Shoot Growth and Gross Photosynthesis of Evergreen Azaleas

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Additional index words. gibberellic acid, photosynthetic photon flux density, *Rhododendron*

Abstract. The influence of photosynthetic photon flux density (PPFD) and gibberellic acid (GA₃) sprays on shoot elongation was determined for 'Coral Bells' (Kurume or *R. obtusum* hybrid), 'Fashion' (Glen Dale or *R. indicum* × Kurume hybrid), 'Hexe' (*R. obtusum* × *R. simsii* hybrid), 'Hinocrimson' (Kurume or *R. obtusum* hybrid), 'Hinodegiri' (Kurume or *R. obtusum* hybrid), and 'Red Wing' (Brooks hybrid) azalea. GA₃ at 1 mM was more effective in stimulating shoot elongation of 'Coral Bells', 'Fashion', 'Hinodegiri', and 'Red Wing' than of 'Hexe' or 'Hinocrimson'. GA₃ sprays were more effective in stimulating elongation when applied to plants growing at irradiance levels of 350 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ than to plants growing at either 200 or 100 $\mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$. Gross photosynthesis of leaf segments was higher for a slow-growing cultivar (Hinocrimson) than for a faster-growing cultivar (Fashion). 'Hinocrimson' produced stouter shoots (greater dry weight/cm) than did 'Fashion'.

The time required for shoot elongation of evergreen azaleas (*Rhododendron* cvs) is

considerably longer than for other stages of production (Batson, 1975). Faster shoot elongation should lead to a decreased time between prunings and a shorter production time. Gibberellic acid (GA₃) has stimulated shoot elongation of azalea seedlings (Sink and Walker, 1964). Greenhouse azaleas of the Belgian indica group that have a high rate of photosynthesis when grown at high photosynthetic photon flux density (PPFD), also

Received for publication 21 Nov. 1988. I acknowledge support from the Faculty Research Fund of the Univ. of Victoria. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

Fig. 1. Influence of PPFD and leaf age on gross photosynthesis of leaf segments of 'Fashion' and 'Hinocrimson' azaleas. (A) Young leaves: youngest fully expanded leaves on 7-week-old shoots. (B) Middle leaves: second oldest leaves on 10-week-old shoots. (C) Older leaves: top, fully expanded leaves on 8-month-old shoots pruned 4 weeks before leaf removal. Means are of four replicates. Vertical bars represent standard errors of the means. **Indicates correlation coefficients that are significant at $P = 0.01$. *Above a mean for 'Fashion' indicates that it is significantly different from the respective 'Hinocrimson' mean at $P = 0.05$.

have a high rate of shoot elongation, and a correlation between shoot growth and photosynthesis of cultivars was indicated (Ceulemans et al., 1984).

The purpose of these studies was to determine the influence of PPFD and GA₃ on shoot elongation of evergreen azalea cultivars hardy in southwestern British Columbia, and to investigate the relationship between gross photosynthesis and shoot elongation of these cultivars.

One-year-old plants were dug in the field and potted into 15-cm-diameter (1.41-liter) azalea pots with 1 peat :1 sand (v/v) in June

1986 and placed in an unshaded greenhouse held at $16 \pm 1^\circ\text{C}$ night temperature for 2 weeks to become established in pots. In the greenhouse, daytime maxima ranged from 25 to 40°C. Maximum PPFD was 900 $\mu\text{mol} \cdot \text{s}^{-1} \cdot \text{m}^{-2}$ at midday, the low midday PPFD was 70 $\mu\text{mol} \cdot \text{s}^{-1} \cdot \text{m}^{-2}$ and the mean midday PPFD was $427 \pm 3 \mu\text{mol} \cdot \text{s}^{-1} \cdot \text{m}^{-2}$, as determined with a LI-COR Quantum Sensor (LI-COR, Lincoln, Neb). Plants were fertilized monthly with 100 ml ammonium sulfate (2.6 g·liter⁻¹) and 20-20-20 (20N-8.8P-16.6K) (0.75 g·liter⁻¹).

All shoots were pruned to four to six leaves

2 weeks before the plants were placed in growth chambers, when axillary shoots could only be detected with a binocular microscope. Growth and photosynthetic relationships between cultivars did not depend on time of digging or time of year in which the plants were held in the greenhouse. In growth chambers, the photoperiod was 15 h, days were at $22.7 \pm 0.3^\circ\text{C}$ and nights at $13.5 \pm 0.2^\circ\text{C}$ (an attempt to approximate late spring and summer temperatures in southwestern British Columbia). Light sources were cool-white fluorescent tubes providing 89% of the irradiation and incandescent bulbs providing 11% of the irradiation. Growth chamber PPFDs were 100, 200, and 350 $\mu\text{mol} \cdot \text{s}^{-1} \cdot \text{m}^{-2}$. Where GA₃ (1 mM in 0.1% Tween 20) was applied, five weekly sprays were used. Controls contained 0.1% Tween 20. Plants were sprayed to runoff. Sprays began 2 weeks after plants were placed in the growth chambers. GA₃ at 1 mM was considered to be a concentration sufficient to stimulate shoot growth at a cost low enough to have commercial potential. Shoots were measured after plants had been in the growth chambers for 8 weeks.

