Growth Suppression and Raised Tissue Cl⁻ Contents in NH₄⁺-fed Marigold, Petunia, and Salvia

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Abstract. *Ageratum houstonianum* Mill. (tolerant), *Tagetes patula* L. (French marigold, very sensitive), *Petunia hybrida* Vilm. (sensitive), and *Salvia splendens* F. Sellow et. Roem & Schult. (very sensitive) were grown with NO₃⁻, NH₄⁺NO₃⁻, or NH₄⁺ as the N source to examine whether NH₄⁺-related growth suppression (NH₄⁺-RGS) in the NH₄⁺-sensitive species was associated with excessive Cl⁻ absorption from the nutrient solution. Amounts of Cl⁻ applied were 4 or 11 meq-liter⁻¹ (Expt. 1) and 0 or 4 meq-liter⁻¹ (Expt. 2). When fertilized with NH₄⁺ as a sole N source, marigold, petunia, and salvia showed NH₄⁺-RGS symptoms with yield reduction regardless of altered Cl⁻ levels in the nutrient solution, while ageratum showed no such symptoms. When grown with NH₄⁺ solution, these sensitive plants had shoot fresh and dry weight reductions of ≈ 50% compared to those grown with the NH₄⁺ + NO₃⁻ solution. Plants fertilized with NH₄⁺ showed more severe NH₄⁺-RGS symptoms when grown in rockwool (RW) than in peat-lite mix (PL). The NH₄⁺-grown plants contained more NH₄⁺ and much more Cl⁻ in the tissue than plants fertilized with NO₃⁻ or NH₄⁺ + NO₃⁻, irrespective of the Cl⁻ level in the nutrient solution. However, NH₄⁺-RGS symptoms in marigold, petunia, and salvia appear to be caused by the uptake of NH₄⁺, but not in association with Cl⁻ from the nutrient solution.

The anion and cation charge balance in nutrient solutions involving different N forms is complicated. Nitrate solutions are accompanied by raised concentrations of cations, while NH₄⁺ solutions are accompanied by raised concentrations of anions in the solution. Differences in plant growth and tissue ion contents often result from variations in the relative ratios of NH₄⁺ to NO₃⁻ and its effect on the balances of other ions in the nutrient solution. For example, tissues of plants fertilized with NH₄⁺ contained sharply reduced levels of Ca²⁺ and Mg²⁺ (Barker and Maynard, 1972) and increased amounts of P and S (Blair et al., 1970) compared to those of the NO₃⁻-fertilized plants.

Evidence for the essential role of Cl⁻ in higher plants has been documented (Bove et al., 1963; Broyer et al., 1954; Hind et al., 1969). Plants normally accumulate Cl⁻ to the extent of 50 to 500 μmol-g⁻¹ dry weight; halophytes accumulate even more (Clarkson and Hanson, 1980). Chloride is a readily transported anion and is tolerated over a wide concentration range (Clarkson and Hanson, 1980). An increased Cl⁻ salinity, however, retards the formation and differentiation of leaf primordia (Gausman and Cardenas, 1968) and cell division (Stronogonov, 1962), while reducing crop yield (Cole, 1985).

A close relationship between Cl⁻ and NO₃⁻ uptakes was found in many plants, where nitrate inhibits Cl⁻ influx (Glass and Siddiqi, 1985; Grazyna et al., 1988; Kafkafi et al., 1982; Smith and Fox, 1977; Weigel et al., 1973). Jeong (1990) found extremely high levels of Cl⁻ in the tissues of NH₄⁺-fertilized bedding plants, but relatively lower Cl⁻ contents in NO₃⁻-fer-

tilized plants. It was also found that marigold and salvia were extremely sensitive to NH₄⁺ as a sole N source. While most other species tested showed a moderate sensitivity, ageratum was found to be tolerant to NH₄⁺ as a sole N source.

Experiments were conducted to examine whether the growth disturbance of the species sensitive to NH₄⁺ nutrition was caused by increased Cl⁻ absorption from the nutrient solution containing NH₄⁺ or by NH₄⁺ toxicity.

