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Growth Responses of Seed Geranium and Petunia to N Source and Growing Media[1]

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Abstract. Pelargonium hortorum **(Bailey) 'Sprinter Scarlet' and *Petunia hybrida* (Bailey) 'Candy Apple' seedlings were grown in 2 media and watered with 5 nutrient solutions containing varying ratios of NO_3^-:NH_4^+, each resulting in a total NO_3^- plus NH_4^+ concentration of 15 meq liter^{-1}. There were no significant differences in height, fresh and dry weights, or number of vegetative breaks in soil-grown plants due to the N forms. Plant growth in the soilless medium was substantially reduced as the proportion of NH_4^+ increased above 50%.**

Fertilizer recommendations for bedding plants are vague, inconsistent, and do not appear to be based upon fundamental principles concerning nutrient uptake by plants. Previous nutritional research on petunias and seed geraniums yielded recommendations involving various parts per million levels of N, P and K, with or without slow release fertilizers and pre-planting additions (10, 15, 27). Specific partitioning between NO_3^- and NH_4^+ was seldom mentioned, although White (39) suggested the use of soil and tissue analysis to regulate N-P-K levels in vegetatively propagated geraniums, with half the N source as NO_3^- and the other half as NH_4^+.

The proportion of N, absorbed as NO_3^- and/or NH_4^+, needed by a plant to attain optimum growth depends on the plant species in question. Numerous vegetables (2, 17, 20, 24, 36), fruit (36) and an ornamental (13) exhibited increased growth responses as the proportion of NO_3^- to NH_4^+ increased. Other species (8, 9, 11, 15) thrived on an all NH_4^+ source. Other plants (14, 29, 31, 38) exhibited superior growth when various proportions of both N forms were present. Some plants that are normally sensitive to NH_4^+-nutrition often respond to increasing proportions of NH_4^+ if the media pH is controlled. Lemon seedlings maintained at pH 5.8 to 6.0 were reported to have comparable growth in all NH_4^+ treatments except the 100% of NH_4^+ nutrient solution (37). Similar results have been obtained for other species (4, 12, 13, 20). Adverse effects of an abundant supply of NH_4^+ ions on plant growth are well documented (20, 22, 25, 30, 35). NH_4^+ assimilation into organic compounds may also lead to depletion of carbohydrates and metabolic energy, thus limiting plant growth (21).

The confusion in recommendations and lack of information on N fertilization programs for bedding plant culture prompted this study to determine the ratios of NO_3^-:NH_4^+ that would provide quality growth of seed geraniums and petunias when grown in soil and soilless (peat-lite) media.

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Materials and Methods

Five combinations of 2 nitrogen forms and 2 growing media were factorially combined in a randomized complete block design with 2 replicates. The experiment was repeated 3 times between October, 1978 and April, 1979. Total NO_3^- + NH_4^+ was kept constant at 15 meq liter^{-1} and K+ at 4.25 meq liter^{-1}, however the ratio of NO_3^-:NH_4^+ varied (Table 1). All solutions had a cation plus anion concentration of 44.5 meq liter^{-1}. Each nutrient solution was applied, at every watering, to the point of leaching. The soil medium consisted of Fort Collins clay loam:1 Canadian sphagnum peat moss:1 No. 6 perlite, (v/v). The soilless medium (peat-lite) was composed of Canadian sphagnum peat moss:1 No. 2 vermiculite (v/v). Both substrates had a preplant addition of treble superphosphate, 0-46-0, at 3 kg m^{-3}. A wetting agent, Ortho X-77, was added to the soilless medium at a rate of 191 ml/m^{-3}. No calcium was added to either medium.

Pelargonium hortorum 'Sprinter Scarlet' and *Petunia hybrida* 'Candy Apple' seeds were germinated and transplanted at the 2 to 3 leaf stage into cell packs, 32 geranium and 48 petunia plants per treatment (Table 2). Plants were grown in a glass covered greenhouse heated to 16°C day and night and cooled to 21° during the day. Carbon dioxide was injected to maintain 1000 ppm on clear days with no ventilation. Ten randomly selected plants from each treatment were harvested, when the first treatment became salable, and data recorded. Data included fresh and dry weights and heights of geraniums and fresh and dry weights, stem length, number of laterals and total flowers and buds of petunias. Soil and tissue samples were taken at the termination of each experiment.

