

Effects of Nitrpyrin and Nitrogen Form on Tomato Growth, Water Relations, and Ion Composition¹

Wallace G. Pill and Donald L. Sparks²

Plant Science Department, University of Delaware, Newark, DE 19711

Additional index words. *Lycopersicon esculentum*, 2-chloro-6(trichloromethyl) pyridine, N-Serve, nitrate-nutrition, ammonium-nutrition, water stress.

Abstract. Nitrpyrin (NI) at 10 ppm, compared to water control, added to a soil-sand-peat medium decreased shoot growth of tomatoes (*Lycopersicon esculentum* Mill. cv. Marglobe) grown with NO₃-N nutrition but had no effect on growth with NH₄-N nutrition. While plant water stress was decreased by NI compared to the control with NO₃-N nutrition, the toxic effect of increased uncombined NH₄ concentration in the shoots may have caused the growth reduction. Denitrification suppression by NI with NO₃-N nutrition was evidenced by increased media and shoot NO₃ concentrations. Nitrification suppression by NI with NH₄-N nutrition was evidenced by increased media and shoot NH₄ concentrations. Nitrpyrin, irrespective of N form, decreased shoot Ca concentration, increased shoot K and uncombined NH₄ concentrations, and had no effect on shoot Mg concentration. Plant water stress was decreased by NI with both N forms at the third and fifth weeks after final transplanting. While NI decreased the differential effect of N form on transpiration rate and leaf diffusive resistance (R_l), in NI's absence, NH₄-N nutrition decreased transpiration and increased R_l relative to NO₃-N. Decreased shoot growth with NH₄-N relative to NO₃-N nutrition, both in the presence and absence of NI, was associated with increases in plant water stress, root hydraulic resistance, and shoot uncombined NH₄ concentration, but a decrease in shoot Ca concentration.

Nitrpyrin (2-chloro-6(trichloromethyl)pyridine), N-Serve (Dow Chemical Co.), was developed to inhibit *Nitrosomonas* spp activity (7). By inhibiting nitrification, nitrpyrin (NI) tends to conserve the more stable ammoniacal-N in the growth medium (7) and therefore would be expected to accentuate the deleterious effects of NH₄ nutrition on tomato. Toxicity symptoms of NH₄ nutrition include reduced vegetative growth (10, 17) and leaf and stem lesion formation (10). These symptoms have been linked to reduced plant Ca and Mg concentrations, increased anion concentration (8, 9), and increased uncombined NH₄ concentration in plants (2, 17). Ammonium nutrition, compared to NO₃ nutrition, increased plant water stress (18), increased root and leaf resistances to water flux (17), and decreased plant water use efficiency (8).

It has been reported recently that NI increased NO₃ retention with NO₃ fertilization in a soil-peat-sand medium (12), a pine bark-sand medium (13), and a peat-vermiculite medium (16). Nitrpyrin was hypothesized to exert an inhibitory effect on bionitrification as well as on nitrification (12). This hypothesis was further substantiated when it was found that decreased nitrous oxide generation in NI-treated media was due neither to depletion of substrate NO₃ nor inadequate carbon source (5). Since it is estimated that 10-30% of the N applied to soils is denitrified, with values often being much higher in excessively wet soils (7), a NI-mediated reduction in denitrification would be of great value in conserving medium NO₃.

In this study, tomato responses to medium-incorporated NI with NO₃-N and NH₄-N nutritions were examined. The objectives were to determine whether NI incorporation altered the deleterious and beneficial effects of NH₄-N and NO₃-N nutritions, respectively, on tomato growth.

Materials and Methods

After steam pasteurization (82°C minimum, 30 min) of a 1 Matapeake silt loam:1 sphagnum peatmoss:1 sand (by volume) medium, dolomitic lime and triple super-phosphate were incorporated at the rate of 5.5 and 2.8 kg m⁻³, respectively. To one half of the medium, an aqueous emulsion of 24E nitrpyrin (NI) was incorporated by atomization at the rate of 10 ppm (weight a.i. per medium volume). The remaining half of the growth medium received the same volume of distilled water (the control treatment).