Materials and Methods

For Expt. 1, seeds of *Ageratum houstonianum* 'Blue Blazer', *Tagetes patula* (French marigold) 'Inca Yellow', *Petunia hybrida* 'Red Flash', and *Salvia splendens* 'Red Hot Sally' were sown in plug trays (648 cells per tray) containing PL mix (Sunshine Mix #3, Fisons, Vancouver, B.C.) on 1 Sept. (ageratum, petunia, and salvia) or 6 Sept. 1988 (marigold) and germinated under intermittent mist for 6 days. Seedlings at the two to three true leaf stage were transplanted on 4 Oct. into cellpacks (5.5 × 5.0 × 5.5 cm) using PL mix (Sunshine Mix #2, Fisons) or RW cubes (5.5 × 5.0 × 5.5 cm) (Grodania, Denmark). For Expt. 2, seedlings of ageratum 'Blue Blazer', petunia 'Red Flash', and salvia 'Red Hot Sally' grown in plug trays (406 cells per tray) at Tagawa Greenhouses (Brighton, Colo.) were transplanted at the two to three true leaf stage into PL or RW in cellpacks on 8 Apr. (ageratum and salvia) and 10 Apr. 1989 (petunia).

The transplanted seedlings were watered with a large quantity of deionized water for 2 days to allow nutrient leaching from the growing media until the treatments started. Plants were treated with nutrient solutions containing NO₃⁻, NH₄⁺, + NO₃⁻, and NH₄⁺ as N sources (Table 1). The amounts of macroelements were varied to fix the total concentration of anions and cations in each solution at 50 meq-liter⁻¹. For Expt. 1, the total solution N concentration was also fixed at 16 meq-liter⁻¹ and the two

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Abbreviations: EC, electrical conductivity; ICP, inductively coupled agron plasma; PL, peat-lite; RGS, related growth suppression; RW, rockwool.

Table 1. Ion concentrations of the nutrient solutions used in experiments.^z

N source	Cl ⁻ level (meq·liter ⁻¹)	Ion concentration (meq·liter ⁻¹)							Total
		K ⁺	Ca ²⁺	Mg ²⁺	NH ₄ ⁺	NO ₃ ⁻	SO ₄ ²⁻	H ₂ PO ₄ ⁻	
<i>Expt. 1</i>									
NO ₃ ⁻	4	6	10	9	0	16	3	2	50
NH ₄ ⁺ + NO ₃ ⁻	4	6	6	5	8	8	11	2	50
NH ₄ ⁺	4	6	2	1	16	0	19	2	50
NH ₄ ⁺	11	6	2	1	16	0	12	2	50
<i>Expt. 2</i>									
NO ₃ ⁻	0	5	11	9	0	15	7	3	50
NO ₃ ⁻	4	5	11	9	0	15	3	3	50
NH ₄ ⁺ + NO ₃ ⁻	0	5	6	5	9	9	13	3	50
NH ₄ ⁺ + NO ₃ ⁻	4	5	6	5	9	9	9	3	50
NH ₄ ⁺	0	6	6	4	9	0	22	3	50
NH ₄ ⁺	4	6	6	4	9	0	18	3	50

^zEach solution contained (μM) 46.3 B, 0.31 Cu, 28.3 Fe (FeEDDHA), 9.10 Mn, 0.52 Mo, and 0.76 Zn. pH was adjusted to 6.0 with 2 N KOH and 2 N H₂SO₄ solutions.

NH₄⁺ treatments contained the same amounts of all the other ions but 4 or 11 meq·liter⁻¹ Cl⁻ in combination with 19 or 12 meq·liter⁻¹ SO₄²⁻, respectively. The NO₃⁻ and the NH₄⁺, + NO₃⁻ treatments also contained 4 meq·liter⁻¹ Cl⁻ in the solution. For Expt. 2, six nutrient solutions, two for each N source with and without Cl⁻ (4 meq·liter⁻¹), were used. The total solution N concentrations were 15 and 18 meq·liter⁻¹ for the NO₃⁻ and the NH₄⁺ + NO₃⁻ treatments, respectively. In the NH₄⁺ solution, the total N concentration was lowered to 9 meq·liter⁻¹ in an attempt to reduce NH₄⁺-RGS.

Plants were watered as needed with the treatment solution using a hand-held watering can dedicated to each solution. The experiments were conducted in a fiberglass greenhouse and daily average air temperature, relative humidity, and radiation ranged from 17.9 to 21.1°C, 52% to 95%, and 135 to 235 W·m⁻², respectively. At the end of each experiment, plant height and shoot fresh and dry weights were determined. The replicated samples of dried tissue and growing media were combined separately for each treatment and ground for analyses.

