Reduced Water Supply Induces Fall Acclimation of Evergreen Azaleas

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Abstract. The primary cause of losses in evergreen azaleas injured by early freeze is bark split on lower stems. Delayed acclimation in the fall is thought to permit this injury. We examined whether reduced water supply affects acclimation of *Rhododendron* L. 'Coral Bell', 'Hinodegiri', and 'Red Ruffle'. Containerized plants were grown under four watering regimes and placed outdoors or in the greenhouse. The water content of the growing medium was maintained at either 0.3 to 0.4 or 0.5 to 0.6 m³·m⁻³ from 16 June to 30 Aug. 1993, when half of the plants under each of these regimes was switched to the other watering regime. Freeze tests were conducted on 30 Aug. and 9 Oct. Injury to leaves, and lower, middle, and upper stems was evaluated visually. Acclimation of leaves and upper stems before the August test, in most cases, was not stimulated by reduced water content, while the response of lower and middle stems was cultivar- and location-specific. The lower water content treatment after 30 Aug. generally increased freeze tolerance of all plant parts regardless of the previous watering regime. The higher water content treatment after 30 Aug. either prevented or delayed acclimation. This study demonstrated that the reduced water supply provided a feasible means of promoting acclimation of evergreen azaleas in late summer.

Early freeze, particularly if preceded by a period of warm and wet weather, can severely injure evergreen azaleas. The primary cause of such injuries is bark split occurring on lower stems, although upper stems can also be affected. The injury is not evident immediately and may remain unnoticed until the following spring, when the plants are water stressed, resulting in foliage discoloration, stem dieback, and plant death (Brooks, 1974; Cook, 1978). Delayed acclimation of evergreen azaleas in the fall is thought to cause bark split injury (Alexander and Havis, 1980a; Flint, 1966). This delayed acclimation is especially manifested in the lower stems, which tend to lag behind upper parts of the plant. Alexander and Havis (1980a) attributed slow rate of lower stem acclimation in evergreen azaleas to a preferential acropetal movement of hypothetical hardiness promoters.

High temperatures in a root zone, common in containerized nursery stock, can further prevent proper acclimation of lower stems. Alexander and Havis (1980b) speculated that lower stems of evergreen azaleas go through two stages of acclimation, the second of which requires a root temperature below 16°C. In many areas, particularly the southeastern United States, exposure to acclimating temperatures is inadequate to harden evergreen azaleas sufficiently before the first freeze.

Low temperature in a root zone reduces water uptake by roots (Kramer, 1983). Decreased root conductivity was observed in red osier dogwood during cold acclimation (McKenzie et al., 1974; Parsons, 1978). It has been recognized that restricting water supply can increase cold hardiness in woody plants even under nonhardening temperature conditions. Yelenosky (1979) demonstrated that acclimation induced by water stress and low temperature resulted in similar cold hardiness of young citrus trees. Chen et al. (1975, 1977) found that cold hardiness of stems of red osier dogwood plants could be increased by water stress. Cold hardiness in several species of herbaceous plants was also induced by

imposing water stress (Burrows et al., 1989; Cloutier and Siminovitch, 1982; Cox and Levitt, 1976; Thomas and James, 1993).

Measures to prevent bark split of azaleas include fall applications of growth retardants (Norcini and Aldrich, 1990). However, this treatment suppresses initial spring growth and delays flowering. Since watering azaleas is universally practiced by nursery growers, reducing or even withholding irrigation is the easiest cultural manipulation available. Therefore, the purpose of this study was to examine whether reduced water supply can induce earlier acclimation of three cultivars of evergreen azaleas.

Materials and Methods

Commercially grown plants of three cultivars of evergreen azaleas, *Rhododendron* 'Coral Bell' (CB), 'Hinodegiri' (HD), and 'Red Ruffle' (RR), were used in field and greenhouse studies.

Field study. Four-year-old plants were grown in 9-liter containers placed in the open field. Growing medium contained 1 peat: 1 composted pine bark (v/v). Plants were fertilized (3 g·liter⁻¹) with Osmocote (18N-2.6P-9.9K, Grace Sierra Horticultural Co., Milpitas, Calif.) once after planting into containers in May.

Greenhouse study. Three-year-old plants were grown in 2.2-liter containers in an unheated greenhouse. The growing medium (Metro Mix 300, Grace Sierra) contained Canadian sphagnum peat, vermiculite, processed bark ash, and washed sand. Plants were fertilized (1 g·liter⁻¹) with Sta-green (11N-5P-5K, Progress Growers Supply, Canton, Ga.) three times between March and June.

