Low Irradiance Levels and the Rooting of Selected Easy- and Difficult-to-Root Tree Taxa

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INTRODUCTION

The formation of adventitious roots by stem cuttings depends upon a complex interaction between endogenous and environmental factors. Environmental factors, such as irradiance, can have dramatic effects on adventitious root formation. For example, etiolation and opaque banding treatments when applied to plants prior to cutting collection, can increase rooting success of difficult-to-root species (Maynard and Bassuk, 1986; Bollmark and Eliasson, 1990; Leakey and Storeton-West, 1992). However, etiolation can be difficult and costly to apply, especially on mature trees (Hecht-Poinar et al., 1989). Zaczek et al. (1997) in a recent study with typically difficult-to-root mature tree species demonstrated that rooting was significantly improved in some species by subjecting shoot cuttings to shade levels up to 97% of ambient irradiance in the rooting environment. Potentially, high levels of shade applied in the rooting environment could, therefore, prove to be useful in the rooting of cuttings from other recalcitrant taxa. This study reviews our propagation studies with high shade levels in the rooting environment, with and without hormone application, on the rooting of cuttings of selected tree taxa.

MATERIALS AND METHODS

Propagation Environment. The rooting chamber was located in a greenhouse at Penn State University, University Park, Pennsylvania, and consisted of a frame (1-meter-tall [3.3-ft]) constructed of polyvinyl chloride (PVC) pipe on three 1.7 m × 3.0 m (5.5 ft × 10 ft) roller benches. The frame was covered by a single sheet of 6-mil (1 mil = 1 thousandth of an inch) polyethylene; this configuration formed a single rooting chamber which minimized potential humidity and temperature differences among treatments. Intermittent cool fog was provided by four ultrasonic humidifiers (Sunbeam model 667, Northern Electric Co., Chicago, Illinois) set outside opposing ends (two per end) of the rooting chamber. Whitewash (Kool-Ray white shading compound, Continental Products Co., Euclid, Ohio) was applied to the exterior of the greenhouse to reduce irradiances and limit solar heating inside the polytent. It is essential to provide relatively heavy shading to minimize solar heating during summer use of polytent systems in climates with high irradiance. Previous experience (Zaczek, 1994) has shown that moderate temperatures can be maintained in a polytent rooting environment with ca. 80% to 85% shade. Therefore, we selected a shade level in this range for our control treatment. Shade treatments in the rooting chamber were made by subdividing the chamber into three compartments and the application of shade cloth. Two compartments had black polypropylene shade fabrics (Yonah Manufacturing Co., Cornelia, Georgia) suspended 10 cm (4 inches) above the roof and along the vertical walls of two sections of the rooting chamber. The third compartment (control) received no shade fabric except was bordered by a 47% shade fabric wall from the adjacent shading treatment. Shade fabric on the inside of the chamber between shade levels was suspended from the top of the chamber down below the top of the cuttings but leaving the lower 25 cm open. This coupled with the porous nature of the shade fabric allowed for humidity and air exchange between the three compartments.

Percentage shading e[B the three treatments was determined by measuring photosynthetic photon flux density (PPFD, μmoles m^{-2} s^{-1}) on different days and times during daylight hours at 15 locations in each treatment and outside the greenhouse using the quantum sensor of a portable infrared gas analyzer (model LCA-2, Analytical Development Co., Ltd., Hertz, England). The percentage reduction of ambient irradiance for each compartment was determined relative to the outside ambient PPFD [(1-(PPFD tray/PPFD outside))x100]. Shade levels were 97%, 91%, and 83% (control). For reference, the average ambient PPFD was 1584 μmoles m^{-2} s^{-1}.

Cuttings were then inserted in a mix of peat moss, perlite, and sand (1 : 1 : 1, by volume) in Ray Leach Single Cell Cone-tainers$^{\text{Tm}}$ (Stuewe and Sons Inc., Corvallis, Oregon).

Relative humidities were maintained at 100% except for short time periods when the chamber was opened to check for roots, apply fungicides, or change chart paper. Air temperatures varied less than 1C (1.8F) on average among shade treatments.

