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Influence of Different Levels and Timing of Supplemental Irradiation on Pot Chrysanthemum Production

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Abstract. **Supplemental photosynthetically active radiation (PAR; 77, 148 and 231 µmol s^{-1}m^{-2}) was provided to *Chrysanthemum morifolium* Ramat 'Paragon' during 14 days each of rooting (24 hr daily), long days (LD; 24 hr daily) or short days (SD; 9 hr daily) in a greenhouse. Crop growth efficiency (calculated as the ratio of the observed to potential dry weight gain) was highest under the 77 µmol s^{-1}m^{-2} treatment during each stage and decreased markedly at higher irradiances. Relative growth rates were increased by all levels of supplemental PAR at each stage. The increases were proportionately smaller than the increase in total PAR in treatments above 77 µmol s^{-1}m^{-2}. Flower number, and flower and vegetative dry weight increased in response to 77 µmol s^{-1}m^{-2} supplemental PAR, but increased irradiances had no further effect. Extension of the 77 µmol s^{-1}m^{-2} treatment beyond rooting to LD significantly improved all traits over single stage treatments. Further extension into SD, however, was not beneficial.**

Supplemental irradiation, using high intensity discharge lamps (HID), has improved quality and productivity of chrysanthemums grown in commercial greenhouses in northern areas of Europe and North America (3). The commercial production of pot chrysanthemums typically proceeds through 3 stages from rooting of cuttings, through vegetative development during long days (LD) and flower induction and development during short days (SD). Installation and running costs may dictate use of HID lamps for limited periods during production of the crop.

Carpenter (1) showed that, in some cultivars, little can be gained in harvest quality by supplementing natural daylight beyond the long day stage. Recently, work in greenhouses at Kentville (6) has suggested that maximum economic benefit will accrue from treatments during rooting and LD when plants and/or pots are closely spaced and developmental requirements permit an uninterrupted photoperiod. The aim of the present study was to examine chrysanthemum growth and development in relation to different levels of supplemental irradiation during each production stage and thereby determine optimal irradiance and timing of treatments for commercial production.

On 25 Oct. 1983, 1056 unrooted cuttings of Paragon were obtained from a commercial propagator. The cuttings, which varied in fresh weight between 0.5 and 1.0 g, were stuck in 12 wooden flats (88 cuttings per flat). Each flat occupied 0.15 m^2 of bench area and was filled with a 2 peat:1 vermiculite (v/v) medium. Three pairs of flats were placed in separate areas of a misting bed and were provided with continuous supplemental irradiation from high pressure sodium lamps (HPS; Phillips HDK 602, 400 W). Average photosynthetically active radiation (PAR) measured with a LI-190S quantum sensor (LI-COR Inc., Lincoln, Neb.) at plant height was 77 ± 6, 148 ± 19, and 231 ± 25 µmol s^{-1}m^{-2}. The distance from lamp to plants was kept constant in each of the treatments: the number of lamps was varied to achieve the required irradiance. The other 6 flats were not subjected to supplemental irradiation. Immediately following sticking, 12 cuttings were chosen at random from each set of flats, dried at 90°C for 24 hr and weighed. A similar procedure was followed at 3-day intervals throughout the 14-day rooting period.

Following the rooting phase, the remaining cuttings from the nonirradiated flats were transplanted into 8-cm diameter peat pots (1 plant/pot), and filled with a 1 peat: 1 vermiculite: 1 sand medium (by volume). Peat pots were grouped together in 4s and were held in 19-cm diameter plastic pots. These pots then were distributed to 4 greenhouse benches and arranged so that each group of plants occupied 0.03 m^2 of bench area with pot rims touching. This arrangement was chosen to approximate a commercial pot format where plants are sometimes grown 4 to a 16-cm pot. The usual arrangement of 5 plants per 16 cm pot could not be accomodated in this study. Throughout the following 14 days (LD stage), each group received continuous supplemental irradiation at the same levels as established during rooting, or ambient irradiance. Twelve peat pots were removed randomly at 3-day intervals for the determination of plant dry weight. After each harvest, the remaining peat pots were rearranged to maintain the 4-plant groupings.

