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AMMONIUM REDUCES GROWTH, FRUIT YIELD AND FRUIT QUALITY OF WATERMELON

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ABSTRACT: Watermelon (*Citrullus lunatus* Thunb.) plants cv 'Sugar Baby' were grown hydroponically in a greenhouse under NO_3:NH_4 ratios of 3:1, 1:1, and 1:3. Plants receiving the high ammonium treatment expressed symptoms of NH4-toxicity and declined rapidly after bloom. Reducing NO_3:NH_4 from 3:1 to 1:1 significantly reduced growth, water use, fruit yield, flesh soluble solids and uptake of NO_3, NH_4, K, Ca and Mg.

INTRODUCTION

Watermelons (*Citrullus lunatus* Thunb.) are widely grown on sandy soils in the southeastern United States. High fertilization maximizes yields and fruit quality. Increasing N-applications from 50 to 100 kg N/ha increased fruit yields (Bhosale et al., 1978; Hedge, 1988) and banded N-fertilizer resulted in higher yields than did broadcast fertilizer (Elmstrom et al., 1973). Increasing P (Bhosale et al., 1978), K and Ca (Sundstrom and Carter, 1983) applications also increased yields. Low levels of Ca induced blossom-end rot (BER), while adequate Ca reduced BER (Cirulli and Ciccarese, 1981) and fusarium wilt (Jones et al., 1975).

Important quality parameters for watermelon fruits are firmness and sweetness. Increasing rates of K (Sundstrom and Carter, 1983) and Ca (Waters and Nettles, 1960) resulted in greater rind thickness at the fruit equator, which improved resistance to transport damage. Soluble solids increased with increasing applications of P and K (Deswal and Patil, 1984, were not affected by N-levels (Deswal and Patil, 1984; Hedge, 1988). Irrigation (Yadav et al., 1989), fruit load, leaf area, night temperature (Welles and Buitelaar, 1988), and variety (Elmstrom et al., 1973) also affected soluble solids.

Nitrate and ammonium are the main nitrogen forms used by plants (Barker and Mills, 1980). Because NO_3^- and NH_4^+ differ in charge and oxidation state, NO_3:NH_4 ratios affect the growth and yield of several vegetable crops. Increasing levels of NH_4 reduced growth and the yield of onion (Gamiely et al., 1991) and bell pepper (Marti and Mills, 1991). Increasing NH_4 levels reduced the uptake of K, Ca and Mg by cucurbits (Barker and Maynard, 1972; Elamin and Wilcox, 1986). In the cell, NH_4 disrupted the thylakoid membranes and reduced the availability of carbon skeletons for growth (Wakiuchi et al., 1971).

Because nutrient uptake patterns during watermelon growth are poorly defined, split fertilizer applications (Mizelle, 1988) or slow release fertilizers (Elmstrom et al., 1975) are commonly used. Current recommendations are 135N-60P-110K-10S kg/ha for a population of 3300 plants/ha (Mizelle, 1988), but do not specify nitrogen sources. N-form influence on growth, yield and fruit quality of watermelon is not well documented, and watermelon plants could be exposed to high levels of NH_4 due to NH_4-releasing fertilizers or over-irrigation. This study determined the effects of three NO_3:NH_4 ratios on nutrient uptake, water use, growth, dry matter production, and nutrient partitioning of watermelon plants. Fruit yield, flesh composition and flesh soluble solid responses to N-form were also evaluated.

MATERIALS AND METHODS

Seeds of 'Sugar Baby' watermelons were planted in sand in a greenhouse on June 6, 1991, and watered daily. Two seedlings were transplanted 30 days after planting (DAP) to 16-liter pots and stayed in water for 5 days before growing in solution culture. Each pot contained 14 liters of continuously aerated nutrient solution. Treatments consisted of three NO_3:NH_4 ratios (3:1, 1:1 and 1:3).

All treatments received (mg/liter) 150 N, 35 P, 100 K, 56 Ca and 20 Mg, as combinations of KNO_3, K_2SO_4, $(NH_4)_2SO_4$, $Ca(NO_3)_2 \cdot 4H_2O$, $CaSO_4 \cdot 4H_2O$, $(NH_4)_2PO_4$ and $MgSO_4 \cdot 4H_2O$. Micronutrient levels were (mg/liter) 5 Fe as Fe-EDTA, 0.5 Zn as $ZnSO_4 \cdot 7H_2O$, 0.25 B as H_3BO_3, 0.25 Mn as $MnCl_2 \cdot 4H_2O$, 0.05 Cu as $CuSO_4 \cdot 5H_2O$, and 0.01 Mo as MoO_3.

Water levels were adjusted daily to replace transpiration losses and nutrient solutions were changed every six days. In this paper, a 6-day period is considered one week. At 45 DAP, a wooden frame was installed over the buckets to allow the vines to grow horizontally. Plants were not moved during solution change to avoid mechanical stress and flower abortion (Simonne and Mills, unpublished data).

