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 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) (Grodan, 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 macromeasures 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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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⁻, 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⁻, 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 1. Ion concentrations of the nutrient solutions used in experiments.

| N source       | Cl⁻ level (meq-liter⁻¹) | K⁺ | Ca²⁺ | Mg²⁺ | NH₄⁺ | NO₃⁻ | SO₄²⁻ | H₂PO₄⁻ | Total |
|----------------|------------------------|----|------|------|------|------|-------|--------|-------|
| Expt. 1        |                        |    |      |      |      |      |       |        |       |
| NO₃⁻          | 4                      | 6  | 10   | 9    | 0    | 16   | 3     | 2      | 50    |
| NH₄⁺ + NO₃⁻   | 4                      | 6  | 6    | 5    | 8    | 8    | 11    | 2      | 50    |
| NH₄⁺          | 4                      | 6  | 2    | 1    | 16   | 0    | 19    | 2      | 50    |
| NH₄⁺          | 11                     | 6  | 2    | 1    | 16   | 0    | 12    | 2      | 50    |
| Expt. 2        |                        |    |      |      |      |      |       |        |       |
| NO₃⁻          | 0                      | 5  | 11   | 9    | 0    | 15   | 7     | 3      | 50    |
| NO₃⁻          | 4                      | 5  | 6    | 5    | 9    | 9    | 13    | 3      | 50    |
| NH₄⁺ + NO₃⁻   | 0                      | 5  | 6    | 5    | 9    | 9    | 9     | 3      | 50    |
| NH₄⁺          | 0                      | 6  | 6    | 4    | 9    | 0    | 22    | 3      | 50    |
| NH₄⁺          | 4                      | 6  | 6    | 4    | 9    | 0    | 18    | 3      | 50    |

*Each 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.*
Table 2. Plant height, shoot fresh and dry weights of ageratum, petunia, and salvia grown in PL or RW media and fertilized with NO\textsubscript{3}\textsuperscript{−}, NH\textsubscript{4}\textsuperscript{+}, and NH\textsubscript{4}\textsuperscript{+} + NO\textsubscript{3}\textsuperscript{−} solutions containing 4 or 11 meq·liter\textsuperscript{−1}\textsuperscript{−} Cl\textsuperscript{−} (Expt. 1).

| Medium | N source | Solution Cl\textsuperscript{−} (meq·liter\textsuperscript{−1}) | Plant ht (cm) | Shoot fresh wt\textsuperscript{a} (g) | Shoot dry wt\textsuperscript{a} (g) | Leaf area (cm\textsuperscript{2}) |
|--------|----------|------------------|---------------|-----------------|-----------------|-----------------|
| PL     | NO\textsubscript{3}  | 4                | 10.1          | 44.5            | 4.6             | ---             |
|        | NH\textsubscript{4} + NO\textsubscript{3} | 4                | 11.0          | 53.7            | 5.5             | ---             |
|        | NH\textsubscript{4}  | 4                | 10.8          | 57.0            | 5.7             | ---             |
|        | NH\textsubscript{3}  | 11               | 11.1          | 60.8            | 5.9             | ---             |
| RW     | NO\textsubscript{3}  | 4                | 9.2           | 37.0            | 3.9             | ---             |
|        | NH\textsubscript{4} + NO\textsubscript{3} | 4                | 10.9          | 47.4            | 4.5             | ---             |
|        | NH\textsubscript{4}  | 4                | 9.2           | 34.6            | 4.3             | ---             |
|        | NH\textsubscript{3}  | 11               | 9.5           | 35.8            | 4.3             | ---             |

Source df
Repetition 2  NS  NS  NS  ---
Medium 1  *  **  **  ---
Treatment 3  NS  NS  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  ---