At the end of the LD period, random plastic pots from the ambient irradiance bench were spaced on separate benches to provide 0.09 m^2 of bench area per pot in preparation for the SD stage. Lamps were rearranged to provide the same 3 irradiances for 9 hr each day, whereas a 4th group continued to receive ambient irradiance only. This SD treatment period lasted for 14 days. Destructive sampling was repeated at 3-day intervals for 12 plants from each treatment as described previously. At the completion of each treatment period, a group of 6 plastic pots (24 plants) from each group were transferred to a bench and received ambient irradiance until harvest. In addition, 24 plants which received supplemental irradiation at 77 µmol s^{-1}m^{-2} during rooting were maintained under the same conditions during 14 LD and then were transferred to ambient irradiance conditions. Another group of 24 plants received the 77 µmol s^{-1}m^{-2} treatment through rooting, LD and 14 SD and finally completed development under ambient conditions.

Greenhouse temperatures were 20° ± 2°C (day) and 17° ± 2° (night). Rooting flats and pots were randomized on the benches at 3-day intervals. Individual irradiation treatments were not replicated, but lamps and treatment location within the greenhouse were randomized twice during each stage. Plants were irrigated with nutrient solutions containing N (200 mg liter^{-1}), K, Ca, and micronutrients once a week. Other essential nutrients were premixed into the potting medium. All plants were pinched at the start of the SD period. Daminozide (0.25% solution) was applied as a foliar spray two weeks after pinch.

Dry weight data were used to generate plots of weight versus time for individual treatments in each stage. Curves were fitted using the exponential relationship: $\ell nW = ae^{bt}$; where W is plant dry weight in grams, t is time from the start of the treatment period in days, a and b are constants representing the size of the plant at the start of the treatment period (i.e., the value of ℓnW when $t = 0$), and relative growth rate (RGR; g g^{-1} day^{-1}), respectively. The growth of plant groups as a function of incident radiant energy was examined by calculating a crop growth efficiency (CGE; 5, 9, 10) for certain treatments. CGE is defined as the ratio of observed dry weight gain to the potential dry weight gain of a crop (plant group) and was calculated

Table 1. Percentage crop growth efficiencies in relation to supplemental irradiation treatments during each 14 day stage.

Treatment stage	Ambient	Ambient + 77 µmol s^{-1}m^{-2}	Ambient + 148 µmol s^{-1}m^{-2}	Ambient + 231 µmol s^{-1}m^{-2}
Rooting	5.1	7.1	5.7	4.5
LD	2.5	3.5	1.5	1.6
SD	5.6	6.7	2.4	1.1

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in this study according to the methods of Merritt and Kohl (10). For calculation purposes, a single flat of cuttings constituted the crop during the rooting stage, whereas during LD and SD, a crop was considered as a single 19-cm pot containing 4 plants.

At final harvest, the parameters measured on each plant were the number of stem breaks with flowers greater than 5 cm diameter, the average length of stem breaks, and the total dry weight of flowers and vegetative tissue, excluding roots. Harvest data were subjected to single factor analysis of variance. Comparisons between selected treatment means were made by single degree of freedom contrasts.