Nitrate and NH_4 concentrations in the initial and final solutions were determined by a continuous flow nitrogen analyzer (Lachat Nitrogen Autoanalyzer, Milwaukee, WI). Concentrations of P, K, Ca and Mg were determined by inductively coupled plasma spectroscopy (Thermo Jarrell Ash ICP 9000, Jarrell Ash, Franklin, MA). Weekly uptakes of NO_3-N, NH_4-N, P, K, Ca and Mg were computed as the difference between initial and final concentrations, multiplied by the volume of solution (14 liters). Weekly uptake of nitrogen (all-N) was computed by adding weekly uptake values of NO_3-N and NH_4-N.

Bloom started 53 DAP and lasted nine days. During this period, plants were hand-pollinated twice daily. Treatments did not affect flower set and an average of five flowers per plant was fertilized. Plants were sprayed for aphids (76 DAP) with Orthene (S-dimethyl acetylphosphoramidothioate) at 1.84 g/liter.

At harvest, roots, stems, leaves and fruits were separated. Vegetative parts were dried in a forced air oven (G.C.A. Corp., Chicago, IL) at 70°C for 72 hours and ground in a Wiley mill (Arthur H. Thomas Co., Philadelphia, PA) to pass a 20-mesh screen. Tissue N was determined by a modified Kjeldahl procedure and continuous flow colorimetry (Jones and Case, 1990). Tissue P, K, Ca and Mg were determined by dry ashing and ICP spectroscopy (Jones and Case, 1990). Total and marketable yields were determined. Misshaped fruits were considered unmarketable. Water efficiency was computed as t[illegible] between water use and total yield. Nitrogen efficiency was computed as the ratio between all-N and total yield. The flesh of the marketable fruits was separated from the rind, blended (Waring blender 7011, New Hartford, CT), homogenized (Vertis homogenizer, Gardiner, NY) and filtered with cheese cloth. Aliquots of 4 and 5 ml were used for Kjeldahl-N and other elements analysis, respectively. Kjeldahl-N and P, K, Ca and Mg were determined as mentioned above. Soluble solids in the flesh were measured with a hand refractometer (Bausch & Lomb, Rochester, NY).

The experimental design was a completely randomized block design with three blocks and two replications within blocks. As plants in same pots looked alike, each observation was the average of the two measurements. Treatment significance and treatment means comparisons were performed with analysis of variance and orthogonal contrasts, respectively (SAS, 1985). Contrast 1 (C1) was 'ammonium as the main N-source' (NO_3:NH_4 of 1:3 vs the average of 1:1 and 3:1). Contrast 2 (C2) was 'nitrate as the main N source' (NO_3:NH_4 of 3:1 vs 1:1).

RESULTS AND DISCUSSION

Plants from the 1:3 treatment were harvested after bloom (72 DAP) as they expressed symptoms similar to those of NH_4 toxicity and began to dry. Because watermelon cv 'Bush Jubilee' tolerated a NO_3:NH_4 ratio of 1:3 under the same growing conditions (Simonne and Mills, 1991), it was concluded that watermelon varieties differ in their tolerance to NH_4. The harvest of the 3:1 and 1:1 treatments was postponed until the fruits ripened (107 DAP) to allow the determination of the influence of N-form ratio throughout the growth cycle. Different harvests would not affect the contrasts.

Total Nutrient Uptake: The NO_3:NH_4 ratios significantly ($p < 0.01$) affected the total uptake of NO_3-N, NH_4-N, P, K, Ca and Mg (Table 1). Differences in all-N uptake were due to different harvest dates. In a previous study on another cucurbit by Chance and Mills (1990), all-N uptake was higher when NO_3 was the main nitrogen source. However, in the present research, all-N uptake by watermelon plants was higher with the 3:1 than with the 1:1 treatment, but the difference was not significant. Total uptake of NO_3-N and NH_4-N increased with increased NO_3:NH_4 ratios. Significantly higher amounts of NO_3-N were absorbed when NO_3 was the main nitrogen form, whereas increased NH_4-N in the nutrient solution did not result in a significant increase in NH_4-N uptake. Because NO_3:NH_4 ratios absorbed by the 3:1 and 1:1 treatment were 0.7 and 0.9, respectively, it was concluded that the ratio of N-form absorbed by watermelon plants reflected the ratio of N-forms in the growing medium. These results suggest that NO_3 should be the dominant N-form to maximize nutrient uptake. Significantly higher quantities of P, K, Ca and Mg were absorbed by plants receiving the 3:1 treatment as compared to the 1:1 and 1:3 treatments. These results show that the presence of ammonium reduces the total uptake of other essential cations and are consistent with previous results on other crops (Sasseville and Mills, 1979; Chance and Mills, 1990; Marti and Mills, 1991).