Ageratum

| Medium | N source | Solution Cl\textsuperscript{−} (meq·liter\textsuperscript{−1}) | Plant ht (cm) | Shoot fresh wt\textsuperscript{a} (g) | Shoot dry wt\textsuperscript{a} (g) | Leaf area (cm\textsuperscript{2}) |
|--------|----------|------------------|---------------|-----------------|-----------------|-----------------|
| PL     | NO\textsubscript{3}  | 4                | 9.3           | 35.7            | 3.2             | ---             |
|        | NH\textsubscript{4} + NO\textsubscript{3} | 4                | 10.0          | 43.9            | 3.8             | ---             |
|        | NH\textsubscript{4}  | 4                | 9.3           | 38.9            | 3.2             | ---             |
|        | NH\textsubscript{3}  | 11               | 8.9           | 33.0            | 2.8             | ---             |
| RW     | NO\textsubscript{3}  | 4                | 9.5           | 29.3            | 2.7             | ---             |
|        | NH\textsubscript{4} + NO\textsubscript{3} | 4                | 10.2          | 41.8            | 3.6             | ---             |
|        | NH\textsubscript{4}  | 4                | 7.0           | 11.0            | 1.1             | ---             |
|        | NH\textsubscript{3}  | 11               | 7.0           | 10.4            | 1.0             | ---             |

Source df
Repetition 2  NS  NS  NS  ---
Medium 1  **  **  **  ---
Treatment 3  **  **  **  ---
Medium × Treatment 3  **  **  **  NS  ---
Mean square error 14  0.11  1.98  0.02  ---
LSD(0.05)  0.42  1.74  0.18  ---

Marigold

| Medium | N source | Solution Cl\textsuperscript{−} (meq·liter\textsuperscript{−1}) | Plant ht (cm) | Shoot fresh wt\textsuperscript{a} (g) | Shoot dry wt\textsuperscript{a} (g) | Leaf area (cm\textsuperscript{2}) |
|--------|----------|------------------|---------------|-----------------|-----------------|-----------------|
| PL     | NO\textsubscript{3}  | 4                | 9.3           | 129             | 8.4             | 1,650           |
|        | NH\textsubscript{4} + NO\textsubscript{3} | 4                | 10.0          | 142             | 8.8             | 1,847           |
|        | NH\textsubscript{4}  | 4                | 9.3           | 119             | 8.0             | 1,488           |
|        | NH\textsubscript{3}  | 11               | 8.9           | 109             | 5.9             | 1,163           |
| RW     | NO\textsubscript{3}  | 4                | 9.5           | 102             | 7.1             | 1,229           |
|        | NH\textsubscript{4} + NO\textsubscript{3} | 4                | 10.2          | 110             | 7.3             | 1,304           |
|        | NH\textsubscript{4}  | 4                | 7.0           | 35.1            | 3.6             | 357             |
|        | NH\textsubscript{3}  | 11               | 7.0           | 33.8            | 3.5             | 386             |

Source df
Repetition 2  NS  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

Petunia

| Medium | N source | Solution Cl\textsuperscript{−} (meq·liter\textsuperscript{−1}) | Plant ht (cm) | Shoot fresh wt\textsuperscript{a} (g) | Shoot dry wt\textsuperscript{a} (g) | Leaf area (cm\textsuperscript{2}) |
|--------|----------|------------------|---------------|-----------------|-----------------|-----------------|
| PL     | NO\textsubscript{3}  | 4                | 18.0          | 45.4            | 6.2             | ---             |
|        | NH\textsubscript{4} + NO\textsubscript{3} | 4                | 18.4          | 51.9            | 6.4             | ---             |
|        | NH\textsubscript{4}  | 4                | 10.5          | 7.8             | 2.4             | ---             |
|        | NH\textsubscript{3}  | 11               | 8.5           | 4.7             | 1.4             | ---             |
| RW     | NO\textsubscript{3}  | 4                | 17.4          | 37.9            | 5.5             | ---             |
|        | NH\textsubscript{4} + NO\textsubscript{3} | 4                | 18.0          | 44.4            | 5.7             | ---             |
|        | NH\textsubscript{4}  | 4                | 8.8           | 4.0             | 1.1             | ---             |
|        | NH\textsubscript{3}  | 11               | 6.8           | 4.2             | 1.2             | ---             |

Source df
Repetition 2  **  NS  NS  NS  ---
Medium 1  **  **  **  **  ---
Treatment 3  **  **  **  **  ---
Medium × Treatment 3  NS  NS  NS  NS  ---
Mean square error 14  0.66  12.07  0.20  ---
LSD(0.05)  1.01  4.30  0.55  ---

Salvia

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\textsuperscript{a}Mean values for six plants.

\textsuperscript{b}Not determined.

