Timing of Low Solar Irradiance Affects Quercus and Acer Propagation©

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INTRODUCTION

In recent years, work by the authors has shown increases in rooting of cuttings for several traditionally difficult-to-root tree species after applying treatments of severely limiting solar irradiance (shading) during the rooting phase (Zaczek, 1994; Zaczek et al., 1997). In these studies, rooting of semihardwood cuttings in a polytent rooting system within a greenhouse was greatest at or above 91% shading of ambient irradiance for most taxa tested. However, maintaining cuttings under low irradiance after root induction may affect the subsequent survival of rooted propagules. The study presented here evaluated the effect of varying durations of low irradiance exposure during the rooting phase on rooting characteristics and survival of cuttings of six tree taxa.

MATERIALS AND METHODS

Plant Material. In mid-June 1997, semihardwood shoots of maple (*Acer rubrum* 'Bowhall', and *A. truncatum*) and oak (*Quercus imbricaria, Q. nigra, Q. palustris, Q. rubra*) were collected from several sources and kept cool and moist until processing into cuttings and application of treatments. Shoots from *A. truncatum* (purpleblow maple) were collected from two trees, each approximately 4 m (13 ft) tall and 5 cm (2 inches) in caliper. *Quercus nigra* and *A. rubrum* cuttings were collected from field-grown trees of *A. rubrum* and *Q. nigra* trees that were approximately 4 to 6 m (13 to 19 ft) tall and 5 to 10 cm (2 to 4 inches) in caliper at The Buddies Nursery, Birdsboro, Pennsylvania. Shoots from *Q. palustris* (pin oak) were collected from the most recent growth flush in mid to upper unshaded crowns of three 20-year-old trees. The *Q. imbricaria* (shingle oak) shoots were collected from the lower crowns of three open-grown mature trees, each greater than 51 cm (20 inches) in diameter at breast height. Shoots of *Q. rubra* (northern red oak) were collected from approximately 200 2-year-old field-planted grafts whose scions originated from seedlings.

Shoots from each of the taxa were prepared as cuttings for treatment the day after collection. Oak shoots had all but the uppermost three leaves removed and were trimmed to 15 cm (6 in) long. Maple shoots were prepared as single-node cuttings. Immediately after preparation, cuttings were immersed for 5 min in a solution of

Olympic Triathlon (Olympic Horticultural Prod., Mainland, Pennsylvania) at a concentration of 1.3 ml liter^{-1} of water (1 tsp gal^{-1}). Then, cuttings were rinsed in water, soaked for 5 min in a fungicide solution (Cleary 3336-F, 1.6 ml liter^{-1} water (0.2 oz gal^{-1}), W. A. Cleary Chemical Corp., Somerset, NJ), removed, and air dried. The basal ends of oak cuttings were freshly trimmed and dipped for 5 sec 2 cm (0.8 inches) deep in a 10,000 ppm IBA (indole-3-butyric acid) solution in ethanol and allowed to dry. Maple cuttings were treated similarly except were dipped in a 5000 ppm IBA solution in ethanol. Cuttings were then inserted in a premoistened mix of peat moss, perlite, and sand (1 : 1 : 1, by vol) in Ray Leach Single Cell Cone-tainers™ (Stuewe and Sons Inc., Corvallis, Oregon). For each species, 150 cuttings were processed, except that 450 cuttings were prepared for *Q. rubra*. By taxa, the cuttings were randomly grouped into fifths, and then randomly assigned to one of the five shade duration treatments located in the rooting chamber.

The rooting chamber was a single chamber [polyethylene covered tent (polytent)] located within a greenhouse. Cool fog was intermittently provided by four ultrasonic humidifiers (Sunbeam model 667, Northern Electric Co., Chicago, IL) located outside opposing ends of the polytent. The greenhouse exterior was whitewashed (Kool-Ray white shading compound, Continental Products Co., Euclid, OH) to reduce irradiance and limit solar heating inside the polytent. Polytent systems necessitate using relatively heavy shading to minimize solar heating during summer in climates with high irradiance (Loach 1988). Our own experiences, as well as others', indicate that moderate temperatures can be maintained within a polytent rooting environment under 80% to 85% shade of ambient outdoor solar irradiance (Lewandowski and Gouin, 1985; Zaczek 1994; Zaczek et al., 1997). Therefore, we consider a shade level in this range a 'control' treatment when using a polytent system.