A second shoot growth experiment involving 'Fashion' and 'Hinocrimson' was carried out in 1987. Plants were dug in the field in August, potted and pruned and placed in the greenhouse for 2 weeks, and then placed in a growth chamber at 250 $\mu\text{mol} \cdot \text{s}^{-1} \cdot \text{m}^{-2}$ for 6 weeks, a photoperiod of 15 h, days at $22.7 \pm 0.3^\circ\text{C}$ and nights at $13.5 \pm 0.2^\circ\text{C}$. Then the plants were returned to the $16 \pm 1^\circ\text{C}$ (night temperature) greenhouse and shoot elongation and dry weight were determined after plants had been in the greenhouse for 7 weeks.

Gross photosynthesis of leaf segments was measured with the Clark O₂ electrode (Steffen and Palta, 1986) that rapidly determines the oxygen flux of irradiated tissues (Badger, 1985). Five leaf disks were cut from leaves on shoots of 'Hinocrimson' and 'Fashion' plants growing at 300 $\mu\text{mol} \cdot \text{s}^{-1} \cdot \text{m}^{-2}$ under a 15-h photoperiod, days at $22.7 \pm 0.3^\circ\text{C}$ and nights at $13.5 \pm 0.2^\circ\text{C}$. Leaves were selected from three positions on the shoots. Young leaves were the youngest fully expanded leaves on 7-week-old shoots; middle leaves were the second oldest leaves on 10-week-old shoots; and older leaves were the top fully expanded leaves on 8-month-old shoots that were pruned 4 weeks before leaf removal. Five leaf disks, 4 mm in diameter, were cut from each of two leaves (10 disks total). Each of the leaf disks was cut in half and 20 leaf segments were placed in 3 ml 50 mM HEPES and 0.5 mM CaSO₄ (Steffen and Palta, 1986). The leaf segments were vacuum infiltrated twice (to avoid excessive bubbling) for 3 min with a water aspirator that achieved a vacuum of 722 mm Hg, measured with a Marsh Mastergauge (Marsh Instrument Co., Mississauga, Ont.). Leaf segments were given a 10-min pre-illumination of 500 $\mu\text{mol} \cdot \text{s}^{-1} \cdot \text{m}^{-2}$; in preliminary experiments there was little difference between this pre-illumination PPFD and a pre-illumination PPFD identical to the reaction

Table 1. Influence of cultivar, irradiance during growth (PPFD), and GA₃ on azalea elongation.

Cultivar	GA ₃	Shoot elongation over 8 weeks (cm)		
		Photosynthetic photon flux density (μmol·s ⁻¹ ·m ⁻²)		
		100	200	350
Coral Bells	—	5.1 ^z	4.3	4.1
	+	7.8	7.0	9.3
Fashion	—	7.1	6.3	5.3
	+	9.2	8.4	10.8
Hexe	—	5.9	5.0	4.8
	+	6.4	6.3	6.2
Hinocrimson	—	5.4	4.2	4.5
	+	6.0	6.3	6.4
Hinodegiri	—	4.5	4.0	5.0
	+	7.8	7.6	7.6
Red Wing	—	5.9	4.7	3.6
	+	8.4	7.0	7.8
ANOVA				
PPFD		**		
Gibberellin		***		
Cultivar		***		
PPFD × gibberellin		**		
Gibberellin × cultivar		**		
PPFD × cultivar		NS		
PPFD × gibberellin × cultivar		NS		
LSD _{0.05}		1.53		

^zMean of five replicates.NS, Nonsignificant or significant at $P = 0.01$ or 0.001 , respectively.

PPFD. Following pre-illumination, 0.1 ml NaHCO₃ (final concentration 12.4 mM) was added and O₂ evolution was determined with a YSI Model 53 Clark oxygen electrode (YSI, Silver Spring, Md.) at the PPFD indicated and 30°C (employed because it was found to be optimal for gross photosynthesis of azalea leaf segments). This temperature has been found to be optimal for spinach chloroplast activity (McEvoy and Lynn, 1972) and pea leaf gross photosynthesis (Hellmuth, 1971). The reaction PPFDs were 100, 300, and 800 μmol·s⁻¹·m⁻². Shoot elongation had been determined at the lowest reaction PPFD in the growth chamber, and the rate of gross photosynthesis at 800 μmol·s⁻¹·m⁻² was the same as that measured at 2000 μmol·s⁻¹·m⁻² (assumed as saturating).

