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Effects of NH_4 and NO_3 Nutrition with and without pH Adjustment on Tomato Growth, Ion Composition, and Water Relations[1]

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Abstract. **Fertilization of tomato (*Lycopersicon esculentum* Mill.) in solution culture with NH_4-N resulted in reduced shoot and root concentration of Ca, Mg, K, P, and NO_3, increased leaf and root resistances to water flux, and decreased water use efficiency as compared to plants cultured with NO_3-N. Solution adjustment to pH 6.5 decreased shoot/root fresh weight ratio with both N forms; decreased leaf diffusive resistance and water stress but increased root resistance to water flux and shoot NH_4 concentration under NH_4-N nutrition. Solution pH had little effect on tissue ion concentration.**

Ammonium-N, as compared to NO_3-N, has resulted in lower plant Ca and Mg concn and higher anion concn, especially phosphate (1, 5, 7, 14, 16, 21), produced leaf and stem lesions (9, 18), reduced growth (1, 17, 18), caused root injury (29), and inhibited water uptake and root exudation and decreased leaf water potential (24).

The detrimental effects of NH_4 nutrition have been related to root environment acidity (11, 22). Maintaining pH near neutrality has resulted in nearly normal growth of plants under NH_4-N (3, 4, 6, 7, 11, 31). The beneficial effects of acidity control have been attributed to increased Ca supply (22), a general increase in cation absorption by roots (11), or to increased conversion of NH_4 to nontoxic metabolites in the root (3, 4).

The influence of N form, with and without pH adjustment on growth, ion concn, and water relations of tomato in solution culture were determined in an attempt to elucidate the relationship between nutrition and water stress.

Materials and Methods

Seeds of Missouri breeding line 76-1-60-8 were sown in vermiculite. Fifty-four uniform seedlings were transferred 18 days later to aerated NO_3-N (12.5 meq/liter) solutions in a controlled environment chamber. Plants were supported by styrofoam stoppers, the roots extending through a central hole into the solution contained in 0.946 liter blackened glass jars. The growth chamber was maintained at 16-hr photoperiod (24°C, ca. 70% RH) and 8-hr nyctoperiod (16°C). Light intensity at plant ht was 1200–1500 ft-c.

Following 3 weeks growth in the 12.5 meq NO_3/liter solution with solution replacement on alternate days, plants were subjected to the following factorially combined treatments: 20.0 meq N/liter as NO_3-N or NH_4-N; pH regimes (no pH adjustment, pH adjustment to 4.0 or 6.5); and length of treatment (1, 2, or 3 weeks). Treatments were arranged in completely randomized design with 3 single-plant replicates. All data except initial solution pH and electrical conductivity (EC) were subjected to analysis of variance.

Solutions were formulated to supply Ca, Mg, K and H_2PO_4 at 15, 4, 6 and 1 meq/liter, respectively, and micronutrients as suggested by Hoagland (12). The only ions varying in concn besides NO_3 and NH_4 were Cl and SO_4. Solutions were prepared in 40-liter volumes and pH's were adjusted with 0.1N NaOH or HCl. Solutions in the jars were replaced on alternate days during the first 2 weeks and daily in the 3rd week.

For each of the 18 plants harvested at the end of a time period, plant fresh wt and solution use were determined gravimetrically at each solution replacement. The pH and EC of the remaining solution prior to solution replacement were determined. On the last day of each week, water losses from both intact plants and excised tops (cut under water) in 3-hr periods were determined. Shoot and root fresh wt and leaf area (Lambda portable leaf area meter, Model LI-3000) were determined.

Shoots and roots were dried in a forced-air oven at 65°C and ground in a Wiley mill to pass 20-mesh screen. Root samples were composited across time periods to increase sample size. Total Ca and Mg were determined with an atomic absorption spectrophotometer and total K with a flame photometer. Phosphorus was determined with an ammonium molybdate procedure (13). Tissue NO_3 (20) and NH_4 (19) were determined potentiometrically.

Abaxial leaf diffusive resistance (R_L) was determined with a calibrated Lambda diffusive resistance meter and a horizontal diffusion porometer (15). Leaf xylem pressure potential (ψ_p) was determined with a pressure chamber (25). Three midday determinations per plant of both R_L and ψ_p were made at 2-day intervals on each of the 18 plants harvested each week.