The polytent rooting chamber built on three roller benches was 3 m × 5 m (10 ft × 16.5 ft) and was subdivided into two shade level compartments. The low irradiance treatment compartment had 80% black polypropylene shade fabric (Yonah Manufacturing Co., Cornelia, Georgia) suspended above the roof and along the three vertical walls outside of the rooting chamber. The control irradiance treatment compartment did not receive shading from fabric except for a wall within the polytent that formed the adjacent low irradiance treatment. The inner shade fabric wall was suspended from the top of the chamber down below the top of the cuttings but leaving the lower 25 cm (10 in) open. This, coupled with the porous nature of the shade fabric, allowed for air exchange and minimized humidity and temperature differences between compartments. Previous studies in the same rooting chamber showed that air temperatures varied less than 1°C (1.8°F) on average among shade treatments (Zaczek, 1994; Zaczek et al., 1997).

Percentage shading for each treatment was determined by measuring photosynthetic photon flux density (PPFD, μmoles m^{-2} s^{-1}) at different times during daylight hours over several days at 10 locations in each treatment and outside the greenhouse by using a quantum sensor. Percentage reduction of ambient sun (percentage shade) for each compartment was calculated by [(1-(PPFD compartment/PPFD outside))×100]. Shade levels were 93% (7% irradiance) and 82% or control (18% irradiance). For reference, the average outdoor PPFD was 1584 μmoles m^{-2} s^{-1} during a prior summer at the same location between 0900 and 1700 h (Zaczek, 1994).

Cuttings were placed in the rooting chamber for 119 days (except for *A. rubrum* and

Q. nigra which were in the chamber for 117 days) under five low-irradiance duration regimes. Cuttings received either 0, 10, 20, 40, or 119 days of 93% shade (0, 10, 20, 40, or 117 for *A. rubrum* and *Q. nigra*) and then were transferred to the control treatment (82% shade) for the remainder of time in the rooting chamber.

Fungicide solutions were sprayed on all cuttings approximately every 2 weeks using either Cleary 3336-F at 0.7 ml per liter water (½ tsp gal^{-1}) or Chipco Aliette (Rhone-Poulenc Company, Research Triangle Park, NC) at 1.2 g $liter^{-1}$ (0.2 oz gal^{-1}). Approximately weekly, the containers were checked for emerging roots. Cuttings with roots were examined and the number of roots at least 5 mm (0.2 inches) long were noted. In mid October, all remaining cuttings were checked for roots.

Rooted cuttings were potted in moistened Pro-Mix BX (Dorval, Quebec, Canada) and placed under fog and 82% shade for a week, followed by transfer to ambient greenhouse conditions. In mid November, cuttings were transferred to a minimally heated greenhouse for overwintering. In early spring, cuttings were moved back to a heated greenhouse to stimulate budbreak. Overwinter survival was noted for cuttings that broke bud and formed new shoots by mid June.

Pairwise comparisons among shade duration treatments for percentage rooting means were made at the $P=0.05$ level using CONTRAST, a computer program (Hines and Sauer, 1989) based on a chi-square procedure (Sauer and Williams, 1989). Overwinter survival was tested between treatments by pooling across all taxa. For each taxa, to test for differences in the number of roots per rooted cutting and the number of days to root between shade duration treatments, analysis of variance (at $P=0.05$) (Steel and Torrie 1980) was used. When treatment effects for the number of roots per cutting and number of days to root were detected, Duncan's multiple range test was used to compare treatment means. Log transformation was used for the number of roots per cutting because the data were not normally distributed, the treatment standard deviations were proportional to the treatment means, and some of the values were less than 10 (Fowler and Cohen, 1990, Steel and Torrie, 1980).

RESULTS AND DISCUSSION

For each taxa, the greatest rooting percentage required at least 10 days of low irradiance, although the differences were not significantly greater for *Q. rubra* and *Q. imbricaria* when compared to control conditions. The oaks tended to show a greater degree of variability in response to the treatments (Fig. 1) while the maples tended to be more consistent (Fig. 2).

