Effects of Fall Fertilization on Freeze Resistance, Flowering, and Growth of 'Hinodegiri' Azalea[1]

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Abstract

Five fertigation treatments were initiated August 1, 2002: 1) no additional fertilizer, 2) N at 75 mg·L^{-1} from August 1 to September 29, 3) N at 125 mg·L^{-1} from August 1 to September 29, 4) N at 75 mg·L^{-1} from August 1 to November 28, and 5) N at 125 mg·L^{-1} from August 1 to November 28. Freeze resistance of stems and leaves was analyzed monthly, November to February. Flower counts began prior to budbreak, and continued to flower expression. Fall fertigation increased azalea leaf and stem dry weights (DWs) compared to azaleas that received no additional fertigation after July 31. Fertigation N applied at 75 or 125 mg·L^{-1} from August 1 to November 28 did not increase leaf or stem DWs compared to plants fertigated at the same N rate from August 1 to September 29. High N treatments (N at 125 mg·L^{-1} from August 1 to September 29 or November 28) increased above ground DW, but reduced stem freeze resistance in November and March compared to plants that received N at 75 mg·L^{-1} from August 1 to September 29. Early flower budbreak and decreased total flower production resulted when N was applied at 125 mg·L^{-1} from August 1 to November 28 compared to 75 mg·L^{-1} from August 1 to September 29.

Index words: *Rhododendron ×kurume*, evergreen azalea, cold hardiness, nitrogen, liquid feed, fertigation.

Significance to the Nursery Industry

Interactions between fertilizer application rate and timing can influence growth and freeze resistance of container-grown horticultural crops. Fall fertilization can be used to increase the growth of container-grown azaleas without increasing freeze damage. A moderate rate of fall fertilization (N at 75 mg·L^{-1}) (1) can be extended through late fall (November 28) without reducing stem or leaf freeze resistance. A high rate of fertilization (N at 125 mg·L^{-1}) (1) may increase plant growth, compared to plants fertilized at a moderate rate. However, high rates of fertilization may reduce freeze hardiness, even when fertilization is terminated in September, well before the first freeze event. To maximize growth and stem freeze resistance, azalea producers in USDA Plant Hardiness 7 should maintain moderate fertility through August and September. Sustaining moderate fertility levels past late September achieves no additional growth benefit.

Introduction

Late summer and fall fertilization may increase mineral nutrient reserves and promote spring growth and flowering of woody ornamentals. Spring growth of container-grown ibolium privet (*Ligustrum ibolium* Coe ex Rehder) and winged burning bush (*Euonymus alatus* (Thunb.) Siebold) (8), Chinese juniper (*Juniperus chinensus* L.) (3), border forsythia (*Forsythia × intermedia* Zabel) (16), common lilac (*Syringa vulgaris* L.) (15), and field-grown domestic apple (*Malus domestica* Borkh.) (17) increased after fertilizer applications during the previous fall. Kiplinger and Bresser (13) reported that the number of flower buds per plant on azalea 'Coral Bells' (*Rhododendron* ×*kurume* 'Coral Bells') increased from 127 to 171 as N fertigation applied through September 20 was increased from 10 to 50 mg·L^{-1}.

High rates of fertilization applied in fall may reduce freeze resistance when growth cessation (11, 6) and bud development (6) are delayed in fall, or when new vegetative growth is promoted either late (20, 22) or early (2) in the growing season. A negative correlation was found between the application rate of granular fertilizers and freeze resistance for container grown scarlet firethorn (*Pyracantha coccinea* M. Roem.) and Japanese holly (*Ilex crenata* Thunb.) (12), *Forsythia × intermedia* (18) and Kurume azalea (*Rhododendron obtusum* (Lindl.) Planch.) (22). However, N applied in fall to container-grown *Ilex crenata* (9), redosier dogwood (*Cornus alba* L.) (18), and field grown crape myrtle (*Lagerstroemia indica* L.) (14) had no effect on freeze resistance.

