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Onion Plant Growth, Bulb Quality, and Water Uptake following Ammonium and Nitrate Nutrition

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Abstract. **Nitrogen applied as NH_4-N or NO_3-N (75 mg·liter^{-1}) affected onion *(Allium cepa* L.) plant growth when grown in solution culture. Nitrate alone or in combination with NH_4-N increased leaf fresh and dry weight, leaf area, root fresh and dry weight, and bulb dry weight when compared to growth with NH_4-N as the sole N source. Bulb fresh weight was highest with an NH_4-N : NO_3-N ratio between 1:3 and 3:1. Maximum leaf fresh weight was not necessary to produce maximum bulb fresh weight when onions were subjected to different N-form ratios. Precocious bulbing resulted when NH_4-N was the sole N source; however, high bulbing ratios early in plant development were not correlated with final bulb fresh weight. Nitrogen form also influenced water uptake and pungency, as measured by enzymatically developed pyruvate concentration, but did not affect bulb sugar concentration.**

Nitrogen form influences growth and development in many plant species. Nitrate is generally the preferential source for crop growth, but the magnitude of preference varies within plant species and other environmental factors (Barker and Mills, 1980). While high concentrations of NH_4-N in solution can be toxic to plant growth (Barker and Mills, 1980), several studies have reported increased plant growth when NH_4-N was supplied in low concentrations or at specific developmental stages. Mills and McElhannon (1982) demonstrated that NO_3-N uptake was highest during tasseling of 'Silver Queen' sweet corn, whereas NH_4-N uptake was higher during ear development and resulted in greater plant productivity. They concluded that efficient use of N should be tied to specific growth stages. In another study, vegetative growth was shown to increase significantly just before tomato fruit set when 25% of the N was supplied as NH_4-N (Hartmen et al., 1986). In addition, N form had no affect on flower and fruit development, but NH_4-N suppressed growth during other stages of tomato plant development.

Several plant species respond well to ammonium nutrition. Krajina et al. (1973) have shown that several members of the genus *Pinus* have increased shoot growth in a medium high in NH_4-N. Conover and Poole (1986) demonstrated that height, length, and grade of *Dieffenbachia maculata, Nephrolepis exalata, Aglaonema schott,* and *Philodendron scandens oxycardium* foliage plants were either unaffected by N form or increased when N sources contained 25% to 100% NH_4-N.

Optimum N supply is necessary for maximum onion production and performance (Brewster and Butler, 1989; Brown et al., 1988; Hassan, 1977; Smittle, 1984; Vavrina and Granberry, 1988). Excessive N applied late, however, can limit yields (Riekels, 1972; Sypien et al., 1973) and increase storage losses (Vaughan et al., 1964; Walz and Burr, 1977), while inadequate N can hasten maturity and limit yields (Scully et al., 1945). The effect of N form on onion production, however, has received no attention. The objectives of this study were to evaluate the effect of N-form ratios on plant growth, water uptake, and bulb quality of onion.

The study was conducted in solution culture during the winter and early spring under greenhouse conditions at Athens, Ga. Seed of 'Granex 33', a short-day onion, were sown in flats containing Cecil clay soil. Seedlings were fertilized four times at 22 g/application per flat (0.13 m^2) with a 21N-7P-7K commercial fertilizer containing 14% NH_4-N, 2.1% NO_3-N, and 4.9% urea.

When the plants were 70 days old, uniform plants having three fully expanded leaves were transplanted into 15-liter solution culture pots, three plants per pot. Roots were cut to 1 cm before transplanting. The onion plants were grown in nutrient solutions from 20 Jan. 1988 until maturity on 8 Apr. 1988. Full-strength modified Hoagland solution (Hoagland and Arnon, 1950) with an initial pH of 6.6 was used. Sodium hydroxide was used to adjust the pH for the different N-form ratios. Nitrogen was supplied as $(NH_4)_2SO_4$ and/or $Ca(NO_3)_2$ at 7.5 mg N/liter. Nitrogen concentration was determined from a preliminary experiment. Ratios of NH_4-N to NO_3-N were: 1:0, 3:1, 1:1, 1:3, and 0:1. Initial solution concentration for P, K, Ca, Mg, Mn, Mo, Zn, B, Cu, and Fe were similar for all treatments. Sulfur varied proportionally with NH_4-N in the various N-form ratios. Calcium chloride was used to balance Ca as the amount of NO_3-N varied in the different N-form ratios. Chloride varied proportionally with NO_3-N in the various N-form ratios. Water loss was replaced with deionized water four times per week. The cumulative water replacement volumes were recorded as water uptake per week. The spent solution was replaced with a new solution every 7 days. pH never varied more than ± 0.5 from the initial concentration between solution changes. The design was a randomized complete block with six replications.