Plants in each of the experiments were grown under four different watering regimes. The volumetric water content of the growing medium was maintained at either 0.30 to 0.40 m³·m⁻³ (dry) or 0.50 to 0.60 m³·m⁻³ (wet) between 16 June and 30 Aug. 1993. Pots were watered when water content of the medium approached lower limits of the intended ranges. Between 30 Aug. and 9 Oct., the previously imposed watering regime remained unchanged or was switched to the other regime, producing dry/dry, dry/wet, wet/wet, and wet/dry watering regimes. In the field study, no attempt was made to exclude natural rainfall; therefore, occasionally water content could exceed intended levels. However, the average intended water content ranges were maintained for each treatment. Volumetric water content of the medium was monitored

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twice a week with a time-domain reflectometry technique described by (Anisko et al., 1994). The method used a cable tester (Tektronix 1502C metallic time domain reflectometer, Tektronix, Beaverton, Ore.) to measure the apparent dielectric permittivity of the growing medium which strongly depended on water content. An empirical relationship between dielectric constant and water content was developed in a form of calibration equation (Anisko et al., 1994). Plants were organized in three randomized complete blocks with eight plants per each block $\times$ cultivar $\times$ watering regime. A randomly selected pot in each block $\times$ cultivar $\times$ watering regime was used for monitoring volumetric water content. Mean air temperature was calculated based on average of minimum and maximum temperature for each sunup to sunup day.

Cold hardness of plants was evaluated in the laboratory with freeze-tolerance tests on leaves and stems. Stem sections ≈ 4 to 5 cm long were sampled in the morning from three locations on a plant: lower stems were the most basal stems up to 4 cm from the roots, upper stems were the current season's growth leafy stems, and middle stems were leafless stems of the intermediate position. The freezing tolerance tests were performed on 30 Aug. and 9 Oct.. Samples were wrapped in moist cheesecloth, placed in test tubes, and inserted in a freezing bath (Forma Scientific, Marietta, Ohio). Sample temperature was recorded by thermocouples placed next to a stem or leaf. To avoid excessive supercooling of tissue water, when the temperature of the samples stabilized at $-2.0 \pm 0.5^\circ\text{C}$, the samples were inoculated with ice crystals. Following freezing of the samples, the temperature was lowered at the rate of 4°C per hour. After retaining the selected temperature (-2 to -12°C at 2-degree intervals) for 1 h, samples were removed from the bath and thawed in the refrigerator at $2.0 \pm 0.5^\circ\text{C}$. Control samples were kept on ice for the duration of the test. To evaluate injury, thawed samples were placed in polyethylene bags for 7 days and incubated at room temperature. Freezing injury was evaluated visually with oxidative browning of injured tissues as the criterion and rated on a scale of 0 = no browning, 1 = browning light or in small areas, 2 = browning darker or in larger areas, and 3 = all sample dark brown. The Richards function fitting to the rating values was performed by modified Gauss-Newton method using NLIN procedure of SAS (SAS Institute, 1985). The inflection point of the Richards function was used as an estimate of the lethal temperature (von Firks and Verwijst, 1993).

Results

Field study. Field plants were exposed to lower temperatures compared to the greenhouse plants for the duration of the experiment (Table 1). This factor, in addition to the natural rainfall and larger container size, may account for relatively higher water content of the growing medium of the dry watering regimes in the field study than in the greenhouse study. Nevertheless, before 30 Aug. lower and middle stems of HD and RR as well as upper stems and leaves of CB under the dry watering regime acclimated to temperatures $\approx 2^\circ\text{C}$ lower than under the wet watering regime (Figs. 1-3).

Continuation of the dry conditions between 30 Aug. and 9 Oct. allowed further acclimation in all plant parts of three cultivars except for leaves of CB. Imposing dry conditions on plants previously grown under the wet watering regime also increased freeze tolerance of most of the plant parts except for middle stems of HD and CB. Leaves of three cultivars and upper stems of CB reached the same level of freeze tolerance by 9 Oct. when grown under dry conditions between 30 Aug. and 9 Oct. regardless of their previous treatment. Lower and middle stems of plants, except for HD lower stems, grown under the dry watering regime after 30 Aug. acclimated to lower temperature if previously maintained under dry conditions than those maintained previously under wet conditions. Imposing wet conditions between 30 Aug. and 9 Oct. either prevented or delayed acclimation in all plant parts of three cultivars, regardless of their previous treatment, compared to dry conditions. In the 9 Oct. freeze test, most plant parts reached similar hardness as a result of wet conditions between 30 Aug. and 9 Oct. regardless of the watering regime before 30 Aug.. However, upper stems and leaves of RR and in lower stems and leaves of HD plants previously under dry conditions acclimated to lower temperature then in plants previously under wet conditions, despite the wet treatment between 30 Aug. and 9 Oct.

Greenhouse study. Only plants of RR tolerated stress imposed by dry watering regime. Plants of CB died or declined severely by 30 Aug., while plants of HB died by 9 Oct., as a result of dry conditions. Plants of RR, except for their lower stems, acclimated to lower temperature under dry watering regime before 30 Aug. but were later very prompt to reacclimate when exposed to wet conditions. Continuation of dry condi-

Table 1. Mean air temperature and average volumetric water content for field and greenhouse studies and four watering regimes.

