handling at transplanting, but it resulted in poor root development as compared to shoot development. Our data show that NH_4-N is preferentially taken up by celery seedlings. This difference leads to an important decrease in pH of the SME, which is accentuated by low NO_3:NH_4 ratios and by seedling development. Generally, the N composition of the fertilizer solution had more striking effects on the nutrition of young celery seedlings than older ones. A minimum of 250 mg N/liter at a NO_3:NH_4 ratio of 2:1 is recommended for celery seedlings grown in multicells.

Literature Cited

1. Adler, P.R., R.J. Dufault, and L. Waters, Jr. 1984. Influence of nitrogen, phosphorus and potassium on asparagus transplant quality. HortScience 19(4):565–566.
2. Dufault, R.J. 1985. Relationship among nitrogen, phosphorus and potassium fertility regimes on celery transplant growth. HortScience 20(6):1104–1106.
3. Dufault, R.J. 1986. Influence of nutritional conditioning on muskmelon transplant quality and early yield. J. Amer. Soc. Hort. Sci. 111(5):698–703.
4. Elamin, O.M. and G.E. Wilcox. 1986. Nitrogen ratio influence on muskmelon growth, composition, and manganese toxicity. J. Amer. Soc. Hort. Sci. 111(3):320–322.
5. Grasmanis, V.O. and G.W. Leeper. 1965. Ammonium versus nitrate in culture solutions. Agrochimica 10(1):54–63.
6. Isaac, R.A. and W.C. Johnson. 1976. Determination of total nitrogen in plant tissue using a block digestor. J. Assn. Offic. Anal. Chem. 59(1):98–100.
7. Johansen, C., D.G. Edwards,, and J.F. Loneragan. 1968. Interactions between potassium and calcium in their absorption by intact barley plants: 1. Effects of potassium on calcium absorption. Plant Physiol. 43(10):1717–1721.
8. Kirven, D.M. 1986. An industry viewpoint: Horticultural testing—is our language confusing? HortScience 21(2):215–217.
9. Kratky, B.A. and H.Y. Mishima. 1981. Lettuce seedling and yield response to preplant and foliar fertilization during transplant production. J. Amer. Soc. Hort. Sci. 106(1):3–7.
10. Lindt, T. and U. Feller. 1987. Effect of nitrate and ammonium on long distance transport in cucumber plants. Bot. Helvetica 97(1):45–52.
11. Marschner, H., V. Römheld, W.J. Horst, and P. Martin. 1986. Root-induced changes in the rhizosphere: Importance for the mineral nutrition of plants. Z. Pflanzenernaehr. Bodenk. 149:441–456.
12. Peet, M.M., C.D. Raper, Jr., L.C. Tolley, and W.P. Robarge. 1985. Tomato responses to ammonium and nitrate nutrition under controlled root-zone pH. J. Plant Nutr. 8(9):787–798.
13. Precheur, R.J. and D.N. Maynard. 1983. Growth of asparagus transplants as influenced by nitrogen form and lime. J. Amer. Soc. Hort. Sci. 108(2):169–172.
14. Römheld, V. 1986. pH changes in the rhizosphere of various crop plants, in relation to the supply of plant nutrients. Potash Rev. 12:1–8.
15. Salter, P.J. 1985. Crop establishment: Recent research and trends in commercial practice. Sci. Hort. 36:32–47.
16. Scherer, H.W. and C.T. MacKown. 1987. Dry matter accumulation, N uptake, and chemical composition of tobacco grown with different N sources at two levels of K. J. Plant Nutr. 10(1):1–14.
17. Thomas, R.J., K.A.B. Logan, and A.D. Ironside. 1987. Effects of nitrogen source on root-induced pH changes around grass and clover roots. J. Plant. Physiol. 128:189–192.
18. Tremblay, N., S. Yelle, and A. Gosselin. 1987. Effects of CO_2 enrichment, nitrogen and phosphorus fertilization during transplant production on growth and yield of celery. HortScience 22(5):875–876.
19. Wurr, D.C.E., E.F. Cox, and J.R. Fellows. 1986. The influence of transplant age and nutrient feeding regime on cauliflower growth and maturity. J. Hort. Sci. 61(4):503–508.