Table 1. Influence of NO_3:NH_4 Ratios on Total Uptake of NO_3-N, NH_4-N, all-N, P, K, Ca and Mg by Watermelon Plants cv 'Sugar Baby' Grown in Nutrient Solution

NO_3:NH_4 Ratio	Nutrient						
	NO_3-N	NH_4-N	all-N	P	K	Ca	Mg
	g/plant						
3:1	2.1	2.5	4.3	2.0	10.7	5.8	1.0
1:1	1.7	2.3	4.1	1.7	9.6	4.2	0.7
1:3	0.6	0.6	1.2	0.5	2.0	0.8	0.2
p1[z]	0.01	0.01	0.01	0.01	0.01	0.01	0.01
p2[y]	0.01	0.27	0.20	0.01	0.08	0.01	0.01

[z] C1 p-value.
[y] C2 p-value.

Nutrient Uptake Pattern: Weekly analysis showed that the uptake of NO_3-N, NH_4-N, all-N, K, Ca and Mg was significantly ($p < 0.05$) affected by physio-

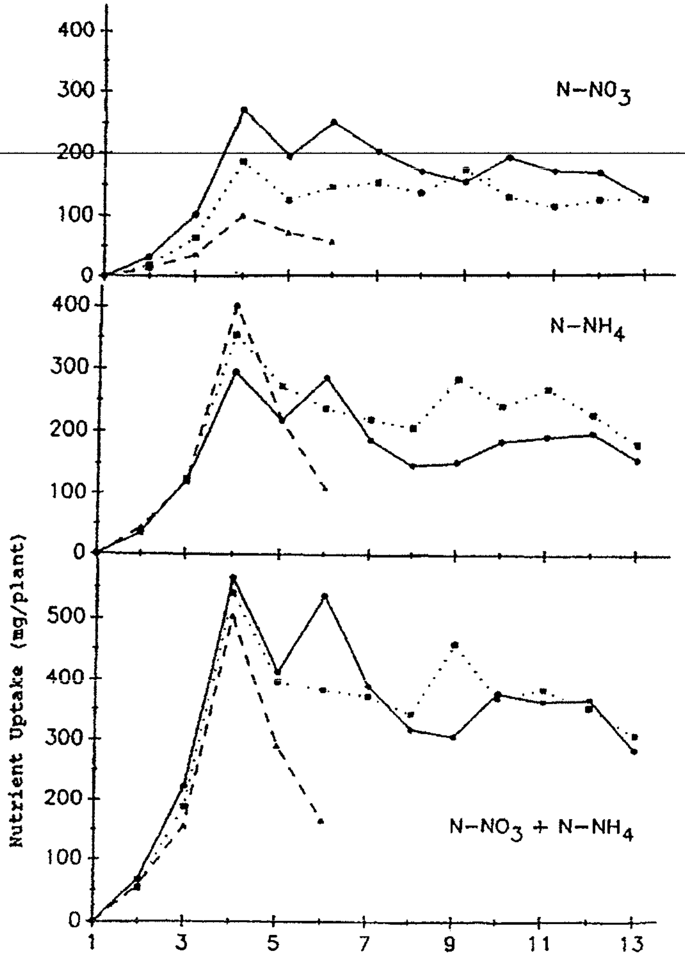

Figure 1. Influence of NO$_3$:NH$_4$ ratios of 3:1 (solid line), 1:1 (doted line) and 1:3 (dashed line) on NO$_3$-N, NH$_4$-N and all-N uptake by watermelon plants cv 'Sugar Baby'.

logical stages (Figure 1). The uptake pattern of these elements was similar for the 3:1 and 1:1 treatments during the vegetative period (36 to 42 DAP). Uptake was maximum at bloom (54 DAP). After bloom a different uptake pattern occurred. The uptake of NO$_3$-N and NH$_4$-N decreased slightly and remained almost constant throughout fruit development. The 1:3 treatment also showed a peak in nutrient uptake at bloom, but the plants declined rapidly. The uptake of all-N was similar for the 3:1 and 1:1 treatments. These results, showing that all-N uptake was not affected by NO$_3$:NH$_4$ ratios and that N-uptake remained high during fruit development for both N-forms, differ from those reported on corn (Mills and McElhannon, 1982). The pattern of NH$_4$ uptake by plants receiving the 1:3 treatment suggested that high NH$_4$ uptake during bloom was detrimental to the plant. However, it is not known if the plants receiving the 1:3 treatment declined because the total amount of NH$_4$-N absorbed was lethal, or because watermelon plants are sensitive to NH$_4$-N during bloom.

The uptakes of K, Ca and Mg from bloom to 77 DAP were higher with NO$_3$:NH$_4$ of 3:1 than 1:1, but were higher for the NO$_3$:NH$_4$ of 1:1 between 77 to 95 DAP. From 95 DAP to 107 DAP, the uptakes of Ca and Mg tended to decline in both treatments. These results, indicating that increased NH$_4$-N in the nutrient solution depresses the uptake of K, Ca and Mg, agree with previous results on other crops (Chance, 1990; Marti and Mills, 1991; Smittle and Threadgill, 1982), but differ from those on corn (Mills and McElhannon, 1982) and bell pepper (Marti and Mills, 1991).