Chlorophyll concentrations of the leaf segments were obtained using 96% ethanol (Wintermans and DeMots, 1965).

Determinations of shoot elongation of the new shoots that emerged following pruning were made from five plants per treatment. Gross photosynthesis determinations were replicated four times, each replicate from a separate plant. Analysis of variance followed by determinations of the least significant difference were carried out on shoot elongation data. Regressions were computed according to Li (1964) on gross photosynthesis data. Differences between means were tested at $P = 0.05$.

GA₃ was most effective in stimulating shoot elongation when applied to plants receiving 350 μmol·s⁻¹·m⁻² (Table 1). Also, GA₃ was more effective in stimulating shoot elongation in 'Coral Bells', 'Fashion', 'Hinodegiri' and 'Red Wing' than in 'Hexe' or 'Hinocrimson'. The rate of shoot elongation of 'Fashion' was greater than that of the other cultivars. The GA₃ treatment stimulated shoot elongation in all cultivars but not at all PPFDs. Except for 'Hexe' and 'Hinocrimson', GA₃

increased shoot elongation sufficiently to permit more frequent pruning, assuming that a shoot length of 7 cm can be pruned rapidly and easily. Overall, 'Fashion' had the highest rate of shoot elongation and its rate of shoot elongation was increased by GA₃. 'Hinocrimson' had the lowest rate of shoot elongation and GA₃ had little effect on its shoot elongation.

Gross photosynthesis of leaf segments of the faster-growing 'Fashion' was significantly less than the slower-growing 'Hinocrimson' (Fig. 1). This difference did not depend on leaf position or reaction PPFD.

When shoots were allowed to grow for 15 weeks, the shoots of 'Hinocrimson' were 3.6 cm long and those of 'Fashion' were 7.3 cm. Dry weight of 'Hinocrimson' was 39 mg per cm of shoot, and 25 mg·cm⁻¹ for 'Fashion'. In each case, differences were significant at $P = 0.05$. Such a difference in dry weight/cm may reflect a difference in the rate of photosynthesis observed in these cultivars.

GA₃ has been effective in increasing shoot elongation of some azalea cultivars, especially at the highest PPFD of 350 μmol·s⁻¹·m⁻² used in these studies (Table 1). Thus, GA₃ could be a satisfactory means of increasing the rate of shoot elongation of cultivars (Coral Bells, Fashion, Hinodegiri, and Red Wing) growing in unshaded or shaded greenhouses (GA₃ also stimulated shoot elongation of these cultivars at 100 μmol·s⁻¹·m⁻²) or in the open field. Without GA₃ treatment, only 'Fashion' growing at 100 μmol·s⁻¹·m⁻² grew at a rate that would permit frequent pruning. However, plant responses in growth chambers may not be identical to responses in greenhouses or in the open field.

The effectiveness of GA₃ in stimulating shoot elongation at the highest PPFD (350 μmol·s⁻¹·m⁻²) may be compared to the greater effectiveness of GA₃ in breaking

flower bud dormancy at a high light intensity (Furuta and Straiton, 1966). Perhaps photosynthesis is required for GA₃ action or its translocation.

While GA₃ treatments may permit more frequent prunings, they often result in a decrease of frost hardness (Levitt, 1980). Thus, GA₃-treated plants growing outside may be more susceptible to freezing injury and may be more suitably grown in a greenhouse.

In 'Fashion' and 'Hinocrimson' azalea, elongation was not related to photosynthesis. However, 'Hinocrimson' is a Kurume or *R. obtusum* hybrid and 'Fashion' is a Glenn Dale or *R. indicum* × Kurume hybrid (Galle, 1985); thus, the two cultivars are not closely related. However, in the study carried out by Ceulemans et al. (1984), the slower-growing and photosynthesizing 'Apollo' was a parent of the faster-growing and photosynthesizing 'Knut Erwen' (Heursel, 1985), both being Belgian indica cultivars. In this study, there was no difference in the dark respiration rate between 'Fashion' and 'Hinocrimson', and the rate of photosynthesis would seem to account for observed differences in oxygen flux. Photosynthesis should be a satisfactory means of predicting shoot elongation of hybrids produced from closely related cultivars, especially in the Belgian indica group, but gross photosynthesis may not be used to predict shoot elongation in other hybrids. Gross photosynthesis may be used to predict dry weight/cm of shoots, but shoot dry weight and shoot elongation are not always closely related. Many factors other than photosynthesis rate may determine shoot elongation, including translocation of photosynthate and endogenous phytohormone levels.

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