Two weeks after sowing in vermiculite, seedlings of 'Marglobe' tomato were transplanted at 3 × 3 cm spacing in vermiculite. Eighteen days later, 48 seedlings were transplanted singly into 4.5-liter glazed ceramic pots each containing 4 liters of the growth medium.

Beginning 7 days after final transplanting, 6 weekly applications of 25 meq of NO₃-N or NH₄-N (0.35 g N) per pot were made. Nitrate-N was supplied as KNO₃, and NH₄-N as (NH₄)₂SO₄ with 1.87 g KCl to balance K. The salts were added to the medium surface and watered in.

The 2 N forms and 2 NI levels in factorial combination were arranged in randomized complete block design with 6 replications and 2 plants per replication. The staked but unpruned plants were grown under natural light (June-August) on wire mesh benches in a greenhouse maintained at 22 ± 5°C. All treatments were watered as required with the same frequency and with sufficient volume to cause a small amount of drainage through the port at the side wall base.

At 3, 5, and 7 weeks from final transplanting, 3 days after N fertilizations, two 10-ml medium samples were obtained from

¹Received for publication Aug. 17, 1981. Published with approval of the Director of the Delaware Agricultural Experiment Station as Miscellaneous Paper No. 935. Contribution No. 128 of the Plant Science Dept.

The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

²Assistant Professors. The authors acknowledge financial support from the University of Delaware Research Foundation.

a thoroughly mixed core 1–5 cm below the medium surface in each pot. Medium pH, electrical conductivity (EC), and NH_4 concentration were determined on 1 sample at 1:5, growth medium:distilled water volumetric dilution. Medium NO_3 concentration was determined potentiometrically on the other sample at a 1:5 volumetric dilution. Potentiometric methods were described previously (16).

Leaf xylem pressure potential (ψ_p), abaxial leaf diffusive resistance (R_L), and abaxial leaf transpiration rate were determined on all plants during the 3rd, 5th, and 7th week from final transplanting, 1 day after medium pH, EC, and NO_3 and NH_4 concentration determinations. Two hours after container capacity had been reached, ψ_p was determined from 1300–1430 hr on leaflets from the plant mid-portion using a pressure chamber (18). Leaflet abaxial transpiration rate and R_L were determined at 1430–1600 hr with a Li-Cor 1600 steady-state porometer.

Shoot NO_3 and uncombined NH_4 concentrations, and shoot total N, Ca, Mg, and K concentrations were determined by methods described previously (16).

After medium preparation and at the end of the study, medium total N concentration and exchangeable- NH_4 and fixed- NH_4 concentrations were determined by the methods of Orion (15), Bremner and Keeney (4), and Silva and Bremner (19), respectively.

Results and Discussion

The reduced shoot growth associated with NH_4 -N nutrition compared to that of NO_3 -N that occurred in both NI-treated and control media (Table 1) is documented (10, 17). Mills and Pokorny (13) found NI to reduce tomato growth with NH_4 -N nutrition in a 100% sand medium but to increase growth when sand was 0–75% of a pine bark:sand mix. They concluded that when pine bark comprised part of the medium, growth was enhanced by NI incorporation in part by chemical "tie-up" of NH_4 and in part by increased NO_3 retention in the medium. In the present study, shoot growth was unaffected by NI incorporation in the medium with NH_4 -N nutrition (Table 1) indicating that NI did not intensify the adverse (toxic) effect of NH_4 -N on growth.

