

EFFECTS OF NITROGEN SOURCE AND LEVEL ON THE GROWTH
AND COMPOSITION OF SINNINGIA SPECIOSA LODD,

by

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General Introduction

The gloxinia, Sinningia speciosa Lodd., is usually fertilized with a soluble complete fertilizer at 200 ppm N beginning after transferring seedlings to the finishing pot. Many of the water soluble complete fertilizers contain most of their N in the NH_4^+ and urea forms, which are less expensive than NO_3^- but when they comprise more than 75% of the N source may be toxic to gloxinias.

Ammonium toxicity to other species has been related to nutrient deficiencies, depleted plant carbohydrate reserves and absorption of large quantities of NH_4^+ . Ammonium application to some species reduces tissue levels of K, Ca and Mg via competition for absorption among the NH_4^+ , K^+ , Ca^{2+} and Mg^{2+} cations. Plants grown under low light may have inadequate stored carbohydrates to detoxify NH_4^+ by assimilating it into organic compounds. Low temperatures may promote NH_4^+ toxicity by inhibiting nitrification, thereby allowing time for plants to absorb large quantities of N in this form before it is converted to NO_3^- .

Gloxinia production costs, appearance and sale price depend upon fertilization and liming practices. The experiments described herein were conducted to determine the maximum percentage N that can be supplied as NH_4^+ and the minimum concentration of a soluble complete fertilizer that can be applied without reducing the quality of plants grown in limed and unlimed media under different light and temperature conditions.

Chapter 1

Nitrate and Ammonium Nutrition of Plants

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Abstract. Growth, tissue composition, biochemistry and physiology are often affected by the form in which nitrogen is supplied to plants. This review discusses the effects that fertilizing plants with nitrate, ammonium or a combination of nitrogen sources has on plant size, appearance, tissue composition, photosynthesis, respiration and nitrate reduction.

Introduction

Ammonium and urea are less expensive than nitrate as sources of nitrogen. Many plant growers therefore supply a large proportion of nitrogen as ammonium or urea, and many of the water soluble complete fertilizers contain most of their nitrogen in the ammonium and urea forms. This review addresses the effects of nitrogen source on general plant growth and appearance, tissue composition, biochemistry and physiology.

Effects of nitrogen source on general plant growth and appearance

The effects of absolute and relative amounts of nitrate (NO_3^-) and ammonium (NH_4^+) are highly species dependent. Many plants are subject to NH_4^+ toxicity, whose symptoms include interveinal chlorosis and marginal necrosis of young leaves, leaf distortion, stem lesions, stunting, wilting and even death (8,42,47,66). In sand and nutrient culture studies, higher shoot dry weights of bean (Phaseolus vulgaris L.), white mustard (Brassica hirta Moench), spinach (Spinacea oleracea L.), tomato (Lycopersicon esculentum Mill.), potato (Solanum tuberosum L.) and apple (Malus domestica Borkh.) have been reported when N was supplied as NO_3^- rather than as NH_4^+ (9,33,38,44,49,50). Leaf dry weights of sedum (Sedum telephoides Michx.) grown in a calcareous silty clay were greater when N was supplied as NO_3^- instead of NH_4^+ (36). Tomato and sweet corn (Zea mays L.) grown in quartz sand had lower shoot and root dry weights when given NH_4^+ than when given NO_3^- or both N sources (68). Ammonium as the sole N source reduced the dry weight of southernpea (Vigna unguiculata (L.) Walp.) seed and the number and weight of fruits of tomato plants, and inhibited flowering of duckweed (Lemna perpusilla Torr.) (29,49,56). Application of NO_3^- increased the crown volume and trunk diameter of sand culture-grown apple trees, and reduced the incidence of bitter pit that occurred with 50 or 100% NH_4^+ (38). Leucothoe (Leucothoe catesbaei Gray) shoots were longer and more numerous, and leucothoe and rhododendron (Rhododendron catawbiense Michx.) necrosis was reduced when N was

applied to the soil-based medium as NO_3^- (16).

Supplying all or part of its N as NH_4^+ can injure spinach roots in both acid and alkaline media (44). Lima bean (Phaseolus lunatus L.) root morphology was altered at 50, 100 and 150 ppm N when more than half of the N was in the NH_4^+ form (43). Injured roots become necrotic, have reduced dry weight or are shorter due to smaller, less vacuolated cells (41,57). Root injury by NH_4^+ may precede appearance of unusually dark green, wilted foliage (11).

In some cases, crop yield is maximized by applying a mixture of NO_3^- and NH_4^+ . Increase in terminal length, number of laterals, root volume and trunk cross-section of 4 cultivars of peach (Prunus persica (L.) Batsch) seedlings usually were greatest when 25-50% of the N was supplied as NO_3^- (17). Flower bud initiation of apple trees grown in perlite was increased by NH_4^+ applied any time from December through February as opposed to supplying N as NO_3^- all season (24). Chlorosis of corn grown in quartz sand with culture solutions, maximized with 100% NO_3^- -N, was minimized by applying half of the N as NO_3^- and half as NH_4^+ (65). Yields of cucumber (Cucumis sativus L.) grown in nutrient solutions were greater when N was supplied as a mixture of NO_3^- and NH_4^+ than when either N source was used alone (57). In solution culture, radish (Raphanus sativus L.) growth was reduced at NH_4^+ concentrations ranging from 1 to 240 ppm, but inhibitory effects were reversed when NO_3^- was added to equal or exceed 10% of the NH_4^+ concentration (22). Chrysanthemum (Chrysanthemum x morifolium Ramat.) shoot dry weight

was greater when NH_4NO_3 was applied to the potting mix of hardwood bark and sand than when $(\text{NH}_4)_2\text{SO}_4$ or KNO_3 were used (34). Gloxinia (*Sinningia speciosa* Lodd.) foliage is darker green when some of the N is supplied as NH_4^+ , but when more than 75% of the N is supplied in this form to plants grown under low light and temperature levels, gloxinias are stunted and foliage may become chlorotic (47,48).

Optimal growth of some plants occurs when N is supplied as NH_4^+ or urea. Azaleas (*Azalea* 'Sweetheart Supreme') grown in 3 organic media or in sand became increasingly chlorotic with increased percentage of N supplied as NO_3^- (37). Shoots of 'Tifblue' rabbiteye blueberry (*Vaccinium ashei* Reade) were longer and produced more flower buds from $(\text{NH}_4)_2\text{SO}_4$ application than from NaNO_3 application (59). Apple trees had a higher proportion of flower to vegetative buds when NH_4^+ was the sole N source than when NO_3^- was applied alone (25).

Various quality parameters of some plants are independent of N source. In soil-based media, chrysanthemum maturity, flower diameter and keeping quality, kalanchoe (*Kalanchoe laxiflora* Baker and *K. verticillata* Elliot) root, stem and leaf dry weights, apricot (*Prunus Armeniaca* L.) vegetative and reproductive growth, and rhododendron shoot length and number did not vary with N source (16,30,36,62).

Effects of N form on plants may be modified in several ways (31). Stage of plant development is often important; for example, germinating seeds and young seedlings tend to be especially

sensitive to NH_4^+ toxicity. Concentration of N applied can determine plant response to N source. When N was deficient, the dry weight of southernpea seed was greatest with 100% NO_3^- , but when sufficient N was supplied seed dry weight was similar at 50, 75 and 100% NO_3^- (56).

Type of growth medium can modify the effect of N source. Ammonium depressed growth and leaf tissue K concentration of corn grown in a sandy soil, but neither was affected by N source when corn was grown in a silty loam (15). Fresh weight of New Guinea impatiens (Impatiens platypetala Lindl.) grown in a modified Hoagland's solution decreased as the percentage of N supplied as NH_4^+ increased, but fresh weight of similar plants grown in a soil-based potting mix did not vary with percentage NH_4^+ (66). Height and dry weight of seed geranium (Pelargonium hortorum Bailey) and petunia (Petunia hybrida Bailey) grown in a peat-lite medium were lower when all N was supplied as NH_4^+ rather than as NO_3^- , but geranium dry weight and petunia height and dry weight were unaffected by N source when plants were grown in a soil-based medium (58).

Effects of N source also can vary with pH of the growing medium. When N is supplied as NH_4^+ , roots must excrete H^+ to maintain electrochemical neutrality, thereby causing the media pH to drop (33). The adverse effect of NH_4^+ on vegetable roots was overcome by addition of CaCO_3 (41). Ammonium toxicity to bean plants grown in sand culture was delayed by addition of carbonates in several compounds to control acidity (9). Rhododendron and leucothoe growth with NH_4^+ nutrition was better at pH levels of 6-7

than at pH levels of 4-5, while growth of similar plants given NO_3^- was better at pH 4-5 (14). Below a pH of 4 and above pH 6, NO_3^- uptake is reduced (53).