Shoot cuttings photosynthesize before and during root formation. However, photosynthesis during root formation is not required for root initiation (Davis, 1988) as evidenced by the rooting of leafless hardwood cuttings and the rooting of *Pisum* shoot cuttings in darkness (Davis and Potter, 1981). Supplementing irradiance for cuttings has been shown to have no effect on rooting (French, 1989). Compared to reduced irradiance, high irradiance during rooting can actually be detrimental to unrooted shoots as they can be subjected to internal water deficits (Aminah et al. 1997). It is not essential to provide cuttings with high irradiance until rooting occurs (Dirr and Heuser, 1987; Loach and Gay, 1979). In the present study, the taxa tended to achieve the highest percentage rooting when exposed to at least 10 days of low irradiance (93% shade). However, examining each taxa, exposure to low irradiance throughout the entire duration of the experiment resulted in optimal rooting only

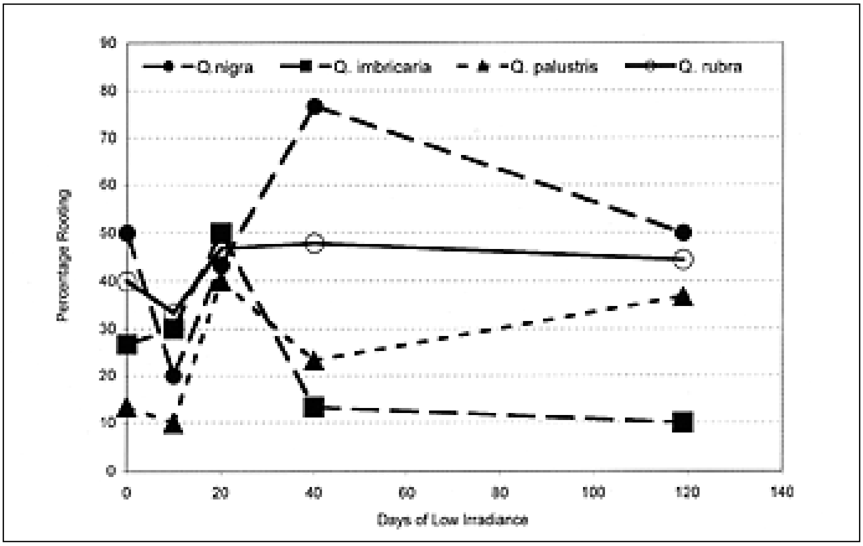

Figure 1. The percentage rooting of oak cuttings in response to low irradiance (93% shade) duration treatments.

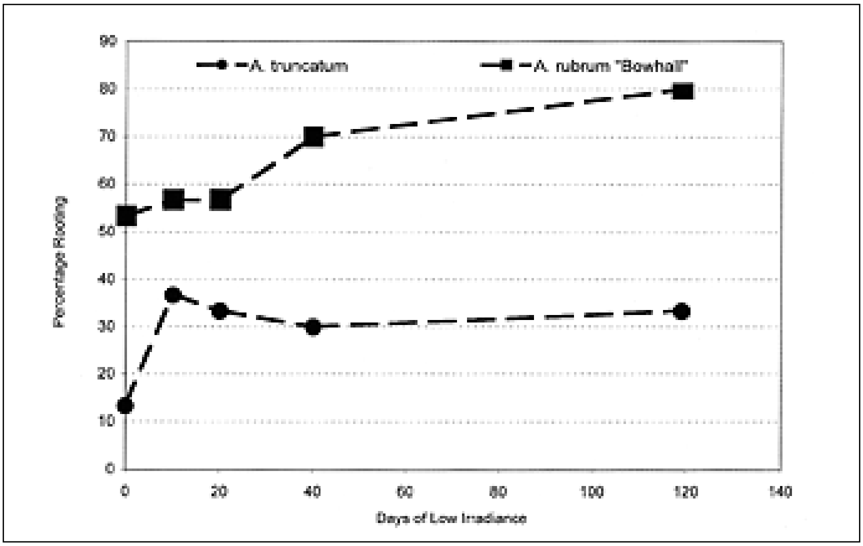

Figure 2. The percentage rooting of maple cuttings in response to low irradiance (93% shade) duration treatments.

for *A. rubrum* 'Bowhall'. This suggests that root initiation maybe stimulated by low irradiances for at least 10 days but, once rooting is initiated, higher irradiances may be beneficial for increased rooting. Moreover, exposing cuttings to low irradiance aids in the induction of rooting but subsequent shifting into higher levels of irradiance further promotes root development. Apparently, relatively higher irradiances during rooting are either unnecessary or detrimental for the taxa tested, at least until rooting occurs.