Of the 3 production stages examined, the rooting period resulted in the highest CGE values for all levels of PAR (Table 1). Leaf area index (LAI) was not measured in this study, but close spacing of cuttings probably resulted in LAI at or above the critical value (about 3) for dry weight gain in chrysanthemum (8). Maximum CGE (7.1%), which occurred under the lowest level of PAR, represents a high value for chrysanthemum crops (9), indicating that photosynthetic sources (leaves and stems) and sinks (principally, the developing stem apex and root system) were in balance under this level of PAR. The reduced values of CGE at the higher irradiances suggest either that sinks were inadequate, and/or that the photosynthetic systems of all plants in the crop were unable to absorb or utilize the higher levels of PAR. During LD, following transplanting to peat pots, CGE was reduced in comparison with the preceding stage. Since the transplants did not form immediately a closed canopy over the area occupied by the 19 cm pot, this reduction was probably partly due to a decline in LAI from the critical value for dry weight gain. During the first few days of the SD stage, the closed canopy was restored and was maintained until harvest. CGE recovered partially under all except the highest level of PAR during the early part of the SD stage. The ambient, and 77 µmol s^{-1}m^{-2} treatments showed relatively high CGE but increased irradiances resulted in decreased values. Since increases in PAR above 77 µmol s^{-1}m^{-2} did not increase the number of stem breaks following pinching at the start of SD (Table 2), the low CGE at the higher irradiances are most readily explained in terms of a deficiency of growing points as sinks for photosynthate.

Supplemental irradiation increased RGR over the control during rooting, LD and SD (Fig. 1). The effects of treatment on RGR were, as expected, mediated by CGE. The greatest increase in RGR in each stage occured with the lowest level of supplemental PAR (77 µmol s^{-1}m^{-2}), which corresponded with the highest CGE. As in previous studies (7), further changes in RGR were proportionately much smaller than the increases in PAR, thus reflecting, in the present experiment, the reduced capacity of the plants to use or absorb additional PAR.

Although the efficiency and rate of growth are clearly important parameters in judging