Effect of fertilizer N form is influenced by nitrification. In many soils NH_4^+ is converted to NO_3^- before NH_4^+ toxicity occurs, but this process is slowed during cool weather (4,8,67). Ammonium applied as $(\text{NH}_4)_2\text{SO}_4$ to several types of soils was in most cases nitrified within 2 to 3 weeks (21). In another study, most of the N supplied as $(\text{NH}_4)_2\text{SO}_4$ or urea had been converted to NO_3^- and leached from the fertilizer band within 40 days of application to a fine sandy loam soil (35). Tomato growth in a pine bark and sand medium decreased as the percentage of N supplied as NH_4^+ increased, but when nitrapyrin was incorporated to inhibit nitrification, more N was retained in the medium which increased growth and total N in the tissue (46).

Effect of N source on nutrient absorption and tissue composition

Ammonium competes with other cations for absorbance. In some plants, NH_4^+ toxicity is linked to a deficiency of other nutrients, notably Ca, Mg, and K (2,3,8,68). The presence of NH_4^+ reduces absorption of Ca^{2+} and Mg^{2+} by apple and forage crops, Mn uptake by highbush blueberry (Vaccinium corymbosum L.), and even NO_3^- absorption by some plants (5,8,12,38,61). Fertilizing forage crops with NH_4^+ increases the incidence of grass tetany in ruminants in the early spring and fall when low soil temperatures inhibit nitrification, allowing the NH_4^+ ion to antagonize Mg^{2+} and

Ca^{2+} absorption without significantly reducing K^+ uptake (5,12,28, 67). Potassium can also suppress absorption of Ca^{2+} and Mg^{2+} , but NH_4^+ reduces their absorption more than K does (15). Ammonium toxicity of tomato was prevented by applying equivalent amounts of NH_4^+ and K^+ to compensate for competitive uptake as well as to enhance NH_4^+ assimilation (3). Fertilizers containing both NH_4^+ and P were found to increase P uptake over application of P alone, while NO_3^- fertilization increased P uptake very little except in late growth stages (45).

Tissue composition often varies with N source. The basic cation content of cucumber and pea (*Pisum sativum* L.) leaves was affected more by N form than by fertilizer N concentration (7). Phosphorous, Ca, Mg, Mn and Fe levels in rabbiteye blueberry leaves, Ca and Mg content of pea leaves, P content of tomato leaves, P and S concentrations in corn, and P, S and Cl levels in white mustard plants were higher with NH_4^+ than NO_3^- fertilization (7,12,33,59). In contrast, Ca and Mg concentrations in corn and tomato leaves, P content of corn leaves, K levels in tomato fruits and bean and cucumber leaves, K, Ca and Mg levels in white mustard plants, and peach seedling concentrations of P, K, Ca and Mg were lower when N was supplied as NH_4^+ (12,15,17,33,41,49,51,65). Magnesium, K and NO_3^- levels in tomato fruits do not always vary with N form, but when NH_4^+ was applied during tomato fruiting, blossom end rot, a physiological disorder caused by Ca deficiency, occurred quickly (49,68).

Tissue N concentration was greater in kalanchoe leaves and roots, bean, corn, cucumber, pea, spinach, blueberry and sedum leaves, chrysanthemum shoots, and white mustard plants when N was supplied as NH_4^+ rather than as NO_3^- (31,34,36,41,44,59). In some cases, this may be due to the concentrating effect of smaller plants with NH_4^+ application. Total N concentration of southernpea seeds was lower at deficient N levels when 25-50% of the N was NH_4^+ than if NO_3^- was the sole N source (56). Nitrogen compounds in plants often become less mobile when more than half of the N is supplied as NH_4^+ (8).

The form in which N is applied affects numerous organic compounds. Total soluble carbohydrate and starch levels were lower for chrysanthemums given NH_4NO_3 than for those fertilized with CaNO_3 (62). Cucumber leaves had lower starch and higher glucose contents as the concentration of applied NH_4^+ increased from 20 to 200 ppm (40). Stored carbohydrates are depleted as they are used in NH_4^+ assimilation into amino acids and amides (5,6,28). Cucumber leaves suffering NH_4^+ toxicity had low glucose-6-phosphate content, but high glucose-1-phosphate, fructose-6-phosphate and uridine diphosphate levels (39). The organic ion and oxalate content of spinach leaves increased and the organic N concentration decreased as the proportion of N supplied as NO_3^- increased (44). White mustard plants contained lower amounts of non-volatile organic acids when plants received NH_4^+ than if given NO_3^- (33).

Increased amide synthesis may suppress NH_4^+ toxicity to

metabolic processes (54). Roots contain more amides and fewer carboxylates as more NH_4^+ is supplied. Onion (Allium cepa L.), for example, can assimilate NH_4^+ into amides in its roots and bulbs, which may explain its high NH_4^+ tolerance (41). Bean leaves grown in acidic solutions accumulated NH_4^+ , amino acids and amides, while roots of beans grown in nearly neutral solutions accumulated amino acids and amides (41). White mustard plants given NH_4^+ contained more free amino acids than those given NO_3^- (33). Fertilizing some species with NH_4^+ increases the proportion of aspartate to glutamate, raises the ratio of asparagine to aspartate and glutamate, and increases leaf concentrations of asparagine and arginine, all reflecting efficient carbon use in assimilating NH_4^+ (6,26,54,55). This frees more energy and carbohydrates for plant growth (8).

Plant growth under NH_4^+ nutrition is often improved by adding CaCO_3 to the growth medium. Work with bean (Phaseolus vulgaris L.) suggests that this improvement results from increased synthesis of organic N compounds in roots and from decreased transport of free NH_4^+ to shoots (10). Ammonium assimilation was inhibited in bean shoots but increased in roots by CaCO_3 application (41). Maintenance of a neutral pH enhanced NH_4^+ assimilation into nontoxic amino acids and amides in bean roots (9).

Effects of N source on photosynthesis and respiration

Chlorosis is a common symptom of NH_4^+ toxicity. Chlorophyll contents of tomato, sedum and Kalanchoe laxiflora leaves decreased

when NH_4^+ was applied (36,51,52). Reduced chlorophyll content of cucumber leaves paralleled a yield reduction as the NH_4^+ concentration in the nutrient solution was increased (57). The activity of ribulose biphosphate carboxylase, important in the reductive pentose phosphate cycle of photosynthesis, was reduced by half in radish seedlings given NH_4^+ rather than NO_3^- , perhaps explaining their lower CO_2 fixation rate (23). The radish seedlings' chlorophyll content decreased continuously after growing for 3 days in a nutrient solution with 240 ppm N supplied as NH_4^+ .

Use of NH_4^+ as the sole N source alters or inhibits chlorophyll biosynthesis in many plants. Detailed studies of tomato leaf chloroplasts during NH_4^+ toxicity showed distinct changes in chloroplast placement and structure (52). Chloroplasts touched one another and were not close to the cell wall as in healthy plants. Chloroplasts frequently exhibited small protrusions extending from the membrane, had fewer compartments per granum or even no grana, and were usually round in cross section. In cases of severe NH_4^+ toxicity, granal and fret components became vesiculated, and the membranes were disrupted, possibly explaining the increase in soluble N.

Uncoupling of photophosphorylation by NH_4^+ decreases the energy available for protein synthesis, and the decrease in photosynthesis caused by NH_4^+ toxicity lowers the supply of carbohydrate, reducing detoxification of NH_4^+ (18,41,52,57,67). This in turn limits protein metabolism, which greatly affects the

chloroplasts, as they contain up to 70% of the protein in leaves (52,60).

Since NH_4^+ assimilation requires carbon skeletons, older, healthy plants with stored carbohydrates and ketoacids are less susceptible to NH_4^+ toxicity than plants with little stored carbohydrate. Ammonium in roots is converted to glutamate by reductive amination of alpha-ketoglutarate, and to glutamine and asparagine by enzymatic synthetases (54). Excess NH_4^+ reverses the oxidative deamination of glutamate, which requires the cofactor NAD^+ , thereby inhibiting alpha-ketoglutarate entry into the TCA cycle (40). Succinate oxidation, which does not require the cofactor NAD^+ , is not inhibited by NH_4^+ (64). Ammonium activates succinyl-CoA synthase in tobacco (Nicotiana tabacum L.), and pyruvate kinase in pea roots and leaves (14,19). Both enzymes use the cofactor ADP.

Plants grown under high light intensity may produce more energy than their photosystems can use. Nitrate reduction to NH_3 requires 8 electrons, providing a pathway for use of excess energy and promoting CO_2 assimilation into carbohydrate. This may explain why some species require a higher proportion of their N to be applied as NO_3^- in the summer than in the winter. Net photosynthesis of carnation (Dianthus caryophyllus L.) increased with increasing percentage of NO_3^- under high solar radiation levels (27).