\textsuperscript{c}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 \( \text{NO}_3^- \), \( \text{NH}_4^+ \), and \( \text{NH}_4^+ + \text{NO}_3^- \) solutions containing 0 or 4 meq·liter\(^{-1}\) Cl (Expt. 2).

| Medium | Solution N source | Cl\(^-\) (meq·liter\(^{-1}\)) | Plant ht (cm) | Shoot fresh wt (g) | Shoot dry wt (g) |
|--------|------------------|-----------------|---------------|-------------------|-----------------|
| Ageratum |
| PL     | \( \text{NO}_3^- \) | 0               | 18.1          | 66.5              | 7.2             |
|        | \( \text{NO}_3^- \) | 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            |
|        | \( \text{NH}_4^+ \) | 0               | 13.2          | 42.7              | 6.1             |
|        | \( \text{NH}_4^+ \) | 4               | 16.5          | 54.1              | 7.3             |
| RW     | \( \text{NO}_3^- \) | 0               | 11.5          | 29.1              | 3.9             |
|        | \( \text{NO}_3^- \) | 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             |
|        | \( \text{NH}_4^+ \) | 0               | 11.0          | 24.5              | 4.3             |
|        | \( \text{NH}_4^+ \) | 4               | 12.5          | 25.8              | 4.8             |

| Source | df | Replication | NS | NS | NS |
|--------|----|-------------|----|----|----|
| N source | 2 | ** | ** | ** | ** |
| Cl- level | 1 | * | * | * | * |
| Medium | 1 | ** | ** | ** | ** |
| N source \( \times \) Cl- level | 2 | NS | NS | NS | NS |
| N source \( \times \) Medium | 2 | ** | * | - | - |
| Cl- level \( \times \) Medium | 1 | NS | NS | NS | NS |
| N source \( \times \) Cl- level \( \times \) Medium | 2 | NS | NS | NS | NS |
| Mean square error | 22 | 1.98 | 47.78 | 0.45 | 1.19 | 5.85 | 0.57 |
| LSD(0.05) | 0.90 | 3.09 | 0.32 |

**Table 3. continued.**

| Medium | Solution N source | Cl\(^-\) (meq·liter\(^{-1}\)) | Plant ht (cm) | Shoot fresh wt (g) | Shoot dry wt (g) |
|--------|------------------|-----------------|---------------|-------------------|-----------------|
| Petunia |
| PL     | \( \text{NO}_3^- \) | 0               | 11.2          | 78.5              | 5.6             |
|        | \( \text{NO}_3^- \) | 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             |
|        | \( \text{NH}_4^+ \) | 0               | 8.5           | 46.5              | 4.4             |
|        | \( \text{NH}_4^+ \) | 4               | 8.8           | 61.5              | 5.1             |
| RW     | \( \text{NO}_3^- \) | 0               | 6.8           | 27.6              | 2.3             |
|        | \( \text{NO}_3^- \) | 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             |
|        | \( \text{NH}_4^+ \) | 0               | 4.3           | 14.1              | 1.7             |
|        | \( \text{NH}_4^+ \) | 4               | 4.2           | 16.3              | 2.1             |

| Source | df | Replication | NS | NS | NS |
|--------|----|-------------|----|----|----|
| N source | 2 | ** | ** | ** | ** |
| Cl- level | 1 | NS | NS | NS | NS |
| Medium | 1 | ** | ** | ** | ** |
| N source \( \times \) Cl- level | 2 | NS | NS | NS | NS |
| N source \( \times \) Medium | 2 | ** | - | - | - |
| Cl- level \( \times \) Medium | 1 | NS | NS | NS | NS |
| N source \( \times \) Cl- level \( \times \) Medium | 2 | NS | NS | NS | NS |
| Mean square error | 22 | 0.39 | 47.31 | 0.38 | 0.53 | 5.82 | 0.52 |

| Salvia |
|--------|------------------|-----------------|---------------|-------------------|-----------------|
| PL     | \( \text{NO}_3^- \) | 0               | 18.2          | 41.5              | 5.9             |
|        | \( \text{NO}_3^- \) | 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             |
|        | \( \text{NH}_4^+ \) | 0               | 16.5          | 29.4              | 4.5             |
|        | \( \text{NH}_4^+ \) | 4               | 17.7          | 39.1              | 5.4             |
| RW     | \( \text{NO}_3^- \) | 0               | 12.0          | 15.5              | 2.0             |
|        | \( \text{NO}_3^- \) | 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             |
|        | \( \text{NH}_4^+ \) | 0               | 11.1          | 11.5              | 1.6             |
|        | \( \text{NH}_4^+ \) | 4               | 10.0          | 13.3              | 1.9             |

