who reported the water dispersable granular formulations of Pendulum and Factor were phytotoxic to *Photinia* x *fraseri* Dress while the granular formulations were not. Granular herbicides containing pendimethalin were the least injurious among the dinitroaniline herbicides; however, all granular formulations containing pendimethalin caused some lodging during this study. Consequently, granular pendimethalin formulations should not be used at potting of small pampas grass liners. The non-dinitroaniline herbicides (Ronstar and Regal O-O) appear safe for use on small pampas grass liners at potting.

Literature Cited

1. Davies, F.T. Jr. and S.A. Duray. 1992. Effect of preemergent herbicide application on rooting and subsequent liner growth of selected nursery crops. J. Environ. Hort. 10:181–186.

2. Gilreath, J.P. 1985. Response of statice to selected herbicides. HortScience 20:1068–1069.

3. Glaze, N.C., M. Singh, and S.C. Phatak. 1980. Response of pampas grass and two azalea cultivars to alachlor, oxadiazon, and oxyfluorfen. Proc. Weed Sci. Soc. Amer. 229:32.

4. Glaze, N.C., M. Singh, and S.C. Phatak. 1981. Orzyalin for weed control in container-grown pittosporum, cleyera, gardenia, pampas grass, liriope, and aucuba. Proc. Southern Nurserymen's Assoc. Res. Conf. 26:235.

5. Neal, J.C. and A.F. Senesac. 1991. Preemergent herbicide safety in container-grown ornamental grasses. HortScience 26:157–159.

6. Stamps, R.H. and C.A. Neal. 1990. Evaluation of dinitroaniline herbicides for weed control in container landscape plant production. J. Environ. Hort. 8:52–57.

7. Thetford, M. and C.H. Gilliam. 1991. Herbicide use in propagation: effects on rooting and root growth of stem cuttings. J. Environ. Hort. 9:21–23.

8. Wehtje, G.R., C.H. Gilliam, and B.F. Hajek. 1993. Adsorption, desorption, and leaching of oxadiazon in container media and soil. HortScience 28:126–128.

9. Wehtje, G.R., C.H. Gilliam, and B.F. Hajek. 1994. Adsorption, desorption, and leaching of oryzalin in container media and soil. HortScience 29:824.

Nitrogen Nutrition of Containerized *Cupressus arizonica* var. *glabra* 'Carolina Sapphire'[1]

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Abstract

Rooted stem cuttings of 'Carolina Sapphire' smooth Arizona cypress [*Cupressus arizonica* var. *glabra* (Sudw.) Little 'Carolina Sapphire'] grown in calcined clay in 3.8 liter (#1) containers were fertilized daily for 16 weeks with a complete nutrient solution containing 0, 20, 40, 80 or 160 mg N/liter supplied as ammonium nitrate. Plant heights and stem diameters were unaffected by N rate suggesting that a daily nutrient application of 20 mg N/liter was adequate for maximizing growth. Nitrogen fertilization increased heights and stem diameters by 71% and 56%, respectively, compared to the nontreated controls (0 mg N/liter). Even though shoot growth was unaffected by increasing N levels, foliage N concentration was positively correlated ($r = 0.75$, $P < 0.0001$) to N levels. As N concentration increased, total root area and total root length increased quadratically. Nitrogen fertilization increased root area and root length 119% and 108%, respectively, compared to the nontreated controls. Phosphorus concentration of shoots increased quadratically with increasing N levels. Nitrogen rate failed to affect K concentration of shoots. Shoot Ca and Mg concentrations decreased with increasing N levels.

Index words: fertilization, conifer, foliar analysis, arcillite, container production, mineral nutrition.

Significance to the Nursery Industry

'Carolina Sapphire' smooth Arizona cypress [*Cupressus arizonica* var. *glabra* (Sudw.) Little] is a versatile, fast growing evergreen tree which can be utilized as a specimen plant, an attractive screen or as a Christmas tree. Since its introduction in 1987, interest and subsequent demand for this cultivar have increased, accompanied by a need for information related to container production. Maximum shoot growth and excellent root growth of 'Carolina Sapphire' were realized by daily application of a complete nutrient solution containing 20 mg N/liter. Rates of N > 20 mg/liter failed to stimulate additional shoot growth although N concentrations of shoots increased with higher rates of N. Even though additional N was absorbed at higher rates, there were no further growth benefits, and leaching of N would certainly increase with increasing N concentration. Thus, high N substrate concentrations should be avoided during production of 'Carolina Sapphire' smooth Arizona cypress.

