auf Bewurzelung und nachfolgendes Wachstum, Blütenbildung und Blütenstielertrag von *Gypsophila paniculata* 'Perfecta'.

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Summary

The effects of different light conditions on rooting and on subsequent growth and yield of flowering stems in *Gypsophila paniculata* 'Perfecta' grown in greenhouse were studied. Cuttings rooted in long day (LD) at high daily light integral (HLI-LD) rooted faster than the cuttings rooted in LD at low daily light integral (LLI-LD). Cuttings rooted in short day (SD) at low daily light integral (LLI-SD) rooted at a similar speed as those in LLI-LD. The fresh and dry weight of the aboveground part of the cuttings did not increase during first two weeks. After 4 weeks, when more than 90 % of the cuttings in all treatments were well rooted, the mean fresh and dry weight of rooted cuttings under HLI-condition had increased by nearly 100 % and 75 % respectively compared to initial weight, while cuttings from the two LLI-treatments showed only about 40 % and 25 % increase of fresh and dry weight respectively. Nearly doubling the DLI during rooting promoted the rate of development until the visible bud stage in LD, but this effect diminished in the plants given a period of SD after transplanting. Giving a SD-treatment after rooting prolonged the time to visible bud and the first open flower by 12-14 days, but significantly increased the leaf numbers, and number of flowering shoots in the plants compared to the plants grown under continuous HLI-LD. Photoperiod during rooting period did not influence the time to flower, length of the main stem, or yield of flowering shoots.

Zusammenfassung

Die Wirkungen verschiedener Lichtbedingungen auf Bewurzelung und nachfolgendes Wachstum, Blütenbildung und Blütenstielertrag von *Gypsophila paniculata* 'Perfecta' wurden geprüft. Die Bewurzelung der Stecklinge nahm mit Erhöhung der Lichtsumme zu, wurde aber nicht von der Photoperiode beeinflußt. Während der ersten zwei Wochen gab es keine Zunahme bei der Frisch- und Trockenmasse der Stecklinge. Nach vier Wochen hatten die Stecklinge zu 90 % Wurzeln gebildet und die Entwicklung der oberirdischen Biomasse zeigte deutliche Unterschiede, die auf den wachstumfördernden Effekt der Erhöhung der Lichtsumme hinweist. Eine Erhöhung der Lichtsumme bei der Bewurzelung verkürzt außerdem die Zeitspanne bis zur Bildung der ersten Knospen unter den nachfolgenden Langtagbedingungen. Die Erntereife der Blütenstiele wurde dagegen nicht von der Lichtsumme bei der Bewurzelung beschleunigt. Die Photoperiode bei der Bewurzelung hatte keinen Einfluß auf die Kulturzeit, das Längenwachstum und den Ertrag. Eine Kurztagperiode nach der Bewurzelung führte zu einer Verlängerung der Kulturzeit und zu einem gesteigerten Ertrag an Blütenstielen.

Introduction

Gypsophila paniculata is grown year round as a protected crop in northern regions (HICKLENTON 1986). In Norway, winter flowering under limiting light conditions is obtained by supplementing natural light with artificial light at photosynthetic photon flux (PPF) levels of 120 to 150 $\mu mol\, m^{-2} s^{-1}$ by high pressure sodium lamps (HPS) for 18-20 $h\, day^{-1}$ from transplant to harvest (WILLUMSEN 1994). The starting material for flower production is rooted cuttings produced in countries at southern latitudes. However, due to quality problems caused by a long transportation period, some growers may want to propagate non-licensed cultivars by themselves or buy rooted cuttings from local suppliers. Vegetative propagation can be done by plantlets from tissue culture or by traditional harvest of cuttings from stock plants. The latter technique is still preferred for the majority of commercial production.

G. paniculata has been classified as a long day plant (RAMALEY 1931), but there appear to be no published reports that focus on the effect of photoperiod and light level during rooting of the cuttings. The rooting capacity of *G. paniculata* cuttings varies with maturity and time of year (SHIN et al. 1988), and cuttings have to be harvested from stock plants before flower initiation begins (RAULSTON et al. 1972). Stock plants are therefore maintained at high natural light intensities under natural SD-conditions at southern latitudes. Difficulties in rooting of cuttings under low light conditions and short natural daylengths during wintertime are likely to occur at northern latitudes. If the use of supplementary light has to be limited to the light period under SD, the light-use efficiency will be low, and high

levels of supplementary light may impose water stress in the cuttings. Further, if current photosynthesis and/or long photoperiod are beneficial for root formation, it may be more favourable to increase the daylength than to increase the light intensity in SD. However, as stock plant shoots with 12 initiated leaves have passed the juvenile phase (KUSEY et al. 1981), cuttings of commercial size are induceable. LD-conditions and/or high light levels may therefore induce flowering in the main shoot of the cuttings before a rosette of lateral shoots has been formed, and thus reduce the number of lateral flowering shoots of sufficient length that can be harvested as separate stems from the plants.