Effect of N source on nitrate reduction

Absorbed NO_3^- and NO_2^- must be reduced within plants by a

series of enzyme-catalyzed reactions. Therefore, nitrate and nitrite reductase levels usually are higher in plants when N is supplied as NO_3^- . Application of NH_4^+ decreases the concentrations of these enzymes in some species (13). Nitrate reductase contains Mo, hence the chlorotic appearance of plants deficient in Mo (18). Nitrate reductase is activated by light, and in most plants NO_3^- accumulates under short photoperiod and low light intensity (32,63). Azaleas, however, reduced NO_3^- more readily under 800 than 2100 foot candles (37). The leaves of ericaceous plants contain very little nitrate reductase, possibly causing their generally poor growth when NO_3^- is the N source. Studies of Chlorella vulgaris indicate that synthesis of nitrate reductase from amino acids may be preceded by an enzymatically inactive protein precursor (20). Subsequent synthesis of nitrate reductase may require a substrate or enzyme not present in plants grown completely with the NO_3^- form of N.

Summary

Extensive research has determined many effects of N source on plant growth. Plant size, quality and crop yield often depend upon the form in which N is applied, showing external evidence of the effects of N source on internal biochemical and physiological processes. Nutrient absorption and tissue composition can vary greatly with N source, sometimes causing deficiencies or imbalances of other essential elements. Starch, sugar, amino acid, amide and

carboxylate contents vary with N form as these compounds are used or formed in N assimilation into organic compounds. Nitrogen form indirectly affects photosynthesis and respiration by influencing chloroplast morphology and the synthesis of organic compounds.

Plant response to absolute and relative amounts of NO_3^- and NH_4^+ depends upon many internal and external conditions. The plant species, its ability to reduce NO_3^- , its supply of carbohydrates and ketoacids, and its overall nutrient status are important. Growth medium type and pH influence plant response. Light modifies the effect of N form as it determines carbohydrate and energy production. Temperature affects plant response directly through its influence on plant processes and indirectly through its effect on nitrification.

Efficient use of fertilizer depends upon understanding all factors affecting crop response to N form. Plant growers can improve plant yield and quality by applying the optimal ratio of NO_3^- to NH_4^+ , and by adjusting this proportion to changes in the crop and its environment. As crop response to N source is quite variable, this optimal ratio must be determined by experimentation.

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Chapter 2

Effect of Nitrogen Source on Gloxinia (Sinningia speciosa Lodd.)

Grown Under Low Light and Temperature Conditions

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Additional index words. Ammonium toxicity, nitrogen nutrition

Abstract. In the winters of 1980-81 and 1981-82, gloxinia (Sinningia speciosa Lodd.) seedlings were grown in an organic medium or sand under low light (95-154 langleys day⁻¹) and temperature (19-20°C day, 14-16°C night) levels and fertilized with different ratios of NH₄⁺:NO₃⁻ to determine the effects of N source on gloxinia growth and to relate these effects to changes in tissue composition. Both winters, shoot dry weight was lower at 100% NH₄⁺ than at 0, 25 or 50% NH₄⁺. Gloxinias given 4, 8, 12 or 16 meq N liter⁻¹ had greater shoot dry weights with 100% NO₃⁻ rather than with 100% NH₄⁺. Days until flower buds became visible and the number of flowers and flower buds on plants at harvest did not vary with percentage NH₄⁺ or fertilizer N concentration. Total N concentration in tissue was greater at 100% NH₄⁺ than at 0-50% NH₄⁺ in 1980-81, and increased with increasing applied N level. Tissue levels of P, K, Ca and Mg did not vary with percentage NH₄⁺ or fertilizer N concentration. Gloxinia seedlings grown in quartz sand for 35 days had higher concentrations of chlorophylls a and b, and total chlorophyll when grown with 100% NH₄⁺ rather than with 100% NO₃⁻.

Introduction

The form in which N is supplied to plants often affects their color, size, shape and chemical composition (5,6,8,10,14). Crop response to absolute and relative amounts of NO_3^- and NH_4^+ varies with plant type and environmental conditions (6,22). Ammonium and urea are less expensive N sources than NO_3^- , but reduced production costs must be weighed against final plant quality and saleability.

The gloxinia often exhibits symptoms of NH_4^+ toxicity when fertilized with water soluble fertilizers which supply about 75% of their N as NH_4^+ and urea (15,20). The following experiments were conducted to determine the maximum percentage NH_4^+ with which gloxinias can be fertilized under low light and temperature levels without inhibiting their growth and flowering and to study the effect of percentage NH_4^+ on gloxinia tissue composition.

Materials and Methods

Experiments I and II. *Sinningia speciosa* 'Improved Red Velvet' seedlings were planted October 23, 1980 in 15-cm azalea pots containing a 6 Canadian peat:2 vermiculite:1 perlite:1 coarse sand (by volume) mixture frequently used as a growth medium for gloxinias. Plants were grown in a glasshouse under 50% shade cloth. Environmental conditions for all experiments discussed in this paper are described in Table 1.

Experiment I. Plants were fertilized with a modified Hoagland's solution (9) containing 16 meq N liter⁻¹ supplied as 0, 25, 50, 75 or

Table 1. Dates and environmental conditions of 4 experiments.

Experiment	Dates		Mean greenhouse			
	Plant	Harvest	Solar radiation (langleys day ⁻¹)		Temperature (°C)	
			First mo.	Expt.	Day	Night
I	10-23-80	1-13-81	142	125	20	16
II	10-23-80	1-13-81	142	125	20	16
III	1-20-82	3-23-82	128	154	19	14
IV	12-7-81	1-12-82	95	95	19	14

100% NH_4^+ , with the balance supplied as NO_3^- . Six replicates of each treatment were arranged in a randomized complete block design with blocking over benches to account for environmental differences.

Experiment II. Seedlings in the concurrent study, experiment II, were potted and grown similarly, but fertilized with modified Hoagland's solutions with 4, 8, 12 or 16 meq N liter⁻¹ supplied either as NO_3^- or NH_4^+ . These plants were placed in a 4 x 2 factorial arrangement with 6 replicates in a randomized complete block design, blocked by benches. In both experiments, the date on which the first flower bud on each plant was easily visible with a diameter of 0.3 cm was recorded. All plants were harvested January 13, 1981, when 10% of the crop had flower buds showing color and several plants had recently died. Flowers and flower buds were counted, then shoot tissue was dried under forced air for 96 hours at 70°C before weighing. The third fully expanded pair of leaves of each plant in both studies was ground for tissue analysis. Total N was determined by the micro-Kjeldahl method. Aliquots of ashed tissue dissolved in 0.3 N HNO_3 were analyzed colorimetrically for P (4), and for K, Ca and Mg by atomic absorption spectrophotometry. Data were subjected to analyses of variance, with significant effects further subjected to Duncan's multiple range test at the 5% level of significance.

Experiment III. Experiment I was repeated with seedlings planted January 10, 1982 and harvested March 23, 1982 shortly after the death of several plants in order to keep results comparable. In this

study, the fertilizer solutions contained only 12 meq N liter⁻¹, 2 kg hydrated limestone (128% CaCO₃ equivalency, 100% passed through No. 20, 98% through No. 60, 95% through No. 100 U.S. standard seive) was incorporated per 1 m³ media, and there were 8 replications of each treatment. Data were taken and statistically analyzed as described above.

Experiment IV. Until NH₄⁺ toxicity induces chlorosis, gloxinias supplied NH₄⁺ tend to be darker green than those supplied NO₃⁻. A separate study was conducted to determine if this is reflected in the chlorophyll content. Sinningia speciosa 'Improved Red Velvet' seedlings were planted on December 7, 1981 in 4-liter glazed ceramic crocks containing quartz sand. A 1-cm hole near the bottom of each crock was covered with polyester pillow fill and a watchglass, and fitted with a stopper attached to a black rubber tube. Plants were irrigated 4 times daily with a modified Hoagland's solution containing 12 meq N liter⁻¹ in either the NO₃⁻ or NH₄⁺ form. As they drained, treatment solutions were collected; solutions were used for one week before being replaced. Treatments were arranged in a randomized complete block with 8 replications. The second fully expanded leaf pair of each plant was harvested January 12, 1982. A 50 mg sample of the fresh tissue was analyzed for chlorophylls a and b content according to the method developed by Arnon (3), and a second sample was analyzed for dry weight: fresh weight to standardize data through analysis of covariance.

Results and Discussion

Leaves of gloxinias given 75 or 100% NH_4^+ were dark green early in experiments I-III, but later became chlorotic, twisted and quilted. Many of these plants appeared permanently wilted, and most of those given 100% NH_4^+ were dead or nearly dead by the end of the studies. Days to visible flower buds and flower bud count at harvest did not vary with percentage NH_4^+ (Table 2); even plants with only 2 leaves produced flower buds, although buds on plants receiving 100% NH_4^+ rarely matured.

In experiment II, when 4-16 meq N liter⁻¹ are applied, gloxinia growth and appearance under low light and temperature levels depended more upon fertilizer N source than N level, with no main effect interactions. Similar results have been reported for other species (12). Shoot dry weight was greater for gloxinias given 100% NO_3^- rather than 100% NH_4^+ , regardless of fertilizer N concentration, but did not vary with N level (Table 3). In experiment I, gloxinias receiving 100% NH_4^+ had lower shoot dry weights than those receiving 0-75% NH_4^+ , and in experiment III shoot dry weight was lower with 75 and 100% NH_4^+ than with 0% NH_4^+ (Table 4). Numerous other crops react similarly to NH_4^+ (6,10,11,14,16,21,23).