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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 | Cl- (meq liter⁻¹) | pH | EC | N | S | NH₃-N | NO₃-N | Ca²⁺ | Mg²⁺ | K⁺ | P | Cl⁻ |
|----------|-------------------|----|----|---|---|-------|-------|------|------|----|---|-----|
| Ageratum |                   |    |    |   |   |       |       |      |      |    |   |     |
| NO₃⁻     | 0                 | 6.4| 1.4 | 0.15| 0.60| 17    | 36    | 93   | 98   | 162| 33| 15  |
| NO₃⁻     | 4                 | 6.2| 2.3 | 0.28| 0.57| 16    | 47    | 196  | 179 | 232| 60| 72  |
| NH₄⁺ + NO₃⁻| 0            | 7.1| 1.9 | 0.08| 0.64| 12    | 118   | 112  | 135 | 254| 33| 43  |
| NH₄⁺ + NO₃⁻| 4            | 6.9| 1.9 | 0.05| 0.63| 18    | 219   | 103  | 117 | 289| 35| 112 |
| NH₄⁺     | 0                 | 5.4| 4.2 | 1.06| 0.66| 61    | 106   | 475  | 282 | 441| 64| 14  |
| NH₄⁺     | 4                 | 5.3| 3.7 | 1.04| 0.67| 39    | 71    | 362  | 270 | 391| 117| 157 |
| Petunia  |                   |    |    |   |   |       |       |      |      |    |   |     |
| NO₃⁻     | 0                 | 6.9| 1.2 | 0.15| 0.55| 9     | 32    | 121  | 140 | 45 | 39| 10  |
| NO₃⁻     | 4                 | 6.8| 1.0 | 0.09| 0.58| 7     | 38    | 96   | 105 | 45 | 35| 82  |
| NH₄⁺ + NO₃⁻| 0            | 5.9| 1.7 | 0.11| 0.61| 29    | 78    | 165  | 153 | 70 | 53| 8   |
| NH₄⁺ + NO₃⁻| 4            | 5.9| 1.9 | 0.22| 0.56| 25    | 57    | 208  | 192 | 73 | 62| 47  |
| NH₄⁺     | 0                 | 5.8| 1.7 | 0.14| 0.60| 27    | 32    | 146  | 126 | 117| 48| 7   |
| NH₄⁺     | 4                 | 5.8| 1.7 | 0.19| 0.57| 16    | 19    | 165  | 149 | 118| 52| 46  |
| Salvia   |                   |    |    |   |   |       |       |      |      |    |   |     |
| NO₃⁻     | 0                 | 6.6| 1.6 | 0.10| 0.65| 25    | 62    | 105  | 124 | 181| 39| 43  |
| NO₃⁻     | 4                 | 6.6| 1.8 | 0.12| 0.60| 29    | 118   | 126  | 136 | 203| 38| 114 |
| NH₄⁺ + NO₃⁻| 0            | 6.0| 2.9 | 0.63| 0.67| 48    | 84    | 295  | 240 | 221| 78| 45  |
| NH₄⁺ + NO₃⁻| 4            | 6.3| 2.3 | 0.22| 0.70| 35    | 106   | 161  | 172 | 279| 53| 88  |
| NH₄⁺     | 0                 | 5.4| 3.7 | 0.72| 0.63| 29    | 46    | 355  | 274 | 366| 109| 36  |
| NH₄⁺     | 4                 | 5.4| 3.6 | 0.72| 0.63| 28    | 47    | 418  | 295 | 289| 102| 93  |

| Dry wt (%) | PPM |
|-----------|-----|
| PL        |     |
| RW        |     |

See Table 1 for concentration.
Paste extraction.
EC 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.