Table 1. Nutrient solution composition used at each irrigation on petunia 'Candy Apple' and seed geranium 'Sprinter Scarlet' grown in soil and soiless media.

Treatment[z]	Cations (meq/liter^{-1})				Anions (meq/liter^{-1})		
(NH_3^-:NH_4^+	K^+	Ca^{+2}	Mg^{+2}	NH_4^+	NO_3^-	SO_4^{-2}	Cl^-
1:0	4.25	13.00	5.50	0.00	15.00	4.50	3.25
3:1	4.25	10.50	4.25	3.75	11.25	6.00	5.50
1:1	4.25	8.00	3.00	7.50	7.50	8.00	7.25
1:3	4.25	5.00	2.25	11.25	3.75	10.00	9.00
0:1	4.25	2.50	1.00	15.00	0.00	12.00	10.75

[z]All solutions contained the following micronutrients per liter (16): H_3BO_3, 2.86 mg; $MnCl_2$, 1,81 mg; $ZnSO_4 \cdot 7H_2O$, 0.22 mg; $CuSO_4 \cdot 4H_2O$, 0.08 mg; $HMnO_2$, 0.02 mg; and FeDTPA (Sequestrene 330), 5 mg.

Table 2. Sowing, transplanting, and harvesting dates for seed geranium 'Sprinter Scarlet' and petunia 'Candy Apple' fertilized with 5 NO_3^-: NH_4^+ ratios and grown in soil and soilless media.

Plant	Crop	Sown	Transplanted	Harvested
Geranium	1	Oct. 17, 1978	Nov. 10, 1978	Jan. 3, 1979
	2	Jan.1, 1979	Feb. 7, 1979	Mar. 23, 1979
	3	Feb. 13, 1979	Mar. 9, 1979	Apr. 30, 1979
Petunia	1	Oct. 17, 1978	Nov. 28, 1978	Jan. 10, 1979
	2	Jan. 16, 1979	Feb. 21, 1979	Apr. 2, 1979
	3	Feb. 13, 1979	Mar. 16, 1979	Apr. 24, 1979

Soil samples were analyzed at the Colorado State University Soil Testing Laboratory using water and NH_4HCO_3-DTPA extraction methods (33). Tissue analyses were performed at the Plant Testing Laboratory, Horticulture Department, Pennsylvania State University. Data were subjected to analysis of variance and Tukey's HSD mean separation at the 5% level.

Results

The reported results are of the third repetition of the experiment (Table 2). The results were comparable to production timing in the bedding plant industry and were consistent with two previous repetitions.

Geraniums. Fresh and dry weight and plant height responses varied with the growing media (Table 3). Plants growing in the soil medium grew well in all treatments. The 1 NO_3^-: 0 NH_4^+ and 3 NO_3^-:1 NH_4^+ treatments were, however, significantly taller than the 0 NO_3^-:1 NH_4^+ treatment. Foliage of all plants was dark green. Root development of plants receiving 1 NO_3^-:1NH_4^+ or more NO_3^- was greater than that in the 3 NO_3^-:1 NH_4^+ to 0 NO_3^-:1 NH_4^+ treatments.

Plants growing in the soilless medium were greatly affected by the form of N nutrition. In all cases, fresh and dry weights and plant height decreased gradually as the nutrient treatment ranged from 1 NO_3^-:0 NH_4^+ to 1 NO_3^-:3 NH_4^+, with a highly significant reduction occurring in the 0 NO_3^-: NH_4^+ treatment. Plants receiving 0 NO_3^-:1 NH_4^+ were stunted with interveinal chlorosis and occasional red pigments in the leaves. The 1 NO_3^-:3 NH_4^+ treatment showed signs of mild chlorosis. All other treatments were dark green. Vigorous root development was observed in plants receiving 1 NO_3^-:1 NH_4^+ or more NO_3^-; it was less vigorous with 1 NO_3^-:3 NH_4^+, and very poor in the 0 HO_3^-:1 NH_4^+ treatment.

Petunias. The growing media also affected petunia growth under the different N treatments (Table 4). Soil-grown plants showed no significant differences when grown under the various N treatments. All plants looked normal except those in the 0 NO_3^-:1 NH_4^+ treatment which had slightly thickened leaves, a distinct yellowing of the leaf margin, and slightly reduced root growth.