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Introduction

'Carolina Sapphire' smooth Arizona cypress has potential in the nursery and Christmas tree industries due to its fast growth, drought tolerance, and blue gray foliage. Native primarily to central Arizona (16), smooth Arizona cypress is typically found at elevations ranging from 1400 to 2200 m (4600 to 7200 ft) and reaches heights of 7 to 15 m (25 to 50 ft). 'Carolina Sapphire' forms a broad pyramidal crown with an open growth habit. It has an extremely fast growth rate of up to 1.8 m (6 ft) per year on young plants (3).

Since the commercial value of woody landscape species is generally based on size (height and stem diameter), a nutrient regime that maximizes shoot growth with a minimum amount of fertilizer is desirable (14). Such a regime will maximize profits while minimizing salt build-up in the substrate and potential environmental pollution. Since N typically elicits the greatest growth response in plants (12), N fertility for 'Carolina Sapphire' deserves further study.

Plant response to N varies with species, frequency of application, method of application, and concentration. Landis et al. (12) reported a general recommendation for conifers under constant fertilization of 100 to 150 mg N/liter. Jull et al. (11) demonstrated that 25 mg N/liter applied three times weekly promoted maximum growth of 'Elegans Aurea' Japanese cedar [*Cryptomeria japonica* (L.f.) D. Don 'Elegans Aurea']. Henry et al. (5) reported optimal growth in eastern redcedar (*Juniperus virginiana* L.) with 115 mg N/liter applied weekly. Other research on Douglas fir [*Pseudotsuga menziesii* (Mirb.) Franco] and Sitka spruce [*Picea sitchensis* (Bong.) Carr.] indicated that daily applications of 50 mg N/liter maximized growth (20). Due to lack of a fertilization protocol for 'Carolina Sapphire' smooth Arizona cypress, the objective of this study was to determine the influence of N concentration on growth and mineral nutrient status of containerized 'Carolina Sapphire' smooth Arizona cypress.

Methods and Materials

On April 19, 1995, uniform, unbranched, rooted stem cuttings of 'Carolina Sapphire' smooth Arizona cypress were potted in 3.8 liter (#1) black plastic containers with arcillite, a calcined, montmorillonite and illite clay. Arcillite was selected as a substrate because it allows recovery of intact root systems at harvest (6) and releases minimal amounts of mineral nutrients into the substrate solution (21). A preliminary study demonstrated that 'Carolina Sapphire' smooth Arizona cypress responded similarly when grown in a substrate of milled pine bark [(<13 mm) (0.5 in)]:sand (8:1 by vol) or arcillite (data not presented). In the present study, plants were grown in a glass greenhouse under natural photoperiod and irradiance with day/night temperatures of 27 ± 5C (80 ± 9F) /21 ± 5C (70 ± 9F).

Table 1. Source and concentration of mineral nutrients in the nutrient solution.

Mineral nutrient	Source	Concn. (mg/liter)
N	NH_4NO_3	0, 20, 40, 80, or 160
P	$K_2H_2PO_4$	20
K	K_2SO_4	50
Ca	Ca acetate	50
Mg	$MgSO_4$	25
Fe	Iron chelate	5.0
B	H_3BO_3	0.5
Cu	$CuSO_4$	0.02
Mn	$MnCl_2$	0.5
Mo	$(NH_4)_6(Mo_7O_{24})$	0.1
Zn	$ZnSO_4$	0.05

The experiment, a randomized complete block design with 10 single-plant replications, consisted of five N concentrations (0, 20, 40, 80 or 160 mg N/liter) supplied daily as ammonium nitrate. Most conifers respond better to ammonium nitrate as the N source than either ammonium or nitrate alone (10, 18). All other mineral nutrients (P, K, Ca, Mg, Fe, B, Cu, Mn, Mo, and Zn) were present at constant levels (Table 1). Nutrient solutions were composed of reagent grade chemicals dissolved in tap water. Tap water contained 0.10, 0.0, 0.5, 4.0, 20.0 and 2.0 mg/liter NO_3, NH_4, P, K, Ca, and Mg, respectively, with a pH of 7.0. All nutrient solutions were adjusted to pH 6.0 using 1N H_2SO_4. Three weeks after potting, N treatments were initiated. Eight hundred ml of nutrient solution was applied daily at 0900 HR to each container. No other irrigation was needed throughout the study.