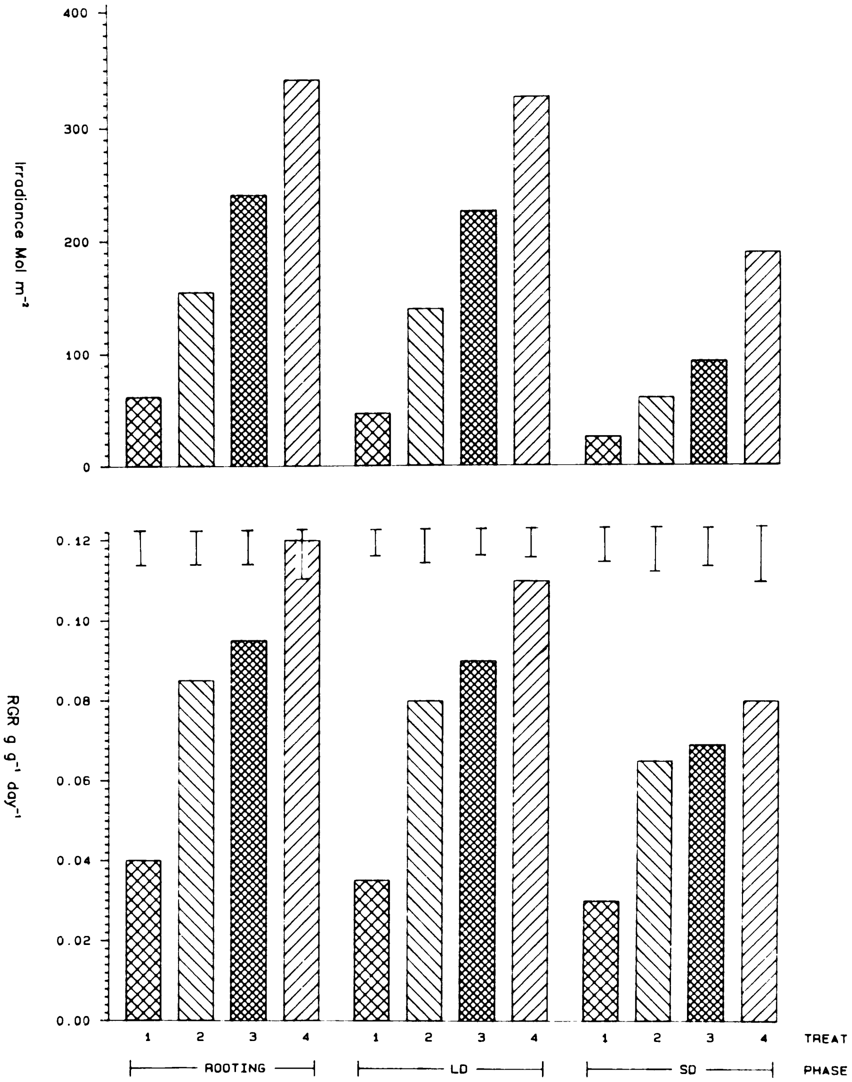

Fig. 1. Total photosynthetic irradiance and relative growth rates (RGR) for 14-day treatment periods during rooting, LD and SD. RGR calculated from fitted exponential curves as described in the text. Bars represent SE of RGR for individual treatments; 1: Ambient irradiance; 2: Ambient + 77 µmol s^{-1}m^{-2}; 3: Ambient + 148 µmol s^{-1}m^{-2}; 4: Ambient + 231 µmol s^{-1}m^{-2}.

Table 2. Effect of different levels and combinations of supplemental irradiation treatments on harvest traits.

Treatment^z	Flowering stem breaks (No./plant)	Harvest (Days/plant)	Vegetative^y dry wt. (g/plant)	Flower dry wt. (g/plant)	Mean length stem break (cm)
Constant ambient	2.0	68.8	1.57	0.92	15.0
77 R	2.6	65.2	2.03	1.39	15.9
148 R	2.7	64.8	2.01	1.45	15.8
231 R	2.8	64.6	2.18	1.58	16.0
77 L	2.4	64.8	2.13	1.42	16.0
148 L	2.4	64.8	2.35	1.43	17.1
231 L	2.4	64.6	2.69	1.50	17.0
77 S	2.4	66.5	2.14	1.35	19.2
148 S	2.6	66.8	2.44	1.61	20.1
231 S	2.6	66.8	2.40	1.60	18.1
77 R + L	3.1	63.1	3.38	2.48	16.8
77 R + L + S	3.3	63.4	3.95	2.52	20.2
Difference between means:					
Const. Amb. vs others	**	**	**	**	**
77R + 148R vs. 231R	NS	NS	NS	NS	NS
77L + 148L vs. 231L	NS	NS	*	NS	NS
77S + 148S vs. 231S	NS	NS	NS	NS	*
77R + L vs. others	**	**	**	**	NS
77R + L vs. 77R + L + S	NS	NS	**	NS	**

^{z}Numerals refer to supplemental PAR (µmol s^{-1}m^{-2}); R: rooting; L: long days; S: short days.

^{y}Excluding roots.

^{NS,*,**}Nonsignificant (NS), or significant at 5% (*) or 1% (**) level.

the potential benefits of supplemental irradiation, crop productivity also depends on the allocation of dry matter within the plant (particularly to above ground vegetative and floral tissue), and on the rate of flower development. In these respects, the lowest level of supplemental PAR during either rooting, LD or SD, again proved to be most beneficial. Time to harvest, final vegetative and flower dry weight and number of flowering stem breaks were all improved by supplemental PAR of 77 μmol s^{-1}m^{-2} (Table 2). The 148 and 231 μmol s^{-1}m^{-2} treatments did not result in further improvements.

The most significant effects on harvest traits resulted from combined treatments of 77 μmol s^{-1}m^{-2} during rooting and LD or during rooting, LD and SD. Extension of the treatment into SD, however, only resulted in further increases in vegetative dry weight, and stem length. This response agrees with previous results (6) and probably reflects a partitioning of excess photosynthate to stem tissue in the absence of a large number of individual stem breaks. Procedures, such as successive pinches to induce further stem break development at the start of SD, could improve CGE and patterns of photosynthate allocation under supplemental irradiation during this stage.