Results

Growth. Growth was greater with N supplied as NO_3. Plant fresh wt and leaf area increased with time under NO_3-N but remained constant under NH_4-N nutrition (Table 1). Solution pH was without effect on plant fresh wt or leaf area. Shoot/root fresh wt ratio was reduced by NO_3-N in the first week and increased by NH_4-N in the third week (Table 2). Under each pH regime, the shoot/root ratio was greater under NH_4-N, but the ratio was reduced with both N forms by solution adjustment to pH 6.5 (Table 2).

Tissue composition. Ammonium nutrition decreased the Ca, Mg, K, P, and NO_3 concn of both shoots and roots (Tables 3

Table 1. Fresh wt and leaf area of tomato plants as influenced by solution N form and length of treatment.[z]

N form	Length of treatment (weeks)	Plant fresh wt (g)	Leaf area (cm^2)
NO_3	1	204.7c	2173c
	2	291.6b	3259b
	3	393.4a	4451a
NH_4	1	119.1d	1481d
	2	118.4d	1370d
	3	125.9d	1184d

[z]Mean separation within a column by Duncan's multiple range test, 5% level.

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Table 2. Tomato shoot/root fresh wt ratio as influenced by solution N form, solution pH, and length of treatment.[z]

N form	Shoot/root fresh wt ratio					
	Weeks of treatment			pH		
	1	2	3	Control	4.0	3.5
NO_3	3.150c	3.637b	3.705b	3.611b	3.668b	3.213c
NH_4	3.756b	3.887b	4.647a	4.250a	4.180a	3.860b

[z]Mean separation within weeks of treatment or pH by Duncan's multiple range test 5% level.

and 5). In general, shoot concn of these ions decreased with increasing length of treatment. Whereas NH_4-N increased shoot NH_4 concn, it did not affect root NH_4 concn. Root Ca concn of NH_4-plants was very low, being only 2.18% that of roots grown with NO_3-N. Initial solution pH did not affect root ion concn, but changed shoot Mg, P, and NH_4 concn (Table 4). Under NO_3-N, Mg and NH_4 concn were unaffected by solution pH, but shoot P concn was increased in the order pH 6.5>pH4.0> control. Under NH_4-N, shoot P concn was unaffected by solution pH and shoot NH_4 concn was increased by adjustment to pH 6.5. As compared to the control, shoot Mg was increased by solution adjustment to pH 4.0, and adjustment to pH 6.5 gave an intermediate Mg concn.

Abaxial leaf diffusive resistance (R_L). The R_L was increased by NH_4 nutrition, especially in treatment weeks 2 and 3 (Table 6). While solution pH did not consistently affect R_L of NO_3-plants, under NH_4 nutrition R_L in treatment weeks 2 and 3 were increased in the order control>pH 4.0>pH 6.5.

Leaf xylem pressure potential (ψ_p). The ψ_p was decreased (more negative) by NH_4 nutrition during treatment weeks 2 and 3 (Table 6). While solution pH did not affect ψ_p of NO_3-plants, under NH_4 nutrition solution adjustment to pH 6.5 increased ψ_p (less negative) in the third week of treatment.

Transpiration rate. Transpiration rates for both intact plants and excised plant tops were reduced by NH_4 nutrition (Table 7). Since the interaction of N form × solution pH × treatment length was not significant, mean values for 3 weeks of treatment are shown. Solution pH under either N form did not influence the transpiration rates of intact plants. With both N forms, however, transpiration rates of excised plant shoots were increased by solution adjustment to pH 6.5. Adjustment of NH_4 solutions to pH 6.5 gave an excised shoot transpiration rate similar to that of shoots under NO_3-N without solution pH adjustment or adjustment to pH 4.0.

The difference in transpiration rates between excised shoots and intact plants was used as an estimate of root resistance to water flux. Whereas under NO_3 nutrition, the transpiration rates of intact plants and excised shoots were the same, the excised shoots of NH_4-plants showed greater transpiration rates than intact NH_4-plants. This increased root resistance under NH_4 nutrition was particularly pronounced in solutions adjusted to pH 6.5.