Some studies show NI incorporation in media to have little if any effect on crop growth with 100% NO_3 -N nutrition (12, 13). In agreement with previous work (16), NI with NO_3 -N nutrition decreased shoot fresh and dry weights by 9.6 and 16.5%, respectively (Table 1). Mills and Pokorny (13) attributed increased tomato growth with NI incorporation in the media to increased NO_3 concentration when NO_3 -N comprised 0–75% of the NO_3 : NH_4 -N nutrition. In the present study, medium NO_3 concentration was increased by NI incorporation with NO_3 -N nutrition (Fig. 1) as shown by others (5, 13, 16). Since both medium NO_3 concentrations (Fig. 1) and shoot NO_3 concentration and content (Table 2) were increased by NI treatment compared to the control treatment with NO_3 -N nutrition, it can be concluded that NI suppressed denitrification, since NO_3 uptake was unhindered. The significant interaction of N form and nitrapyrin on shoot NO_3 concentration and content (Table 2) showed that nitrapyrin, compared to its absence, increased shoot NO_3 concentration and content only with NO_3 -N nutrition. This shoot NO_3 accumulation (120 and 86% increase in concentration and content, respectively) may reflect a NI-mediated reduction in nitrate reductase activity as reported by Notton et al. (14).

The decreased shoot Ca concentration and content, and yet the increased shoot uncombined NH_4 concentration with NI treat-

Table 1. Effect of nitrapyrin and N form on shoot fresh and dry weights, and shoot dry weight as a percentage of fresh weight^a

Nitrapyrin ^b	Nitrogen form ^c	Shoot fresh wt (g)	Shoot dry wt (g)	Shoot dry wt (%)
Nitrapyrin	NO_3	473.8b	58.2	12.25
Nitrapyrin	NH_4	405.7c	49.2	12.12
Water	NO_3	524.7a	69.7	13.26
Water	NH_4	402.5c	55.3	13.80

Statistical analysis				
Nitrapyrin		NS	*	*
Nitrogen form		**	*	NS
Nitrapyrin × Nitrogen form		*	NS	NS

^aMean separation within columns by Duncan's multiple range test, 5% level. Statistical analysis: NS = not significant, and significant at 5% (*) and 1% (**) levels.

^bNitrapyrin = 10 ppm wt a.i. per medium volume, applied initially.

^c25 meq NO_3 or NH_4 per pot, applied weekly.

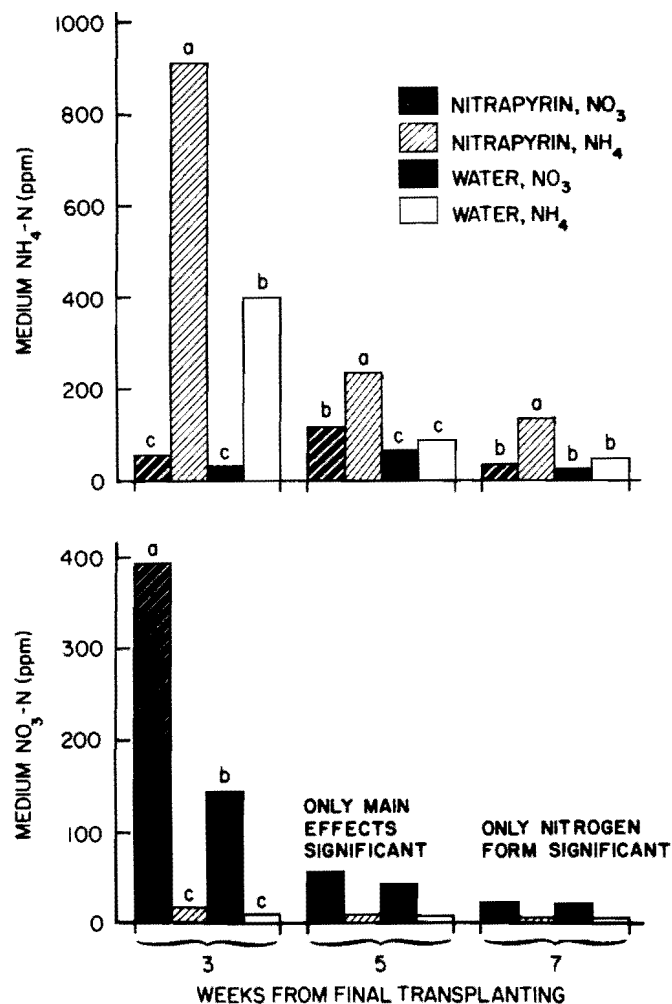


Fig. 1. Effect of nitrapyrin and N form on growth medium suspension NO_3 and NH_4 concn at 3, 5, and 7 weeks from final transplanting. Mean separation of significant interactions within a week by Duncan's multiple range test, 5% level.