Tissue N concentration of gloxinias grown in experiment II increased as the level of N applied increased but was unaffected by N source and there was no source x level interaction (Table 5). Tissue level of total N did not vary with N source in experiment III, but was greater with 100% NH_4^+ than with 0-50% NH_4^+ in experiment I

Table 2. Mean days to visible flower buds, flower bud count, and tissue concentration of P, K, Ca and Mg of gloxinias grown with varied fertilizer N source and concentration under low light and temperature levels^z (experiments I and III).

Variable	Days to		Bud		----- Concentration (% dry wt.) -----							
	0.3 cm buds		count		P		K		Ca		Mg	
	1981	1982	1981	1982	1981	1982	1981	1982	1981	1982	1981	1982
% total N as NH ₄ ⁺ ^y	48	50	10	5	0.33	0.27	2.5	4.6	1.7	2.9 ^x	0.38	0.51 ^x
N concentration ^w	47	--	8	-	0.34	--	2.8	--	1.8	--	0.41	--

^zA single mean is given due to lack of significant treatment differences.

^yNitrogen was supplied as 0, 25, 50, 75 or 100% NH₄⁺, with the balance supplied as NO₃⁻.

^xGround hydrated limestone was incorporated into the media in winter 1982 only.

^wFertilizer solutions contained 4, 8, 12 or 16 meq N liter⁻¹.

Table 3. Effect of nitrogen source on shoot dry weight of gloxinias given 4, 8, 12 or 16 meq N liter⁻¹ (experiment II).

N Source	Dry weight (g) ^z
NO ₃ ⁻	5.0a ^y
NH ₄ ⁺	3.2 b

^zDry weight did not vary with fertilizer N level.

^yMean separation by Duncan's multiple range test, 5% level.

Table 4. Effect of nitrogen source on shoot dry weight and total N of gloxinia grown in two winters (experiments I and III).

% total N as NH ₄ ⁺	Shoot dry weight		Total N	
	(g)		(% dry weight)	
	1981	1982	1981	1982
0	5.0a ^z	3.2a	3.5bc	4.0a
25	5.5a	2.5abc	3.4c	4.1a
50	4.5a	2.8ab	3.6bc	4.0a
75	4.4a	1.4bc	3.8ab	3.8a
100	1.7b	1.1c	4.0a	3.8a

^zMean separation within columns by Duncan's multiple range test, 5% level.

Table 5. Effect of fertilizer N level on
tissue total N content of gloxinias
given 100% NO_3^- or 100% NH_4^+ (experiment II).

N level (meq liter ⁻¹)	Tissue N content ^z (% dry weight)
16	3.8a ^y
12	3.4b
8	2.9c
4	2.0d

^zTissue N content did not vary with N source.

^yMean separation by Duncan's multiple range
test, 5% level.

(Table 4). The increase in total N with increasing percentage NH_4^+ has been reported for other plants, frequently due to the concentrating effect of smaller plants (11,19). Tissue levels of P, K, Ca and Mg were unaffected by N source and level.

Symptoms of NH_4^+ toxicity have in some cases been alleviated by CaCO_3 application, which simultaneously raises the pH, supplies Ca which might otherwise be deficient, and reduces accumulation of NH_4^+ and amides in plant tops (7,13,23). Incorporation of Ca(OH)_2 did not improve gloxinia growth in experiment III; in general at each percentage NH_4^+ gloxinias were smaller and more misshapen in 1982 than in the previous winter when the media were not limed. The high tissue concentrations of Ca and Mg in 1982 (Table 2) indicate that NH_4^+ toxicity to gloxinias does not induce a Ca or Mg deficiency as it does in some plants (1,2,5,18,23).

Prior to the onset of chlorosis in the first 3 studies, gloxinias given 75 or 100% NH_4^+ had darker green leaves than those given 0-50% NH_4^+ . Darker green color after 1 month may be attributed to a higher content of chlorophylls a and b and total chlorophyll (Table 6). The higher dry weight:fresh weight for plants grown with NH_4^+ could have contributed to the darker color via the concentrating effect of reduced leaf water content.

Under the relatively low light and temperature conditions of these studies, supplying 75-100% of the N as NH_4^+ reduced gloxinia shoot dry weight and caused distortion and discoloration of the leaves. This NH_4^+ toxicity to gloxinias may be related to

Table 6. Chlorophyll content of gloxinia leaves grown in quartz sand with NO_3^- or NH_4^+ , as adjusted for dry weight (experiment IV).

N source	mg dry wt. 50 mg fr. wt.	Chl a (mg) ^z	Chl b (mg)	Total chl (mg)	Chl a Chl b
NO_3^-	3.9	0.015b ^y	0.010b	0.025b	1.87a
NH_4^+	5.5	0.061a	0.025a	0.086a	2.44a

^zChlorophylls a and b and total chlorophyll are expressed as mg chlorophyll per 50 mg fresh tissue.

^yMean separation within columns by Duncan's multiple range test, 5% level.

environmental conditions. Even in the greenhouse, average temperatures and light levels were relatively low throughout these experiments (Table 1). Slow conversion of NH_4^+ to NO_3^- at low temperatures allows time for large quantities of NH_4^+ to be absorbed (22). Low light levels reduce the plants' supplies of carbohydrates and ketoacids available to detoxify NH_4^+ by assimilating it into organic compounds (13,17,22). Further research is necessary to determine if gloxinias are subject to NH_4^+ toxicity when grown under high light and temperatures or if NH_4^+ toxicity is induced by low light and temperature levels.

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Chapter 3

Effect of Nitrogen Source on Gloxinia (Sinningia speciosa)

Grown Under Relatively High and Moderate

Light and Temperatures in Two Media

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Abstract. Gloxinia (Sinningia speciosa Lodd.) seedlings were grown in 2 media and irrigated with nutrient solutions of different NH_4^+ : NO_3^- ratios to determine the effects of N source on gloxinia growth under relatively high light (295-355 langleys day^{-1}) and temperature (26-27°C day, 17-18°C night) levels or under moderate conditions (215 langleys day^{-1} , 24°C day, 16°C night) and to relate these effects to N form and concentration of leachates. Shoot dry weight of gloxinias grown in an organic potting mix under moderate conditions was lower when 100% of the N was supplied as NH_4^+ than when 0 or 50% of the N was in this form with the balance supplied as NO_3^- , but did not vary with applied N form under high light and temperature levels. Root dry weight of plants grown in sand was greater at 0% than at 50 or 100% NH_4^+ under high light and temperatures. Time to flower bud set was unaffected by N source under all conditions. The number of flowers and flower buds on plants at harvest did not vary with N source at high light and temperature levels, but was reduced at 100% NH_4^+ when grown under moderate conditions. These studies indicate that the N source in fertilizers has little effect on gloxinias grown under relatively high light and temperature levels, but the use of 100% NH_4^+ reduces plant quality under moderate light and temperature conditions. Gloxinia response to N source is related to light intensity and temperature-mediated changes in fertilizer N form after application to the growth medium.

Introduction

Plant vegetative and reproductive growth, color and elemental composition often depend upon the form of applied N (8,9,10,12,18). Ammonium and urea, less expensive N sources than NO_3^- , are toxic to many plants under certain conditions (1,2,7,11,14,18). The effects of N form on plants may be modified by temperature, light, media type and pH, and plant age and health (6,17,19).

In previous studies by the author, gloxinias grown under low light and temperature levels exhibited symptoms of NH_4^+ toxicity including leaf distortion, discoloration and stunting when 75-100% of the N was supplied as NH_4^+ (15). The following studies were initiated to determine the effects of N source on gloxinia growth and elemental composition under high light and temperatures and to relate these effects to changes in treatment solutions after interaction with the growth media.

Materials and Methods

In each study, Sinningia speciosa 'Improved Red Velvet' seedlings were planted singly in 4-liter glazed ceramic crocks placed in a glasshouse under 50% shade cloth. A 1-cm hole near the bottom of each crock was fitted with a stopper attached to a black rubber tube. Fertilizer treatment solutions applied each week at a rate of 1 liter per container were collected as they drained and were reused for 1 week. Leachate volume and pH were determined at the end of each week and leachate N content analyzed with an HNU Systems NH_3

electrode and an Orion Research NO_3^- electrode. At the end of each experiment harvested tissue was dried for 96 hours under forced air at 70°C before weighing. Data were subjected to analyses of variance, with significant effects further subjected to Duncan's multiple range test at the 5% level (16).