Plants grown in the soilless substrate were affected much more by the form of N nutrition. Fresh and dry weight, height, total flowers and buds, and number of laterals were considerably lower in the 0 NO_3^-:1 NH_4^+ treatment. Height, fresh and dry weight and the number of laterals showed no statistical difference in treatments ranging from 1 NO_3^-:0 NH_4^+ to 1 NO_3^-:3 NH_4^+. Total flower and bud yield in the 1 NO_3^-:3 NH_4^+ and 0 NO_3^-:1 NH_4^+ treatments was significantly lower than in the other treatments. Plants growing with 1 NO_3^-:1 NH_4^+ or more NO_3^- looked normal. Plants in the 1 NO_3^-:3 NH_4^+ treatment had slightly thickened leaves with definite yellow margins that cupped upwards. The 0 NO_3^-:1 NH_4^+ grown plants were extremely stunted with thickened leaves that were light green, cupped upwards, and had a distinct yellow margin. Root development was very poor in the 0 NO_3^-:1 NH_4^+ treatment, improved in the 1 NO_3^-:3 NH_4^+ treatment, and quite vigorous in the 1 NO_3^-:1 NH_4^+ or more NO_3^- treatments.

Soil and tissue analysis. Definite differences in NO_3^- and NH_4^+ levels occurred in both media; the soilless substrate showed the greatest difference (Table 5). The pH of the soil medium was consistently higher than that of the soilless medium. In both cases, the pH decreased as the proportion of NH_4^+ in the nutrient solution increased. The concentrations of K^+, Fe^{+2}, and Zn^{+2} were higher in the soilless substrate while Mn^{+2} and electrical conductivity were greater in the soil mixture.

Tissue analyses of plants grown in both media were similar, the concentration differences for plants in the soilless mixture being greater than those in the soil medium (Table 6). In general, K^+, Ca^{+2}, and Mg^{+2} decreased as the proportion of NH_4^+ in the nutrient solution increased. P levels remained the same or decreased slightly with increased NH_4^+.

Discussion

Both geraniums and petunias showed reduced growth in the soilless medium with NH_4^+ ratios greater than 1:1 of the total nitrogen supplied (Tables 3 and 4). The results were in agreement with those of other researchers (17, 20, 37). Reduced root growth was also noted in both species as NH_4^+ increased from 50 to 100% of the total N supply. Wander and Sites (37) reported similar results for rough lemon seedlings; as the 200 ppm N nutrient solution changed from 100% NO_3^- to 100% NH_4^+, roots became short, thickened, brown colored, and fewer in number. They observed that the NH_4^+ fertilized plant roots were inferior, which was substantiated by the reduction in root CEC as the proportion of NH_4^+ increased. Reduced root growth with increased NH_4^+ has also been observed in other species (2, 22, 32). Water absorption in relation to root development has also been found to be adversely affected by increased NH_4^+ in poinsettia (7) and other crops (23, 24, 26, 34, 37). While no quantitative measurements on water absorption were made on the petunias and geraniums studied, it was observed that the 1 NO_3^-:3 NH_4^+ and 0 NO_3^-:1 NH_4^+ nutrient solutions needed replenishment less often than the other solutions. Reduced root development and lower water absorption apparently limited nutrient uptake, thereby contributing to the reduced shoot growth.

Tissue analyses of both geranium and petunia foliage showed decreased concentrations of CA^{+2} and Mg^{+2} when foliage was subjected to increasing NH_4^+ levels, particularly in the soilless substrate (Table 6). This same phenomenon has been found in other plants (18, 19, 23, 24) and is thought to be predominately a cation-anion balance effect (6). The loss of membrane integrity (23) and chloroplast structural changes (24) of tomato are thought to be related to the lower levels of CA^{+2} associated with NH_4^+ fed plants. In this study, the lower Ca^{+2} and Mg^{+2} levels probably led to lower rates of photosynthesis, reduced plant growth, and the chlorotic leaves observed.

Tissue analyses also revealed decreasing K^+ concentrations with increasing proportions of NH_4^+ in both species (Table 6). K^+ deficiency symptoms were not apparent in either species. However, studies performed with tomato indicate that NH_4^+ accumulation (1, 21, 36) and toxicity symptoms (1, 3, 21, 36) can be reduced or eliminated by increasing K^+ concentrations.