Table 2. Effect of nitrapyrin and N form on shoot Ca, K, Mg, N, NH₄, and NO₃ concentration and content¹.

Treatment	Concn (dry wt basis)					
	Ca (%)	K (%)	Mg (%)	N (%)	NH ₄ (ppm)	NO ₃ (ppm)
<i>Nitrapyrin</i> ²						
Nitrapyrin	0.09	5.33	0.70	2.70	1929	1716
Water	0.11	3.88	0.70	2.37	1571	821
	*	**	NS	*	*	**
<i>Nitrogen form</i> ³						
NO ₃	0.12	4.72	0.73	2.39	1320	2210
NH ₄	0.08	4.49	0.67	2.68	2180	327
	*	NS	NS	*	**	**
Content (concentration × dry weight)						
	Ca (mg/shoot)	K (g/shoot)	Mg (mg/shoot)	N (g/shoot)	NH ₄ (mg/shoot)	NO ₃ (mg/shoot)
<i>Nitrapyrin</i> ²						
Nitrapyrin	49.08	2.85	377.83	1.43	100.83	96.42
Water	71.92	2.43	434.00	1.46	93.67	53.58
	**	*	**	NS	NS	**
<i>Nitrogen form</i> ³						
NO ₃	79.17	2.96	463.42	1.50	82.75	133.42
NH ₄	41.83	2.32	348.47	1.39	111.69	16.58
	**	*	**	NS	**	**

¹Statistical analysis by main effect for each variable significant at 5% (*) and 1% (**) levels. All nitrapyrin × nitrogen form interaction effects, except those on shoot NO₃ concentration (*) and content (*), were not significant.

²Nitrapyrin = 10 ppm wt a.i. per medium volume, applied initially.

³25 meq NO₃ or NH₄ per pot, applied weekly.

ment compared to the control treatment or with NH₄-N compared to NO₃-N nutrition (Table 2), may be explained on the basis of cation competition for absorption sites (3) or cation-anion balance (9). That both shoot K content and concentration were increased by NI treatments compared to control treatments with both N forms (Table 2) indicates that K uptake was enhanced by NI. Increased shoot K concentration and content with NI treatment compared to the control (Table 2) in plants receiving NH₄-N may be attributed to increased transpiration rate (Fig. 2). While shoot Mg concentration was unaffected by NI treatment or N form, increased shoot Mg content (Table 2) was associated with the increased growth observed in the control and NO₃-N treatments (Table 1).

Compared to the control treatment, NI increased uncombined shoot NH₄ concentration 22.8% but had no effect on shoot uncombined NH₄ content (Table 2). Shoot total N concentration likewise was increased, but total N content was unaffected by NI treatment with both N forms (Table 2). With NH₄-N nutrition, the increased shoot uncombined NH₄ and total N concentrations with NI treatment compared to the control treatment (Table 2) may be attributed at least in part to increased NH₄ uptake since exchangeable- and suspension-NH₄ concentrations were increased (Table 3 and Fig. 1). That exchangeable- and suspension-NH₄ concentrations were increased and yet suspension NO₃ concentration was unaffected by NI treatment compared to the control treatment indicates that nitrification was inhibited throughout the study.

While exchangeable NH₄ concentration was increased by NI incorporation in media with NO₃-N nutrition, presumably a result of an equilibrium shift from fixation sites and subsequent inhibition of nitrification, suspension NH₄ concentration was

increased slightly only at week 5 (Fig. 2). It has been shown in *Phaseolus* that the majority of uncombined NH₄ accumulating in leaves was from the breakdown of organic N compounds (1). The observed increased shoot uncombined NH₄ concentration in NI-treated compared to control media with NO₃-N nutrition therefore may be attributed to increased breakdown of organic N compounds, to increased NH₄ uptake, and to a concentrating effect of reduced growth.