Experiment I. Seedlings were planted May 27, 1981 in sterile quartz sand that had been leached with distilled water. Seedling roots were gently washed to remove the organic medium in which they had been grown. Plants were irrigated at least twice daily with modified Hoagland's solutions (11) at pH 5.6, containing 112 or 224 mg total N liter⁻¹ supplied as 0, 50 or 100% NH_4^+ , with the balance supplied as NO_3^- . A 2 x 3 factorial arrangement was used with 8 replicates. Solar radiation under the shade cloth averaged 355 langleys day⁻¹, with average greenhouse temperatures of 27°C (day) and 18°C (night). Time until flower buds became easily visible with a diameter of 0.3 cm was recorded for each plant. Plants were harvested July 20, 1981 and the roots and shoots dried separately. Leachate volume, pH, and NH_4^+ and NO_3^- concentrations were measured every week, beginning with the second week.

Experiment II. Seedlings were planted August 4, 1981 in a 6 Canadian peat:2 vermiculite:1 perlite:1 sand (by volume) potting mix which has been successfully utilized by a commercial gloxinia specialist (Earl J. Small Growers, Inc., Pinellas Park, FL 33565). Hydrated limestone (CaCO_3 equivalency 128%, particle size distribution such that 100% passed through No. 20, 98% through No. 60 and

95% through No. 100 U.S. standard sieve) was incorporated at a rate of 2 kg per m³ media. Plants were irrigated with modified Hoagland's solutions with a pH of 5.6 containing 140 mg N liter⁻¹ supplied as 0, 25, 50, 75 or 100% NH₄⁺. Treatments were arranged in a randomized complete block design with 8 replicates. Solar radiation under the shade cloth averaged 295 langley's day⁻¹. Temperatures averaged 26°C (day) and 17°C (night). The date on which the first flower bud on each plant became easily visible with a diameter of 0.3 cm was recorded. Plants were harvested October 13, 1981 when 10% of the crop had flower buds with color. After drying and weighing, the third fully expanded leaf pair of each plant was ground for tissue analysis. Total N was determined by the Kjeldahl method. Aliquots of ashed tissue dissolved in 0.3 N HNO₃ were analyzed colorimetrically for P (4) and by atomic absorption spectroscopy for K, Ca and Mg. Leachate data were taken every week, beginning the second week.

Experiment III. Seedlings were planted September 10, 1981 in the organic potting mix amended with hydrated lime described above. Treatments were arranged in a 2 x 3 factorial design with N supplied at 112 or 224 mg N liter⁻¹ as 0, 50 or 100% NH₄⁺. Modified Hoagland's solutions had a pH level of 5.6. Solar radiation averaged 215 langley's day⁻¹, while temperatures averaged 24°C (day) and 16°C (night). Leachate data were collected every other week for 8 weeks. Plants were harvested November 30, 1981, and flowers and flower buds on each plant were counted. Shoot tissue was dried, weighed and

analyzed for N, P, K, Ca and Mg as described above.

Results

Experiment I. Shoot dry weight did not vary with applied N source or level (Table 1). Root dry weight was greater at 0% NH_4^+ than at 50 or 100% NH_4^+ , but did not vary with N level. Bud set occurred earlier at 112 than at 224 mg N liter⁻¹, but was unaffected by N form.

Leachate volume and composition response to treatment did not vary over time in any of these studies. After 1 week's use, the percentage of the N supplied as NH_4^+ did not change at either N level (Table 2). Leachate NH_4^+ -N concentration increased and the NO_3^- -N concentration decreased as the percentage NH_4^+ -N in the stock treatment solutions increased, and the concentration of each N form was greater at the higher application rate. The total N concentration of leachates did not vary with N source, but was greater for the higher fertilizer N level. Leachate N was more concentrated than N in stock treatment solutions due to the greater relative absorption of water than of N.

The amount of N remaining in the leachate of each container was unaffected by N source and the percentage N remaining did not vary with N level. Leachate volume did not vary with N source or level. At both application rates, leachate pH was higher with 0% NH_4^+ than with 50 or 100% NH_4^+ .

Experiment II. After 1 week of use, leachate N form was similar

Table 1. Effect of N source and level on gloxinias grown in quartz sand under relatively high light and temperature levels.

N level (mg N liter ⁻¹)	N source (% total N as NH ₄ ⁺)	Dry weight (g)		Days to 0.3 cm buds
		Shoot	Root	
112	0	3.7a ^z	1.0a	36b
	50	4.0a	0.6b	38b
	100	3.1a	0.4b	39ab
224	0	3.9a	0.9a	41a
	50	3.4a	0.4b	43a
	100	2.9a	0.4b	42a

^zMean separation within columns by Duncan's multiple range test, 5% level.

Table 2. Effect of N source and level on leachates 1 week after application to gloxinias grown in quartz sand (experiment I).

Treatment		N in leachates				Leachate N ^z	Leachate
N level	N source	N form	NH ₄ ⁺ -N	NO ₃ ⁻ -N	Total N	per unit N applied	Vol. ^z pH
(mg liter ⁻¹)	(% total N as NH ₄ ⁺)	(% NH ₄ ⁺)	(ppm)	(ppm)	(ppm)	(%)	(ml)
112	0	2c ^y	2c	116a	118a	73a	711a 5.4a
	50	48b	54b	59b	113a	73a	711a 4.8b
	100	93a	107a	8c	115a	73a	693a 4.8b
224	0	1c	2c	251a	253a	77a	692a 5.4a
	50	47b	116b	128b	244a	82a	752a 4.8b
	100	96a	226a	7c	233a	77a	721a 4.8b

^zMean value per container.

^yMean separation within columns within levels by Duncan's multiple range test, 5% level. These means are averaged over all weeks as there was no significant treatment x week interaction.

for all treatments regardless of original N source (Table 3), as were shoot dry weight, days to bud set, and elemental composition of the tissue (Table 4). The concentration of NH_4^+ -N did not vary with treatment but leachate NO_3^- -N and total N concentrations decreased as the percentage NH_4^+ in stock solutions increased. This was due to the concentrating effect of increased water absorption by plants given 0 or 25% NH_4^+ , as shown by the decreased volume of leachate. From 36-71% of the N applied remained in the leachates, with a higher percentage N remaining in leachates of plants receiving 50-100% NH_4^+ than in leachates of plants receiving 0% NH_4^+ . Leachate pH was variable, but well within the range required for optimal gloxinia growth.

Experiment III. Gloxinia shoot dry weight was greater with 0 or 50% than with 100% NH_4^+ at both N application levels (Table 5). Plants given 0% NH_4^+ had more flower buds at harvest than those given 100% NH_4^+ . Tissue content of N and K did not vary with N source, but P concentration was greater and Ca and Mg concentrations lower with 0% NH_4^+ than with 50 or 100% NH_4^+ .

Regardless of N source, shoot dry weight was greater when treatment solutions contained 112 rather than 224 mg N liter⁻¹ (Table 6). Flower bud count did not vary with N level. Tissue concentrations of P, Ca and Mg did not vary with N level, but tissue contained more total N and less K at the higher application rate.

A maximum of 25% of the N leachate was present as NH_4^+ ; this percentage was unaffected by application rate and decreased with

Table 3. Effect of N source on leachates 1 week after application to gloxinias grown in an organic medium (experiment II).

Treatment	N in leachates				Leachate N ^z per unit N applied	Leachate	
	N form	NH ₄ ⁺ -N	NO ₃ ⁻ -N	Total N		Volume ^z	pH
N source (% N as NH ₄ ⁺)	(% NH ₄ ⁺)	(ppm)	(ppm)	(ppm)	(%)	(ml)	
0	3a ^y	6a	197a	203a	36c	316c	5.9a
25	8a	15a	182ab	197a	50bc	406b	5.3b
50	7a	13a	175b	188a	71a	444ab	5.5ab
75	7a	17a	153c	170b	57b	443ab	5.7a
100	2a	9a	157c	166b	71a	494a	5.8a

^zMean value per container.

^yMean separation within columns by Duncan's multiple range test, 5% level. These means are averaged over all weeks as there was no significant treatment x week interaction.

Table 4. Effect of nitrogen source on growth and elemental composition of gloxinias grown under high light and temperature levels in an organic potting mix.

N source (% N as NH_4^+)	Shoot dry weight (g)	Days to 0.3 cm buds	N -----% dry weight-----	P	K	Ca	Mg
0	14.0 ^z	56	3.7	0.37	4.6	2.6	0.86
25	11.3	56	3.6	0.33	4.9	2.6	0.84
50	10.0	60	3.6	0.30	4.7	2.4	0.75
75	11.0	56	3.7	0.40	4.2	2.6	0.91
100	9.1	55	3.5	0.40	4.1	2.7	0.89

^zNone of the parameters varied significantly with N source.

Table 5. Effect of N source on growth and chemical composition of gloxinia grown under moderate light and temperature levels.

N source (% N as NH_4^+)	Shoot dry wt. (g)	Bud count	N -----	P -----	K -----	Ca -----	Mg -----
			% dry weight				
0	12.0a ^z	58a	3.8a	0.44a	4.6a	2.3b	0.8b
50	10.8a	55ab	3.8a	0.34b	4.2a	2.7a	1.0a
100	8.5b	41b	3.8a	0.32b	3.9a	2.6a	1.1a

^zMean separation within columns by Duncan's multiple range test, 5% level.