The soilless medium had greater fluctuations in NO_3^- and NH_4^+ that were positively related to the type of N nutrition given the plants (Table 5). Lack of increased substrate NH_4^+ with increased solution NH_4^+ in the soil medium may, in part, be attributed to the presence of active nitrifying bacteria that oxidize

Table 3. Mean height, fresh and dry weight of geranium 'Sprinter Scarlet' grown in soil (S) and soiless (SL) media fertilized with 5 NO_3^-:NH_4^+ ratios.

Treatment (NO_3^-:NH_4^+)	Height (cm)		Fresh wt (g)		Dry wt (g)	
	SL	S	SL	S	SL	S
1:0	11.43	9.22	17.43	10.89	10.20	6.50
3:1	10.82	8.97	16.86	10.26	9.05	6.15
1:1	10.23	8.71	15.47	10.19	8.10	6.05
1:3	8.97	8.54	13.18	10.83	6.85	6.05
0:1	4.80	7.58	4.80	10.51	3.55	5.60
HSD (5%)	1.26	1.26	3.61	2.36	2.36	2.36

Table 4. Mean height, fresh weight, dry weight, number of lateral branches, and flowers and buds of petunia 'Candy Apple' grown in a soil (S) and soiless (SL) media fertilized with 5 NO_3^-:NH_4^+ ratios.

Treatment (NO_3^-:NH_4^+)	Height (cm)		Fresh wt (g)		Dry wt (g)		No. lateral branches		No. flowers and buds	
	SL	S	SL	S	SL	S	SL	S	SL	S
1:0	17.74	16.50	24.89	21.75	1.87	1.59	5.10	4.20	1.70	1.50
3:1	18.10	18.90	27.57	25.91	1.82	1.89	4.60	3.60	1.65	2.00
1:1	15.88	19.10	24.65	26.23	1.78	1.84	4.60	3.80	1.90	1.85
1:3	13.98	17.25	21.01	25.46	1.39	1.89	3.50	3.70	0.70	1.80
0:1	3.45	14.75	7.16	24.60	0.59	1.90	0.20	3.10	0.50	1.50
HSD (5%)	5.87	5.87	4.75	4.75	0.46	0.46	2.62	2.62	0.92	0.92

Table 5. Soil analysis of geranium 'Sprinter Scarlet' and petunia 'Candy Apple' grown in a soil and soilless media fertilized with 5 NO_3^-:NH_4^+ ratios.

Treatment NO_3^-:NH_4^+	NO_3^- (ppm)	NH_4^+ (ppm)	P (ppm)	K^+ (ppm)	Fe^{+2} (ppm)	Zn^{+2} (ppm)	Mn^{+2} (ppm)	Cu^+ (ppm)	pH	EC[z]
Geranium										
Soil medium										
1:0	64	15	1180	1000	77	9.0	63	2.3	6.1	4.9
3:1	68	28	1120	1396	80	9.0	83	2.6	5.8	5.5
1:1	92	4	1140	1320	85	9.6	96	2.6	5.5	4.9
1:3	62	14	1060	1484	91	10.0	96	2.8	5.4	6.2
0:1	66	138	1040	1376	92	12.0	98	3.1	5.6	6.2
Soiless medium										
1:0	300	39	560	2436	244	11.0	29	1.2	4.2	1.8
3:1	172	472	730	2862	316	17.0	29	1.7	3.9	1.7
1:1	132	1460	720	3504	292	14.6	32	1.7	3.9	2.2
1:3	24	2150	460	3372	251	16.1	45	2.1	3.7	2.7
0:1	24	4080	500	5208	297	27.0	61	2.0	3.3	3.4
Petunia										
Soil meduim										
1:0	640	10	1160	414	92	8.5	122	2.5	6.7	3.9
3:1	270	11	950	488	79	8.6	108	2.9	6.4	3.9
1:1	760	92	850	516	82	7.9	113	2.4	5.9	3.5
1:3	760	83	900	600	84	8.2	118	3.1	5.7	4.7
0:1	760	77	870	456	86	8.2	111	3.9	5.8	4.3
Soiless medium										
1:0	880	11	560	996	181	6.4	33	3.5	5.5	2.1
3:1	580	32	420	1110	261	12.6	29	3.0	4.5	1.9
1:1	380	272	470	1092	274	8.9	34	3.0	3.7	2.5
1:3	152	914	440	744	268	10.0	31	2.5	3.3	2.9
0:1	24	1500	530	1482	290	7.9	32	2.0	4.2	1.2
Soil medium, pretreatment										
	22	93	1560	760	85	7.5	88	2.2	6.7	1.9
Soiless medium, pretreatment										
	16	58	960	642	128	11.0	32	1.9	4.3	2.1

[z]Electrical conductivity = millimhos cm^{-1}, saturated paste.