Nitrapyrin incorporation in the media increased exchangeable NH₄ concentrations by 192% and 30% with NO₃-N and NH₄-N nutritions, respectively, by the end of the study (Table 3). All treatments, with the exception of NO₃-N nutrition in the absence of NI, resulted in increased exchangeable NH₄ concentration over the pretreatment imposition value of 11.3 ± 1.5 ppm. While exchangeable NH₄ concentration was increased by NH₄-N nutrition compared to NO₃-N nutrition in both NI-treated and control media, final suspension NH₄ concentration was increased by NH₄-N nutrition only in NI-treated media (Table 3). Final suspension NO₃ concentration was uninfluenced by NI with both N forms but was increased by NO₃-N nutrition in both NI-treated and control media.

Neither N form nor NI influenced medium total N concentration determined at the study's end (Table 3), although values were higher than the pretreatment imposition values of 1121 ± 119 ppm. Since initial and final fixed NH₄ values were below the limit of accurate estimation (< 0.1 ppm), they are not reported.

With NO₃-N nutrition, suspension NO₃ concentration was increased by NI incorporation in the media at weeks 3 and 5 by 169% and 34%, respectively (Fig. 1). This, together with the increased shoot NO₃ concentration and content, suggests that NI inhibited denitrification.

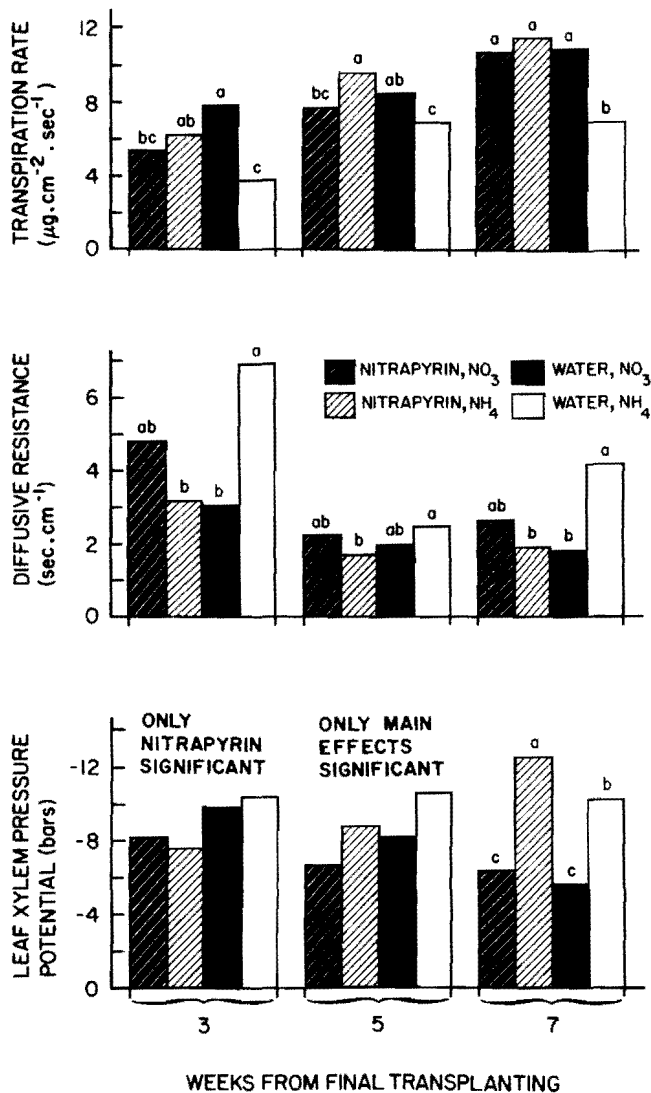


Fig. 2. Effect of nitrapyrin and N form on abaxial leaf transpiration rate, abaxial leaf diffusive resistance, and on leaf xylem pressure potential of tomato at 3, 5, and 7 weeks from final transplanting. Mean separation of significant interactions within a week by Duncan's multiple range test, 5% level.