The number of roots per cutting was significantly influenced by low irradiance treatments during the rooting phase only for *A. rubrum* 'Bowhall' cuttings (Table 1). In other studies, with different species, the number of roots per cutting was increased (Marczynski and Joustra, 1993; Zaczek, 1994; Zaczek et al., 1997), decreased (Davis and Potter, 1981), or remained unchanged (Aminah et al., 1997; Behrens, 1988; Zaczek et al., 1997) by lower irradiances during rooting.

The number of days for cuttings to root was influenced by low irradiance for *A. truncatum* and *A. rubrum* 'Bowhall' (Table 1). For these species, rooting tended to occur most rapidly in the 10-, 20-, and 40-day low irradiance treatments and tended to take longer with either no exposure or continual exposure to low irradiance. This further suggests that rooting may be induced by a period of low irradiance but

Table 1. The average number of roots per cutting and the average number of days to root for maple species under low irradiance (93% shade) duration treatments.

Species	Low irradiance treatment (days)	Number of roots per cutting		Number of days to root	
Acer truncatum	0	3.3	a [Y,Z]	117	a
	10	2.5	a	82	bc
	20	2.3	a	66	c
	40	2.0	a	68	c
	119	2.0	a	101	ab
	mean	2.3		83	
Acer rubrum 'Bowhall'	0	9.8	b	46	ab
	10	14.6	ab	38	bc
	20	18.5	a	32	c
	40	8.8	b	45	abc
	117	7.3	b	54	a
	mean	11.4		44	

[Y] For each species, 30 cuttings per treatment were used.
[Z] Within a species, means in a column with the same letter are not different at the P=0.05 level as determined by Duncan's Multiple Range Test.

subsequent exposure to higher irradiance augments rapid root development.

Overwinter survival pooled across species averaged 58.8%. Paired contrasts showed that there were no significant differences in percentage overwinter survival among the treatments.

For some recalcitrant woody plant species, rooting success has been influenced by stock plant irradiance. Supplemental irradiance provided to stock plants has decreased rooting capacity (Pellicer et al., 1998). Rooting may improve after severely reducing irradiance to the stock plant prior to cutting collection, a process referred to as etiolation or blanching (Bolmark and Elliasson, 1990; Leakey and Storeton-West, 1992; Maynard and Bassuk, 1992; van den Driessche, 1985). However, stock plant irradiance reduction treatments are difficult to apply to mature trees (Hecht-Poinar et al., 1989). Results of this study show that low irradiances applied to cuttings for at least 10 days at the start of the rooting phase are also effective in increasing rooting of some woody taxa.

Shading during rooting does not appear to be beneficial to all species or cultivars, especially to those that already have reasonably successful propagation protocols (Zaczek et al., 1997). However, species that are recalcitrant have shown rooting improvement with low irradiance treatment during rooting. For example, *A. rubrum* 'Bowhall', considered difficult-to-root (Flemer, 1982), was shown to benefit greatly from shade levels at or greater than 91% (Zaczek et al., 1997). In this study, this taxon exhibited high percentage rooting when maintained under low irradiance for the entire duration in the rooting environment.

Oak species are notoriously poor rooters (Dirr and Heuser, 1987; Flemer, 1962; Teclaw and Isebrands, 1987), but we have reported positive results in several experiments depending on treatment, species, and maturity of the stock plant (Zaczek, 1994; Zaczek and Steiner, 1997; Zaczek et al., 1997). *Quercus nigra* and *Q. palustris* in the present study had the highest rooting percentage with at least 20 days in 93% shade. In another study, *Q. alba* and *Q. palustris* rooted most readily in the lowest irradiance (91% shade) level. Results from Zaczek (1994) over 2 years showed that rooting of cuttings from mature trees benefitted from shading up to 97% during rooting, which is near the light compensation point for seedlings of that species. However, cuttings from the first growth flush of juvenile (1-yr-old) *Q. rubra* did not benefit from low irradiance in the same study. Cuttings from juvenile (90-day-old) plants of other tree species had reduced rooting with reduced irradiance (Haissig, 1990). These results suggest that low irradiance during rooting appears to be most beneficial for taxa that are traditionally difficult-to-root and, especially, for mature trees.

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