Table 3. The Ca, Mg, K, P, NO_3, and NH_4 concn of tomato shoots as influenced by solution N form and length of treatment.[z]

N form	Length of treatment (wks)	Shoot composition–dry wt basis					
		Ca (%)	Mg (%)	K (%)	P (%)	NO_3 (ppm)	NH_4 (ppm)
NO_3	1	3.81a	0.81a	3.66a	0.99a	13306a	292c
	2	3.34b	0.77a	3.11b	0.99ab	12903a	252c
	3	3.05b	0.62c	3.14b	0.97c	13181a	195c
NH_4	1	3.06b	0.70b	2.64c	0.97c	3600b	940a
	2	2.09c	0.51d	1.93d	0.97c	1667c	495b
	3	1.71d	0.42e	1.91d	0.98bc	1173c	504b

[z]Mean separation within columns by Duncan's multiple range test, 5% level.

Table 4. The Mg, P, and NH_4 concn of tomato shoots as influenced by solution N form and solution pH.[z]

N form	pH	Shoot composition–dry wt basis		
		Mg (%)	P (%)	NH_4 (ppm)
NO_3	Control	0.71a	0.96c	214c
	4.0	0.73a	0.99b	243c
	6.5	0.76a	1.00a	281c
NH_4	Control	0.50c	0.96c	541b
	4.0	0.58b	0.98bc	605b
	6.5	0.55bc	0.98bc	792a

[z]Mean separation within columns by Duncan's multiple range test, 5% level.

Solution uptake. Solution uptake per g plant fresh wt increase per week was greater for NH_4-plants, particularly for those plants grown in solutions adjusted to pH 4.0 (Table 7).

Solution pH and electrical conductivity. The pH of NO_3-N solutions increased to near neutrality irrespective of initial pH regime, while NH_4 nutrition resulted in solution acidification to approx pH 3.5 irrespective of initial pH regime (Table 8). Solution pH and EC values stabilized after 5–6 hr. Solution EC increased with time for both N sources with values for NH_4 solutions being greater than for NO_3 solutions initially and at the time of solution change.

Discussion

Less plant growth from NH_4 nutrition is well documented (1, 17, 18). The NH_4 ion or NH_3 has been reported to accelerate respiratory breakdown of carbohydrates (2), uncouple photosynthetic phosphorylation (10), and result in disruption of chloroplast membranes (23). The increased water stress shown by NH_4-plants (Table 6) would contribute directly to restricted growth. The toxic effect of NH_4-N on growth was further shown by the constancy of plant fresh wt and leaf area with time under NH_4-N as contrasted to their increases under NO_3-N nutrition.

The decrease in tissue Ca and Mg with NH_4 nutrition has also been well documented (1, 5, 7, 14, 16, 21). Tissue K also has been decreased by NH_4 nutrition (7, 32). In contradiction to our observed decrease, tissue P has been reported to be increased by NH_4-N (5, 16, 21). The increase in tissue NO_3 and NH_4 concn by NO_3- and NH_4-nutritions, respectively, has been reported previously (8). The reduction in tissue ion concn with increasing exposure time may be explained by growth dilution under NO_3-N. Loss of membrane integrity, possibly as a result of Ca deficiency (23, 30) under NH_4 nutrition, may explain reduced uptake and/or increased loss of ions.

Previous studies (3, 4, 31) have shown that solution pH adjustment to neutrality increased NH_4 utilization and near normal growth ensued. In this study, solution pH did not affect plant fresh wt or leaf area but initial solution adjustment to pH 6.5 resulted in reduced shoot/root fresh wt ratios of plants

Table 5. The Ca, Mg, K, P, NO_3, and NH_4 concn of tomato roots as influenced by solution N form.[z]

N form	Root composition–dry wt basis					
	Ca (%)	Mg (%)	K (%)	P (%)	NO_3 (ppm)	NH_4 (ppm)
NO_3	2.56a	0.96a	2.14a	1.12a	9674a	135a
NH_4	0.06b	0.25b	1.11b	0.99b	582b	118a

[z]Mean separation within columns by Duncan's multiple range test, 5% level.

Table 6. Abaxial leaf diffusive resistance and leaf xylem pressure potential as influenced by solution N form, solution pH, and length of treatment.[z]

N form		Leaf diffusive resistance (sec cm^{-1}) Weeks of treatment 1	2	3	Leaf xylem pressure potential (−bars) Weeks of treatment 1	2	3
NO_3	Control	3.85j	5.36ghi	5.18ghi	3.57i	4.13e	3.69hi
	4.0	3.92j	5.56gh	3.81j	3.33j	3.98efg	4.04ef
	6.5	3.60j	6.32f	3.86j	3.51ij	4.02ef	3.89fg
NH_4	Control	4.89i	19.49b	20.43a	3.58i	4.65d	6.08a
	4.0	5.65g	16.72c	14.81d	3.59hi	4.97c	5.65b
	6.5	5.04hi	12.11e	11.96e	3.78gh	4.74d	5.04c

[z]Mean separation within columns and rows for abaxial leaf diffusive resistance and for leaf xylem pressure potential by Duncan's multiple range test, 5% level.