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Growth, Nutrient Status, and Yield of Celery Seedlings in Response to Urea Fertilization

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Abstract. **Celery seedlings (*Apium graveolens* L. cv. Florida 683) were seeded in multicell styrofoam trays containing a commercial peat mix. They were fertilized with nutrient solutions at two nitrogen fertilizations (150 or 350 mg N/liter), two NO_3:NH_4 ratios (2:1 or 3:1), and two urea–N levels (0% or 50%) in factorial combinations to determine main and interactive effects of urea on seedling growth, nutrient status, and crop yield. Urea used in combination with low N improved the percentage of shoot dry matter and increased leaf area, shoot and root dry weight, and root : shoot ratio of the seedlings. Urea proved beneficial in improving transplant yield potential under high–N fertilization.**

Urea is a pure N source with no ballast cation or anion, and is a very soluble, noncorrosive, non-toxic, and inexpensive chemical. As a non-ionized molecule, urea can help reduce the osmotic potential of nutrient solutions (7). The effects of urea on plant growth and nutrition are not as well-known as NO_3-N and NH_4-N, partly because it undergoes a complete transformation to these N forms (5), and a significant fraction of urea may also be volatilized as NH_3 (2).

Klougart (7) recommended that urea should not be used in a universal nutrient solution for pot plants because of its unpredictable effects. Nevertheless, several commercial soluble fertilizers contain an important proportion (up to ≈80%) of urea, together with NO_3-N and NH_4-N, because of beneficial effects on growth and yield (6). Ammonium and urea-N sources yielded acceptable foliage plant quality without phytotoxicity, and sometimes outperformed NO_3-N sources (1). Information is lacking on the appropriateness of including urea in the fertilizer solution of celery transplants, as there is a need to determine its effect on seedling growth and nutrition and its effect on subsequent crop development.

The objective of this study was to determine the main and interactive effects of urea, N fertilization, and NO_3:NH_4 ratio on seedling growth, nutrient status, and yield of celery.

The growing conditions were as previously described (9), with the following differences: Styrofoam trays (Todd Planter flats No. 080A) were cut to obtain 48 experimental units each with 78 cells (13 × 6). Celery seeds were sown on 31 Mar. 1987 (day 0). The trays were placed in the growth chamber under photosynthetic photon flux of 309 ± 16 $\mu mol \cdot s^{-1} \cdot m^{-2}$. The medium was kept moist with distilled water until emergence was completed (day 15).

The plants were then fertilized every day around 1600 HR, except on Sundays, when distilled water replaced the fertilization treatments. The treatments were factorial combinations of low- or high-N fertilizations (150 or 350 mg N/liter), NO_3-N:NH_4-N ratios (2:1 or 3:1), and percentage of N as urea (0% or 50%). All nutrient solutions had the same concentrations ($mg \cdot liter^{-1}$) of P (100), K

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Table 1. Effect of nitrogen dose, NO_3:NH_4 ratio, and urea on growth of celery seedlings.

Treatment	Shoot growth: Leaf area (cm^2/plant)	Dry wt (mg/plant)	Dry matter (%)	SLA[z] ($cm^2 \cdot g^{-1}$)	Root growth: Dry wt (mg/plant)	Dry matter (%)	Root : shoot dry wt ratio
N dose ($mg \cdot liter^{-1}$)							
150	33.7	182	11.2	185	44	7.0	0.24
350	42.9	238	11.3	181	41	8.2	0.17
Significance	***	***	NS	NS	NS	***	***
NO_3:NH_4 ratio							
2:1	39.3	215	11.4	183	45	7.8	0.21
3:1	37.3	205	11.1	184	40	7.4	0.20
Significance	*	*	**	NS	**	**	**
Urea							
None	38.1	207	11.0	184	41	7.4	0.20
50%	38.5	213	11.5	182	45	7.8	0.22
Significance	NS	NS	*	NS	**	**	**
Dose × ratio	NS	NS	NS	NS	NS	NS	NS
Dose × urea	***	*	NS	NS	**	NS	*
Ratio × urea	NS	NS	NS	NS	NS	**	NS

[z]Specific leaf area.
NS, *, **, ***Nonsignificant or significant at the 5%, 1%, or 0.1% levels, respectively.

Table 2. Covariance analysis on the influence of nitrogen dose, NO_3:NH_4 ratio, and urea on pH, salinity, and nitrate and ammonium concentrations of the saturated medium extract.