Tissue and soil samples were analyzed at the Colorado State Univ. Soil Testing Laboratory using methods described by Workman et al. (1988) with modifications. All plant samples were tested for total N, NH₄⁺, -N, NO₃⁻-N, P, K⁺, Ca²⁺, Mg²⁺, Cl⁻, and S. Soil samples were tested for pH and electrical conductivity (EC) in addition to those ions tested for tissue samples.

For total N determination, 0.20-g tissue or 0.30-g soil of well-mixed samples was weighed into a 75-ml Kjeldahl tube. After adding a catalyst (K₂SO₄/CuSO₄/pumice) and 5 ml of concentrated sulfuric acid, samples per set were digested for 5 h at 350°C. Total N was determined using a calorimetric flow injector (Lachat Instruments, Mequon, Wis.). Two wavelengths, 630 and 520 nm, were used for NH₄⁺ and NO₃⁻, respectively. The results of the analyses were based on at least four calibration standard concentrations and a control standard placed in every 10 or 15 samples.

Tissue NH₄⁺-N, NO₃⁻-N, and Cl⁻ were extracted out from a 1-g sample with 25 ml (2%) acetic acid for 1 h on a shaker. Soil NH₄⁺-N and NO₃⁻-N were extracted from 2-g samples with 50 ml 2 M KCl solution. The mixture of sample and extracting solution was then filtered through one layer of qualitative P5 filter paper (Fisher Scientific, Pittsburgh). The filtrate was injected into the flow injector for NH₄⁺-N and NO₃⁻-N determination. Tissue Cl⁻ content was determined using a Cl⁻-specific

electrode (Combination Cl 96-17-00, Orion Research, Boston) combined with a pH/mv meter.

Tissue and soil total S was measured using a S determinator (Sulfur Determinator SC132, Leco Corp., St. Joseph, Mich.). About 0.1 to 1.0 g of sample was combusted in an O₂ atmosphere where the S was oxidized to SO₂, which was measured by a solid state infrared detector.

To determine the rest of the elements in the tissue, samples were digested overnight in a block on a hot plate (Model P.C.-100, Corning Glass Works, Corning, N.Y.) with concentrate HNO₃ until the digestant dried out. The dried digestant was then suspended in 5 ml (25%) HNO₃ and left for precipitation. The clear top portion was decanted and analyzed with inductively coupled argon plasma (ICP) (975 Plasma Atomcomp, Jarrell-Ash, Franklin, Mass.).

For determination of pH, EC, and the rest of elements in the growing medium, samples were extracted with distilled and deionized H₂O for 24 h at saturation and then filtered through one layer of P5 filter paper. EC and pH were determined using a pH meter and an EC meter (Model CDM3; Radiometer, Copenhagen, Denmark), respectively. Other ions were determined as tissue samples using ICP.

Each experiment consisted of three replications, each with three cellpacks of six cells. A completely randomized-block design was used. Data for each species in each experiment were analyzed separately using the SAS (Release 6.03 by SAS Institute, Cary, N.C.) general linear models procedure.

Results and Discussion

Ageratum grew equally well in all treatments except for NO₃⁻ alone, which suppressed growth significantly (Table 2). In PL, shoot fresh and dry weights of ageratum grown with NH₄⁺ as a sole source of N plus 4 or 11 meq·liter⁻¹ Cl⁻ were slightly higher than those from NH₄⁺ + NO₃⁻. Plant growth was similar with 4 and 11 meq·liter⁻¹ Cl⁻ when the N source was NH₄⁺. In RW, height and shoot fresh weight were reduced by NH₄⁺ compared to NH₄⁺ + NO₃⁻. However, height and shoot fresh weight were not affected by Cl⁻ levels in the NH₄⁺ treatments. Nitrogen source, growing medium, solution Cl⁻ level, and interactions between N source and growing medium significantly affected growth of ageratum.