Bulb diameter and neck diameter were measured weekly using calipers, starting 7 weeks after transplanting. Bulbing ratio was calculated by dividing bulb diameter by neck diameter. Leaf area was determined by the nondestructive method of Gamiely et al. (1991) using the equation: area = -93.1 + 1.83 L + 38.6 C_{25}, where L is total leaf length (in centimeters) and C_{25} is leaf circumference (in centimeters) at 25% total leaf length from the leaf base. This equation gave high predictability with a coefficient of determination of 0.96.

The experiment was terminated at bulb maturity, as characterized by neck softening and reduced solution uptake. Plants were harvested and separated into shoots, bulbs, and roots. Fresh weights were measured, and the individual plant parts then were dried at 70C in a forced-air oven. Dry weights were determined and plant materials were ground to pass a 20-mesh screen. Total sugars were determined using the procedure of Smittle (1988). Onion pungency was measured by the pyruvic acid procedure of Schwimmer and Weston (1961). Sulfur was determined using the methods of Gaines and Mitchell (1979).

Leaf, root, and bulb fresh weight, and leaf area were influenced by N-form ratio (Table 1). Plant growth was lowest with an N-form

Table 1. Effect of N-form ratio on growth and development of 'Granex 33' onions in solution culture.

NH_4-N : NO_3-N ratio	Fresh wt (g/plant)^z Leaf	Root	Bulb	Bulb dry wt (%)	Leaf area (cm^2)
1:0	55 c	3.9 c	211 c	7.2 c	1796 b
3:1	152 b	10.7 bc	359 a	7.4 bc	3675 a
1:1	203 a	19.4 ab	320 ab	7.8 ab	4023 a
1:3	218 a	28.0 a	315 ab	8.3 a	4273 a
0:1	175 ab	23.7 a	261 bc	8.2 a	3668 a

^{z}Mean separation in columns by Duncan's multiple range test ($P \leq 0.01$).

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Table 2. Effect of N-form ratio on weekly neck and bulb diameter and bulbing ratio of 'Granex 33' onions grown in solution culture.

NH_4-N : NO_3-N ratio	Weeks 7	8	9	10	11
		Bulb diam (cm)[z]			
1:0	3.63 a	4.97 a	6.15 a	6.89 b	7.64 c
3:1	3.14 ab	4.51 ab	6.49 a	8.14 a	9.74 a
1:1	2.77 bc	3.78 ab	5.48 a	7.37 ab	9.12 ab
1:3	2.62 bc	3.46 b	5.40 a	7.18 ab	9.17 ab
0:1	2.30 c	3.37 b	4.92 a	6.51 b	8.32 bc
		Neck diam (cm)[z]			
1:0	1.38 c	1.46 c	1.44 b	1.33 b	1.29 b
3:1	1.76 ab	2.05 ab	2.06 a	2.09 a	1.90 a
1:1	1.79 a	2.13 a	2.18 a	2.18 a	2.00 a
1:3	1.75 ab	2.05 ab	2.19 a	2.20 a	2.09 a
0:1	1.57 bc	1.92 b	2.09 a	2.08 a	1.94 a
		Bulbing ratio[z,y]			
1:0	2.64 a	3.41 a	4.27 a	5.17 a	5.93 a
3:1	1.78 b	2.19 b	3.16 b	3.90 b	5.13 b
1:1	1.54 bc	1.76 bc	2.52 bc	3.39 bc	4.57 bc
1:3	1.50 c	1.67 c	2.46 bc	3.26 bc	4.39 bc
0:1	1.46 c	1.74 bc	2.35 c	3.13 c	4.28 c

[z]Mean separation in columns by Duncan's multiple range test ($P \leq 0.01$).
[y]Bulbing ratios expressed as bulb diameter divided by neck diameter.

Table 3. Effect of N-form ratio on weekly water uptake by 'Granex 33' onions grown in solution culture.

NH_4-N : NO_3-N ratio	Water uptake (liters/plant per week)[z] Weeks 7	8	9	10	11	Total
1:0	0.75 b	0.76 b	0.56 c	0.56 c	0.42 c	3.07 c
3:1	1.78 a	2.21 a	1.96 b	1.58 b	0.98 b	8.51 b
1:1	1.70 a	2.09 a	2.21 ab	2.09 ab	1.50 a	9.60 a
1:3	1.75 a	2.22 a	2.35 a	2.26 a	1.86 a	10.44 a
0:1	1.61 a	2.06 a	1.94 b	1.62 b	1.47 a	8.70 b

[z]Mean separation in columns by Duncan's multiple range test ($P \leq 0.01$).