Within weeks, NO$_3$:NH$_4$ ratios did not significantly ($0.05 < p < 0.20$) affect P uptake. The uptake of P was maximum at bloom for all the treatments, declined at fruit set and remained almost constant until final harvest (data not shown).

In earlier field trials, watermelon plants also responded to N-forms (Volk and Gammon, 1964). These authors reported higher yields with urea or NH$_4$NO$_3$ than with NaNO$_3$, whereas our results show that under controlled conditions maximum nutrient uptake occurs when NH$_4$ does not represent more than 50% of the nitrogen.

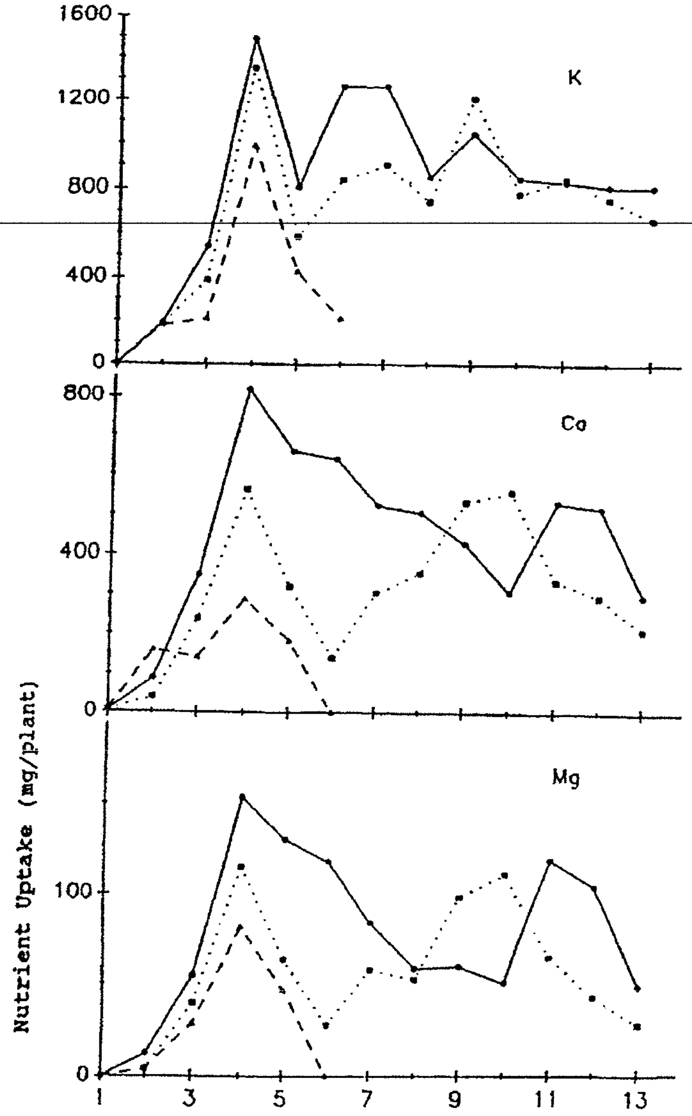

Figure 2. Influence of NO_3:NH_4 ratios of 3:1 (solid line), 1:1 (doted line) and 1:3 (dashed line) on K, Ca and Mg uptake by watermelon plants cv 'Sugar Baby'.

Table 2. Response of Dry Matter (DM), Kleldahl-N (N), P, K, Ca, and Mg Partitioning to NO_3:NH_4 Ratios by Watermelon Plants cv 'Sugar Baby'

NO_3:NH_4	DM	N	P	K	Ca	Mg
	g/plant	------------	------------	mg/plant	------------	------------
Leaves						
3:1	50	185	28	120	315	23.3
1:1	45	97	21	135	62	23.0
p2[z]	0.47	0.01	0.57	0.37	0.01	0.93
Stems						
3:1	20	85	11	69	73	4.2
1:1	25	72	14	83	24	4.9
p2[z]	0.34	0.47	0.44	0.21	0.01	0.24
Roots						
3:1	3	16	2.0	8	4.7	0.6
1:1	4	10	2.2	9	1.7	0.5
p2[z]	0.37	0.04	0.76	0.55	0.01	0.10

[z] C2 p-value.

Dry Matter Production and Partitioning: The NO_3:NH_4 ratios affected total dry matter production and partitioning in roots, stems and leaves (Table 2). Total dry matter production was 73, 74, and 28.5 g/plant for the 3:1, 1:1, and 1:3 treatment, respectively. The differences were mainly due to differences between harvests (the p-values for C1 and C2 were 0.01 and 0.15, respectively). As plants were harvested at different dates, only data for the 3:1 and 1:1 are presented.

The NO_3:NH_4 ratios significantly affected N and Ca content in the leaves and in the roots, and Ca in the stems. These results show that high NH_4 reduces cation levels in the leaves and are consistent with the uptake results. Because nutrient compositions of the roots and stems were affected by N-ratios, these results also show that N-form ratio affects primarily le[illegible]wth. These results support the findings of Wakiuchi et al. (1971) that more carbon skeletons are available for growth when small amounts of NH_4-N are detoxified. Calcium was higher in all parts of the plants receiving the 3:1 treatment as compared to the 1:1, suggesting that watermelons grown on high NO_3-N would be less prone to Ca disorders.