Fungicide solutions, either Cleary's 3336-F at a rate of 0.7 ml liter^{-1} water (0.5 tsp gal^{-1}) or Chipco Aliette (Rhone-Poulenc Company, Research Triangle Park, North Carolina) at a rate of 1.2 g liter^{-1} (0.2 oz gal^{-1}) were sprayed on the leaves ca. every 2 weeks during the rooting period. Approximately weekly, the chamber was opened and the Leach cells were checked for emerging roots.

Plant Material.

Experiment 1. Softwood shoot cuttings of *Quercus rubra* were collected from 1-year-old seedlings and mature trees at Penn State University, University Park, Pennsylvania. In this experiment, shade levels of 88% and 97% were used. All *Quercus* cuttings were treated with 10,000 ppm of indole-3-butyric acid (IBA).

Experiment 2. Softwood shoot cuttings of *Acer rubrum* 'Bowhall', *A. rubrum* 'Franksred' Red Sunset$^{\text{Tm}}$ red maple, and *Cornus kousa* were collected from several sources and kept cool and moist until treatment application. *Cornus kousa* cuttings were collected from mature trees located on the campus of The Pennsylvania State University and processed the same day. *Acer rubrum* cultivar cuttings were collected at The Buddies Nursery, Birdsboro, Pennsylvania and processed for rooting over the next 2 days. Field-grown trees of *A. rubrum* cultivars were between 4 to 5 m (13 to 16 ft) tall and approximately 5 cm (2 inches) in caliper. For each species, 180 cuttings were processed except for *C. kousa* where 216 cuttings were used. One-half of the number of cuttings of each species were treated with IBA. All the bases of freshly trimmed cuttings were dipped for 5 sec 2 cm (0.8 inches) deep in either 95% ethanol (control) or in an IBA and ethanol solution. The concentration of the hormone solution was 10,000 ppm for *C. kousa* and 5000 ppm for *A. rubrum* cultivars.

Experiment 3. In this experiment, the effect of length of shade (93%) treatment was studied. *Acer rubrum* cultivars and *Q. imbricaria* cuttings were collected at The Buddies Nursery, Birdsboro, Pennsylvania and processed as in Experiment 2. The length of the study was 117 days for *A. rubrum* and 119 days for *Q. imbricaria* and cuttings were subject to 0, 10, 20, 40, or 117/119 days of 93% shade. The remainder of the days was at 82% shade. Hormone treatments were as above.

All cuttings were trimmed to size, soaked in a solution of Olympic Triathlon, (Olympic Horticultural Prod., Mainland, Pennsylvania, U.S.A.) at a rate of 1.3 ml liter^{-1} of water (1 tsp gal^{-1}) for 5 min, rinsed in water, soaked in a solution of Clearys 3336-F (W. A. Cleary Chemical Corp., Somerset, New Jersey, U.S.A.) at a rate of 1.6 ml liter^{-1} water (0.2 oz gal^{-1}) for 5 min, removed, and air dried.

RESULTS

The effect of light reduction from 88% of ambient to 97% of ambient is shown in Table 1. The resulting increase from 30.5% to 54.6% in rooting with *Q. rubra* provided our first results suggesting that a reduction in irradiance to a very low level may prove promotive to rooting.

Table 1. Percent rooting of juvenile and mature *Quercus rubra* cuttings.

Age	88% shade (control)	97% shade
1-yr-old seedlings	73.5% (n=49)	92.3% (n=52)
mature trees	30.5% (n=154)	54.6% (n=119)

In Experiment 2 we studied the effect of low irradiance on the of rooting easy- and difficult-to-root cultivars of *A. rubrum* and also the easy-to-root dogwood, *C. kousa*. Again, the difficult-to-root taxon, *A. rubrum* 'Bowhall', show a dramatic increase in rooting; the easy-to-root cultivar, Red Sunset$^{\text{Tm}}$ red maple and the easily rooted *C. kousa* exhibited little effect (Table 2). As found with *Q. rubra*, rooting was influenced by shade and hormone treatments.