At treatment initiation, plant heights and stem diameters were taken at the surface of the substrate. In addition, five plants were harvested to determine initial nutrient concentration of shoots (aerial tissue), root dry weight, and shoot dry weight. Initial shoot mineral nutrient concentrations for N, P, K, Ca, and Mg were 1.16%, 0.15%, 0.63%, 0.93%, and 0.23%, respectively. Initial heights and stem diameters were 22 cm (8.7 in) and 2.3 mm (0.09 in), respectively.

After 16 weeks, plant heights and stem diameters were measured, roots were washed free of arcillite and each plant separated into shoots and roots. All tissue was dried at 70C (158F) for 72 hr. Before drying, total root length and total root area of three randomly chosen replications per treatment were measured using a Monochrome Agvision System 286 Image Analyzer (Decagon Devices, Inc., Pullman, WA). Height, stem diameter, total root length, and total root area were used to calculate the following: relative growth rate of height and stem diameter per day [RGR = (log final measurement – log initial measurement) ÷ 114], percent increase in height and stem diameter {[(final measurement – initial measurement) ÷ initial measurement] × 100}, estimated mean root diameter [ERD = (root area ÷ root length) ÷ 3.1416] and root area to root length ratio (RA:RL = root area ÷ root length).

Following drying, shoots were ground in a Wiley mill to pass a 40-mesh [0.425 mm (0.017 in)] screen. Tissue samples [1.3 g (0.04 oz)] were combusted at 490C (914F) for 6 hr. The resulting ash was dissolved in 10 ml 6 N HCl and the volume adjusted to 50 ml with deionized, distilled water. Phosphorous, K, Ca, and Mg concentrations were determined by inductively coupled plasma emission spectroscopy (P2000; Perkin Elmer, Norwalk, CT). Nitrogen was determined using 10 mg (0.00035 oz) samples in a CHN analyzer (PE 2400, Perkin Elmer).

Data were subjected to regression analyses. Analyses showed statistical significance for most growth measurements only if the nontreated control (0 mg N/liter) was included. Therefore, the nontreated control was excluded from the regression analyses and a linear contrast was used to test for differences between a pooled N treatment effect and nontreated control (15).

Table 2. Effect of N concentration on various growth measurements and growth ratios of 'Carolina Sapphire' smooth Arizona cypress.

Nitrogen concn. (mg/liter)	Height (cm)	Stem diam. (mm)	Total root area (cm^2)	Total root length (m)	RA:RL[z]
0	28	3.4	193	2.9	0.067
20	49	5.0	488	6.8	0.072
40	42	4.8	373	5.5	0.067
80	48	5.5	281	4.3	0.065
160	51	5.6	552	7.5	0.074
Significance[y]					
Linear	NS	NS	*	*	*
Quadratic	NS	NS	*	*	*
N rate vs. control[x]	***	***	*	**	NS

[z]RA:RL = total root area ÷ total root length.

[y]NS, *, **, *** Nonsignificant or significant at $P \leq 0.05$, $P \leq 0.01$ or $P \leq 0.001$, respectively. Zero rate not included in regression analysis.

[x]Linear contrast. N rate = pooled nitrogen treatment. Control = 0 mg N/liter.

Results and Discussion

Height, stem diameter, relative growth rates of height and stem diameter, and percent increase in height and stem diameter responded similarly. Therefore, of these data, only height and stem diameter are presented.

Neither height nor stem diameter was affected by N rate, suggesting that under the conditions by which this research was conducted, 20 mg/liter was adequate for maximum growth (Table 2). This agrees with other fertility studies conducted with various conifers (11, 20). However, this N concentration is low when compared to some general recommendations of 100 to 150 mg N/liter (10, 12, 23). Hypotheses for the low N requirement may be that 'Carolina Sapphire' requires little N or the daily nutrient solution application maximized growth at a lower N concentration. Elliott and Nelson (2) and Landis et al. (12) reported that if nutrient levels are maintained at a constant level, maximum growth can be obtained at reduced nutrient concentrations, supporting the latter hypothesis. This hypothesis is supported by studies conducted with controlled-release fertilizers (CFRs). These products are formulated to maintain relatively constant substrate solution concentrations that can maximize growth at lower than commonly recommended nutrient concentrations (13, 19, 21). Although shoot growth was unaffected among levels of N, addition of N increased height growth by 71% and stem diameter by 53% when compared to nontreated controls (0 mg N/liter) [48 vs. 28 cm (18.9 vs. 11.0 in) and 5.2 vs. 3.4 mm (0.20 vs. 0.13 in), respectively]. Plants not receiving N (0 mg/liter) were stunted and chlorotic.