Fruit Yield: Total fruit yields were 1.70, 1.16 and 0.06 kg/plant for the 3:1, 1:1, and 1:3 treatment, respectively, and they were significantly affected by N-ratios ($p < 0.01$). Marketable and total yield were similar for the 3:1 and 1:1 treatments, while marketable yield of the 1:3 treatment was 0. Under the severe NH_4 toxicity of the 1:3 treatment, the whole crop was lost. These results indicate that fruit yields are higher when NO_3 is the major N-source and agree with similar research performed with other crops (Sasseville and Mills, 1979; Marti and Mills, 1991; Gamiely et al., 1991).

Water Uptake: The NO_3:NH_4 ratios significantly ($p < 0.01$) affected water use by watermelon plants ($p < 0.01$ for C1 and C2). Total water use for NO_3:NH_4 of 3:1, 1:1 and 1:3 were 189, 143, and 26 liters/plant, respectively. Because C2 p-value was 0.83 for water efficiency, it was concluded that the increase in water use was not due to an increase in transpiration per leaf area unit but because the plants receiving the 3:1 treatment had a higher total leaf surface. These results agree with the findings that the reduction in water use by squash in response to increased NH_4 was due to reduced leaf area, and not to transpiration rate (Chance, 1990).

Because N-form influences total leaf area but not water efficiency, the NO_3:NH_4 ratio influences irrigation needs. When the supply of water is limited, reducing the NO_3:NH_4 ratio within tolerable limits by the plant would reduce water demand. Although such response has been observed for different crops (Chance, 1990; Gamiely et al., 1991), little practical importance is given to the N-form in assessing water requirements.

Table 3. Influence of NO_3:NH_4 Ratios on Soluble Solids, Protein, K, Ca, and Mg Levels in a 100 g Eatable Portion of Watermelon Fruits cv 'Sugar Baby' and Comparison to Standard Values

NO_3:NH_4 Ratio	Quality Parameter					
	SS	Protein[z]	P	K	Ca	Mg
	°Brix	%	mg			
3:1	8.0	1.1	15	670	18	47
1:1	7.0	1.0	20	790	12	47
p-value[y]	0.01	0.34	0.01	0.12	0.20	0.98
Reference[x]	ND[u]	0.5	10	100	7	8
Reference[w]	ND	0.6	9	110	8	11
Reference[v]	ND	0.6	9	120	8	10

[z] computed as Kjeldahl-N * 6.25
[y] C2 p-value.
[x] from Salunkhe et al., 1973.
[w] from Gebhardt et al., 1982.
[v] from Leveille et al., 1983.
[u] not determined.

Fruit Quality: Increasing NO_3:NH_4 ratios significantly ($p = 0.01$) increased soluble solids in fruit flesh (Table 3). Phosphorus content in the flesh was higher in fruits from the 1:1 treatment than from the 3:1 treatment. The responses of Kjeldahl-N, K, Ca and Mg to NO_3:NH_4 ratios were not significant at the 5% level. The differences between these results and values from other studies (Salunkhe et al., 1973; Gebhardt et al., 1982; Leveille et al., 1983) were attributed to differences in variety and growing conditions. The variability of quality parameters within treatments suggested that factors like maturity, position on the vine, and genotype may affect fruit composition along with N-nutrition. Because C2 p-value for nitrogen efficiency was 0.91, it was concluded that the ratio between nitrogen absorbed and fruit yield is little affected by N-form. This result is consistent with protein content in the flesh being little affected ($p = 0.34$) by the NO_3:NH_4. The results of flesh analysis show soluble solids were significantly higher in fruits from the NO_3:NH_4 3:1 treatment than in those from the 1:1 treatment. These results also support the theory that detoxification of NH_4 reduces the availability of carbon skeletons, and subsequent sugar content in the fruits.

CONCLUSIONS

High NH_4-N in the nutrient solution significantly reduced the uptake of NO_3, K, Ca, and Mg, but had little effect on P uptake. On similar harvest days, total dry matter production was not significantly affected by N-form, but plants of the 3:1 treatment produced more leaves with higher calcium levels. Increasing NH_4-N significantly reduced fruit yield. The results on total dry matter production, dry matter partitioning, yield and soluble solids support the theory that the detoxification of NH4 reduces the availability of carbon skeletons, which reduces total leaf area, fruit production, and sugar levels in the flesh. Because watermelon plants are sensitive to high NH_4, a 3:1 NO_3:NH_4 ratio in the growing medium will increase yield and fruit quality as compared to a 1:1 ratio.