Study and watering regime	Period	
	16 June–30 Aug.	31 Aug.–9 Oct.
A) Field study		
Mean air temperature [$^\circ\text{C}$]	23.1	18.0
Volumetric water content [m^3m^{-3}] (average $\pm$ SD)		
Wet/wet	0.51 ± 0.05	0.55 ± 0.06
Wet/dry	0.51 ± 0.05	0.41 ± 0.04
Dry/wet	0.40 ± 0.03	0.53 ± 0.05
Dry/dry	0.39 ± 0.03	0.39 ± 0.05
B) Greenhouse study		
Mean air temperature [$^\circ\text{C}$]	29.5	25.5
Volumetric water content [m^3m^{-3}] (average $\pm$ SD)		
Wet/wet	0.53 ± 0.05	0.59 ± 0.04
Wet/dry	0.52 ± 0.05	0.34 ± 0.01
Dry/wet	0.34 ± 0.02	0.58 ± 0.04
Dry/dry	0.35 ± 0.02	0.36 ± 0.03

Fig. 1. Lethal temperature for leaves, lower, middle, and upper stems of *Rhododendron* 'Coral Bell' plants grown under dry/dry (■), dry/wet (□), wet/dry (▲), and wet/wet (△) watering regimes in the field (A) and greenhouse (B) study on 30 Aug. and 9 Oct..

tions stimulated further acclimation in leaves and upper stems of RR, but not in lower and middle stems. By 9 Oct., plants of RR under dry watering regime reached similar level of hardiness regardless of their treatment before 30 Aug., except for lower stems which acclimated to lower temperature if previously grown under wet conditions. Continuation of wet watering regime after 30 Aug. either prevented or delayed acclimation of all plant parts of RR and CB and in lower stems of HD compared to plants exposed to dry conditions. Leaves and middle and upper stems of HD acclimated at the same rate, irrespective of watering. Imposing dry conditions after 30 Aug. generally enhanced acclimation in all plant parts of three

cultivars except for lower and middle stems of previously stressed plants of RR.

Discussion

Acclimation of upper plant parts (leaves and upper stems), in most cases, was not stimulated by reducing water supply between 16 June and 30 Aug. Response of lower plant parts (lower and middle stems) to water stress at that time was cultivar and location (greenhouse or field) specific. Water stress under field conditions promoted early acclimation of RR and HD, but not of CB. Interestingly, CB plants were also the

Fig. 2. Lethal temperature for leaves, lower, middle, and upper stems of *Rhododendron* 'Hinodegiri' plants grown under dry/dry (■), dry/wet (□), wet/dry (▲), and wet/wet (△) watering regimes in the field (A) and greenhouse (B) study on 30 Aug. and 9 Oct..

least tolerant of more severe water stress under the greenhouse study conditions. Similarly, Norcini and Aldrich (1990) found that the degree of foliar and bark-split injury reduction obtained by applying growth retardants in azaleas was cultivar-specific. The preventive effect of high temperatures on hardening of lower plant parts of azaleas discussed by Alexander and Havis (1980b) may explain differences in lower and middle stem acclimation between cultivars in the field study. Apparently, the same temperatures that prevented early acclimation in HD and RR when fully supplied with water were permissive for CB acclimation. In fact, in the latter cultivar, the lower plant parts were even harder than the upper parts. This obser-

vation indicates that delayed acclimation of lower stems compared to upper stems typical for high temperature conditions did not occur in the field-grown CB. However, such a delayed acclimation of lower stems was observed in CB and RR in the greenhouse study, where plants were exposed to relatively higher temperatures.

Imposing water stress after 30 Aug. generally increased freeze tolerance of all plant parts regardless of the previous watering regime. In contrast, maintaining high water content of the growing medium during that time prevented acclimation in some cases or even caused deacclimation as in the plants stressed before 30 Aug. Parsons and Li (1979) noted that the water stress-induced hardi-

Fig. 3. Lethal temperature for leaves, lower, middle, and upper stems of *Rhododendron* 'Red Ruffle' plants grown under dry/dry (■), dry/wet (□), wet/dry (▲), and wet/wet (△) watering regimes in the field (A) and greenhouse (B) study on 30 Aug. and 9 Oct.

ness in red osier dogwood was lost after recovery from the stress if plants were kept under long-day conditions.

Under higher temperature conditions of the greenhouse study, lower stems of CB and RR acclimated at the slower rate than the upper plant parts in late summer. This confirms findings of Steponkus and Lanphear (1967), Sakai (1968), and Alexander and Havis (1980a) that the induction of freeze tolerance proceeds in phases throughout the plant, with the apices being the first area to acclimate and lower stem area being less hardy than the upper parts in many woody plants. However, under lower temperatures in the field, no such pattern of differential rates of acclimation among various

plants was observed. Apparently, high temperatures accompanied by sufficient water supply, as in the greenhouse study, can delay acclimation of lower stems more than the acclimation of the upper plant parts. Creech and Hawley (1960) reported that mulching increased bark split injury of evergreen azaleas, a result they attributed to the delayed acclimation caused by a higher soil moisture content and higher soil temperatures under mulch in the fall.

Reducing water supply provides a feasible mean of promoting acclimation of evergreen azaleas in late summer. In most cases, short-term reduction of water supply was as efficient in increasing freeze tolerance as the long-term reduction through-

out the entire summer. This allowed for better freeze protection without reducing plant growth.

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