Several studies utilized fertigation systems to control the timing of mineral nutrient application and analyze accurately the effects of fall fertilizer application on freeze resistance. Hawkins et al. (10) exposed container-grown seedlings of Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco] to three fertilization timing treatments and found differences in fertilization timing which did not affect mineral nutrient (N and P) concentrations of leaves influenced freeze resistance. Bigras et al. (4) reported that compared to container-grown *Juniperus chinensis* L. fertilized through July 31 in Quebec, Canada, fertilization through September increased spring growth of shoots without reducing freeze resistance of shoots or roots.

Fall fertilization may increase plant growth and flower production, but additional research is needed to understand how application rate and timing affect freeze resistance. Therefore, the objective of this study was to investigate whether timing and rate of fertigation influence growth, flower production and freeze resistance of 'Hinodegiri' azalea.

Materials and Methods

Uniform rooted liners of *R.* ×*kurume* 'Hinodegiri' were transplanted into 2.2 liter (#1) containers May 1, 2002, and

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grown in an unsheltered, gravel container nursery bed located on the University of Georgia campus in Athens, GA. Plants were exposed to ambient air temperature that ranged from –12.4 to 37.3C (9.7 to 99.1F). The growing substrate was aged pine bark amended with 6.74 kg·m^{-3} (4 lb·yd^{-3}) dolomitic limestone and 1.67 kg·m^{-3} (1 lb·yd^{-3}) Micromax® Micronutrients Granular (The Scotts Co., Marysville, OH). Prior to the initiation of fertility treatments on August 1, all plants were fertigated daily with 0.5 liter (0.13 gal) solution that contained at N at 75 mg·L^{-1} (4% NH_4, 6% NO_3, and 10% urea), P at 33 mg·L^{-1} (P2O5) and K at 62 mg·L^{-1} K (K_2O). Beginning August 1, 2002, plants were grown under five different fall fertility regimes, 1) no additional fertilizer beginning August 1, 2) 60 days of extended fertigation (from August 1 to September 29) at a moderate rate (N at 75 mg·L^{-1}), 3) 60 days of extended fertigation (from August 1 to September 29) at a high rate (N at 125 mg·L^{-1}), 4) 120 days of extended fertilizer application (from August 1 to November 28) at a moderate rate (N at 75 mg·L^{-1}) and 5) 120 days of extended fertilizer application (from August 1 to November 28) at a high rate (N at 125 mg·L^{-1}). Fertilizer treatments were randomly assigned and applied using a constant liquid feed fertilizer application. Plants were fertigated daily with 0.5 liter (0.13 gal) solution of Harrell's (Sylacauga, AL) 16.0–3.5–6.6 (N–P–K) liquid fertilizer that contained N as NO_3 (1.6%), and urea (14.4%), P as P2O5, and K as K_2O. Electrical conductivity of leachate was monitored daily throughout the study to maintain electrical conductivity of the substrate below 1.0 mS·cm^{-1}, using the Virginia Tech Extraction Method (23). Floating row cover (Specialty Converting and Supply Inc., Nashville, GA) was applied for freeze protection when minimum temperatures fell below –6.7C (20F).

This experiment was a factorial arrangement of five fall fertigation treatments in a randomized complete block design with three replications. Leaves and stems were harvested from three azaleas per treatment-replication combination on November 12, and December 11, 2002, and January 14, February 18, and March 19, 2003. Samples from each treatment-replication combination were combined, wrapped in moist paper towels, put in plastic bags, and placed on ice for transport to the lab. Within four hours of collection leaves and stems were prepared for freezing. Leaf and stem freeze resistance was estimated using the technique outlined by Lindstrom et al. (14). Thirty-six leaf, and 5 cm (2 in) long stem segments from each treatment-replication combination were analyzed under laboratory conditions. Four leaves and stem segments from each treatment-replication combination were removed from a freezing temperature bath at 3C (5F) temperature intervals. Samples were exposed to temperatures between –3 and –27C (26.6 and –16.6F) for freeze analysis in November, December, and March, and to temperatures between –6 and –30C (21.2 and –22F) in January and February. Controls were kept at 4C (39F) for the duration of the freezing test. The Spearman-Karber Method (5) was used to estimate the temperature at which 50% of leaf or and stem samples were killed (T_{50}).