While NI-mediated suppression of denitrification appeared to be lost between weeks 5 and 7 from final transplanting under $\text{NO}_3\text{-N}$ nutrition, NI-mediated nitrification suppression remained intact throughout the study under $\text{NH}_4\text{-N}$ nutrition (Fig. 1). Touchton et al. (20) found the NI half-life to be < 7–21 days in 2 soil series and that its disappearance rate increased with increasing soil pH. The apparent quicker NI loss from media with $\text{NO}_3\text{-N}$, compared to $\text{NH}_4\text{-N}$ nutrition, thus may be associated with the increase in medium pH with $\text{NO}_3\text{-N}$ nutrition (Table 4). Temporal pH increase with $\text{NO}_3\text{-N}$ nutrition is documented (2, 19).

In $\text{NO}_3\text{-N}$ fertilized media, pH and EC were the same in NI-treated and control media at the three measurement periods (Table 4). With $\text{NH}_4\text{-N}$ nutrition, NI incorporation increased media pH at weeks 3 and 5, and increased media EC at week 3. Ammonium-N when compared to $\text{NO}_3\text{-N}$ fertilization, in both NI-treated and control media, raised media EC and lowered pH at every measurement period. In both NI-treated and control media, pH was temporally increased under $\text{NO}_3\text{-N}$ and decreased under $\text{NH}_4\text{-N}$ nutrition (Table 4).

The NI treatment, when compared to the control, resulted in higher (less negative) ψ_p values during the third and fifth weeks from final transplanting with both N forms (Fig. 2). Reduced growth with NI- compared to control-treatment in plants receiving $\text{NO}_3\text{-N}$ thus can not be ascribed to increased plant water stress. By the seventh week, however, plant water stress was unaffected by NI with $\text{NO}_3\text{-N}$ nutrition, but was increased by NI with $\text{NH}_4\text{-N}$ nutrition.

In both NI and control treatments, subsequent to the first measurement period (week 3) at which time plant water stress was uninfluenced by N form, ψ_p increased with $\text{NO}_3\text{-N}$ nutrition. With $\text{NH}_4\text{-N}$ nutrition subsequent to week 3, ψ_p remained constant in control plants but decreased in plants subjected to NI (Fig. 2).

Reduced shoot growth with $\text{NH}_4\text{-N}$ relative to $\text{NO}_3\text{-N}$ nutrition in both NI and control treatments can be attributed at least partially to a direct effect of increased plant water stress (17) and to the toxic effects of increased shoot uncombined NH_4 concentration and content (2).

Abaxial leaf transpiration rate was increased and R_L decreased by the NI treatment compared to the control with $\text{NH}_4\text{-N}$ nutrition at every measurement period. With $\text{NO}_3\text{-N}$ nutrition, however, NI increased R_L and decreased transpiration rate at week 3 but

Table 3. Effect of nitrapyrin and N form on total N, exchangeable NH_4 , suspension NH_4 , and suspension NO_3 concentrations in the growth medium at end of study^a.

Nitrapyrin ^b	Nitrogen form ^a	Total N (ppm)	Exchangeable NH_4 (ppm)	Suspension NH_4 (ppm)	Suspension NO_3 (ppm)
Nitrapyrin	NO_3	1359	26.34	37.83b	21.18
Nitrapyrin	NH_4	1387	39.16	137.17a	9.34
Water	NO_3	1450	9.03	22.67b	21.17
Water	NH_4	1512	30.11	41.00b	8.15
Statistical Analysis					
Nitrapyrin		NS	**	**	NS
Nitrogen form	NS	**	**	*	
Nitrapyrin × Nitrogen form	NS	NS	*	NS	

^aMean separation within columns by Duncan's multiple range test, 5% level. Statistical analysis: NS = not significant, and significant at 5% (*) and 1% (**) levels.

^bNitrapyrin = 10 ppm wt a.i. per medium volume, applied initially.

^c25 meq NO_3 or NH_4 per pot, applied weekly.

Table 4. Effect of nitrapyrin and N form on growth medium suspension pH_w and electrical conductivity¹.