Table 7. Transpiration rates of intact plants and excised shoots and solution uptake as influenced by solution N form and solution pH.

N form	pH	Transpiration rate (g dm^{-2} 3h^{-1})[zy] Intact plant	Excised top	Solution uptake per g fresh wt per week[zy]
NO_3	Control	2.001a	2.020b	21.77c
	4.0	2.097a	2.011b	19.39c
	6.5	2.277a	2.252a	22.66c
NH_4	Control	1.173b	1.625c	46.81b
	4.0	1.277b	1.615c	128.71a
	6.5	1.349b	1.910b	55.33b

[z]Mean separation by Duncan's multiple range test, 5% level.
[y]Values are means for the 3 weeks of treatment.

Table 8. Values initially and at time of solution replacement of solution pH and electrical conductivity.

N form	pH	Initial values[z] pH	EC (μmho cm^{-1})	Values at soln replacement[y] pH	EC (μmho cm^{-1})
NO_3	Control	4.52	2240	6.99a	3170b
	4.0	4.00	2310	7.04a	3051b
	6.5	6.50	2260	7.04a	3253b
NH_4	Control	4.64	3840	3.42b	4369a
	4.0	4.00	3310	3.42b	4378a
	6.5	6.50	3840	3.50b	4451a

[z]Mean of 36 determinations; conductivity by Yellow Springs Inst. Model 31 with YSI 3403 cell.
[y]Mean separation with columns by Duncan's multiple range test, 5% level.

grown with both N forms (Table 2). Roots of NH_4-plants grown in solutions periodically adjusted to pH 6.5 were not discolored as they were under the other pH regimes. Ammonium nutrition has been shown to cause root injury (26, 29) while maintenance of pH 7.0 has promoted root growth under NH_4 nutrition (26).

The decreased ψ_p with NH_4 nutrition (Table 6) probably resulted from increased root resistance to water flux. Slatyer (27) suggested that water uptake inhibition resulted from a change in membrane structure. Loss of membrane integrity by NH_4-induced Ca deficiency has been related to the toxic effects of NH_4 on chloroplasts (23) and mitochondria (30). The inhibiting effect of NH_4-N on water uptake in our studies was attributed to the NH_4 ion, in agreement with Quebedeaux and Ozbun (24), rather than to NH_3 as suggested by Stuart and Haddock (28) since solution pH under NH_4-N did not exceed pH 7.0.

Although water stress and leaf and root resistances to water flux were greater under NH_4 nutrition, solution uptake per fresh wt increase per week (Table 7) was increased by NH_4, implying that the reduction in tissue ion concn under NH_4-N was due primarily to nutritional rather than to water flux effects. Decreased water use efficiency with NH_4 nutrition has been observed previously (14).

Under NH_4-N, solution pH did not affect intact plant transpiration (Table 7) but did affect R_L (Table 6) suggesting that transpiration was controlled by nonleaf resistances. The increased transpiration rate of excised shoots of NH_4-fed plants at pH 6.5 was likely due to decreased R_L. Under NH_4-N, leaf resistance was lowest and root resistance highest at pH 6.5. It is possible that periodic adjustment of solution acidity gave greater NH_4 uptake and greater synthesis into organic compounds (3, 4) resulting in a more negative cellular osmotic potential. The ensuing less negative cellular turgor potential might then give a less negative ψ_p.

In contradiction to previous observations of reduced shoot NH_4 concn (3, 4, 8) with acidity control under NH_4-N, an increased shoot NH_4 concn was observed. This apparent contradiction may reflect short-lived acidity control in the low-buffered solutions. Increased NH_4-N uptake and/or increased deamination of the transport amino acids may have been involved also.

This study has shown that NH_4-nutrition resulted in fresh wt reductions because of both increased water stress and impaired ion uptake. Under NH_4-N, solution acidity control improved root growth and reduced plant water stress but was without effect on either total plant fresh wt or ion concn of roots and shoots with the exception of increased shoot NH_4-N concn.