Flower counts began February 24, 2003, prior to initial budbreak, and continued to full flower expression (F_{max}). Flowering was defined as budbreak showing petal color, and flowers were counted on five plants per treatment-replication combination three times weekly. Linear regression analysis was used to characterize the relationship between Julian date and flower count. Regression equations were then used to calculate F_{50} (date which 50% of flowers were in bloom, or $F_{max}/2$) for each treatment × replicate combination.

The same five azaleas from each treatment-replication combination used in F_{50} and F_{max} analyses were harvested May 5, 2003, separated into leaves and stems, and dried at 55C (131F) for 72 hr to determine leaf, stem and total above ground DWs.

DWs, leaf freeze resistance, stem freeze resistance, flower production, and flower budbreak were analyzed using the GLM procedures (SAS Inst., Inc., Cary, NC). Tukey's studentized range (HSD) means comparison test was used to detect differences in pairwise comparison of treatment means.

Results and Discussion

Fertilization extended through September 29 (60 days) or November 28 (120 days) increased leaf, stem and total plant DW of azaleas compared to plants that received no fertilization after July 31 (Table 1). These results are similar to other studies reporting fall fertilization increased growth (3, 7, 17). Results from this study demonstrated that compared to azaleas which received 60 days of extended fertilization at the moderate rate (N at 75 mg·L^{-1} from August 1 to September 29), the high rate of fertilization (N at 125 mg·L^{-1}) applied during the same time period increased total plant DW. Extended fertilization for 120 days at the high rate (N at 125 mg·L^{-1} from August 1 to November 28) increased leaf and total plant DWs relative to azaleas that received 60 days of extended fertilization at the moderate rate. However, compared to azaleas that received 60 days of extended fertilization at a moderate rate (N at 75 mg·L^{-1}, August 1 to September 29), dry weight production was not increased when fertilization was extended at the same rate for 120 days (N at 75 mg·L^{-1}, August 1 to November 28).

Freeze resistance of azalea leaves was not affected by fall fertilization in November, December, January, or March (Table 2). Higher levels of extended fall fertilization reduced leaf freeze resistance in February, as leaves of azaleas that received no fertilization from September 30 to November 28 had greater freeze resistance than azaleas that received the high rate of fertilization for 120 days (N at 125 mg·L^{-1}, August 1 to November 28).

Termination of fertigation in late summer (no fertilizer applied after July 31) did not reduce freeze resistance of azalea stems compared to other fertigation treatments (Table 3). These results differ from those of Edwards (6) who found

Table 1. Effect of fertilization treatments on leaf, stem and total above ground DW of *R. ×kurume* 'Hinodegiri'.

N fertilization (mg N·L^{-1})		Dry weight (g)		
Aug. 1 to Sept. 29	Sept. 30 to Nov. 28	Leaf	Stem	Total
0	0	9.2d[z,y]	8.3b	17.4d
75	0	17.2bc	12.4a	29.6c
125	0	20.0ab	14.2a	34.3ab
75	75	16.4c	14.2a	30.6bc
125	125	22.0a	15.0a	37.1a

[z]Each mean based on observations of five plants in each of three replicates.

[y]Mean separation within columns by Tukey's Studentized range test at P ≤ 0.05.

Table 2. **Effect of fertilization treatments on freeze resistance of leaf tissue of *R.* ×*kurume* 'Hinodegiri'.**