When ageratum was grown with three different N sources, with and without 4 meq·liter⁻¹ Cl⁻ ions in Expt. 2, NH₄⁺ low-

Table 2. Plant height, shoot fresh and dry weights of ageratum, petunia, and salvia grown in PL or RW media and fertilized with $\text{NO}_3^- \text{NH}_4^+$ and $\text{NH}_4^+ + \text{NO}_3^-$ solutions containing 4 or 11 meq-liter⁻¹ Cl⁻ (Expt. 1).

Medium	N source	Solution Cl ⁻ (meq·liter ⁻¹)	Plant ht (cm)	Shoot fresh wt ^z (g)	Shoot dry wt ^z (g)	Leaf area (cm ²)
<i>Ageratum</i>						
PL	NO_3^-	4	10.1	44.5	4.6	---
	$\text{NH}_4^+ + \text{NO}_3^-$	4	11.0	53.7	5.5	---
	NH_4^+	4	10.8	57.0	5.7	---
	NH_4^+	11	11.1	60.8	5.9	---
RW	NO_3^-	4	9.2	37.0	3.9	---
	$\text{NH}_4^+ + \text{NO}_3^-$	4	10.9	47.4	4.5	---
	NH_4^+	4	9.2	34.6	4.3	---
	NH_4^+	11	9.5	35.8	4.3	---
Source		df				
Replication		2	NS	NS	NS	---
Medium		1	*	**	**	---
Treatment		3	NS	*	**	---
Medium × Treatment		3	NS	**	NS	---
Mean square error		14	0.92	25.23	0.13	---
LSD(0.05)			1.19	6.22	0.45	---
<i>Marigold</i>						
PL	NO_3^-	4	9.3	35.7	3.2	---
	$\text{NH}_4^+ + \text{NO}_3^-$	4	10.0	43.9	3.8	---
	NH_4^+	4	9.3	38.9	3.2	---
	NH_4^+	11	8.9	33.0	2.8	---
RW	NO_3^-	4	9.5	29.3	2.7	---
	$\text{NH}_4^+ + \text{NO}_3^-$	4	10.2	41.8	3.6	---
	NH_4^+	4	7.0	11.0	1.1	---
	NH_4^+	11	7.0	10.4	1.0	---
Source		df				
Replication		2	NS	NS	NS	---
Medium		1	**	**	**	---
Treatment		3	**	**	**	---
Medium × Treatment		3	**	**	**	---
Mean square error		14	0.11	1.98	0.02	---
LSD(0.05)			0.42	1.74	0.18	---
<i>Petunia</i>						
PL	NO_3^-	4	9.3	129	8.4	1,650
	$\text{NH}_4^+ + \text{NO}_3^-$	4	10.0	142	8.8	1,847
	NH_4^+	4	9.3	119	8.0	1,488
	NH_4^+	11	8.9	109	5.9	1,163
RW	NO_3^-	4	9.5	102	7.1	1,229
	$\text{NH}_4^+ + \text{NO}_3^-$	4	10.2	110	7.3	1,304
	NH_4^+	4	7.0	35.1	3.6	357
	NH_4^+	11	7.0	33.8	3.5	386
Source		df				
Replication		2	NS	NS	NS	NS
Medium		1	**	**	**	**
Treatment		3	**	**	**	**
Medium × Treatment		3	**	**	*	NS
Mean square error		14	0.11	80.51	0.68	57319.6
LSD(0.05)			0.42	11.11	1.02	296.4
<i>Salvia</i>						
PL	NO_3^-	4	18.0	45.4	6.2	---
	$\text{NH}_4^+ + \text{NO}_3^-$	4	18.4	51.9	6.4	---
	NH_4^+	4	10.5	7.8	2.4	---
	NH_4^+	11	8.5	4.7	1.4	---
RW	NO_3^-	4	17.4	37.9	5.5	---
	$\text{NH}_4^+ + \text{NO}_3^-$	4	18.0	44.4	5.7	---
	NH_4^+	4	8.8	4.0	1.1	---
	NH_4^+	11	6.8	4.2	1.2	---
Source		df				
Replication		2	**	NS	NS	---
Medium		1	**	**	**	---
Treatment		3	**	**	**	---
Medium × Treatment		3	NS	NS	NS	---
Mean square error		14	0.66	12.07	0.20	---
LSD(0.05)			1.01	4.30	0.55	---

^zMean values for six plants.

^yNot determined.