In Experiment 3 the effect of length of shade treatment on rooting was studied. The purpose of this study was to examine if the shade reduction was needed for the entire rooting period. As shown in Table 3, the difficult-to-root *A. rubrum* 'Bowhall' showed a continued increase in number of cuttings with roots during the entire 80-day rooting period. *Quercus imbricaria*, on the other hand, peaked at 20 days and then decreased.

Table 2. Percentage rooting and the average number of roots per rooted cutting by species, shade, and hormone treatment.

Species	Shade (%)	Rooting (%)		Roots per cutting	
		IBA	no IBA	IBA	no IBA
Acer rubrum 'Bowhall'	83	26.7	6.7	4.6	2.5
	91	66.7	20.0	7.1	2.5
	97	66.7	23.3	13.5	12.7
Acer rubrum 'Franksred' Red Sunset^{Tm} red maple	83	80.0	56.7	16.7	5.7
	91	86.7	46.7	18.0	3.4
	97	76.7	40.0	16.3	3.0
Cornus kousa	83	77.8	44.4	10.4	6.8
	91	83.3	47.2	11.0	5.7
	97	83.3	50.0	11.4	6.0

Table 3. Effect of length of shade treatment on rooting of *Acer rubrum* 'Bowhall' and *Quercus imbricaria* (n=30 per treatment).

Treatment[1]	*Acer rubrum* 'Bowhall' rooted (no.)	*Quercus imbricaria* rooted (no.)
0	16	8
10	17	9
20	17	15
40	21	4
117/119	24	3

[1] Treatment numbers refers to number of days out of 117/119 in 93% shade; i.e., 0 = 0 days of 93% shade and 117 (*Acer*)/119 (*Quercus*) days of 82% shade.

DISCUSSION

Beneficial effects of stockplant etiolation, shading, and banding pretreatments have long been recognized and well studied (Maynard and Bassuk, 1988); this extensive literature has shown the promotive effects of such treatments on adventitious root initiation, however such treatments are difficult and costly to apply.

It is commonly assumed by propagators that leafy cuttings should be subjected to a rooting environment with an irradiance that is conducive to photosynthesis (Davis, 1988; Hartmann and Kester, 1983). Hess and Snyder (1955) suggested that an important advantage of mist was the higher irradiances which could be tolerated, thus increasing photosynthesis in cuttings. However, little scientific evidence supports this assumption (Davis, 1988) and cuttings do not require high irradiances until rooting occurs (Dirr and Heuser, Jr., 1987; Loach and Gay, 1979). There is evidence that photosynthesis may be limited by the restricted sink-capacity for carbohydrates in unrooted cuttings (Loach and Gay, 1979) and by stomatal closure, so a low irradiance is needed to saturate photosynthesis (Davis and Potter, 1987).

Only limited research is available which addresses the interaction between root initiation and irradiances during the rooting process in leafy cuttings. Shading experiments have suggested that reduced irradiance can be beneficial for rooting of some species under mist (Grange and Loach, 1983). Veierskov (1993), working with *Hibiscus* cuttings, reported that the best light conditions for rooting occurs at an irradiance just above the light compensation point. In the present report, the reduction of irradiance to very low levels, in our case down to 3% of ambient irradiance during summer propagation in central Pennsylvania, has shown a promotive effect with several difficult-to-root tree taxa — *Quercus* and *A. rubrum*. In the case of *A. rubrum*, a comparison of easy-to-root and difficult-to-root cultivars has shown that the promotive effect was confined to the difficult-to-root cultivar with no significant effect on the easy-to-root cultivar. In a study with aseptically cultured shoot apices of juvenile and adult forms (adult forms are difficult to root) of *Hedera helix*, Hackett (1970) found that a reduction in irradiance brings about a qualitative change in the rooting response of adult shoot tips to indole-3-acetic acid (IAA) and catechol. There was essentially no response to IAA and catechol when adult tips were grown in high irradiance but when grown in low irradiance adult tips responded markedly to these factors and in much the same manner which juvenile shoot tips responded to those factors in high irradiance. Hackett was not able to extract the light controlled factor from mature apices that promoted rooting.

The physiological changes leading to increased rooting in difficult-to-root taxa reported here is not known, however, additional research is necessary if they are broadly applicable to other plants.

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