N fertilization (mg·L⁻¹)		T_{50} (C, F)				
		Leaf harvest dates				
Aug. 1 to Sept. 9	Sept. 30 to Nov. 28	Nov. 12	Dec. 11	Jan. 14	Feb. 18	Mar. 19
0	0	–8.75 (16.3)a[z,y]	–20.00 (–4.0)a	–19.50 (–3.1)a	–21.00 (–5.8)b	–10.25 (13.6)a
75	0	–9.00 (15.8)a	–19.75 (–3.6)a	–22.50 (–8.5)a	–21.25 (–6.3)b	–10.25 (13.6)a
125	0	–9.50 (14.9)a	–18.00 (–0.4)a	–21.75 (–7.2)a	–20.00 (–4.0)b	–9.50 (14.9)a
75	75	–7.75 (18.1)a	–18.75 (–1.8)a	–19.00 (–2.2)a	–19.75 (–3.6)ab	–9.75 (14.5)a
125	125	–6.00 (21.2)a	–18.50 (–1.3)a	–21.00 (–5.8)a	–16.75 (1.9)a	–10.25 (13.6)a

[z]Each mean based on observations of four leaf samples at each of 9 different freezing temperature increments in each of 3 replicates.

[y]Mean separation within columns by Tukey's Studentized range test at $P \leq 0.05$.

that reduced fertilization in late summer increased conifer seedling freeze damage.

In November and March, stem tissue from azaleas that received 60 days of extended fertilization at the high rate (N at 125 mg·L⁻¹ from August 1 to September 29) was less freeze resistant than stem tissue of azaleas that received the moderate rate of fertilization (N at 75 mg·L⁻¹) during this same time period (August 1 to September 29). Stem tissue of azaleas that received the high rate of extended fertilization (N at 125 mg·L⁻¹ from August 1 to November 28) was less freeze resistant in November, December, January and March than plants that received the moderate rate of fertilization (N at 75 mg·L⁻¹) through September 29.

In the present investigation, fall fertilization treatments that increased total plant DW did not always reduce freeze resistance. Compared to azaleas that were not fertilized after July 31, extended fertilization at a moderate rate (N at 75 mg·L⁻¹) through September 29 or November 28 increased leaf, stem and above ground DW without effecting stem freeze resistance. These results agree with the work of Bigras et al. (3) who found fall fertigation increased growth of *Juniperus chinensis* L. without reducing stem freeze resistance. However, the high rate of fall fertigation (N at 125 mg·L⁻¹ from August 1 to September 29 or November 28) increased azalea growth, but reduced stem freeze resistance in November and March compared to plants that either received no fall fertilization after July 31, or received extended fertilization at a moderate rate (N at 75 mg·L⁻¹) through September 29.

Based on their analysis of the effects of fertilization and temperature on the growth of *Ilex crenata*, Wright and Blazich (21) recommended when plants have entered the cold acclimation phase, fertilizer applied at half the rate applied in the growing season may be beneficial to support growth and cold acclimation. Unlike the results of Wright and Blazich, in this study when fertilization was extended 60 days (through September 29) versus 120 days (through November 28) at the moderate rate (N at 75 mg·L⁻¹), sustaining fall fertilization for 120 days through November 28 affected neither stem freeze hardiness nor DW accumulation. The high rate of fertilization (N at 125 mg·L⁻¹) reduced azalea freeze resistance in fall and early spring even when fertilization was terminated in September, well before the first freeze event.

The high rate of extended fertilization (N at 125 mg·L⁻¹ from August 1 to November 28) promoted early flower budbreak and decreased the total number of flowers compared to azaleas that received N at 75 mg·L⁻¹ from August 1 to September 29 (Table 4). These findings support those of Benzian et al. (2), and Van Den Driessche (19) who reported high tissue N content accelerated budbreak. However, using high N to promote early flowering and thus marketing of azaleas is not advisable because fertilization with high N rates reduces cold hardiness.

In this study, when fall fertilization was extended 60 days at a moderate rate (N at 75 mg·L⁻¹ from August 1 through September 28), growth increased with no affect on freeze resistance. Sustaining this moderate rate of fertilization later in the season (through November 28) did not further increase growth or decrease freeze resistance. A high rate of fertilization (N at 125 mg·L⁻¹) may increase azalea DW production. However, this high rate of fertilization may also reduce freeze hardiness in fall and early spring even when fertilization is terminated in September well before the first freeze event. Therefore, results herein indicate azalea growers in Zone 7 should maintain moderate fertility levels