NS, *, ** Nonsignificant or significant at $P = 0.05$ or 0.01 , respectively.

Table 3. Plant height, shoot fresh and dry weights of ageratum, petunia, and salvia grown in PL or RW media and fertilized with NO_3^- , NH_4^+ , and $\text{NH}_4^+ + \text{NO}_3^-$ solutions containing 0 or 4 meq·liter⁻¹ Cl^- (Expt. 2).

Medium	N source	Solution Cl^- (meq·liter ⁻¹)	Plant ht (cm)	Shoot fresh wt ^z (g)	Shoot dry wt ^z (g)
<i>Ageratum</i>					
PL	NO_3^-	0	18.1	66.5	7.2
	NO_3^-	4	20.7	72.4	7.2
	$\text{NH}_4^+ + \text{NO}_3^-$	0	18.7	78.1	9.5
	$\text{NH}_4^+ + \text{NO}_3^-$	4	19.0	95.2	10.8
	NH_4^+	0	13.2	42.7	6.1
RW	NO_3^-	4	16.5	54.1	7.3
	NO_3^-	0	11.5	29.1	3.9
	NO_3^-	4	11.5	29.0	3.6
	$\text{NH}_4^+ + \text{NO}_3^-$	0	15.9	54.4	6.7
	$\text{NH}_4^+ + \text{NO}_3^-$	4	16.1	57.0	7.3
	NH_4^+	0	11.0	24.5	4.3
	NH_4^+	4	12.5	25.8	4.8
Source		df			
Replication		2	NS	NS	NS
N source		2	**	**	**
Cl^- level		1	*	*	*
Medium		1	**	**	**
N source × Cl^- level		2	NS	NS	NS
N source × Medium		2	**	*	*
Cl^- level × Medium		1	NS	*	NS
N source × Cl^- level × Medium		2	NS	NS	NS
Mean square error		22	1.98	47.78	0.45
LSD(0.05)			1.19	5.85	0.57
<i>Petunia</i>					
PL	NO_3^-	0	11.2	78.5	5.6
	NO_3^-	4	10.7	80.2	5.7
	$\text{NH}_4^+ + \text{NO}_3^-$	0	10.8	98.4	8.3
	$\text{NH}_4^+ + \text{NO}_3^-$	4	10.6	97.2	7.3
	NH_4^+	0	8.5	46.5	4.4
RW	NO_3^-	4	8.8	61.5	5.1
	NO_3^-	0	6.8	27.6	2.3
	NO_3^-	4	6.8	31.8	2.5
	$\text{NH}_4^+ + \text{NO}_3^-$	0	8.8	63.9	5.4
	$\text{NH}_4^+ + \text{NO}_3^-$	4	8.9	72.7	5.5
	NH_4^+	0	4.3	14.1	1.7
	NH_4^+	4	4.2	16.3	2.1
Source		df			
Replication		2	NS	NS	NS
N source		2	**	**	**
Cl^- level		1	NS	*	NS
Medium		1	**	**	**
N source × Cl^- level		2	NS	NS	NS
N source × Medium		2	**	**	NS
Cl^- level × Medium		1	NS	NS	NS
N source × Cl^- level × Medium		2	NS	NS	NS
Mean square error		22	0.39	47.31	0.38
LSD(0.05)			0.53	5.82	0.52
<i>Salvia</i>					
PL	NO_3^-	0	18.2	41.5	5.9
	NO_3^-	4	18.2	42.3	6.0
	$\text{NH}_4^+ + \text{NO}_3^-$	0	18.8	45.8	6.3
	$\text{NH}_4^+ + \text{NO}_3^-$	4	19.4	47.5	6.2
	NH_4^+	0	16.5	29.4	4.5
RW	NO_3^-	4	17.7	39.1	5.4
	NO_3^-	0	12.0	15.5	2.0
	NO_3^-	4	12.4	16.0	2.1
	$\text{NH}_4^+ + \text{NO}_3^-$	0	15.5	31.9	4.7
	$\text{NH}_4^+ + \text{NO}_3^-$	4	17.2	32.8	4.6
	NH_4^+	0	11.1	11.5	1.6
	NH_4^+	4	10.0	13.3	1.9

Table 3. *continued.*

Medium	N source	Solution Cl^- (meq·liter ⁻¹)	Plant ht (cm)	Shoot fresh wt ^z (g)	Shoot dry wt ^z (g)
Source		df			
Replication		2	NS	NS	*
N source		2	**	**	**
Cl^- level		1	NS	*	NS
Medium		1	**	**	**
N source × Cl^- level		2	NS	NS	NS
N source × Medium		2	**	**	**
Cl^- level × Medium		1	NS	NS	NS
N source × Cl^- level × Medium		2	NS	NS	NS
Mean square error		22	1.14	13.34	0.15
LSD(0.05)			0.90	3.09	0.32

^zMean values for six plants.