Table 6. Tissue analyses of geranium 'Sprinter Scarlet' and petunia 'Candy Apple' grown in a soil and soiless media and fertilized with 5 NO_3^-:NH_4^+ ratios.

Treatment (NO_3^-:NH_4^+)	Tissue concn (% dry wt)				
	N	P	K^+	Ca^{+2}	Mg^{+2}
Geranium					
Soil medium					
1:0	3.88	0.56	4.30	2.98	0.64
3:1	3.42	0.63	3.96	3.24	0.64
1:1	3.85	0.66	4.30	3.17	0.56
1:3	4.42	0.84	4.39	3.10	0.52
0:1	4.33	0.82	4.21	2.80	0.37
Soiless medium					
1:0	3.78	0.89	4.13	2.84	0.96
3:1	4.58	0.92	4.11	2.26	0.78
1:1	4.60	1.16	3.69	1.49	0.68
1:3	4.66	1.29	3.27	1.14	0.48
0:1	4.80	1.07	4.16	1.97	0.76
Petunia					
Soil medium					
1:0	4.00	0.58	5.00	4.05	1.10
3:1	4.58	0.71	4.99	3.55	1.01
1:1	4.80	0.78	5.00	3.50	0.81
1:3	4.68	0.70	4.84	3.62	0.72
0:1	5.20	0.72	4.94	3.18	0.60
Soiless medium					
1:0	5.08	0.63	5.10	2.90	0.99
3:1	5.36	0.59	5.29	2.41	0.98
1:1	5.98	0.68	4.12	2.01	0.99
1:3	6.28	0.70	4.14	1.54	0.86
0:1	6.36	0.66	4.16	1.03	0.65

NH_4^+ to NO_3^-. Black (5) discussed the soil pH-NH_4^+ oxidation relationship and reported that NH_4^+ oxidation decreased as the pH decreased. Dirr (13) noted that the nitrifying bacteria are most active at pH values greater than 5.5. Soil analysis revealed that the soilless medium pH was below pH 5.5 while the soil medium pH was above 5.5. Thus, even if the nitrifying bacteria were present in the soilless mixture, they would be less active and a higher NH_4^+ level would be expected.

The pH of both media decreased as the proportion of NH_4^+ in the nutrient solution increased (Table 5). This would be expected since NO_3^- absorption occurs with an exchange of OH^- or HCO_3^- ions causing pH to increase, and NH_4^+ absorption is accompanied by the exchange of H^+ ions causing pH to decrease (6, 20). The shift in pH not only affects the nitrifying bacteria, but also changes the availability of other nutrients. Riley and Barber (28) have shown that soybean root and shoot P content was positively correlated with pH of the rhizocylinder; NH_4^+ caused a decrease in the pH of the rhizocylinder and thereby increased the availability of P. Many other workers have also found increased P levels in NH_4^+ fertilized plants (6, 32, 24). Contrary to these findings, Yoshida (40) noted no difference in amount or distribution of labeled P^{32} in tobacco plants in NO_3^- and NH_4^+ nutrition studies. Both the petunias and geraniums in this study had fairly constant P levels regardless of N source (Table 6). However, geraniums grown in the lower pH, soilless medium consistently had higher P concentrations in the foliage.

In summary, the soilless medium used in this experiment was much more sensitive to the form of N supplied, 50% or more NO_3^- giving superior plant growth. The soil medium probably had greater "buffering" capacity and provided good plant growth over a wider NO_3^-:NH_4^+ ratio range. Soilless-grown plants were generally taller and heavier than soil-grown plants when supplied with 50% or more NO_3^-. Further work is needed in the area of pH control to determine its effect on the growth of bedding plants in the various N treatments.