Treatments	pH	Salinity ($dS \cdot m^{-1}$)	NO_3-N ($mg \cdot liter^{-1}$)	NH_4-N ($mg \cdot liter^{-1}$)
N dose ($mg \cdot liter^{-1}$)				
150	3.60	1.15	8	2
350	4.15	1.71	139	23
Significance	**	NS	***	***
NO_3:NH_4 ratio				
2:1	4.07	1.42	64	15
3:1	3.63	1.43	83	10
Significance	NS	NS	NS	NS
Urea				
None	3.96	1.43	86	9
50%	3.68	1.42	61	16
Significance	NS	*	NS	**

NS, *, **, ***Nonsignificant or significant at the 5%, 1%, or 0.1% levels, respectively.

(370), Ca (50), Mg (20), Fe (2), B (0.5), Mn (0.5), Cu (0.03), and Mo (0.02). The pH of the solutions were adjusted to 6.5 with NaOH.

On day 41 after seeding, 16 plants per experimental unit were randomly sampled among the 44 centermost cells for growth measurements and saturated medium extraction (SME). Fresh and dry weights of shoots and roots were reported on a per-plant basis. Leaf area was measured with a LI-3050A leaf area meter (LI-COR). Specific leaf area (leaf area/shoot dry weight; SLA), root : shoot dry weight ratio, and percentage of shoot and root dry matter were calculated. The same day, shoot and roots were dried and kept for weighing and mineral analysis purposes.

On day 42, the remaining seedlings were field planted in muck soil used for commercial celery production southwest of Montreal. The eight plants used for transplanting were randomly selected among the remaining seedlings of each mini-tray. Each experimental unit in the field consisted of eight plants in a row, including two guard plants at either end. Harvesting took place 77 days after field planting. Total and marketable shoot weights were determined on three of the four center plants in each plot. Side shoot weight was calculated as the difference between the two previous measurements. Petiole length and number of leaves per plant were determined following procedures outlined by Strandberg (8).

In the growth chamber and the field, the experimental units were distributed according to a completely randomized design and analysis of variance were performed on 2^3 factorials with six replications. Interactions between treatments were considered of importance whenever they represented 25% or more of the treatment sum of square of the model. Since nutrient solutions were not identical with respect to N fertilization, NO_3:NH_4 ratio, salinity and, to a lesser extent, pH (adjusted to 6.5 ± 0.14), we used the initial levels of these variable in the nutrient solutions as covariates to determine the effect of treatments on pH and salinity of the SME and its concentration in NH_4-N and NO_3-N. Data on percentage of shoot dry matter were square-root-transformed to adjust the variance according to Bartlett's test of homogeneity. Ammonium and NO_3-N content in the SME were logarithmically transformed for the same purposes. The means reported for these variables are based on the raw data.

High N increased leaf area and shoot dry weight (Table 1). A low NO_3:NH_4 ratio or the presence of urea in the nutrient solution increased the percentage of shoot dry matter. SLA was not affected by any treatment. High N increased the percentage of root dry matter, but decreased root : shoot ratio. High NO_3:NH_4 ratio or the absence of urea reduced root dry weight, percentage of root dry matter, and root : shoot ratio. Urea increased root dry weight only in combination with low N (data not shown). Thus, the presence of urea favored root development at a low N level. The percentage of shoot dry matter was increased by urea, a desirable characteristic for transplants (12). The decrease in celery leaf area, shoot and root dry weight, and percentage of shoot and root dry matter because of a high NO_3:NH_4 ratio confirms our earlier (9) findings. Compared to equivalent treatments from other studies (3, 9, 10), the root system was relatively less developed in this experiment as shown by a generally lower root : shoot ratio.

Table 2 shows the influence of treatments on pH, salinity, NO_3-N, and NH_4-N, once these variables had been corrected for their initial levels in nutrient solutions. Increasing N increased pH by 0.55 unit, but did not result in higher salinity than the levels initially found in nutrient solutions. In a commercial operation, this means that increasing N may lead to an increase of pH but not of salinity. Dufault (4) reported that salinity remained below excessive levels. Our results confirm the likelihood of N shortage with

Table 3. Effect of N dose, NO_3:NH_4 ratio, and urea on nutrient concentrations of the saturated medium extract (SME).