NS, *, **Nonsignificant or significant at $P = 0.05$ or 0.01 , respectively.

ered yield compared to the NO_3^- alone or $\text{NH}_4^+ + \text{NO}_3^-$ (Table 3). Growth reduction with NH_4^+ alone was probably caused by the low N concentration in the treatment solution (9 meq·liter⁻¹ NH_4^+ compared to 15 meq·liter⁻¹ for NO_3^- and 18 meq·liter⁻¹ for $\text{NH}_4^+ + \text{NO}_3^-$), since growth with NH_4^+ alone was similar to or even better than with the NO_3^- and $\text{NH}_4^+ + \text{NO}_3^-$ treatments when total N concentrations in the treatment solutions were equal in Expt. 1 (Tables 1 and 2). Addition of Cl^- at 4 meq·liter⁻¹ as a replacement of SO_4^{2-} in treatment solutions enhanced ageratum growth.

Marigold, petunia, and salvia were sensitive to NH_4^+ when it was used as a sole N source, developing leaf chlorosis. In both PL and RW, plant height and shoot fresh and dry weights were significantly lower in the NH_4^+ treatment, regardless of Cl^- levels in the treatment solution, than in the NO_3^- and $\text{NH}_4^+ + \text{NO}_3^-$ treatments (Table 2). In these species, growth reduction by NH_4^+ treatment was obvious. Shoot fresh and dry weights of marigold, petunia, and salvia obtained from NH_4^+ alone were <50% of those obtained with $\text{NH}_4^+ + \text{NO}_3^-$. Petunia grown in RW with NH_4^+ developed small (Table 2) and thickened leaves with marginal chlorosis. Marigold and salvia were the most sensitive to NH_4^+ , developing severe chlorosis and eventually dying in RW. In marigold and salvia, NH_4^+ -RGS was noticed from 2 weeks after the initiation of treatment, especially in RW. In marigold, petunia, and salvia, chlorosis initiated on the old leaves and gradually moved to younger leaves, while the old leaves fell off or died.

When treatments with varying Cl^- levels in the nutrient solutions were compared, there was no significant difference in plant growth between treatments. Plants fertilized with NH_4^+ , plus only 4 meq·liter⁻¹ Cl^- still developed NH_4^+ -RGS in all species tested except ageratum. This result suggests that Cl^- level in the nutrient solution was not directly involved in, and NH_4^+ was possibly the major cause for, the NH_4^+ -RGS.

When the total N concentration in the NH_4^+ treatment solution was lowered to 9 meq·liter⁻¹ in Expt. 2, shoot fresh and dry weights of petunia and salvia were still < 50% of those obtained from the NO_3^- and the $\text{NH}_4^+ + \text{NO}_3^-$ treatments in both growing media (Table 3). Plants also were significantly shorter in the NH_4^+ treatment than in the others. Addition of 4 meq·liter⁻¹ Cl^- to the treatment solution significantly increased shoot fresh weight, but not plant height or shoot dry weight, of all species tested. Nitrogen source, growing medium, and their interaction significantly affected growth of petunia and salvia (Table 3).

Table 5. pH, EC, and ion contents of PL and RW media of ageratum, petunia, and salvia as affected by N source and Cl⁻. Analyses were conducted at the end of experiment (Expt. 2).