The main objective of this study was to clarify the effects of photoperiod and two levels of daily light integral (DLI) in LD on rooting performance and growth of the cuttings, and on subsequent growth, flower development, and yield of flowering shoots of *G. paniculata* plants. In addition, we attempted to determine the effects of inserting a SD-treatment after rooting on the same parameters.

Materials and Methods

The experiment was carried out at Aas in Norway (59,5° 56'N) from December to March. Rooting, growth and daylength treatment of the plants was carried out in computer-controlled acrylic greenhouse compartments. Flower development took place in a phytotron.

Terminal cuttings of commercial size (5–7 cm) were harvested from stock plants of cv. Perfecta that had been grown for 4 months (Sept.–Dec.) in the greenhouse at 22 ± 1.0 °C day and night temperature with 146 µmol m^{-2} s^{-1} supplementary lighting from high pressure sodium lamps (HPS) for 10 h day^{-1}, and at 600-800 vpm CO_2 partial pressure. The cuttings were stored at 5 ± 1 °C for 24 hours before the experiment started.

From a batch of 600 harvested cuttings, 30 were randomly selected and examined under a light microscope to check the developmental stage of the cuttings. According to the classification of DOI et al. (1990), they were all in the vegetative stage. The initial mean fresh and dry weight of the cuttings was determined on a second random sample of 30 cuttings. The basal end of the remaining 540 cuttings were dipped into IBA (indolebutyric acid) powder and inserted into Jiffy-7 pots. A randomized block design with two replications of 90 cuttings per treatment was established by dividing the cuttings into two groups of 270 cuttings each, and transferring them into two different greenhouse compartments. Three different light regimes were established in each compartment:

– HLI-LD: Natural light + 146 µmol m^{-2} s^{-1} supplementary light (HPS) for 20 h day^{-1}.
– LLI-SD: Natural light + 146 µmol m^{-2} s^{-1} supplementary light (HPS) for 10 h day^{-1}.
– LLI-LD: Natural light + 146 µmol m^{-2} s^{-1} supplementary light (HPS) for 10 h day^{-1} + 1.3 µmol m^{-2} s^{-1} day extension for 10 h day^{-1} by incandescent lamps.

The pots were placed on capillary mats on greenhouse benches. The cuttings in the HLI-LD treatment received a dark period from 22.00 to 02.00 each night. The 10-h photoperiod in LLI-SD was established daily by creating a tent of black plastic sheet over the plants from 18.00 to 08.00. The 20-h photoperiod in LLI-LD was established by combining a similar 10-h photoperiod with 1.3 µmol m^{-2} s^{-1} incandescent lighting on the plants from 18.00 to 04.00 under the plastic sheet.

Irradiation was measured with a Lambda LI-Cor instrument Model 1-185B. The cuttings were rooted at a constant temperature of 22 ± 2.0 °C at 600–800 vpm CO_2 partial pressure. Relative humidity varied between 70 and 80 %. The mean natural DLI at cuttings level during the rooting period was calculated to be 1.4 mol m^{-2} d^{-1} for all treatments, based on outside measurement of PPF with 50 % reduction due to shading by the greenhouse construction.

During the first week of rooting, pots were irrigated daily to runoff with tap water. The rest of the rooting period, and further throughout the experimental period, the pots were irrigated daily with a complete nutrient solution containing 14.3: 1.0: 5.1 mM N: P: K and a complete mixture of microelements. The electrical conductivity of the solution was 1.5 mS cm^{-1}, and pH was 5.0–5.5.

The percentage of rooted cuttings in each treatment was determined by counting the number of cuttings of the initial 90 that had visible roots on the Jiffy-7 pots after 1 and 2 weeks, and of 60 cuttings after 3 and 4 weeks. Thirty cuttings from each treatment were destructively sampled after 2 and 4 weeks to determine fresh and dry weights of the cuttings. All dry weights were recorded after drying the cuttings in an oven at 80 °C for one week.

After the rooting period of 4 weeks, the remaining 30 cuttings from each treatment were planted in 12-cm plastic pots, using fertilized and limed peat moss as growing medium. One half of the plants (15) from each treatment were then grown for three weeks under the LLI-SD conditions, and the second half for three weeks under the HLI-LD conditions. Five replicate plants from each combination of cutting treatment and post rooting daylength were then transplanted in 22-l plastic pots and transferred to a phytotron where they were grown at 20 ± 1 °C, 70–75 % RH and under HLI-LD conditions until harvest. During the growing period, number of days from transplanting until visible bud (> 5 mM) and anthesis (first open flower) were recorded. At harvest, the number of nodes below the first open flower, main stem length, and number of lateral generative shoots longer than 50 cm were recorded.