Literature Cited

1. Barker, A. V. and D. N. Maynard. 1972. Cation and nitrate accumulation in pea and cucumber plants as influenced by nitrogen nutrition. *J. Amer. Soc. Hort. Sci.* 97:27-30.
2. ———, R. J. Volk, and W. A. Jackson. 1965. Effects of ammonium and nitrate nutrition on dark respiration of excised bean leaves. *Crop Sci.* 5:439-444.
3. ———, ———, and ———. 1966. Root environment acidity as a regulatory factor in ammonium assimilation by pea plants. *Plant Physiol.* 41:1193-1199.
4. ———, ———, and ———. 1966. Growth and nitrogen distribution patterns in bean plants (*Phaseolus vulgaris* L.) subjected to ammonium nutrition I. Effects of carbonates and acidity control. *Soil Sci. Soc. Amer. Proc.* 30:228-233.
5. Blair, F. J., M. H. Miller, and W. A. Mitchell. 1970. Nitrate and ammonium as sources of nitrogen for corn and their influence on the uptake of other ions. *Agronomy J.* 62:530-532.
6. Chouteau, J. 1963. Etude de la nutrition nitrique et ammoniacale de la plante de tabac en presence des doses croissantes de bicarbonate dans le milieu nutritif. *Ann. Inst. Expt. Tabac. Bergerac* 4:319-332.
7. de Classen, M. E. T. and G. E. Wilcox. 1974. Effect of nitrogen form on growth and composition of tomato and pea tissue. *J. Amer. Soc. Hort. Sci.* 99:171-174.
8. Dirr, M. A. 1975. Effect of nitrogen form and pH on growth, NO_3-N, NH_4-N, and total N content of container grown Doublefile Viburnum. *J. Amer. Soc. Hort. Sci.* 100:216-218.
9. Geraldson, C. M. 1957. Factors affecting Ca nutrition of celery, tomato, and peppers. *Soil Sci. Soc. Amer. Proc.* 21:621-625.
10. Gibbs, M. and N. Calo. 1959. Factors affecting light-induced fixation of CO_2 by isolated spinach chloroplasts. *Plant Physiol.* 34:318-323.
11. Gouny, P. 1955. Observations sur les particularites de l'alimentation ammoniacale en l'absence et en presence de calcaire. *Ann. Agronomique* 4:589-614.
12. Hoagland, D. R. and D. I. Arnon. 1938. The water culture method

for growing plants without soil. *Calif. Agr. Expt. Sta. Cir.* 347.
13. Jackson, M. L. 1958. Soil chemical analysis. Prentice-Hall, Englewood Cliffs, N.J.
14. Kafkafi, J. J. Walerstein and S. Feigenbaum. 1971. Effect of potassium nitrate and ammonium nitrate on the growth, cation uptake, and water requirement of tomato grown in sand culture. *Israel J. Agr. Res.* 21:13-20.
15. Kanemasu, E. T., G. W. Thurtell, and C. B. Tanner. 1969. Design, calibration, and field use of a stomatal diffusion porometer. *Plant Physiol.* 44:881-885.
16. Kirkby, E. A. and K. Mengel. 1967. Ionic balance in different tissues of the tomato plant in relation to nitrate, urea, or ammonium nutrition. *Plant Physiol.* 42:6-14.
17. Maynard, D. N., W. S. Barham, and C. L. McCombs. 1957. The effect of calcium nutrition of tomatoes as related to the incidence and severity of blossom-end rot. *Proc. Amer. Soc. Hort. Sci.* 69:318-322.
18. _____and A. V. Barker. 1969. Studies on the tolerance of plants to ammonium nutrition. *J. Amer. Soc. Hort. Sci.* 94:235-239.
19. Orion Research Incorporated. 1972. Instruction Manual- Ammonia Electrode 95-10, Cambridge, MA.
20. Paul, J. L. and R. M. Carlson. 1968. Nitrate determination in plant extracts by the nitrate electrode. *J. Agr. Food Chem.* 16:766-768.
21. Polizotto, K. R., G. E. Wilcox, and C. M. Jones. 1975. Response of growth and mineral composition of potato to nitrate and ammonium nutrition. *J. Amer. Soc. Hort. Sci.* 100:165-168.
22. Prianishnikov, D. N. 1951. Nitrogen in the life of plants (Transl. by S. A. Wilde). Kramer Business Service, Madison, WI.
23. Puritch, G. S. and A. V. Barker. 1967. Structure and function of tomato leaf chloroplasts during ammonium toxicity. *Plant Physiol.* 42:1229-1238.
24. Quebedeaux, B. and J. L. Ozbun. 1973. Effects of ammonium nutrition on water stress, water uptake, and root pressure in *Lycopersicon esculentum* Mill. *Plant Physiol.* 52:677-679.
25. Scholander, P. F., H. T. Hammel, E. D. Bradstreet, and E. A. Hemingsen. 1965. Sap pressure in vascular plants. *Science* 148:339-346.
26. Sheat, D. E. G., B. H. Fletcher, and H. E. Street. 1959. Studies on the growth of excised roots. VIII. The growth of excised tomato roots supplied with various inorganic sources of nitrogen. *New Phytol.* 58:128-141.
27. Slatyer, R. O. 1962. Internal water relations of higher plants. *Annu. Rev. Plant Physiol.* 13:351-378.
28. Stuart, M. and J. L. Haddock. 1968. Inhibition of water uptake in sugar beet roots by ammonia. *Plant Physiol.* 43:345-350.
29. Uljee, A. H. 1964. Ammonium nitrogen accumulation and root injury to tomato plants. *N.Z. J. Agr. Res.* 7:343-356.
30. Vines, H. M. and R. T. Wedding. 1960. Some effects of NH_3 on plant metabolism and possible mechanisms for ammonium toxicity. *Plant Physiol.* 35:820-825.
31. Wander, I. W. and J. W. Sites. 1956. The effects of ammonium and nitrate nitrogen with and without pH control on the growth of rough lemon seedlings. *Proc. Amer. Soc. Hort. Sci.* 68:211-226.
32. Wilcox, G. E., J. E. Hoff, and C. M. Jones. 1973. Ammonium reduction of calcium and magnesium contents of tomato and sweet corn leaf tissue and influence on incidence of blossom-end rot of tomato fruit. *J. Amer. Soc. Hort. Sci.* 98:86-89.