N source ^z	Cl- (meq·liter ⁻¹)	pH ^y	EC ^x	Dry wt (%)		PPM						
				N	S	NH ₄ -N	NO ₃ -N	Ca ²⁺	Mg ²⁺	K ⁺	P	Cl-
PL												
Ageratum												
NO ₃ ⁻	0	6.4	1.4	0.15	0.60	17	36	93	98	162	33	15
NO ₃ ⁻	4	6.2	2.3	0.28	0.57	16	47	196	179	232	60	72
NH ₄ ⁺ + NO ₃ ⁻	0	7.1	1.9	0.08	0.64	12	118	112	135	254	33	43
NH ₄ ⁺ + NO ₃ ⁻	4	6.9	1.9	0.05	0.63	18	219	103	117	289	35	112
NH ₄ ⁺	0	5.4	4.2	1.06	0.66	61	106	435	282	441	124	14
NH ₄ ⁺	4	5.2	3.7	1.04	0.67	39	71	362	270	391	117	157
Petunia												
NO ₃ ⁻	0	6.9	1.2	0.15	0.55	9	32	121	140	45	39	10
NO ₃ ⁻	4	6.8	1.0	0.09	0.58	7	38	96	105	45	35	82
NH ₄ ⁺ + NO ₃ ⁻	0	5.9	1.7	0.11	0.61	29	78	165	153	70	53	8
NH ₄ ⁺ + NO ₃ ⁻	4	5.9	1.9	0.22	0.56	25	57	208	192	73	62	47
NH ₄ ⁺	0	5.8	1.7	0.14	0.60	27	32	146	126	117	48	7
NH ₄ ⁺	4	5.8	1.7	0.19	0.57	16	19	165	149	118	52	46
Salvia												
NO ₃ ⁻	0	6.6	1.6	0.10	0.65	25	62	105	124	181	39	43
NO ₃ ⁻	4	6.6	1.8	0.12	0.60	29	118	126	136	203	38	114
NH ₄ ⁺ + NO ₃ ⁻	0	6.0	2.9	0.63	0.67	48	84	295	240	221	78	45
NH ₄ ⁺ + NO ₃ ⁻	4	6.3	2.3	0.22	0.70	35	106	161	172	279	53	88
NH ₄ ⁺	0	5.4	3.7	0.47	0.61	29	46	355	274	366	109	36
NH ₄ ⁺	4	5.4	3.6	0.72	0.63	28	47	418	295	289	102	93
RW												
Ageratum												
NO ₃ ⁻	0	8.2	1.8	0.5	0.1	29	279	141	235	504	42	32
NO ₃ ⁻	4	8.2	1.1	0.4	0.1	18	144	28	31	316	22	99
NH ₄ ⁺ + NO ₃ ⁻	0	7.0	2.3	0.6	0.2	124	103	94	151	352	64	23
NH ₄ ⁺ + NO ₃ ⁻	4	7.3	1.3	0.7	0.1	186	514	42	36	234	33	64
NH ₄ ⁺	0	6.8	3.3	0.7	0.9	171	182	124	147	464	57	25
NH ₄ ⁺	4	6.7	2.8	0.6	0.7	206	152	49	83	428	15	147
Petunia												
NO ₃ ⁻	0	7.6	0.9	0.5	0.1	16	206	40	62	124	10	14
NO ₃ ⁻	4	8.1	1.1	0.5	0.1	19	161	44	100	122	12	153
NH ₄ ⁺ + NO ₃ ⁻	0	7.4	1.1	0.5	0.1	314	768	63	33	103	23	10
NH ₄ ⁺ + NO ₃ ⁻	4	7.5	1.1	0.6	0.3	173	361	55	44	113	28	43
NH ₄ ⁺	0	7.1	1.9	0.6	0.3	144	164	105	148	224	46	13
NH ₄ ⁺	4	7.0	2.4	0.4	0.2	121	139	105	168	313	49	141
Salvia												
NO ₃ ⁻	0	7.8	1.6	0.7	0.2	33	334	51	131	287	13	33
NO ₃ ⁻	4	7.8	1.1	0.5	0.2	23	461	31	38	233	14	98
NH ₄ ⁺ + NO ₃ ⁻	0	7.2	2.4	0.5	0.6	126	256	90	205	316	58	13
NH ₄ ⁺ + NO ₃ ⁻	4	7.0	3.1	0.6	0.7	187	350	118	212	417	57	23
NH ₄ ⁺	0	7.0	1.8	0.5	0.2	168	209	64	102	241	37	24
NH ₄ ⁺	4	6.8	2.9	0.6	0.8	171	161	117	202	365	59	180

²See Table 1 for concentration.

³Paste extraction.