Table 6. Effect of N level on growth and chemical composition of gloxinia grown in an organic medium under moderate light and temperature levels.

N level (mg liter ⁻¹)	Shoot dry wt. (g)	Bud count	N -----	P -----	K -----	Ca -----	Mg -----
			% dry weight				
112	11.9a ^z	52a	3.6b	0.37a	4.5a	2.5a	0.9a
224	9.2b	51a	3.9a	0.36a	3.9b	2.6a	1.0a

^zMean separation within columns by Duncan's multiple range test, 5% level.

decreasing percentage NH_4^+ in the treatment solutions (Table 7). Leachate concentration of NH_4^+ -N did not vary with N source at 112 mg N liter⁻¹ but increased with increasing treatment NH_4^+ percentage at 224 mg N liter⁻¹, with greater NH_4^+ -N concentrations at the higher application rate. Leachate NO_3^- -N concentrations decreased with increasing percentage NH_4^+ in treatment solutions. At 112 mg N liter⁻¹, leachate total N concentration was greater at 0 and 50% NH_4^+ than at 100% NH_4^+ , while at 224 mg liter⁻¹ total N concentration did not vary with N source and was uniformly greater than leachate total N concentrations at the lower application rate. At the lower N level, the percentage of N remaining in the leachate (36-45%) was unaffected by N source. At the higher N level, a higher proportion of N supplied as 100% NH_4^+ remained in the leachate than when 0 or 50% of the N was supplied as NH_4^+ . Leachate volume did not vary with N source at 112 mg N liter⁻¹ but was greater with 100% NH_4^+ than with 0 or 50% NH_4^+ applied at 224 mg N liter⁻¹. At both N levels, leachate pH was higher at 0% NH_4^+ than with 50 or 100% NH_4^+ .

Discussion

The general appearance of the gloxinias grown in these studies did not vary with the N source or concentration in the stock treatment solutions. The distortion and discoloration observed under relatively low light and temperature conditions did not occur under moderate or high light and temperatures. There are 2 probable

Table 7. Effect of N source and level on leachates 1 week after application to gloxinias grown in an organic medium (experiment III).

Treatment		N in leachates				Leachate N		
		N level (mg liter ⁻¹)	N source (% N as NH ₄ ⁺)	N form (% NH ₄ ⁺)	NH ₄ ⁺ -N (ppm)	NO ₃ ⁻ -N (ppm)	Total N (ppm)	per unit N applied (%)
112	0	1c ^y	1a	133a	134a	45a	291a	5.9a
	50	10b	9a	124b	133a	36a	259a	5.3b
	100	25a	16a	104c	120b	36a	311a	5.3b
224	0	1c	2c	273a	275a	41b	315b	5.8a
	50	12b	19b	252b	271a	38b	309b	5.0b
	100	22a	37a	220c	257a	55a	495a	4.9b

^zMean value per container.

^yMean separation within columns within levels by Duncan's multiple range test, 5% level. These means are averaged over all weeks as there was no significant treatment x week interaction.

reasons for this response.

Plants were grown under relatively high light levels. Carbohydrates and ketoacids accumulate when high light and other factors favor rapid photosynthesis. Under these conditions, the compounds are available to detoxify absorbed NH_4^+ (19). The data in Table 2 indicate that in sterilized quartz sand, little N was converted from NH_4^+ to NO_3^- after the treatment solution had been in use for 1 week. Plants were grown for the entire experiment at 0, 50 or 100% NH_4^+ with no adverse effects to plant tops (Table 1). Root systems were smaller at 50 and 100% NH_4^+ than at 0% NH_4^+ . This has been observed for other plants whose shoots were unaffected by N source, possibly due to NH_4^+ and amide accumulation in the roots rather than in the shoots (7,13).

The gloxinias were grown at temperatures which have been shown to enhance nitrification (3). In experiment II, when temperatures averaged 26°C (day) and 17°C (night), the low proportions of NH_4^+ : NO_3^- , low NH_4^+ -N concentrations and high NO_3^- -N concentrations in all leachates suggest that most NH_4^+ was nitrified to NO_3^- before large quantities of NH_4^+ could be absorbed (Table 3); gloxinia growth and elemental composition in this experiment did not vary with N source (Table 4). In experiment III, with slightly lower average temperatures, leachates contained 75-99% NO_3^- -N, indicating conversion of some NH_4^+ to NO_3^- but allowing some NH_4^+ to be absorbed (Table 7); shoot dry weight and flower bud count were reduced when stock solutions contained 100% NH_4^+ (Table 5).

Ammonium is indirectly toxic to some species by inducing a deficiency of other essential elements, notably K, Ca or Mg (1,2,5, 20). This is not the case with gloxinia. Shoot dry weight and bud count were reduced in experiment III with 100% NH_4^+ , but tissue levels of N, P, K, Ca and Mg were all within suitable ranges for unimpaired gloxinia growth (Table 5).

Plant quality, as measured by shoot and root dry weight, days to bud visibility and flower bud count, was either enhanced at 112 mg N liter⁻¹ or unaffected by fertilization rate (Tables 1 and 6). The leachate data presented in Tables 2, 3 and 7 show that plants did not absorb all of the applied N at any $\text{NH}_4^+:\text{NO}_3^-$ ratio at either fertilization rate, suggesting that under these conditions production costs can be decreased by applying a maximum of 112 mg N liter⁻¹ without reducing plant quality.

The results of these studies support the hypothesis that gloxinia response to N source is a function of environmental conditions. Under relatively low light (95-154 langleys day⁻¹) and temperature (19-20°C day, 14-16°C night) levels gloxinias given 75-100% NH_4^+ were distorted, discolored and smaller than plants given 0-50% NH_4^+ (15). In these 3 studies, moderate to high light promoted tissue carbohydrate accumulation, and moderate to high temperatures enhanced nitrification. Gloxinias showed no symptoms of NH_4^+ toxicity other than reduced shoot dry weight and flower bud count with 100% NH_4^+ under moderate environmental conditions. It is therefore possible under conditions similar to experiments I and II to

supply all N as NH_4^+ without reducing gloxinia quality, but under conditions similar to experiment III approximately 25% of the N should be in the NO_3^- form.

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Chapter 4

Influence of Fertilizer Level and Ca(OH)_2 on Gloxinia
(Sinningia speciosa Lodd.) Grown in Two Seasons¹

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Abstract. Gloxinia (Sinningia speciosa Lodd.) seedlings were grown to maturity under high light and temperatures (summer) and under low light and temperatures (winter), with hydrated limestone added to half of the organic potting media in each study. The experiments were conducted to determine the optimal fertilization rate at every watering for gloxinias grown in the summer and winter in limed and unlimed media, and to determine changes in tissue composition with these treatments. In the summer, plants were irrigated when indicated by physical examination of the media with water containing 0, 200, 400 or 600 ppm N supplied in a 20N-8.7P-16.7K water soluble fertilizer, while the winter irrigation water contained 100, 200, 300 or 400 ppm N. Shoot dry weight was greatest and time until flower buds became visible shortest at 200 ppm N in the summer, while shoot dry weight and number of flower buds were greatest at 100 ppm N in the winter. Days until flowering in the summer and days until flower bud set in the winter were unaffected by fertilizer levels. Lime treatment did not affect any of these growth parameters, but elemental composition of leaves of gloxinias grown in the winter varied with fertilizer level and Ca(OH)_2 treatment.

Introduction

The gloxinia (Sinningia speciosa Lodd.) is usually fertilized with a soluble complete fertilizer at 200 ppm N beginning after transferring seedlings to the finishing pot (1,6,10). However, optimal fertilization practices vary with economic, environmental and cultural conditions. Excess fertilizer raises production costs, contributes to pollution when it leaches into the water supply, and can injure or even kill the crop.

Ammonium toxicity to gloxinias has been reported when more than 75% of the N was supplied as NH_4^+ (9). Many of the water soluble complete fertilizers contain most of their N in the NH_4^+ and urea forms. Ammonium application to apple (Malus domestica Borkh.), barley (Hordeum vulgare L.), sweet corn (Zea mays L.) and tomato (Lycopersicon esculentum Mill.) causes reduced tissue levels of Ca and Mg due to competition among the 3 cations for absorbance (3,7,11; 12). Addition of CaCO_3 has been found to inhibit NH_4^+ toxicity in bean (Phaseolus vulgaris L.), cucumber (Cucumis sativus L.) and pea (Pisum sativum L.) grown in sand by reducing the accumulation of NH_4^+ and amides in the shoots (4,8). Dolomitic lime is usually added to gloxinia growth media to raise the pH to 6.0 (6).

Gloxinia production costs, appearance and sale price depend upon fertilization and liming practices. The following experiments were designed to determine the optimal application rate of a water soluble complete fertilizer under high and low light and temperatures and to determine if this rate varies with addition of hydrated limestone.

