Using Physiological and Anatomical Studies to Optimize the Environment for Rooting Cuttings

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INTRODUCTION

Landis (1993) grouped environmental factors affecting plant propagation into two groups: atmospheric and edaphic. The atmospheric environmental factors include: light, temperature, carbon dioxide, relative humidity, pathogens, insect pests, weeds, and cryptogams. The edaphic environmental factors include: water, mineral nutrients, pathogens, and insect and other pests. The biological agents in the environment may also be beneficial, such as mycorrhizae, root growth-promoting rhizobacteria, and biological-control agents.

If anatomical and morphological events are used to describe the process of adventitious root formation, then rooting occurs in four general stages: (1) dedifferentiation, (2) root initial formation, (3) root primordia formation, and (4) elongation of primordia leading to root system growth and development (Hartmann et al., 1990). Others have described rooting in two stages based on visible root morphology: root initiation (before roots are visible) and root development (after roots are visible). The optimum environment may be different for each stage of adventitious root formation. Physiological indicators of stress may be useful in determining the optimal environmental conditions for each stage of adventitious root formation.

Various physiological responses of cuttings appear to be linked to the anatomical developmental stages of adventitious root formation. Using photosynthetic rates as an example, studies of cuttings from various herbaceous and woody species have shown the coordination of a sudden increase in photosynthetic rates with the development of root primordia or visible root emergence (Davis, 1988; Davis and Potter, 1981; Feldman et al., 1989; Smalley et al., 1991; Svenson et al., 1995; von Schaesberg et al., 1993). Most of these same studies found a gradually declining photosynthetic rate until roots had formed (Davis, 1988; Davis and Potter, 1981; Feldman et al., 1989; Smalley et al., 1991), unless low light levels were used (Svenson et al., 1995). The declining rates of photosynthesis may be an indicator of accumulating stress on the photosynthetic mechanism, suggesting that the propagation light environment is not optimal. Reduced photosynthetic rates prior to root formation may also be related to leaf-water relations (Loach, 1988; Rein et al., 1991), hormone physiology (Smalley et al., 1991), or source-sink physiology (Feldman et al. 1989). Veierskov (1993) reported that *Hibiscus* cuttings root better when provided with a light intensity just above the light compensation point until roots begin to emerge, using higher light intensity to support root growth.

Similar physiological/anatomical links have been shown for stomatal conductance (Gay and Loach, 1977; Smalley et al., 1991; Svenson et al., 1995), transpiration (Smalley et al., 1991; von Schaesberg et al., 1993), leaf water potentials (Grange and Loach, 1985; Rein et al., 1991; Smalley et al., 1991), auxin sensitivity (Gaspar and Hofinger, 1988), and various other physiological responses. In general, cutting

physiological responses to the various stages of adventitious root formation suggest that at least two different environments are needed for optimal rooting of cuttings. Changes in mineral nutrient concentrations may also be linked to the anatomical development stages of adventitious roots (Blazich, 1988; Svenson and Davies, 1995).

The rooting response to heat (temperature) has also been linked to root initiation and development. For optimal root formation and subsequent root growth, Dykeman (1976) noted that the root formation stages have a different optimum temperature than the root growth stage. Dykeman proposed shifting the temperature regime during rooting, using higher temperatures for root initiation and formation, and cooler temperatures for subsequent root growth. Shifting the temperature environment supported the earliest rooting, the largest number of roots formed, and the highest root fresh weight of *Dendranthema* 'Bright Golden Princess Anne'.

Assuming that declining photosynthetic rates during the root formation stage (dedifferentiation, root initial formation, and root primordia formation) indicates that the photosynthetic system is under stress, then lower light levels may be required during this stage. Combining this observation with the observations for temperature reported by Dykeman, then the root formation stages should have lower light and higher temperatures, while the primordia elongation and root growth stage should have higher light and lower temperatures. This hypothesis was tested using poinsettia cuttings.

MATERIALS AND METHODS

Unrooted 'Lilo' poinsettia cuttings were obtained from a commercial vendor (shipped overnight). Basal stems of individual cuttings were stuck 1 in. into a blend of fully moistened sphagnum peat and perlite (1 : 1, v:v) contained in 2 1/4-inch rose pots. All cuttings were placed under mist pulsing at 5 sec every 10 min in a fiberglass-covered greenhouse with air temperatures set at 82/70F (day/night). Eight treatments were prepared using 73% shade cloth spread 3 ft above one end of a 6-ft wide by 40-ft-long mist bench and bottom-heat pads under half the mist bench (lengthwise). The design provided high (4000 fc) and low (1100 fc) light areas with or without bottom heat (78F substrate heated; 70F unheated). Treatments were: (1) low light and no bottom heat (low light control), (2) low light with bottom heat, (3) low light with bottom heat shifted to high light without bottom heat, (4) low light with bottom heat shifted to low light without bottom heat, (5) high light and no bottom heat (high light control), (6) high light with bottom heat, (7) high light with bottom heat shifted to low light without bottom heat, (8) high light with bottom heat shifted to high light without bottom heat. Sixty cuttings were used for each treatment. For shifting environments, cuttings were relocated to the appropriate location on the propagation bench after 8 days. After 16 days, mist was turned off. Use of movable screens would facilitate the shift in light environments for a commercial propagation system that would otherwise provide only one light level.