Literature Cited

1. Ajayi, O., D. N. Maynard, and A. V. Barker. 1970. The effect of potassium on ammonium nutrition of tomato (*Lycopersicon esculentum* Mill.). Agron. J. 62:818–821.
2. 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.
3. Barker, A. V., D. N. Maynard, and W. H. Lachman. 1967. Induction of tomato stem and leaf lesions, and potassium deficiency, by excessive ammonium nutrition. Soil Sci. 103:319–327.
4. Barker, A. V., R. J. Volk, and W. A. Jackson. 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. 30:228–232.
5. Black, A. C. 1968. Soil-plant relationships, 2nd ed. Wiley, New York.
6. 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.
7. Boodley, J. W. 1970. Nitrogen fertilizers and their influence on growth of poinsettias. Flor. Rev. 147(3800):26–27, 69–73.
8. Cain, J. C. 1954. Blueberry leaf chlorosis in relation to leaf pH and mineral composition. Proc. Amer. Soc. Hort. Sci. 64:61–70.
9. Cain, J. C. 1952. A comparison of ammonium and nitrate nitrogen for blueberries. Proc. Amer. Soc. Hort. Sci. 59:161–166.
10. Carlson, W. H. and W. J. Carpenter. 1972. Optimum soil and plant nutrient levels for petunia. Mich. Flor. 496:16–18.
11. Colgrove, M. S. and A. N. Roberts. 1956. Growth of the azalea as influenced by ammonium and nitrate nitrogen. J. Amer. Soc. Hort. Sci. 68:522–536.
12. de Claassen, 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.
13. 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.
14. Grasmanis, W. O. and G. W. Leeper. 1967. Ammonium nutrition and flowering of apple trees. Austral. J. Biol. Sci. 20:761–767.
15. Greidanus, T., L. A. Peterson, L. E. Schrader, and M. N. Dana. 1972. Essentiality of ammonium for cranberry nutrition. J. Amer. Soc. Hort. Sci. 97:272–277.
16. Hanan, J. J., W. D. Holley, and K. L. Goldsberry. 1978. Greenhouse management. Springer-Verlag, Berlin.
17. Kirkby, E. A. 1968. Influence of ammonium and nitrate nutrition on the cation-anion balance and nitrogen and carbohydrate metabolism of white mustard plants grown in dilute nutrient solutions. Soil Sci. 105:133–141.
18. Kirkby, E. A. and A. D. 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 Agr. Chem. Symp.
19. 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.
20. Maynard, D. N. and A. V. Barker. 1969. Studies on the tolerance of plants to ammonium nutrition. J. Amer. Soc. Hort. Sci. 94:235–239.
21. Maynard, D. N., A. V. Barker, and W. C. Lachman. 1968. Influence of potassium on the utilization of ammonium by tomato plants. Proc. Amer. Soc. Hort. Sci. 92:537–542.
22. Nelson, P. V. and K. Hsieh. 1971. Ammonium toxicity in chrysanthemum: critical level and symptoms. Comm. Soil Sci. & Plant Anal. 2:439–448.