Materials and Methods

In the first experiment, Sinningia speciosa 'Improved Red Velvet' seedlings were planted May 26, 1981 in 15-cm azalea pots in a 6 Canadian peat:2 vermiculite:1 perlite:1 coarse sand (by volume) mixture used by our gloxinia supplier (Earl J. Small Growers, Inc., Pinellas Park, FL 33565). Hydrated limestone (CaCO_3 equivalency 128%, particle size distribution such that 100% passed through N. 20, 98% through No. 60 and 95% through No. 100 U.S. standard sieve) was applied to half of the media, increasing the pH from 4.5 to 5.1. The plants were grown under 50% shade cloth in a glasshouse, with average solar radiation levels of 355 langley's day⁻¹. Greenhouse temperatures averaged 27°C (day) and 18°C (night). Gloxinias were irrigated as deemed necessary by physical examination of the media with water containing 0, 200, 400 or 600 ppm N supplied in a 20N-8.7P-16.7K soluble complete fertilizer (Peters 20-20-20, W. R. Grace & Co., Allentown, PA 18104). The number of days until one flower bud on each plant was easily visible with a diameter of 0.3 cm was recorded. Plants were harvested individually as they flowered or died. Shoot tissue was dried 96 hours under forced air at 70°C before weighing. Eight replications of each treatment were arranged in a split block design with blocking on the Ca(OH)_2 treatment. Data were subjected to analyses of variance, with significant effects further subjected to Duncan's multiple range test at the 5% level.

In the second experiment, Sinningia speciosa 'Improved Red Velvet' seedlings were planted January 20, 1982 as described above.

Solar radiation levels under the shade cloth averaged 160 langleys day⁻¹. Temperatures averaged 20°C (day) and 16°C (night). Hydrated limestone was again added to half of the media to raise the pH to 6.6 to determine if the increased pH would improve growth or allow use of a higher fertilizer rate than was found suitable in the summer study. Plants were irrigated as before, with water containing 100, 200, 300 or 400 ppm N supplied by the same soluble complete fertilizer. The 0 ppm N treatment was not included as the potting mix supplied insufficient nutrients for acceptable growth. Plants were arranged as before, but with 7 replications of each treatment. The number of days until one flower bud on each plant attained a diameter of 0.3 cm was recorded. The number of flower buds of this size or larger was counted when the experiment was terminated. All shoot tissue was dried under forced air for 96 hours at 70°C before weighing. The third fully expanded leaf pair was ground for tissue analysis. Total N was determined by the Kjeldahl method. Aliquots of ashed tissue dissolved in 0.3 N HNO₃ were analyzed colorimetrically for P (2), and for K, Ca and Mg by atomic absorption spectroscopy. Data were subjected to analyses of variance, with significant effects further subjected to Duncan's multiple range test at the 5% level.

Results and Discussion

In the summer, shoot dry weight was greatest when plants received 200 ppm N (Table 1). Shoot dry weight decreased as the

Table 1. Influence of fertilizer rate on the growth and flowering of *Sinningia speciosa* 'Improved Red Velvet'.

Experiment	N ^z level (ppm)	Shoot dry wt. (g)	Days to 0.3 cm buds	Days to flower	Flower bud count
Summer	0	1.52c ^y	42a	75a	-
	200	7.48a	32b	77a	-
	400	3.98b	38a	82a	-
	600	2.27c	39a	73a	-
Winter	100	5.12a	48a	-	13a
	200	3.32b	49a	-	9b
	300	1.94c	50a	-	6bc
	400	1.22c	54a	-	2c

^zSupplied in a soluble complete 20N-8.7P-16.7K fertilizer, so all nutrient levels varied; N level is used for convenience.

^yMean separation within columns within experiments by Duncan's multiple range test, 5% level.

fertilizer rate increased from 200 to 600 ppm N applied and was greatly reduced at 0 ppm N. Unfertilized plants were chlorotic, while those given 400 or 600 ppm N were unusually dark green. Several of the plants given 600 ppm N died near the end of the experiment. Flower buds appeared sooner at 200 ppm N than at other fertilizer rates, but the number of days from potting until plants flowered did not vary with fertilizer level. Addition of Ca(OH)_2 did not affect gloxinia color, dry weight, days to bud set or days to flowering (Table 2).

In the winter, shoot dry weight was greatest at 100 ppm N and lowest at 300 and 400 ppm N (Table 1). Plants receiving 100 or 200 ppm N were a normal color and shape, but those receiving 300 or 400 ppm N were much darker green and had quilted, twisted leaves, symptoms of NH_4^+ toxicity (10). The number of flower buds on the plants at harvest decreased as the fertilizer level was increased from 100 to 400 ppm N. The number of days from potting until flower buds attained a diameter of 0.3 cm did not vary with fertilizer rate. Color, shape, dry weight, flower bud count and days to flower bud set were unaffected by addition of Ca(OH)_2 (Table 2).

Tissue concentrations of P, K and Mg did not vary with fertilizer level (Table 3). Nitrogen concentration in the tissue was greatest at a rate of 400 ppm N and lowest at 100 and 200 ppm N. Calcium content was greater at 100 and 200 ppm N than when 400 ppm N was applied. This inverse relationship between N and Ca content may be explained by NH_4^+ competition with Ca^{2+} for absorbance by plants (3,5,11).

Table 2. Influence of Ca(OH)_2 on the growth and time to flower bud set of *Sinningia speciosa* 'Improved Red Velvet'.

Experiment	Ca(OH)_2 treatment	Shoot	Days
		dry wt. (g)	to 0.3 cm buds
Summer	Limed	4.26 ^Z	38
	Unlimed	3.36	38
Winter	Limed	2.95	50
	Unlimed	2.89	49

^ZMean separation within columns within experiments not significant at the 5% level.

Table 3. Influence of fertilizer rate on the elemental composition of the third fully expanded leaf pair of Sinningia speciosa 'Improved Red Velvet' grown in the winter.

N ^z level (ppm)	Concentration (% dry wt.)				
	N	P	K	Ca	Mg
100	4.8c ^y	0.45a	4.2a	1.5ab	0.55a
200	5.1c	0.36a	4.1a	1.7a	0.33a
300	5.6b	0.33a	4.3a	1.4b	0.34a
400	6.5a	0.53a	4.6a	0.8c	0.34a

^zSupplied in a soluble complete 20N-8.7P-16.7K fertilizer, so all nutrient levels varied; N level is used for convenience.

^yMean separation within columns by Duncan's multiple range test, 5% level.

Addition of $\text{Ca}(\text{OH})_2$ did not affect K content of plants grown in the winter, decreased the tissue concentrations of N, P and Mg and greatly increased the Ca content (Table 4). The lower tissue levels of N and Mg may be due to competition between the NH_4^+ , Mg^{2+} and Ca^{2+} cations for uptake (3,5,11).

The optimal application rate of a water soluble 20N-8.7P-16.7K fertilizer was lower in the winter than the 200 ppm N at every watering frequently recommended. It is possible that less than 100 ppm N would be suitable in the winter, and that less than 200 ppm N would be adequate in the summer; optimal application rates would have to be refined with further experimentation. Under the conditions of these experiments, the lower fertilizer rates reduced production costs and increased plant saleability by improving size and appearance. Gloxinia color, size and flowering were the same at a pH level of 4.5 as they were at a pH of 5.1 in the summer and 6.6 in the winter. Incorporation of $\text{Ca}(\text{OH})_2$ altered the elemental composition of dry leaf tissue, but did not reduce NH_4^+ toxicity symptoms in the winter. In these studies, the use of $\text{Ca}(\text{OH})_2$ or excess fertilizer raised production costs without improving the final crop quality.

Table 4. Influence of Ca(OH)_2 on the elemental composition of the third fully expanded leaf pair of *Sinningia speciosa* 'Improved Red Velvet' grown in the winter.

Ca(OH) ₂ treatment	Media pH	Concentration (% dry wt.)				
		N	P	K	Ca	Mg
Unlimed	4.5	6.0a ^Z	0.48a	4.4a	0.8b	0.43a
Limed	6.6	4.7b	0.31b	4.2a	2.2a	0.33b

^ZMean separation within columns by Duncan's multiple range test, 5% level.

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Summary and Conclusions

Sinningia speciosa 'Improved Red Velvet' seedlings are subject to a great deal of individual variation but some general conclusions can be drawn. Gloxinia color, shape, size, time to flower bud set and flower bud count at harvest vary more with fertilizer N source and concentration as light and temperature levels decline.

The maximum percentage of N that can be applied to gloxinias as NH_4^+ is greater under high light and temperature conditions than under low light and temperature levels. Gloxinias grown in the winter with 75-100% NH_4^+ exhibited distortion and discoloration from NH_4^+ toxicity lacking in plants grown with 0-100% NH_4^+ in the fall or summer. Analysis of leachates of plants showing no differential response to N source when grown in quartz sand in the summer indicates that high light levels may be at least partially responsible for this lack of variation. Analysis of leachates of plants grown in an organic medium showed almost complete conversion of NH_4^+ to NO_3^- within 1 week in the summer when no parameters studied varied with N source, and less complete nitrification with the lower temperatures of fall when shoot dry weight and flower bud count were reduced by 100% NH_4^+ .