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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 NH₄⁺-fertilized plants than in plants grown with NO₃⁻ or with NH₄⁺ + NO₃⁻. Tissue Cl levels in the two NH₄⁺-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 NH₄+ contained about seven times as high Cl as that grown with NH₄⁺ + NO₃⁻, regardless of Cl levels in the treatment solution. The basis for the extremely high Cl concentration in the tissue of NH₄⁺-fertilized plants has not been adequately explained. However, in the absence of NO₃⁻, which is a counterion for NH₄⁺ (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 NH₄⁺ 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 NH₄⁺ treatment than in the NH₄⁺ + NO₃⁻ 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 NO₃⁻ from the NO₃⁻ and the NH₄⁺ + NO₃⁻ treatments and less NH₄⁺ from the NH₄⁺ treatment than did ageratum. Growing medium EC was the highest with NH₄⁺ 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 NH₄⁺ treatment: Tissue P and K contents were higher in NH₄⁺-fertilized salvia indicating no direct competition between NH₄⁺ and K⁺.

Since tissue Cl contents were similar, and growth of marigold, petunia, and salvia was suppressed equally in NH₄⁺ treatments irrespective of solution Cl levels, the result of this experiment supports our hypothesis that Cl is the major companion ion for NH₄⁺ uptake in the absence of NO₃⁻ but is not the direct cause of NH₄⁺-RGS in bedding plants nor does it exacerbate toxicity, as occurs when NaCl is compared to SO₄⁻²⁻.

**Literature Cited**

Barker, A.V. and D.N. Maynard. 1972. Cation and NO₃⁻ accumulation in pea and cucumber as influenced by N nutrition. J. Amer. Soc. Hort. Sci. 97:27-30.

Blair, G.J., M.H. Miller, and W.A. Mitchell. 1970. NO₃⁻ and NH₄⁺ as sources of nitrogen for corn and their influence on the uptake of other ions. Agron. J. 62:530-532.

Bove, J.M., C. Bove, F.R. Whatley, and D.I. Arnon. 1963. Chloride requirement for oxygen evolution in photosynthesis. Z. Naturforsch. Teil B. 18:683-688.

Broyer, T.C., A.B. Carlton, C.M. Johnson, and P.R. Stout. 1954. Chlorine-a micronutrient element for higher plants. Plant Physiol. 29:526-534.

Clarkson, D.T. and J.B. Hanson. 1980. The mineral nutrition of higher plants. Annu. Rev. Plant Physiol. 31:239-298.

Cole, P.J. 1985. Chloride toxicity in citrus. Irri. Sci. 6:63-71.

Gausman, H.W. and R. Cardenas. 1968. Effect of soil salinity on external morphology of cotton leaves. Agron. J. 60:566-567.

Glass, A.D.M. and M.Y. Siddiqi. 198.5. NO₃⁻ inhibition of Cl⁻ influx in barley: Implications for a proposed Cl homeostat. J. Expt. Bot. 36:556-566.

Grazyna, K., M.R. Ward, and R.C. Huffaker. 1988. Characteristics of injury and recovery of net-NO₃ transport of barley seedlings from treatments of NaCl. Plant Physiol. 87:878-882.

Hjnd, G., H.Y. Nakatani, and S. Izawa. 1969. The role of Cl⁻ in photosynthesis. 1. The Cl requirement of electron transport. Biochem. Biophys. Acta 172:277-289.

Jeong, B.R. 1990. Ammonium and nitrate nutrition of selected bedding plants. PhD Diss., Colorado State Univ., Fort Collins.

Kafkafi, U., N. Valoras, and J. Letey. 1982. Chloride interaction with NO₃⁻ and PO₄ nutrition in tomato (Lycopersicon esculentum L.). J. Plant Nutr. 5:1369-1385.

Smith, F.A. and A.L. Fox. 1977. Interaction between Cl⁻ and NO₃⁻ uptake in Citrus leaf slices. Austral. J. Plant Physiol. 4:177-182.

Strongononov, B.P. 1962. Physiological basis of salt tolerance of plants. Daniel Davey & Co., New York. p. 83.

Weigel, R.C., Jr., J.A. Schillinger, and B.A. McCaw. 1973. Nutrient-NO₃⁻ levels and the accumulation of Cl⁻ in leaves of snap beans and roots of soybeans. Crop Sci. 13:411-412.

Workman, S.M., P.N. Soltanpour, and R.H. Follett. 1988. Soil testing methods used at Colorado State University for the evaluation of fertility, salinity and trace element toxicity. Tech. Bul. LTB88-2, Agr. Expt. Sta., Dept. of Agron., Colorado State Univ. p. 1-29.