23. Pill, W. G. and V. N. Lambeth. 1977. Effects of NH_4 and NO_3 nutrition with and without pH adjustment on tomato growth, ion composition, and water relations. J. Amer. Soc. Hort. Sci. 102:78–81.
24. Polizotto, K. R., G. E. Wilcox, and C. M. Jones. 1975. Response of growth and mineral composition of potato to nitrate and ammonium nitrogen. J. Amer. Soc. Hort. Sci. 100:165–168.
25. Puritch, G. S. and A. V. Barker. 1967. Structure and function of tomato leaf chloroplasts during ammonium toxicity. Plant Physiol. 42:1229–1238.
26. Quebedeaux, B. and J. L. Ozbun. 1973. Effects of ammonium nutrition on water stress, water uptake, and root pressue in *Lycopersicon esculentum* Mill. Plant Physiol. 52:677–679.
27. Reilly, A. 1978. Growing geraniums for 1979. Flor. Rev. 23(4225):28–29, 72.
28. Riley, D. and S. A. Barber. 1971. Effect of ammonium and nitrate fertilization on phosphorus uptake as related to root-induced pH changes at the root-soil interface. Soil Sci. Soc. Amer. Proc. 35:301–306.
29. Sadasivaiah, S. P. 1973. Ion balance in rose nutrition. PhD Thesis, Colo. State Univ., Fort Collins.
30. Salisbury, F. B. and C. W. Ross. 1978. Plant physiology. Wadsworth Publ., Belmont, Calif.
31. Schekel, K. A. 1971. The influence of increased ionic concentrations on carnation growth. J. Amer. Soc. Hort. Sci. 96:649–652.
32. Smith, P. F. 1957. Studies on the growth of citrus seedlings with different forms of nitrogen in solution culture. Plant Physiol. 32:11–15.
33. Soltanpour, P. N. and A. P. Schwab. 1977. A new soil test for simultaneous extraction of macro-and micro-nutrients in alkaline soils. Comm. Soil Sci. & Plant Anal. 8:195–207.
34. Stuart, D. M. and J. L. Haddock. 1968. Inhibition of water uptake in sugarbeet roots by ammonia. Plant Physiol. 43:345–350.
35. Vines, H. M. and T. D. Wedding. 1960. Some effects of ammonia on plant metabolism and possible mechanisms for ammonia toxicity. Plant Physiol. 35:820–825.
36. Wall, M. E. 1940. The role of potassium in plants. III. Nitrogen and carbohydrate metabolism in potassium deficient plants supplied with either nitrate or ammonium nitrogen. Soil Sci. 49:393–409.
37. 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.
38. Weissman, G. S. 1964. Effect of ammonium and nitrate nutrition on protein level and exudate composition. Plant Physiol. 39:947–952.
39. White, J. W. 1971. Fertilization. p. 105–121. In: J. W. Mastalerz (ed.) Geraniums. Pa. Flower Growers. Univ. Park, PA.
40. Yoshida, D. 1969. Effects of forms of nitrogen supplied on the distribution of nutrients in tobacco plant. Soil Sci. & Plant Nutr. 15:113–117.

ERRATUM

In the paper "Use of Leaf Water Potential to Determine Water Stress in Field-grown Tomato Plants" by Jehoshua Rudich, Edgar Rendon-Poblete, M. Allen Stevens, and Abdel-Ilah Ambri (*J. Amer. Soc. Hort. Sci.* 106(6):732–736. 1981), Figure 1 was reproduced twice in the paper; once in the appropriate position on page 734, and then again in place of Figure 3 on page 735. The correct Figure 3 and caption appear below.

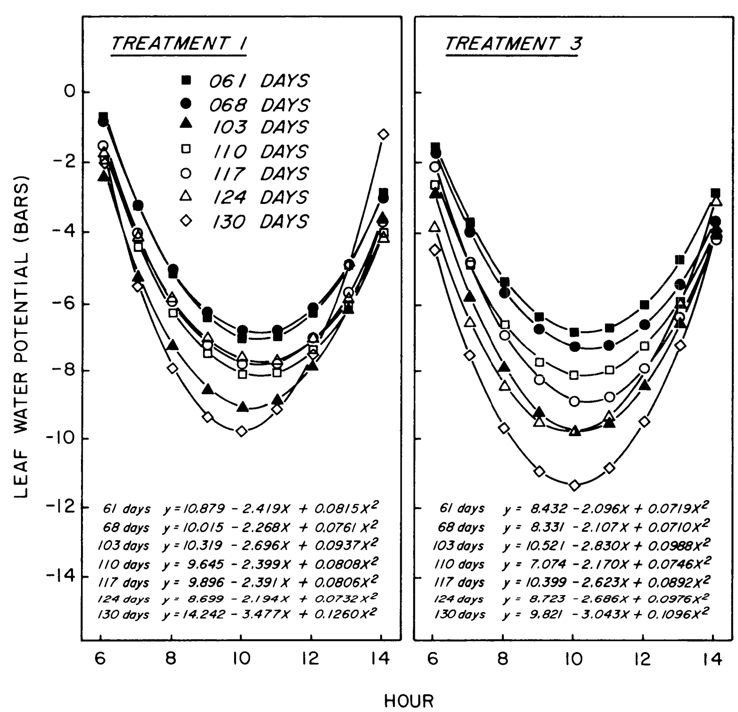

Fig. 3. Changes in leaf water potential from 61 to 130 days after planting for irrigation treatment 1 (470 mm of water applied) and treatment 3 (263 mm of water applied). These curves were derived from the 2nd order polynomial regression equations shown above.