One-way analysis of variance was carried out using Minitab ver. 6.0, and Tuckey's test was used for statistical comparisons among the treatments. Values for rooting and growth parameters are means of two replications, each of 90 (2 weeks), 60 (3 weeks) or 30 (4 weeks) cuttings per treatment, while values for flowering parameters are means of 5 replicate plants.

Results

Cuttings of *G. paniculata* kept in HLI-LD rooted faster than the cuttings kept in LLI-LD or in LLI-SD (Table 1). Rooting percentage of the cuttings from the HLI-treatment was more than double after 2 weeks and significantly higher after 3 and 4 weeks compared to the cuttings from the two LLI-treatments, but the difference was reduced after 3 and 4 weeks. Cuttings kept in LD or

Table 1. Percentage of *G. paniculata* 'Perfecta' cuttings with visible roots on the outside of the rooting medium (Jiffy-7) after rooting for 2, 3 and 4 weeks under three different light regimes.
Prozentualer Anteil bewurzelter Stecklinge von G. paniculata 'Perfecta' nach zwei, drei und vier Wochen bei drei verschiedenen Lichtbedingungen.

	Percent rooting		
Light regime	2 weeks	3 weeks	4 weeks
HLI-LD	34a	94a	99a
LLI-SD	12b	76b	93b
LLI-LD	13b	74b	93b

HLI-LD: Natural light + 146 µmol $m^{-2} s^{-1}$ supplementary light (HPS) for 20 h day^{-1}
LLI-SD: Natural light + 146 µmol $m^{-2} s^{-1}$ supplementary light (HPS) for 10 h day^{-1}
LLI-LD: Natural light + 146 µmol $m^{-2} s^{-1}$ supplementary light (HPS) for 10 h day^{-1} + 1.3 µmol $m^{-2} s^{-1}$ day extension for 10 h day^{-1} by incandescent lamp. Mean separation in columns by Tukey's test at $p < 0.05$.

SD at low daily light integral rooted at a similar speed.

The initial mean fresh and dry weight of the unrooted cuttings was 1.74 g and 0.26 g, respectively. Irrespective of light regime, the aboveground part of the cuttings did not gain any weight neither on a fresh nor on a dry weight basis during first two weeks after inserting, and hence the dry matter content was unchanged (Table 2). After 4 weeks, when more than 90 % of the cuttings in all three treatments were considered well rooted, the mean fresh and dry weight of the cuttings in the HLI-LD treatment had increased by about 100 % and 75 % respectively, while those in the LLI-SD and LLI-LD treatment had increased approximately 40 % and 25 % in fresh and dry weight compared to initial weight. The percent dry matter of the cuttings was lower after 4 weeks compared to 2 weeks, but did not vary between the light regimes.

The number of days from potting to appearance of the first visible bud on the main stem was significantly reduced in the plants rooted under HLI-LD conditions compared with plants rooted under the two LLI-conditions (Table 3). A 3-week SD treatment on rooted cuttings diminished the effect of light regime during rooting. No significant effects of light regime during rooting on development and flowering were observed in plants given a 3-week SD period just after rooting. Plants exposed to LLI-SD for 3 weeks developed visible bud and flowered 10–14 days later than the plants grown continuously under HLI-LD condition. The rate of development from visible bud to first open flower was not influenced by the light regime during rooting. The cuttings kept in LD and SD at the same low DLI during rooting, showed no difference in rate of bud and flower development.

The length of the main shoot, number of nodes to the first open flower, and the number of lateral flowering shoots on the plants was not influenced by the different light treatments during rooting (data not shown). However, the number of nodes on the main stem and the number of lateral shoots were significantly increased by the SD-treatment after rooting compared to the plants grown continuously in HLI-LD, but the length of the main shoot was not influenced by the SD-treatment (Table 4).

Table 2. Fresh weight, dry weight, and dry matter content of *G. paniculata* 'Perfecta' cuttings after rooting for 2 and 4 weeks under three different light regimes.
Frischgewichte, Trockengewichte und Trockenmassegehalt der Stecklinge von G. paniculata 'Perfecta' nach zwei und vier Wochen bei drei verschiedenen Lichtbedingungen.

	FW (g/cutting)		DW (g/cutting)		Dry matter (%)	
Light regime	2 w	4 w	2 w	4 w	2 w	4 w
HLI-LD	1.72a	3.49a	0.27a	0.45a	15.7a	12.9a
LLI-SD	1.64a	2.44b	0.25a	0.31b	15.3a	12.7a
LLI-LD	1.56a	2.45b	0.24a	0.32b	15.4a	13.1a

Lighting treatment as defined in Table 1.