Ten cuttings within each treatment were randomly sampled 10, 12, 16, and 20 days after the cuttings were inserted into the medium, and the percentage of rooted cuttings was recorded. After 20 days, unsampled rooted cuttings were transplanted into 4-in. pots filled with the same substrate. Plants were grown on the same bench under 4000 fc of light (same air temperatures, no mist), and were fertilized daily with 150 ppm N using a commercial 20N-8P-16K liquid fertilizer. Ten plants were sampled 5 and 10 days after transplanting.

RESULTS AND DISCUSSION

All cuttings had rooted by day 20; however, percentage rooting differed among treatments before Day 20 (Table 1a). On Day 10 for both light levels, cuttings provided with a cool substrate had not rooted, but cuttings provided with a warm substrate had at least 10% rooting. On Day 12, cuttings provided with a warm-shifted-to-cool substrate had the highest rooting percentages, with cuttings provided low light having slightly higher rooting than cuttings given higher light. Cuttings provided with low-shifted-to-high light and warm-shifted-to-cool substrate had the highest percentage of rooted cuttings on Days 10, 12, and 16.

If cuttings provided high light and a cool or warm substrate are compared with cuttings provided low light, the cuttings given low light had higher percentages of rooting on Day 12, but not after Day 12. This appears to indicate that using lower light levels during the root formation stage helps the cuttings root faster, but may not necessarily increase the percentage of cuttings that will root.

In general, shifting poinsettia cuttings from a low to a high light level upon formation of root primordia supported faster rooting than use of low or high light throughout the rooting process. Increased rooting using lower light is consistent with the responses reported for *Hibiscus* (Veierskov, 1993; Grange and Loach, 1985), *Forsythia* (Grange and Loach, 1985), and *Mangifera* (von Schaesberg et al., 1993), and with recommendations of Loach (1988). Studies showing better rooting using higher light intensities (Moe and Anderson, 1988) may have measured growth responses related primarily to the primordia elongation and root growth stage. Shifting cuttings from a warm to a cooler substrate also supported faster rooting than use of cool or warm substrate throughout the rooting process. This response is consistent with the response for chrysanthemum reported by Dykeman (1976), and with recommendations of Preece, (1993). It may be important to use a warm substrate without using increased air temperatures to avoid carbohydrate losses from excessive respiration.

The influence of the rooting environment on the subsequent growth of rooted cuttings has not been extensively studied. Light and temperature manipulation during rooting influenced subsequent growth of rooted poinsettia cuttings (Table 1b). Rooted cuttings sampled at transplanting had similar shoot dry weights for all treatments. Cuttings rooted using low-shifted-to-high light, and warm-shifted-to-cooler substrate, had more shoot dry weight 5 and 10 days after transplanting. Using high substrate temperatures throughout the rooting process produced cuttings with less shoot weight 5 and 10 days after transplanting, compared to cuttings rooted with cool substrate or shifted from warm to cool substrate. For poinsettias, the beneficial effects of shifting the light environment and shifting the temperature environment acted synergistically, helping cuttings root faster and supporting faster growth after transplanting.

The ability to use lower light levels during the root formation stages would be helpful when using no-mist propagation systems such as fog or ultrasonic humidification systems. Lower light levels may be especially helpful with subirrigation propagation systems which have been shown to be superior to mist for rooting some cultivars, such as 'Franks Red' maples (Zhang and Graves, 1995).

The difficulty in implementing complicated controls when rooting cuttings on a large scale is the equipment cost associated with the different environmental needs of different species. More than one or two different environmental regimes may be

Table 1. Percentage rooting (a) and shoot dry weight after transplanting (b) for 'Lilo' poinsettia cuttings in response to shifting light and temperature environments during rooting. Root primordia formation began on Day 8.

(a) *Percentage rooting*

Light quantity (fc)		Temperature (F)		Rooted[1] (%)		
Day 1	Day 8	Day 1	Day 8	Day 10	Day 12	Day 16
4000	4000	70	70	0	20	80
4000	4000	78	78	10	40	80
4000	4000	78	70	10	60	90
4000	1100	78	70	10	60	80
1100	1100	70	70	0	40	80
1100	1100	78	78	10	60	80
1100	1100	78	70	10	70	90
1100	4000	78	70	20	80	100

[1] All cuttings were rooted by day 20.

(b) Shoot dry weight after transplanting

Light Quantity (fc)		Temperature (F)		Shoot dry weight (grams) Days after transplanting[1]	
Day 1	Day 8	Day 1	Day 8	5 days	10 days
4000	4000	70	70	1.0 d	1.7 c
4000	4000	78	78	0.8 e	1.6 cd
4000	4000	78	70	1.2 c	1.9 b
4000	1100	78	70	1.0 d	1.7 c
1100	1100	70	70	1.1 cd	1.7 c
1100	1100	78	78	0.9 de	1.5 d
1100	1100	78	70	1.3 bc	2.0 b
1100	4000	78	70	1.6 a	2.2 a

[1] There were no differences in shoot dry weight at transplanting; means within columns separated by Duncan's Multiple Range Test.

difficult for a propagator rooting a wide range of species under the same propagation system. When facilities provide an option, propagators may be able to enhance rooting by using cool air temperatures, warm rooting-substrate temperatures, and low light levels during the root formation stages, followed by cool rooting-substrate temperatures and higher light levels to support rapid root primordia elongation and root growth.

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