⁴EC in mmhos·cm⁻¹.

not known. In Expt. 2, however, tissue NH₄⁺ content was little affected by N sources, probably as a result of lowered NH₄⁺ level in the NH₄⁺ treatment solution, but tissue NO₃⁻ content still differed drastically between treatments.

Although the mechanism of ammonium tolerance in ageratum was not elucidated, it may be related to an increased rate of conversion of inorganic NH₄⁺ to organic N compounds compared to other species. Alternatively, ageratum may have the facility to control the rate of NH₄⁺ uptake by the roots. Salvia contained high levels of NH₄⁺ regardless of the solution Cl⁻ level (Table 4). Although the toxic tissue NH₄⁺ levels for the sensitive species tested are not known, the NH₄⁺-related

growth suppression in these species may have been caused by: 1) high tissue NH₄⁺ contents, resulting from a high rate of NH₄⁺ uptake or an inefficient mechanism for assimilating NH₄⁺ into organic N; 2) rhizosphere acidity resulting from NH₄⁺ uptake by roots; or 3) the combination of the two possibilities. In Expt. 1, tissue K⁺ content was considerably higher in the NH₄⁺-fertilized salvia than that of the NO₃⁻ or the NH₄⁺ + NO₃⁻ treatment. Other macroelement contents were similar among the treatments. In Expt. 2, macroelement contents were not greatly different between treatments, although Cl⁻ presence in the nutrient solution slightly lowered tissue P, K⁺, Ca²⁺, and Mg²⁺ contents.

Tissue Cl^- contents were much higher in plants supplied with a solution containing Cl^- than with a solution without Cl^- (Table 4). Tissue Cl^- level was several-fold higher in NH_4^+ -fertilized plants than in plants grown with NO_3^- or with $\text{NH}_4^+ + \text{NO}_3^-$. Tissue Cl^- levels in the two NH_4^+ -treatments were similar, regardless of the fact that one contained 4 and the other 11 meq·liter⁻¹ Cl^- in the solution. *Salvia* had the highest tissue Cl^- contents among the species tested, followed by *petunia*. *Salvia* fertilized with NH_4^+ contained about seven times as high Cl^- as that grown with $\text{NH}_4^+ + \text{NO}_3^-$, regardless of Cl^- levels in the treatment solution. The basis for the extremely high Cl^- concentration in the tissue of NH_4^+ -fertilized plants has not been adequately explained. However, in the absence of NO_3^- , which is a counterion for NH_4^+ (Jeong and Lee, unpublished) and is known to suppress Cl^- uptake (Glass and Siddiqi, 1985; Grazyna et al., 1988; Kafkafi et al., 1982; Smith and Fox, 1977; Weigel et al., 1973), Cl^- likely acts as a major companion ion for NH_4^+ uptake (Jeong and Lee, unpublished data). For *salvia*, continued application of treatment solution until harvest, even after the death of plants, might have contributed somewhat to the extremely high tissue Cl^- contents.

In Expt. 2, pH of the growing media was slightly lower in the NH_4^+ treatment than in the $\text{NH}_4^+ + \text{NO}_3^-$ treatment of all species as expected (Table 5). Soil pH was slightly higher in the growing medium with *salvia* than in that with *ageratum* treated with the same solution, suggesting that *salvia* took up comparatively more NO_3^- from the NO_3^- and the $\text{NH}_4^+ + \text{NO}_3^-$ treatments and less NH_4^+ from the NH_4^+ treatment than did *ageratum*. Growing medium EC was the highest with NH_4^+ only. Soil P content also was highest in this treatment, which may have resulted from an increased P availability by lowered medium pH in the NH_4^+ treatment: Tissue P and K^+ contents were higher in NH_4^+ -fertilized *salvia* indicating no direct competition between NH_4^+ and K^+ .

Since tissue Cl^- contents were similar, and growth of *mari-gold*, *petunia*, and *salvia* was suppressed equally in NH_4^+ treatments irrespective of solution Cl^- levels, the result of this experiment supports our hypothesis that Cl^- is the major companion ion for NH_4^+ uptake in the absence of NO_3^- but is not the direct cause of NH_4^+ -RGS in bedding plants nor does it exacerbate toxicity, as occurs when NaCl is compared to S O_4^{-2} .

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