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EFFECTS OF NITROGEN SOURCE AND APPLICATION REGIMES ON YIELD AND QUALITY OF VIDALIA TYPE ONION

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Abstract: The effects of N fertilizer formulations, rates, and application regimes on onion growth, yield, and quality were evaluated at Tifton from 1988 to 1991. Nitrates of ammonium, calcium, potassium (15-0-14 and 13-0-44) and sodium were the nitrogen sources. Nitrogen rates of 75-200 lbs/A were applied in 3 or 5 split application regimes from October to April. At higher N rates (150-200 lbs/A), total yields were influenced by the different N sources. Application frequencies, causing an increase in total amounts of N from Feb.-Apr., increased marketable yield by 3.8 T/A in 1989 season. Bulb decay in the field was the highest when ammonium nitrate was applied, whereas less bulb decay resulted from 15-0-14, sodium nitrate, and calcium nitrate. Also, more rots occurred with the 2+3 split regime at higher N rates. Potassium and sodium nitrate applications produced more bolting. But bolting was reduced by calcium nitrate.

Treatment effects on onion quality and shelf-life under natural ambient conditions are being evaluated. Bulb weight loss in 10 weeks of storage was highest to lowest for ammonium nitrate and 13-0-44, respectively. But cal-nitrate resulted in the least bulb decay. Chemical analysis indicate that more frequent applications of higher rates of ammonium, sodium, and potassium nitrates tend to increase the pungency of stored onions. Whereas, calcium nitrate reduced the pungency.

INTRODUCTION

Sweet onions produced in the Coastal Plains of Georgia is a well accepted commodity in the vegetable market. The production acreage in the state is on the increase. However, with increased area of production, farmers are seeking more assistance in dealing with their production practices and fertility problems.

Knowledge and technical skills in proper application of various fertilizer formulations, particularly with different nitrogen sources, and their application frequencies are generally lacking. Some application rates, methods and frequencies have been suggested based on observations and commercial production experiences (Barber, 1985). The recommendations for these practices are dependent on unpredictable plant growth and crop appearances (Granberry, et al., 1990).

Nitrogen fertilization in onion production is, as in many vegetables, the most important aspect of nutritional management. Cold and wet soil conditions which generally prevails during the growing season can contribute to severe nitrogen deficiency in onion plants, even if sufficient amounts were added to the soil (Rickels, et al., 1968).

In addition to environmental factors, soil moisture deficits and nitrogen deficiency may hasten both onion bulbing and maturation. Zink, in 1966, reported that maximum leaf canopy and maximum growth rate for at least 12 weeks are needed to expect optimum levels of dry matter, leading to high yield potentials. Therefore, in order to keep the onion plants actively growing, a steady but gradual supply of N is needed throughout the growing season. On the other hand, an over-supply of N early in the growing period tends to produce excessive top growth and may delay normal maturity (Rickels et al., 1968). Brewer, in 1977, reported that the length of growing season was positively correlated with storage life of harvested onions. More recently, Toledo et al. in 1984 have shown that larger bulb size is associated with softness, root sprouting, decreased dry weight, and increased weight loss. Preliminary studies in Tifton (Batal, 1991) indicated that cultural practices and fertilizer application rates and frequencies may be associated with serious crop losses due to bolting, multiple bulbing, neck thickness, bulb decay, delayed maturation, and in some seasons freeze injury. These experiments were conducted during the 1988-1989 and 1990-1991 seasons with the following objectives: (1) to determine various responses of onion growth and yield to different commercial N fertilizer formulations and their application rates, and (2) to investigate possible effects of application frequencies and timing on bulb size and quality problems experienced in onion production.

MATERIALS AND METHODS

Factorial experiments were designed in randomized complete blocks with 4 replications. In 1988-1989 season, the experiment included five different commercial formulations of Ammonium nitrate (Amm-N), Calcium nitrate (Cal-N), Sodium nitrate (Sod-N), Potassium nitrate "15-0-14" (Pot-N_1), and Potassium nitrate "13-0-44" (Pot-N_2). These were applied at two levels, 75 lbs N/A for low and 150 lbs N/A for high. Applications of each rate were divided into two periods, 1/3 of total N for October-December and 2/3 of total N for January-April. The number of applications in each period varied in different combinations (1+2, 2+1 or 3+2, 2+3 times at 4-wk intervals).

In 1990-1991 season, only four N sources were used by eliminating the Potassium nitrate "13-0-44" treatment. The N rates were increased to 150 lbs N/A for low and 200 lbs N/A for the high level. Application regime was modified to test application times of 1, 2, or 3 for Oct-Dec period, plus 3 applications for Jan-Apr period.

'Grannex-33' onion was direct-seeded in mid-October on raised beds 6 ft. wide in 4 double-rows, 12 inches apart with a Stanhay precision seeder. Plots consisted of two beds 12 ft. long (1988-89) and 18 ft. long (1990-91). Only the two middle rows, 15 ft. length of the central section, were harvested for yield evaluations.

Over-head irrigation was used to supplement rainfall, to ascertain a level of 1.5 inches of water per week throughout the growing season. Soil and plant tissue samples were collected periodically at different stages of plant growth and development. Visual ratings and physical measurements of plant parts were used to evaluate morphological changes during the growing season.