Table 3. **Effect of fertilization treatments on freeze resistance of stem tissue of *R.* ×*kurume* 'Hinodegiri'.**

N fertilization (mg·L⁻¹)		T_{50} (C, F)				
		Stem harvest dates				
Aug. 1 to Sept. 29	Sept. 30 to Nov. 28	Nov. 12	Dec. 11	Jan. 14	Feb. 18	Mar. 19
0	0	–13.50 (7.7)bc[z,y]	–22.50 (–8.5)b	–22.25 (–8.1)ab	–20.25 (–4.5)a	–6.42 (20.4)b
75	0	–15.50 (22.1)c	–21.25 (–6.3)b	–24.00 (–11.2)b	–20.75 (–5.4)a	–6.75 (19.9)b
125	0	–11.50 (11.3)ab	–20.75 (–5.4)b	–21.00 (–5.8)ab	–18.50 (–1.3)a	–4.50 (23.9)a
75	75	–13.75 (7.3)bc	–19.50 (–3.1)b	–22.25 (–8.1)ab	–18.75 (–1.8)a	–5.92 (21.3)ab
125	125	–9.25 (15.4)a	–9.50 (14.9)a	–18.75 (–1.8)a	–18.50 (–1.3)a	–4.00 (24.8)a

[z]Each mean based on observations of four stem samples at each of 9 different freezing temperature increments for each of 3 replicates.

[y]Mean separation within columns by Tukey's Studentized range test at $P \leq 0.05$.

Table 4. **Effect of fertilization treatments on the date 50% of *R.* × *kurume* 'Hinodegiri' flowers were in bloom (F_{50}), and total number of flowers per plant.**

Fertilization treatment ($mg \cdot L^{-1}$)			
Aug. 1 to Sept. 29	Sept. 30 to Nov. 28	F_{50} Julian day	Total number of flowers
0	0	85.4 (Mar. 26)a[z,y]	205.6ab
75	0	85.2 (Mar. 26)a	245.3a
125	0	83.4 (Mar. 24)ab	201.9ab
75	75	81.9 (Mar. 22)ab	206.2ab
125	125	80.1 (Mar. 21)b	151.3b

[z]Each mean based on observations of five plants in each of three replicates.

[y]Mean separation within columns by Tukey's Studentized range test at $P \leq 0.05$.

through late September. Sustaining fertilization past late September achieves no growth benefit, and high fertility rates may promote freeze damage.

Literature Cited

1. Bailey, D.A. and P.V. Nelson. Designing a Greenhouse Crop Fertilization Program. Accessed January 1, 2008. http://www.ces.ncsu.edu/depts/hort/floriculture/plugs/fertprog.pdf.

2. Benzian, B., R.M. Brown, and S.C.R. Freeman. 1974. Effect of late season top dressing of N (and K) applied to conifer transplants in the nursery on their survival and growth on British forest sites. Forestry 47:153–184.

3. Bigras, F.J., R. Paquin, J.A. Rioux, and H.P. Therrien. 1989a. Influence de la photoperiode et de la temperature sur levolution de la tolerance au gel, de la croissance et de la teneur en eau, sucres, amidon et proline des rameux et des racines de genevrier (*Juniperus chinensis* L. 'Pfitzerana'). Can. J. Plant Sci. 69:305–316.

4. Bigras, F.J., J.A. Rioux, R. Paquin, and H.P. Therrien. 1989b. Influence de la prolongation de la fertilisation a liter automne su la tolerance au gel et sur la croissance printaniere du *Juniperus chinensis* 'Pfizerana' cultive en contenants. Phytoprotection 70:75–84.

5. Bittenbender, H.C. and G.S. Howell. 1974. Adaption of the Spearman-Karber Method for estimating the T_{50} of cold stressed flower buds. J. Amer. Soc. Hort. Sci. 99:187–190.

6. Edwards, I.K. 1989. The effects of mineral nutrition on hardening-off of conifer seedlings. Annu. Mtg. Intermountain Forest Nursery Assn., Bismarck, ND, August 14–18, 1989. p. 98–102.