Nitrapyrin ²	Nitrogen form ³	Weeks after final transplanting					
		3		5		7	
		pH ^w	EC ($\mu\text{mho}\cdot\text{cm}^{-1}$)	pH _w	EC ($\mu\text{mho}\cdot\text{cm}^{-1}$)	pH ^w	EC ($\mu\text{mho}\cdot\text{cm}^{-1}$)
Nitrapyrin	NO ₃	5.92a	358	6.53a	76	6.52	77
Nitrapyrin	NH ₄	5.68b	748	5.02b	607	4.43	328
Water	NO ₃	6.08a	171	6.67a	92	6.57	70
Water	NH ₄	5.18c	427	4.33c	498	4.18	366
<i>Statistical analysis</i>							
Nitrapyrin							
Nitrogen form							
Nitrapyrin × Nitrogen form							
		NS	*	NS	NS	NS	NS
			**	*	NS	NS	NS
			**	**	*	**	**
		NS	*	NS	NS	NS	NS

¹Mean separation within columns by Duncan's multiple range test, 5% level. Statistical analysis: NS = not significant, and significant at 5% (*) and, 1% (**) levels.

²Nitrapyrin = 10 ppm wt a.i. per medium volume, applied initially.

³25 meq NO₃ or NH₄ per pot, applied weekly.

thereafter had little effect on these variables (Fig. 2). When NI was incorporated into the medium, N form had little or no effect on transpiration rate or R_L . In the absence of NI, however, transpiration rate was decreased by NH₄-N compared to NO₃-N nutritions.

Increased plant water stress with NH₄-N relative to NO₃-N nutrition may be attributable to increased shoot/root weight ratio (17) and to root injury (17). While root hydraulic conductivity increased initially, but gradually decreased during the log growth phase, root conductance (hydraulic conductivity × root area) continually increased with plant size at rates which depend on the growth rate of the root surface area (6). Increased root growth suppression with NH₄-N relative to NO₃-N nutrition during the log growth phase would therefore result in decreased root hydraulic conductance as was shown by Pill and Lambeth (17). That increased non-leaf resistance to water flux contributed at least partially to the increased plant water stress with NH₄-N relative to NO₃-N nutrition is evidenced by the minimal effect of N form on R_L with the NI treatment and yet the higher R_L value with NH₄-N relative to NO₃-N nutrition in the control treatment (Fig. 2). Since suspension EC equates to only 0.14 and 0.12 bars more negative osmotic potential with NH₄-N relative to NO₃-N nutrition, for NI and control treatments, respectively, when averaged across the three measurement periods (Table 4), it is doubtful that decreased medium osmotic potential could have contributed to the increased plant water stress with NH₄-N relative to NO₃-N nutrition.

That NI treatment, compared to the control treatment, with NH₄-N nutrition increased medium pH (Table 4) and decreased R_L and plant water stress (Fig. 2) is similar to the results of earlier work (17) in which acidity control of NH₄-N solution culture decreased R_L and plant water stress. Since acidity control under NH₄-N nutrition has been shown to decrease shoot/root fresh weight ratio (17), increased root growth relative to shoot growth as a result of the NI-mediated increased medium pH with NH₄-N nutrition may explain the lower plant water stress. By week 7 with NH₄-N nutrition, however, NI did not affect medium pH (Table 4) but did increase plant water stress presumably as a result of increased transpirational water loss (Fig. 2). While the beneficial effect of root environment acidity control with

NH₄-N nutrition has been related to increased conversion of NH₄ to non-toxic metabolites (1), shoot uncombined NH₄ concentration was increased by NI treatment compared to the control treatment with NH₄-N nutrition (Table 2). It might be hypothesized that the expected growth decrease from increased plant uncombined NH₄ concentration with NI treatment compared to the control treatment with NH₄-N nutrition may have been counteracted by decreased plant water stress so that no shoot growth differential occurred.

With NO₃-N, plant water stress magnitude appeared to be related directly to transpiration rate (and inversely to R_L) since NI treatment compared to the control treatment increased ψ_p and R_L but decreased transpiration rate (Fig. 2). Since plant osmotic adjustment is due to increased solute uptake (11), the reduced water stress with NI treatment relative to the controls with both N forms may have been the result of the 34.4% increase in shoot K concentration with NI treatments compared to control treatments (Table 2).