Table 4. The effect of N-form ratio on enzymatically developed pyruvate concentration and sulfur concentration (dry-weight basis) of 'Granex 33' onions grown in solution culture,

NH_4-N : NO_3-N ratio	Pyruvate[z] ($\mu mol \cdot g^{-1}$)	Sulfur (%)
1:0	2.73 b	0.22 b
3:1	4.83 a	0.46 a
1:1	5.10 a	0.47 a
1:3	5.97 a	0.55 a
0:1	5.80 a	0.47 a

[z]Mean separation in columns by Duncan's multiple range test ($P \leq 0.01$).

ratio of 1:0. Leaf and root fresh weights were highest with a ratio between 1:1 and 0:1, whereas bulb fresh weight was highest with a ratio between 3:1 and 1:3. Bulb dry weight percentage was highest when the ratio was between 1:1 and 0:1. Leaf area was significantly lower than for the others only when the ratio was 1:0. These data suggest that, under the conditions of this study, maximum foliar growth, as reflected by leaf fresh weight, was not necessary for maximum bulb fresh weight but was necessary for maximum dry weight percentage.

Bulbs were largest 7 weeks after transplanting when NH_4-N was the only N form (Table 2). Final bulb diameters were largest when the N-form ratio was between 1:3 and 3:1. Significant differences ($P \leq 0.01$) occurred only when the ratio was 1:0 or 0:1. Bulb diameters increased from week 7 to 11 for all N-form ratios ($P \leq 0.01$). The increase in bulb diameter over the successive weeks for each ratio yielded regression coefficients that were similar and nonsignificant for ratios of 3:1 (b = 1.683 ± 0.063), 1:1 (b = 1.629 ± 0.076), and 1:3 (b = 1.682 ± 0.047). The lowest regression coefficient (b = 0.994 ± 0.053) occurred with a 1:0 ratio. Neck diameters were smallest at most sampling dates when NH_4-N was the sole N form (Table 2). There were no differences in neck diameter from week 9 to 11 when NO_3-N was included. High N nutrition has been associated with thick necks in onions (Brewster et al., 1987). In addition, neck diameter has been reported to influence maturity date (Brewster et al., 1987), curing, and storage (Tucker and Morris, 1984). The highest bulbing ratio at week 11 occurred with a ratio of 1:0, primarily from an overall decrease in plant growth and performance (Table 2). After week 8, differences were nonsignificant for bulbing ratios with N-form ratios between 3:1 and 1:3. A 0:1 ratio resulted in the lowest bulbing ratio at all sampling dates except week 8, although these ratios were similar for several combinations of N. Bulbing ratio is important in detecting early bulb formation (Brewster et al., 1987). A bulbing ratio of 2 is considered the onset of bulbing. These results suggest that high bulbing ratios early in plant development are not necessary to obtain high final bulb fresh weights.

Weekly water usage was consistently lowest when NH_4-N was the sole N source (Table 3). When NO_3-N was included in the N-form ratio, water usage increased as the onion plant developed and then decreased as the bulb matured. Total water usage correlated well with leaf fresh weight (r^2 = 0.93), leaf dry weight (r^2 = 0.94), root fresh weight (r^2 = 0.95), and root dryweight (r^2 = 0.97), but poorly with bulb fresh weight (r^2 = 0.24) and bulb dry weight (r^2 = 0.51). The 3:1 N ratio resulted in lower total water uptake than the 1:1 or 1:3 ratios, but bulb fresh weights were not significantly different among the three treatments. Thus, the high proportion of NH_4-N decreased water uptake without decreasing yield, as also reported for tomato (Quebedeaux and Ozbun, 1973) and sugar beet (Breteler, 1973).

Bulb pungency, as measured by enzymatically developed pyruvate concentration, was highest when NO_3-N was part of the N-form ratio. A significant decrease in pyruvate concentration occurred when NH_4-N was the sole N form (Table 4). The pungency of onions has been closely associated with pyruvate concentration (Schwimmer and Weston, 1961); the higher the pyruvate concentration, the more pungent the onions. Increased pungency with NO_3-N was not expected because sulfur would be less available, as ammonium sulfate was deleted from the N-form ratio. Pungency has been positively correlated with sulfur fertilization rate (Freeman and Mossadeghi, 1970). The 1:0 ratio resulted in the lowest percentage of sulfur, albeit the N was derived from ammonium sulfate (Table 4). Nitrogen form, therefore, has a significant influence on sulfur uptake and onion pungency. Whether the influence on pungency is related directly to increases in onion growth or to increasing sulfur metabolism is unknown. Nitrogen form had no effect on bulb sucrose (0.40% to 0.50%), glucose (2.9% to 3.1%), or fructose (2.4% to 2.5%) content (fresh-weight basis).

Nitrate increased leaf and root fresh weight, leaf area; and bulb weight when compared to NH_4-N. The highest bulb fresh weight was achieved when the NH_4-N : NO_3-N ratio was between 1:3 and 3:1. Maximum leaf growth was not necessary to produce maximum yield. Precocious bulbing resulted with NH_4-N as the sole N source, but a high bulbing ratio early in onion development was not correlated to high final bulb fresh weights. Use of NH_4-N only decreased water usage and bulb pungency, but N form did not influence bulb sugar content.

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