Conventional practices were used for weed and pest control, cultivation, harvesting and curing procedures. Onion bulb samples of the medium and large grades were randomly drawn for post-harvest storage and quality evaluations to be made in separate experiments.

RESULTS AND DISCUSSION

In both experiments, averaged over N levels and application regimes, total number of onions produced was not affected by the N-source (Table-1). However in 1991, percentage of large-sized onions was higher for Amm-N than for the Cal-N treatment, with no difference between the means for Amm-N and Pot-N_1 "15-0-14". These results imply that the use of higher rates in 1990-91 may have contributed to variable response to the different nitrogen sources. It was also evident that a higher total number of bulbs were produced in 1991 season. A similar trend of marketable weight response to N-source was evident, indicating that Amm-N and Pot-N_1 produced the heaviest onions, compared to Cal-N treatment. When yields were separated into their grade components, it was evident that a higher number of smaller onions were produced by Cal-N applications in 1991. But, Amm-N and Sod-N resulted in higher numbers of large and jumbo grades (Table- 2).

Application regimes in both experiments influenced size of grades of onion (only 1991 data are presented, Table-3). Averaged over N-sources and N-levels, the 1+3 applications generally resulted in a higher number of small-sized onions, whereas the 2+3 and 3+3 applications gave the highest number of large-sized onions, thus greater high-value grades of marketable onions.

In 1989, cold injury evaluation was at a very low level of effectiveness (Table-4). It was observed that Pot-N_2 "13-0-44" applications produced plants with a higher degree of sensitivity to freezing temperatures. The bolting incidence was affected by N-sources in both seasons, and the trend of bolting response was consistent from 1989 to 1991 season. However, the level of bolting was much lower in 1991. The interactive effects of N-sources X application regimes and N-rates X application regimes were highly significant (data not presented). Consequently, the main effects of N-sources on bolting became more difficult to sort out. Responses of bulb decay were also difficult to interpret with simple effects of N-sources, especially in the 1989 season (Table-4). Never the less, there was a strong evidence that Amm-N and Pot-N_2 applications in 1989 resulted in a higher percentage of rots in the field up to harvest time. In 1991, rotting of bulbs was more general throughout the treatment plots, with no differences in the percentage values among the different N-sources.

The 1+2 application regime in 1989 resulted in the least bolting incidence and the 2+3 applications caused the most bolting in both seasons (Table-5). Three+three applications regime was tested only in 1990-91 season, which resulted in less bolting compared to 2+3 regime. Effects of application regimes on bulb decay were in a reverse order from their effects on bolting. The 2+3 regime produced the lowest percentage of rotted bulbs, whereas the 3+2 regime produced the highest incidence of bulb decay in 1989.

In a simple open-shelf storage experiment in 1989, it was demonstrated that onions produced with Amm-N had the greatest weight loss in 10 weeks. Pot-N_2 "13-0-44" had the lowest weight loss (Table-6). Perhaps additional potassium may have contributed to a higher dry matter, thus slowing down the rate of weight loss. Bulbs produced with 13-0-44 and Cal-N applications decayed the most and the least, respectively (Table-6).

Preliminary results of chemical analyses for pyruvate composition of onion, as a pungency indicator, revealed that different N-sources have some influence on the pungency level of onions (Table-7). Although statistically not significant, the mean values of pyruvic acid appeared to be the highest for Amm-N and the lowest for Cal-N treatments. Since this analysis was done on stored onions, it is conceivable that these results reflect a drastic change in pungency levels from the time of harvesting. This study will be continued with more detailed experiments and laboratory analyses in the near future.

CONCLUSIONS

Based on these experiments, different nitrogen formulations at lower rates, where N might become deficient, did not affect total onion yields. But at higher rates, Ammonium nitrate applications can be very effective in yield increases, especially in the high-value grade categories. Perhaps N rates higher than 200 lbs/A will have to be tested to determine the maximum economic yields without the excessive use of nitrates.

The aspect of N application scheduling or precise timing during the production period appears to be very crucial in maximizing yield potentials and minimizing quality problems which are related to bulb development and market characteristics. It might be concluded that these experiments demonstrated the advantage of split applications in a certain pattern to coincide with the plant development stages during the complete production cycle. There was a strong evidence that this area needs further study to find the balance of N formulation, amounts of N needed, and utilized by the onion plant throughout the long growing period.

Bolting of onion was closely associated with rapid growth and increased onion size. However, cold injury and bulb decay were reduced by more frequent N applications.

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Table 1. Effect of nitrogen source on marketable yield of onion.

Nitrogen source	Total no. x 1000/A all grades)		Percentage of large-sized onions		Marketable weight lbs x 1000/A	
	1989^{z}	1991^{y}	1989	1991	1989	1991
Cal-N	132 a^{x}	142 a	78 a	54 c	21.2 a	26.8 c
Sod-N	128 a	144 a	75 a	57 bc	19.5 a	31.8 b
Amm-N	128 a	147 a	74 a	63 a	19.3 a	36.6 a
Pot-N$_1$	127 a	148 a	74 a	61 ab	18.1 a	33.1 ab
Pot-N$_2$	123 a	--	73 a	--	17.7 a	--

Pot-N$_1$ = 15-0-14 formulation.