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Cadmium and Zinc Toxicity in White Pine, Red Maple, and Norway Spruce[1]

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Abstract. **Excessive accumulation of Cd or Zn in white pine (*Pinus strobus* L.), red maple (*Acer rubrum* L.), and Norway spruce (*Picea abies* L.), resulted in reduced root initiation, poor development of root laterals, chlorosis, dwarfism, early leaf drop, wilting, and necrosis of current season's growth. Positive correlations existed between nutrient culture levels and tissue accumulation when plants were grown in sand. White pine seedlings accumulated more Cd and Zn than either red maple or Norway spruce when compared in similar experiments. White pine appeared to be more tolerant of Cd and Zn accumulation than either red maple or Norway spruce since visual phytotoxicity symptoms were observed only at the higher treatment levels. Accumulation of Cd and Zn from a medium of 2 sand: 1 soil: 1 perlite by volume was also observed.**

The accumulation of heavy metals in trees is a factor which may contribute to stress in highway, commercial, and residential plantings. Positive correlations between heavy metal accumulation and proximity to highways has been demonstrated in areas of high traffic density (3, 9). The heavy metals cadmium and zinc could contribute to the stress of ornamental trees particularly in an urban environment.

The chemical and physical properties of Cd and Zn are similar and often sources of Cd and Zn are such that the two metals are inseparable in industrial grade chemicals. Both metals are released into the environment during the use or breakdown of lubricating oils, vehicle tires, galvanized metals, and fertilizers (5, 8). In addition, waste water from mines, smelters, and sewage treatment centers are other sources which may ultimately contribute to soil contamination (1, 2, 4, 7, 10, 12).

This study was designed to determine concentrations of Cd and Zn in leaves, stems, and roots of 3 woody ornamentals in order to ascertain foliar levels for plants displaying visual toxicity symptoms.

Materials and Methods

Two or 3-year old seedlings of red maple, white pine, and Norway spruce were grown in fiberglass greenhouses under natural daylengths with day and night temp of 27° and 15°C, respectively. All plants were planted in 0.9 liter plastic containers in a medium of acid-washed sand and irrigated with Hoagland's nutrient solution (6), supplemented with either 0, 0.5, 1, 2, 4, 8, or 16 μg/liter Cd. White pine seedlings were also treated with 32 and 64 μg/liter Cd. All 3 species were similarly exposed to 0, 6.25, 25, 50, 100, 200 and 400 μg/liter Zn. All treatments were initiated by saturating the medium with the Cd-enriched nutrient solution after the new growth had

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