Previous work has emphasized the importance of irradiance, during the first 2 weeks of SD, in flower weight and number, and in hastening maturity of chrysanthemums (2). In that study, increasing irradiance over the range 63 to 230 J cm^{-2}day^{-1} about 109 to 203 μmol s^{-1}m^{-2}, 400–700 nm averaged over an 8-hr photoperiod) produced significant improvements in flower traits at harvest in 'Bright Golden Ann', but the influence of similar irradiances during rooting and LD production was not investigated. The present results have failed to demonstrate a similar responsiveness of 'Paragon' to increasing supplemental PAR between 77 and 231 μmol s^{-1}m^{-2}. The data do, however, indicate an improvement in all harvest traits at the lowest level (77 μmol s^{-1}m^{-2}) of supplemental PAR, irrespective of production stage. Since maximum photosynthetic rate in chrysanthemum is not achieved at 77 μmol s^{-1}m^{-2} PAR, (4) it seems that factors other than photosynthetic potential limit further improvement in harvest traits at the 2 higher irradiances. The most likely explanation of this situation lies in reduced ability of plants in the present study to utilize photosynthetic products at the higher irradiances, as suggested by the reduction in CGE in the 148 and 231 μmol s^{-1}m^{-2} treatments.

At the plant spacings and seasonal irradiances recorded in this study, commercial growers would be ill-advised to increase supplemental irradiation of pot chrysanthemums above 77 μmol s^{-1}m^{-2}, since little additional improvement in growth rate, plant size or flower weight can be expected. Some improvement in CGE (and probably RGR and harvest traits) undoubtedly could be achieved during LD by increasing plant density (by, for example, planting 5 rooted cuttings per 15 cm pot), as would occur normally in commercial production. Stimulation of greater sink activity, particularly at the start of SD, might also improve CGE, and possibly improve yield response to supplemental PAR in excess of 77 μmol s^{-1}m^{-2}. A more reliable production strategy appears to be the provision of supplemental PAR of 77 μmol s^{-1}m^{-2} during rooting and LD. This combination significantly improves earliness, plant and flower size and number and permits the efficient and economical use of HPS lamps (6). Extension of the 77 μmol s^{-1}m^{-2} treatment into SD could not be recommended unless procedures are adopted to direct increased dry matter production to a greater number of stem breaks and developing flowers. Increased capital and operating costs for lamp installation for SD use are still likely, however, to make this an uneconomical proposition.

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Suppression of Axillary Bud Growth on Pinched Potted Chrysanthemums with Naphthaleneacetic Acid

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Abstract. **Spray applications of NAA or NAA ethylester at 1000 ppm acid equivalent (A.E.) reduced axillary bud number by 30% and 21%, and weight by 73% and 52%, respectively, on pinched potted chrysanthemums, *Chrysanthemum* x*morifolium* Ramat. 'Mountain Snow' and 'Mountain Peak'. Diameter of floral sprays and vegetative heights also were reduced with increasing concentrations. Flower number was not affected by the treatments. NAA treatments caused leaf epinasty, but NAA ethylester treatments did not. Chemical names used: 1-naphthaleneacetic acid (NAA).**

Pinching of potted chrysanthemums increases the number of terminal flowers and the floral spray size by stimulating the growth of axillary buds located below the decapitated apex; however, some of these buds eventually require disbudding. Growth regulators, such as 2,3-dihydro-5, 6-diphenyl-1,4-oxathiin (P-293) (5, 7), emulsifiable oils (1, 2, 3) and naphthalene compounds such as 1- and 2-methyl naphthalene (1, 4), have been used in an attempt to remove lateral buds on pinched chrysanthemums.

Exogenous auxin has been shown to suppress the growth of axillary buds in decapitated plants by restoring apical dominance (6). The application of auxins to inhibit axillary bud growth and lessen the need for disbudding has not been investigated in pinched chrysanthemums. The objective of

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