Pot-N$_2$ = 13-0-44 formulation.

[z] Average N rate = 112.5 lb N/A.

[y] Average N rate = 175.0 lb N/A.

[x] Means in columns followed by the same letter are not significantly different at 5% level.

Table 2. Effect of N-source on onion yields of different bulb size.

Nitrogen source	No. x 1000/A							
	Small (< 2.5")		Medium (>2.5" < 3")		Large (>3 <3.5")		Jumbo (>3.5")	
	1989	1991	1989	1991	1989	1991	1989	1991
Am-N	34 a	45 b	57 a	47 b	13 a	36 a	--	10 a
Sod-N	33 a	55 ab	64 a	44 b	12 a	30 ab	--	8 a
Pot-N_1	39 a	52 ab	58 a	56 a	11 a	29 bc	--	5 b
Cal-N	38 a	61 a	63 a	50 ab	14 a	23 c	--	3 b
Pot-N_2	33 a	--	57 a	--	11 a	--	--	--
Average bulb weight (lbs)	.07	.15	.23	.30	.46	.45	--	.65

Pot-N_1 = 15-0-14 formulation.

Pot-N_2 = 13-0-44.

Table 3. Effect of nitrate application regime on onion yields of different bulb size, 1991.

Number of N applications[1] (Oct-Dec/Jan-Apr)	No. x 1000/A				Ttl. marketable wt. (bags/A[2]) (>2.5")
	Small (< 2.5")	Medium (>2.5" < 3")	Large (>3 <3.5")	Jumbo (>3.5")	
One + three	65 a	41 b	23 b	5 b	621 b
Two + three	49 b	54 a	31 a	6 ab	819 a
Three + three	45 b	53 a	34 a	8 a	1,188 a

[1] Average N rate = 58.3 lb N/A for Oct.-Dec. period; 116.6 lb N/A for Jan.-Apr. period.

[2] Units of 50 lbs (grades med.-Jumbo) onions/bag.

Table 4. Effect of N-source on onion quality evaluations at harvest.

Nitrogen source	Cold injury (%) 1989	Bolted plants (%) 1989	Bolted plants (%) 1991	Decayed bulbs (%) 1989	Decayed bulbs (%) 1991
Am-N	2.3 b[x]	4.6 a	2.1 a	6.0 a	11 a
Pot-N_2	2.8 a	3.3 b	--	5.1 ab	--
Pot-N_1	2.5 ab	3.9 ab	0.7 bc	4.2 b	11 a
Cal-N	2.6 ab	3.1 b	0.3 c	3.9 b	7 a
Sod-N	2.2 b	4.8 a	1.1 ab	4.2 b	9 a

Pot-N_1 = 15-0-14 formulation.

Pot-N_2 = 13-0-44 formulation.

[y] Percentage of plants or bulbs affected.

[x] Means in columns followed by the same letter are not significantly different at 5% level.

Table 5. Effect of nitrate application regime on onion bolting and bulb decay.

Number of N applications (Oct-Dec/Jan-Apr)	Bolted plants (%)		Decayed bulbs (%)	
	1989	1991	1989	1991
One + two	3.1 c	--	4.3 ab	--
One + three	--	0.2 b	--	9 a
Two + three	5.9 a	1.5 a	3.9 b	11 a
Three + two	4.2 b	--	4.6 a	--
Three + three	--	0.8 b	--	10 a

Table 6. Effect of nitrogen source on onion quality after ten weeks of storage in ambient conditions, 1989.

Nitrogen source	Initial wt. (g/bulb)	10-week storage	
		Wt. loss (g/bulb)	Decayed bulbs (%)
Cal-N	174 a	57 ab	43 b
Sod-N	167 a	51 ab	48 ab
Amm-N	163 a	66 a	52 ab
Pot-N_1	153 ab	45 ab	65 ab
Pot-N_2	136 b	35 b	69 a

Pot-N_1 = 15-0-14 formulation.

Pot-N_2 = 13-0-44.

Table 7. Effects of N-source and application regimes on pyruvates in stored onions.[1]

Nitrogen source	No. of applications Oct.-Dec./Jan.-Apr.) 1 + 3	2 + 3	3 + 3	N-source average
	------------μ mol/ml of onion juice------------			
Am-N	2.6	2.6	2.8	2.66 a[2]
Pot-N	2.3	2.7	2.5	2.50 a
Sod-N	2.3	2.5	2.6	2.46 a
Cal-N	2.6	2.1	2.4	2.37 a
Appln's. avg.	2.5 a	2.5 a	2.6 a	--

[1] Chemical analysis performed on composite samples of 2 replicates of all treatments.

[2] Although there is an increasing trend in pyruvates from onions grown with calcium nitrate to onions grown with ammonium nitrate, the differences were not significant at 5% probability.