Literature Cited

1. Barker, A. V., R. J. Volk, and W. A. Jackson. 1966. Root environment acidity as a regulatory factor in ammonium assimilation by the bean plant. *Plant Physiol.* 41:1193-1199.
2. Barker, A. V. and H. A. Mills. 1980. Ammonium and nitrate nutrition of horticultural crops. *Hort. Rev.* 2:395-423.
3. Blair, G. 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. *Agron. J.* 62:530-532.
4. Bremner, J. M. and D. R. Keeney. 1966. Determination and isotope-ratio analysis of different forms of nitrogen in soils: III. Exchangeable ammonium, nitrate, and nitrite by extraction-distillation methods. *Soil Sci. Soc. Amer. Proc.* 30:577-582.
5. Cribbs, W. H. and H. A. Mills. 1979. Influence of nitrapyrin on the evolution of N₂O from an organic medium with and without plants. *Commun. Soil Sci. Plant Anal.* 10:785-794.
6. Fiscus, E. L. and A. H. Markhart, III. 1979. Relationships between root system water transport properties and plant size in *Phaseolus*. *Plant Physiol.* 64:770-773.
7. Huber, D. M., H. L. Warren, D. W. Nelson, and C. Y. Tsai. 1977. Nitrification inhibitors—new tools for food production. *Bio. Sci.* 27:523-529.

8. 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.
9. Kirkby, E. A. and D. A. Hughes. 1970. Some aspects of ammonium and nitrate nutrition in plant metabolism. p 69-77. In: E. A. Kirkby (ed.). *Nitrogen nutrition of the plant*. Univ. Leeds, Leeds, England.
10. Maynard, D. N. and A. V. Barker. 1969. Studies on the tolerances of plants to ammonium nutrition. *J. Amer. Soc. Hort. Sci.* 94:235-239.
11. Meira, A. and A. Poljakoff-Mayber. 1969. Effect of variations in substrate salinity on the water balance and ionic composition of bean leaves. *Israel J. Bot.* 18:99-112.
12. Mills, H. A., A. V. Barker, and D. N. Maynard. 1976. Effects of nitrapyrin on nitrate accumulation in spinach. *J. Amer. Soc. Hort. Sci.* 101:202-204.
13. Mills, H. A. and F. A. Pokorny. 1978. The influence of nitrapyrin on N retention and tomato growth in sand-bark media. *J. Amer. Soc. Hort. Sci.* 103:662-664.
14. Notton, B. A., E. F. Watson, and E. J. Hewitt. 1979. Effects of N-Serve (2-chloro-6-(trichloromethyl)pyridine) formulations on nitrification and on loss of nitrate in sand culture experiments. *Plant & Soil* 51:1-12.
15. Orion Research Incorporated. 1978. Instruction manual (for) ammonia electrode model 95-10. Cambridge, Mass.
16. Pill, W. G. 1981. Effect of nitrapyrin and nitrate level on growth, elemental composition, and water relations of tomato grown in peat-vermiculite. *J. Amer. Soc. Hort. Sci.* 106:285-289.
17. Pill, W. G. and V. N. Lambeth. 1977. Effects of NH₄ and NO₃ nutrition with and without pH adjustment on tomato growth, ion composition, and water relations. *J. Amer. Soc. Hort. Sci.* 102:78-81.
18. Scholander, P. F., H. T. Hammel, E. D. Bradstreet, and E. A. Hemingsen. 1965. Sap pressures in vascular plants. *Science* 148:339-346.
19. Silva, J. A. and J. M. Bremner. 1966. Determination and isotopic ratio analysis of different forms of nitrogen in soils. V. Fixed ammonium. *Soil Sci. Soc. Amer. Proc.* 30:587-594.
20. Touchton, J. T., R. G. Hoelt, L. F. Welch, and W. L. Argyilan. 1979. Loss of nitrapyrin from soils as affected by pH and temperature. *Agron. J.* 71:865-869.