Both total root area and total root length exhibited a quadratic response to increasing N concentration (Table 2). This result was somewhat unexpected since previous studies with Formosa pine (*Pinus taiwanensis* Hayata) (1), Taiwan Douglas fir (1) and 'Elegans Aurea' Japanese cedar (11) reported total root length decreased with increasing N concentration. However, Hummel et al. (7) working with mountain laurel (*Kalmia latifolia* L.) determined N levels failed to affect root length. Although root area and root length responded similarly to N rate, there was a proportionally greater change in root area compared to root length. This is illustrated by the quadratic response of the root area:root length ratio to increasing N concentration (Table 2). Nitrogen increased root area and root length 119% and 107% [423 cm^2 vs. 193 cm^2 (65.6 in^2 vs. 29.9 in^2) and 6.0 m vs. 2.9 m (6.6 yd vs. 3.2 yd)], respectively, compared to the nontreated controls. Estimated mean root diameter was not affected by N concentration (data not presented).

Nitrogen concentration in shoots of 'Carolina Sapphire' smooth Arizona cypress increased with increasing levels of N (Table 3). Similar results have been reported for eastern redcedar (5), Fraser fir [*Abies fraseri* (Pursh) Poir.] (22), and

Table 3. Effect of N concentration on percent mineral nutrient concentration in shoots of 'Carolina Sapphire' smooth Arizona cypress.

Nitrogen concn. (mg/liter)	Mineral nutrient (% dry weight)				
	N	P	K	Ca	Mg
0	0.88	0.12	1.22	1.42	0.25
20	1.55	0.19	1.60	1.45	0.29
40	2.09	0.23	1.47	1.24	0.25
80	2.20	0.27	1.52	1.20	0.26
160	2.30	0.26	1.47	1.06	0.22
Significance[z]					
Linear	***	***	NS	***	***
Quadratic	***	***	NS	***	NS
N rate vs. control[y]	***	***	***	**	NS

[z]NS, *, **, *** Nonsignificant or significant at $P \leq 0.05$, $P \leq 0.01$ or $P \leq 0.001$, respectively. Zero rate not included in regression analysis.

[y]Linear contrast. N rate = pooled nitrogen treatment. Control = 0 mg N/liter.

Douglas fir and Sitka spruce (20). However, Jull et al. (11) reported that shoot N concentration of 'Elegans Aurea' Japanese cedar was not affected by N levels. Even though shoot growth was not influenced by increasing N rate, shoot N concentration was positively correlated ($r = 0.75$, $P < 0.0001$) to N levels. This would aid in minimizing N losses if excessive N was applied. Shoot P concentration increased quadratically with increasing N levels. Nitrogen reportedly suppresses uptake of P (17), but more recent investigations have supported results of the present study (5, 11). Shoot N and P concentrations were within ranges reported for other conifers (4, 8, 9). Nitrogen rate failed to affect shoot K concentration, but N application increased K concentration 25% compared to nontreated controls (0 mg N/liter) (1.52% vs. 1.22%). Shoot Ca and Mg concentrations decreased with increasing N levels (Table 3). This finding is supported by other fertility studies (5, 11). Reduced levels of Ca and Mg can be attributed to antagonistic effects between cations in the substrate solution competing for uptake by the roots (4, 17).

Growth of 'Carolina Sapphire' smooth Arizona cypress was maximized at a comparatively low application rate of N (20 mg/liter). Although additional N was absorbed at higher rates, there were no further growth benefits, and leaching of N would certainly increase with increasing N concentration. Thus, high N substrate concentrations should be avoided during production of 'Carolina Sapphire' smooth Arizona cypress.

Literature Cited

1. Chiang, C.H., Y.N. Wang, S.T. Lin, S.H. Wu, S.H. Sheu, and K.C. Chang. 1989. Water culture study on *Pinus taiwanensis* and *Pseudotsuga wilsoniana* (II). Growth characteristics of four-month-old-seedlings. J. Expt. For. Natl. Taiwan Univ. 3:21. (Abstr.)