7. Glerum, C. 1985. Frost hardiness of coniferous seedlings: Principles and applications. *In*: M.L. Duryea (Editor) Proc: Evaluating Seedling Quality: Principles Procedures and Predictive Abilities of Major Tests. Workshop held October 16–18, 1984. Forest Res. Lab., Oregon State Univ., Corvallis.

8. Good, G.L. and H.B. Tukey. 1969. Root growth and nutrient uptake by dormant *Ligustrum ibolium* and *Euonymus alatus* 'Compactus'. J. Amer. Soc. Hort. Sci. 94:324–326.

9. Havis, J.R., R.D. Fitzgerald, and D.N. Maynard. 1972. Cold hardiness of *Ilex crenata* Thunb. cv. Hetzi roots to nitrogen source and potassium. HortScience 7:195–196.

10. Hawkins, B.J., G. Henry, and J. Whittington. 1996. Frost hardiness of *Thuja plicata* and *Pseudotsuga menziesii* seedlings when nutrient supply varies with season. 1996. Can. J. For. Res. 26:1509–1513.

11. Hellegren, J. 1981. Frost hardiness development in *Pinus sylvestris* seedlings in response to fertilization. Physiol. Plant. 52:297–301.

12. Kelley, J.D. 1972. Nitrogen and potassium rate effects on growth, leaf nitrogen and winter hardiness of *Pyracantha coccinea* 'Lalandei' and *Ilex crenata* 'Rotundifolia'. J. Amer. Soc. Hort. Sci. 97:446–448.

13. Kiplinger, D.C. and H.B. Bresser. 1951. Some factors affecting multiple bud formation on azaleas. Proc. Amer. Soc. Hort. Sci. 57:393–395.

14. Lindstrom, O.M., R.B. Beverly, and H.A. Mills. 2002. Neither bloom nor postbloom nitrogen application reduces cold hardiness in crapemyrtle. Commun. Soil Sci. Plant Analysis 33:3837–3844.

15. Meyer, M.M. and W.E. Splittstoesser. 1969. Woody ornamental plant growth as related to nitrogen applications. Illinois Res.11:10–11.

16. Meyer, M.M. and H.B. Tukey. 1965. Nitrogen, phosphorus and potassium plant reserves and the spring growth of *Taxus* and *Forsythia*. Proc. Amer. Soc. Hort. Sci. 87:537–545.

17. Millard, P. and G.H. Neilsen. 1989. The influence of nitrogen supply on the uptake and remobilization of stored N for the seasonal growth of apple trees. Ann.Bot. 63:301–309.

18. Pellett, N. 1973. Influence of nitrogen and phosphorus fertility on cold acclimation of roots and stems of two container-grown woody plant species. J. Amer. Soc. Hort. Sci. 98:82–86

19. Van Den Driessche, R. 1991. Late-season fertilization, mineral nutrition reserves, and retranslocation in planted Douglas-fir (*Pseudotsuga menziesii* (Mirb) Franco) seedlings. Forest Sci. 31:485–496.

20. Williams, D.J., E.M. Smith, D.J. Beattie, and T.M. Blessington. 1986. Practices of overwintering container-grown landscape plants. p. 4–11. *In*: D.J. Beattie (Editor). Principles, practices and comparative costs of overwintering container-grown landscape plants. Southern Coop. Series Bul. 313. The Pennsylvania State University Agricultural Experiment Station, University Park.

21. Wright, R.D. and F.A. Blazich. 1983. Nitrogen content of 'Helleri' holy as influenced by ambient temperature and nitrogen fertilization rate. J. Environ. Hort. 1:46–48.

22. Wright, R.D., M.F. George, and D.C. Milbocker. 1978. Effects of Ocmocote rate on winter survival of two container grown azalea cultivars. S. Nurserymen's Assoc. Res. J. 5:27–34.

23. Yeager, T., C. Gilliam, T. Bilderback, D. Fare, A. Niemiera, and K. Tilt. 1997. Best Management Practices: Guide for Producing Container-grown plants. Southern Nurserymen's Assn., Marietta, GA.