	Nutrient concn in the SME ($mg \cdot liter^{-1}$)					
Treatments	P	K	Ca	Mg	Fe	Mn
N dose ($mg \cdot liter^{-1}$)						
150	76	257	80	32	2.8	0.42
350	62	259	109	35	3.0	0.52
Significance	***	NS	***	NS	NS	**
NO_3:NH_4 ratio						
2:1	74	278	110	39	3.1	0.49
3:1	64	238	78	28	2.7	0.45
Significance	***	**	***	***	*	NS
Urea						
None	70	252	75	27	2.8	0.45
50%	68	264	115	39	3.0	0.49
Significance	NS	NS	***	***	NS	NS
Dose × ratio	*	***	NS	NS	NS	NS
Dose × urea	**	NS	NS	*	**	NS
Ratio × urea	**	*	***	*	NS	NS

NS, *, **, ***Nonsignificant or significant at the 5%, 1%, or 0.1% levels, respectively.

Table 4. Effect of N dose, NO_3:NH_4 ratio, and urea on dry matter mineral composition of celery seedling shoot tissue.

	Nutrient concn (dry-matter basis)						
Treatment	N	P	K	Ca	Mg	Fe	Mn
			g/100 g				*μg/g*
N dose ($mg \cdot liter^{-1}$)							
150	2.09	0.85	5.65	0.97	0.35	165	35
350	3.26	0.84	5.52	0.90	0.32	153	38
Significance	***	NS	NS	**	**	NS	***
NO_3:NH_4 ratio							
2:1	2.59	0.79	5.43	0.93	0.34	160	37
3:1	2.76	0.89	5.74	0.94	0.33	158	36
Significance	***	***	**	NS	NS	NS	NS
Urea							
None	2.67	0.89	5.65	0.92	0.33	145	35
50%	2.67	0.80	5.52	0.95	0.34	173	38
Significance	NS	***	NS	NS	NS	NS	**
Dose × ratio	*	NS	NS	NS	NS	**	NS
Dose × urea	NS	***	NS	NS	NS	NS	NS
Ratio × urea	*	NS	NS	NS	NS	NS	*

NS, *, **, ***Nonsignificant or significant at the 5%, 1%, or 0.1% levels, respectively.

only 150 mg N/liter provided through the fertilizer solution (9). Although urea reduced salinity of initial nutrient solutions by 15% to 40% (data not shown), it resulted in almost equivalent salinity values in the SME. This suggests an important urease activity in the media (NH_4^+ released), as confirmed by a significant increase in NH_4-N concentration in the SME. However, urea had no effect on NO_3-N concentration in the SME, which is in agreement with observations of Elliott (5) that nitrification in artificial media is generally limited in comparison with urea hydrolysis. The very low pH monitored in the SME can be explained by a preferential uptake of NH_4-N and the absence of a buffering component in the nutrient solutions (9). The NO_3:NH_4 ratio had no significant effect on the variables listed in Table 2; this is also true for interactions among treatments.

High N increased Ca and Mn but reduced P concentration in the SME (Table 3). Potassium concentration in the SME was reduced by high NO_3:NH_4 ratio at high N (N dose × ratio interaction; data not shown). Iron concentration was increased by urea under low, but decreased under high, N fertilization.

In shoot tissues, the highest N fertilization reduced both Ca and Mg but increased Mn concentration (Table 4). Also, a high NO_3:NH_4 ratio was associated with high P and K concentration. Iron concentration was depressed when a high NO_3:NH_4 ratio was used at low N, but the contrary was true at high fertilization. The effects of N fertilization on N, Ca, and Mn concentration confirm earlier results (9), but the effects of NO_3:NH_4 ratio on Ca and Mg shoot concentration are not consistent. This confirms the hypothesis that some of the so-called effects of the NO_3:NH_4 ratio were caused by a higher proportion of K in solution. Indeed, with uniform K treatment, such as in this experiment, the NO_3:NH_4 ratio effects on Ca and Mg concentration (9) are either different or no longer observed.

In root tissues, K concentration was reduced by high N fertilization (Table 5). A high NO_3:NH_4 ratio decreased P and Mn, while the use of urea decreased K and increased Mn concentration. The presence of urea increased Ca and Mg concentrations under low N but decreased them under high N fertilization. The data on the main effects of N fertilization and NO_3:NH_4 ratio were consistent with those previously reported (9). Thus, the interactive effect of K mentioned above had no important effects on nutrient relationship at this level.

Petiole length and side shoot weight were not significantly affected by treatments and are not presented. The only significant long-term effects of treatments on harvest yield were related to the N dose × urea interaction (Table 6). Marketable shoot fresh weight was

Table 5. Effect of N dose, NO_3:NH_4 ratio, and urea on mineral dry matter composition of celery seedling root tissues.