2. Elliott, G.C. and P.V. Nelson. 1983. Relationships among nitrogen accumulation, nitrogen assimilation and plant growth in chrysanthemums. Physiol. Plant. 57:250–259.

3. Foley, T. and J.C. Raulston. 1994. *Cupressus* evaluation in the NCSU Arboretum. Proc. Southern Nurserymen's Assoc. Res. Conf., 39th Annu. Rpt. p. 369–373.

4. Fowells, H.A. and R.W. Krauss. 1959. The inorganic nutrition of loblolly pine and Virginia pine with special references to nitrogen and phosphorus. Forest Sci. 5:95–112.

5. Henry, P.H., F.A. Blazich, and L.E. Hinesley. 1992. Nitrogen nutrition of containerized eastern red cedar. I. Growth, mineral nutrient concentrations, and carbohydrate status. J. Amer. Soc. Hort. Sci. 117:563–567.

6. Hiller L.K. and D.C. Koller. 1979. Potato growth responses in arcillite and sand. HortScience 14:534–536.

7. Hummel, R.L., C.R. Johnson, and O.M. Lindstrom. 1990. Root and shoot growth responses in three container-grown *Kalmia latifolia* L. cultivars at two locations to growing medium and nitrogen form. J. Environ. Hort. 8:10–13.

8. Ingestad, T. 1959. Studies on the nutrition of forest tree seedlings: II. Mineral nutrition of spruce. Physiol. Plant. 12:568–593.

9. Ingestad, T. 1960. Studies on the nutrition of forest tree seedlings. III. Mineral nutrition of pine. Physiol. Plant. 13:513–533.

10. Ingestad, T. 1979. Mineral nutrient requirements of *Pinus sylvestris* and *Picea abies* seedlings. Physiol. Plant. 45:373–380.

11. Jull, L.G., S.L. Warren, and F.A. Blazich. 1994. Nitrogen nutrition of containerized *Cryptomeria japonica* 'Elegans Aurea'. J. Environ. Hort. 12:212–215.

12. Landis, T.D., R.W. Tinus, S.E. McDonald, and J.P. Barnett. 1989. The container tree nursery manual. Vol. 4. Seedling nutrition and irrigation. U.S. Dept. Agr. Forest Serv., Agr. Hdbk. 674.

13. Midcap, J. T. 1993. Slow release fertilizer evaluations on Coral Bells azalea. Proc. Southern Nurserymen's Assoc. Res. Conf., 38th Annu. Rpt. p. 81–86.

14. Niemiera, A.X. and R.D. Wright. 1982. Growth of *Ilex crenata* Thunb. 'Helleri' at different substrate nitrogen levels. HortScience 17:354–355.

15. SAS Institute, Inc. 1990. SAS/STAT User's Guide. Vol. 2. SAS Institute, Inc., Cary, NC.

16. Schoenike, R.E. 1977. Assessment of gene resources in *Cupressus arizonica* in the United States. Proc. Third World Consultation on Forest Tree Breeding. Canberra, Australia, 21–26 Mar. 1977. p. 63–74.

17. Smith, P.F. 1962. Mineral analysis of plant tissue. Annu. Rev. Plant Physiol. 13:81–108.

18. Tsutsumi, T. 1962. Studies on nutrition and fertilization of some important Japanese conifers. Bul. Govt. Forest Expt. Sta. (Tokyo) 137:1–158.

19. Tucker, K. and D. Wagner. 1993. Monitoring NO_3 losses in leachates from control-release fertilizers during azalea production. Proc. Southern Nurserymen's Assoc. Res. Conf., 38th Annu. Rpt. p. 87–89.

20. van den Driessche, R. 1968. A comparison of growth responses of Douglas fir and Sitka spruce to different nitrogen, phosphorus, and potassium levels in sand culture. Can. J. Bot. 46:531–537.

21. Warren, S.L. and T.E. Bilderback. 1992. Arcillite: Effect on chemical and physical properties of pine bark substrate and plant growth. J. Environ. Hort. 10:63–69.

22. Warren, S.L., W.A. Skroch, and L.E. Hinesley. 1987. Effect of root competition and nitrogen on growth and mineral content of *Abies fraseri*. Can. J. For. Res. 17:1092–1099.

23. Wright, R.D. and A.X. Niemiera. 1987. Nutrition of container-grown woody nursery crops, p. 76–101. *In*: J. Janick (ed.). HortReviews. AVI Publishing Co., Inc., Westport, CT.