Table 3. Combined effect of light regime during rooting (4 weeks) and short or long day treatment of rooted cuttings (3 weeks) on days to visible bud (VB) and first open flower (FOF) in *G. paniculata* 'Perfecta' plants.
G. paniculata 'Perfecta': Effekt der Belichtungsdauer und -intensität während der Bewurzelung sowie der Kurztag- und Langtagbehandlungen der bewurzelten Stecklinge (3 Wochen) auf die Anzahl Tage bis Blüte sichtbar (VB) und erste Blüte offen (FOF).

	light regime, rooted cuttings			
	HLI-LD		LLI-SD	
Light regime, cuttings	Days to VB (> 5 mm)	Days to FOF	Days to VB (> 5 mm)	Days to FOF
HLI-LD	26.0 b	46.0 b	40.2 a	60.0 a
LLI-SD	30.0 a	50.0 a	42.0 a	60.0 a
LLI-LD	30.0 a	49.0 a	42.0 a	60.0 a

Lighting treatment as defined in Table 1.

Table 4. Effects of inserting a 3-week short day period (LLI-SD) during growth of rooted cuttings of *G. paniculata* 'Perfecta' in long days (HLI-LD) on growth and yield of flowering shoots.
Einfluß einer dreiwöchigen Kurztagperiode auf bewurzelte Stecklinge von G. paniculata 'Perfecta' bezüglich Wachstum und Ertrag an Blütenstielen.

Growth parameter	Light regime (3 w)	
	LLI-SD	HLI-LD
Length of main shoot	103.4a	102.2a
No. of nodes to first open flower	22.7a	18.4b
No. of lateral flowering shoots	16.0a	11.9b

Lighting treatment as defined in Table 1.

Discussion

The results clearly show that the cuttings rooted at a similar speed under SD and LD as long as equal DLI's was provided (Table 1). This effect of daylength on rooting is in agreement with the results obtained in wheat (MACDOWALL 1977), *Dianthus* and *Lycopersicon* (BRUGGINK 1992), lettuce (KITAYA et al. 1998), and seems to be a common response to varying day lengths in the rooting phase of plants (KIM et al. 2000). In contrast, POKORNY and KAMP (1960) reported that LD to cuttings of *Dianthus* promoted rooting compared with

SD. This may be due to higher DLI under LD than SD, which we also observed in our investigation (Table 1).

It is generally accepted that increasing amounts of carbohydrates promote rooting (VEIERSKOV 1988), but increased light intensities has often caused reduced photosynthetic activity in the rooting phase of cuttings due to impaired water balance and closed stomata (ELIASSON and BRUNES 1980). However, HATZILAZAROU and ECONOMOU (2000) found that increasing levels of supplementary light combined with high humidity conditions promoted rooting of *Gardenia* cuttings through enhanced photosynthesis and translocation of higher amount of carbohydrates to the basal portion of the cuttings. The present results indicate that the waxy leaves of *G. paniculata* cuttings are able to utilize quite high light levels at rather low air humidity in the rooting phase, thereby producing carbohydrates that will promote root formation. In addition, strongly increased fresh and dry weight of the cuttings after 4 weeks (Table 2), also indicate increased photosynthetic activity in the cuttings as a result of more optimal light conditions. The diminishing effect of DLI on rooting percentage and dry matter content of the cuttings from week 2 to 4 may reflect that current photosynthesis is not absolutely required for root formation if adequate reserves of carbohydrates are available. However, carbohydrates accumulated before root emergence as a result of good light conditions, may have increased the number of initiated roots, and contributed to faster growth of both the roots and aboveground part of the cuttings, thereby decreasing the dry matter content.

The results presented in Table 3 indicate that, during rooting, the daylength itself does not influence the transformation from the vegetative to the generative stage, as measured by number of days to visible bud and flower formation. However, a combination of LD and high DLI during rooting or post rooting, obviously reduce the time to bud formation and flowering, (Table 4), which also demonstrate that light intensity may enhance flower initiation and development in this plant. Previous experiments with the LD plant *Dianthus* showed flowering advancement as a result of increased DLI by supplementary lighting (BUNT and POWELL 1983). Other LD plants are also known to respond to high light intensities in a similar manner, probably by increasing carbon assimilation, which will provide energy for flower initiation (BERNIER 1969). The results in Table 4 also demonstrate that a post rooting SD-period delays flower initiation and/or development, while the number of harvestable shoots is increased by a SD-treatment after rooting. MOE (1988) reported a similar response of *G. paniculata* to daylength. However, a higher DLI in the non-abrupt LD-treatment than in the treatment with a SD-period may have contributed to the results of the present experiment. It may be concluded that rooting of vegetative *G. paniculata* cuttings can take place in LD and at high DLI without any negative after-effects on growth and yield of the plants. A post rooting SD-treatment will delay the flowering time, but increase the number of harvestable shoots.

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