Treatment	N	P	K	Ca	Mg	Fe	Mn
	Nutrient concn (dry matter basis)						
			g/100 g			*µg/g*	
N dose (mg·liter^{-1})							
150	2.51	1.03	5.66	1.11	0.68	1443	171
350	4.00	0.71	3.94	1.08	0.63	1697	164
Significance	***	***	***	NS	NS	NS	NS
NO_3:NH_4 ratio							
2:1	3.24	0.92	4.71	1.14	0.64	1692	186
3:1	3.27	0.83	4.88	1.05	0.67	1449	149
Significance	NS	***	NS	NS	NS	NS	***
Urea							
None	3.18	0.82	4.95	1.08	0.67	1364	152
50%	3.33	0.93	4.64	1.11	0.64	1777	183
Significance	*	***	**	NS	NS	NS	***
Dose × ratio	NS	NS	NS	NS	NS	NS	NS
Dose × urea	*	**	NS	*	*	NS	NS
Ratio × urea	**	NS	NS	NS	NS	NS	NS

NS,*,**,***Nonsignificant or significant at the 5%, 1%, or 0.1% levels, respectively.

Table 6. Effect of N dose and urea content of the fertigation solution provided to seedlings on yield components of celery at harvest.

Treatment: N dose (mg·liter^{-1})	Treatment: Urea (%)	Shoot fresh wt (g): Total	Shoot fresh wt (g): Marketable	No. shoots per plant: Marketable	No. shoots per plant: Side
150	None	1509	1099	19.6	12.1
150	50%	1348	988	17.7	10.9
350	None	1458	1053	18.5	12.0
350	50%	1514	1127	19.4	11.6
Significance		***	***	*	NS

NS,*,**,***Nonsignificant or significant at 5% or 0.1% levels, respectively.

reduced by 11% when urea constituted 50% rather than 0% of applied N in combination with low N, but it was increased by 7% when urea was applied under high N fertilization as a result of one more marketable shoot. The sum of square for the N dose × urea interaction on marketable shoot fresh weight represented 30% of the sum of square of error (uncontrolled variation). A similar interaction of N fertilization was reported with P fertilization (10) and was thought to result from reduced side shoot induction and improved marketable stem development (11).

Therefore, despite apparent deleterious consequences on seedling growth by urea used with high N fertilization, yields were significantly increased.

Literature cited

1. Conover, C.A. and R.T. Poole. 1986. Nitrogen source effects on growth and tissue content of selected foliage plants. HortScience 21(4):1008–1009.
2. Cox, D.A. 1985. Nitrogen recovery by seed Geranium as influenced by nitrogen source. HortScience 20(5):923–925.
3. Dufault, R.J. 1985. Relationship among nitrogen, phosphorus and potassium fertility regimes on celery transplant growth. HortScience 20(6):1104–1106.
4. Dufault, R.J. 1987. Use of slow-release nitrogen and phosphorus fertilizers in celery transplant production. HortScience 22(6):1268–1270.
5. Elliott, G.C. 1986. Urea hydrolysis in potting media. J. Amer. Soc. Hort. Sci. 111(6):826–866.
6. Graifenberg, A., L. Giustiniani, S. Petsas, and P. Du Jardin. 1986. Effects of different nitrogen forms and combinations on tomato plants grown in greenhouse. Acta Hort. 176:83–91.
7. Klougart, A. 1976. Urea as a nitrogen source for pot plants. Acta Hort. 64:103–109.
8. Strandberg, J.O. 1985. Field appraisal of celery growth. Proc. Fla. State Hort. Soc. 98:294–299.
9. Tremblay, N. and A. Gosselin. 1989. Growth and nutrient status of celery seedlings in response to nitrogen fertilization and NO_3:NH_4 ratio. HortScience 24(2):284–288.
10. Tremblay, N., S. Yelle, and A. Gosselin. 1987. Effects of CO_2 enrichment, nitrogen and phosphorus fertilization during transplant production on growth and yield of celery. HortScience 22(5):875–876.
11. Tremblay, N., S. Yelle, and A. Gosselin. 1988. Effects of CO_2 enrichment, nitrogen and phosphorus fertilization during the nursery period on mineral composition of celery. J. Plant Nutr. 11(1):37–49.
12. Wurr, D.C.E., E.F. Cox, and J.R. Fellows. 1986. The influence of transplant age and nutrient feeding regime on cauliflower growth and maturity. J. Hort. Sci. 61(4):503–508.