The minimum concentration of a soluble complete fertilizer that can be applied at each irrigation without reducing plant quality is less than the generally recommended 200 ppm N when plants are grown in the organic medium used in these studies. This concentration must be defined by further experimentation, but lies

between 0 and 200 ppm N under high light and temperatures, and between 0 and 100 ppm N under low light and temperature levels.

Lime application did not affect gloxinia response to N source or concentration under any environmental conditions; it increased production costs without improving plant quality and should therefore be excluded from the organic medium used in these experiments.

Appendix A

Effect of 11 $\text{NH}_4^+:\text{NO}_3^-$ Ratios on Gloxinias Grown Under Relatively High Light and Temperature Levels

(Abstract and Data Tables)

Abstract. Gloxinia (Sinningia speciosa Lodd.) seedlings were grown in an organic potting mix under high light (355 langleys day⁻¹) and temperature (27°C day, 18°C night) levels and irrigated with modified Hoagland's solutions containing 10 meq N supplied as 1 of 11 $\text{NH}_4^+:\text{NO}_3^-$ ratios to determine the maximum percentage N that can be supplied as NH_4^+ without reducing plant quality. Gloxinia color and shape were unaffected by N source. Shoot dry weight and flower bud count were greater when 0-40% of the N was supplied as NH_4^+ than when 100% was in the NH_4^+ form. The number of days until flower buds attained a diameter of 0.3 cm did not vary with $\text{NH}_4^+:\text{NO}_3^-$ ratio. Total N, P, Ca and Mg levels in leaf tissue decreased and K content increased as increasing percentages of the fertilizer N were supplied as NH_4^+ .

Table 1. Effect of N source on growth and flowering of
gloxinias grown in the summer.

N Source (% N as NH_4^+)	Shoot Dry Wt. (g)	Bud Count	Days to Bud Set
0	9.8a ^z	20a	37 ^y
10	9.2a	27a	36
20	9.5a	25a	36
30	9.7a	24a	35
40	9.6a	22a	37
50	9.0ab	19ab	40
60	9.7a	24a	37
70	8.4ab	18ab	34
80	9.4a	27a	35
90	8.4ab	20a	32
100	7.3b	13b	40

^zMean separation within columns by Duncan's multiple range test, 5% level.

^yMeans within this column were not significantly different at the 5% level.

Table 2. Effect of N source on elemental composition of gloxinias grown in the summer.

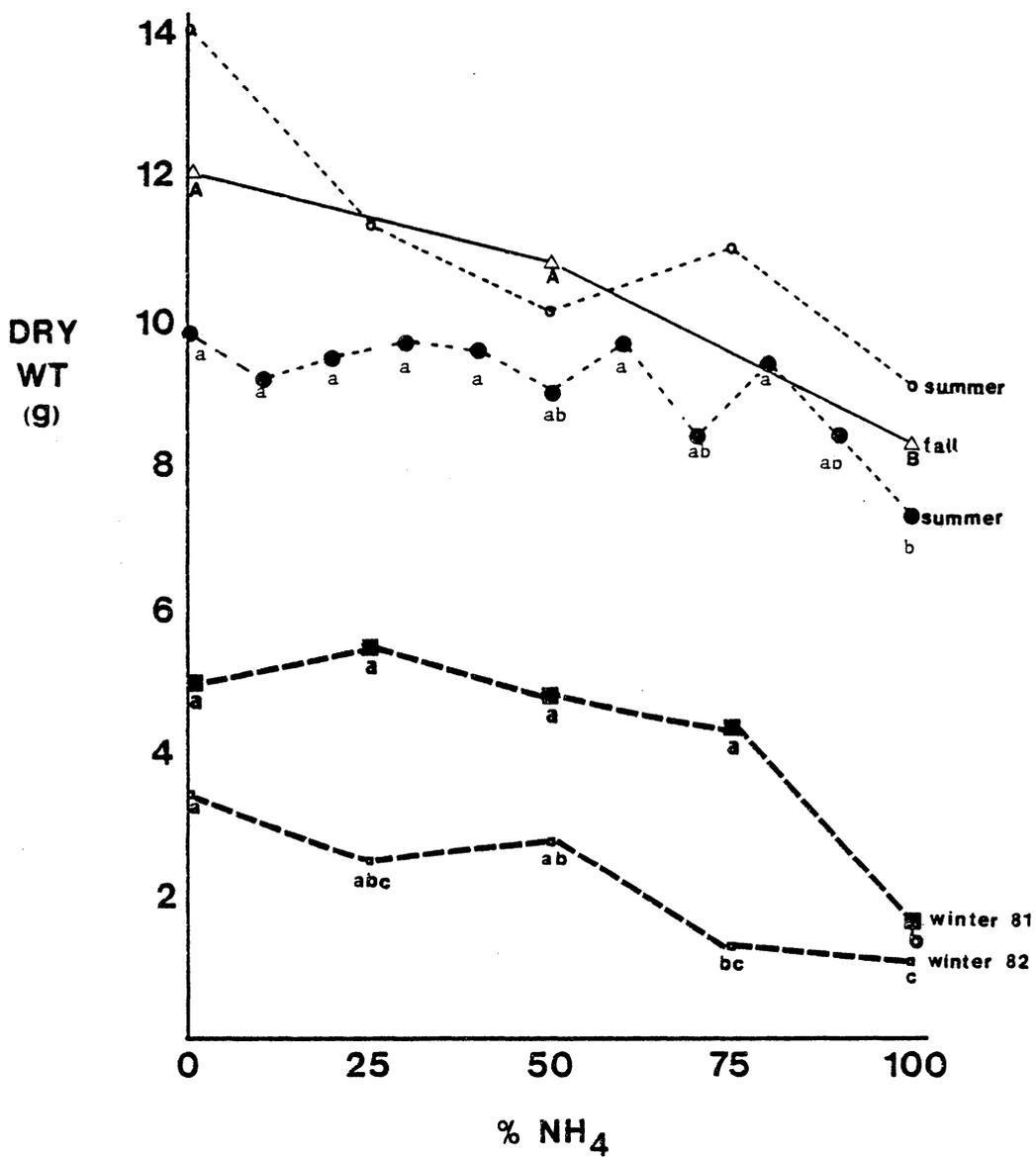
N source (% N as NH_4^+)	Tissue Concentration (% dry weight)				
	N	P	K	Ca	Mg
0	3.6ab ^z	0.47a	5.3ab	1.9a	0.71a
10	3.7a	0.45ab	5.0b	1.9a	0.60abc
20	3.6ab	0.42b	5.0b	1.8a	0.65ab
30	3.5bc	0.35cd	5.4ab	1.6a	0.62ab
40	3.5bc	0.37c	5.6a	1.6a	0.63ab
50	3.7a	0.31de	5.3ab	1.2b	0.50cd
60	3.6ab	0.30e	5.7a	1.3b	0.55bcd
70	3.7a	0.28ef	5.6a	1.2b	0.49d
80	3.6ab	0.28ef	5.7a	1.2b	0.49d
90	3.5bc	0.24f	5.6a	1.2b	0.47d
100	3.4c	0.28ef	5.4ab	1.0c	0.35e

^zMean separation within columns by Duncan's multiple range test, 5% level.

Appendix B

DRY WEIGHT

In Three Seasons



Appendix C

Suggestions for Growing Gloxinias in Nutrient Culture

Roots of plants to be used in nutrient culture studies should be free of all foreign materials. Removal of the organic medium in which gloxinias are grown commercially is hindered by their fibrous, delicate root systems; hence, either a large portion of the medium is left on the roots, or the roots are removed with the medium.

If it is necessary to use gloxinias grown in organic media for nutrient studies, a continuously recirculating nutrient solution should be employed in order to reduce the water stress that otherwise accompanies the loss of roots. Ideally, gloxinias should be started in vermiculite from leaf split-vein cuttings. This eliminates contamination of the quartz sand medium by the unsterile, nutrient-bearing organic medium and prevents the great variation evident among seedlings of the same cultivar.

Appendix D

Conversion From Milliequivalents Per Liter
To Parts Per Million

Meq Liter ⁻¹ Applied	Ppm Applied		Ppm Nitrogen Supplied
	NH ₄ ⁺	NO ₃ ⁻	
4	72	248	56
8	144	496	112
10	180	620	140
12	216	744	168
16	288	992	224

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EFFECTS OF NITROGEN SOURCE AND LEVEL ON THE GROWTH
AND COMPOSITION OF SINNINGIA SPECIOSA LODD.

by

Sharon Lee Nolan

(ABSTRACT)

Gloxinia (Sinningia speciosa Lodd.) seedlings were grown in 2 media to determine the maximum percentage N that can be supplied as NH_4 and the minimum concentration of a soluble complete fertilizer that can be applied without reducing plant quality under different light and temperature conditions.

In one group of experiments, plants were supplied modified Hoagland's solutions in which the N source and level were varied. Shoot dry weight of gloxinias grown in an organic medium in the winter was lower with 100% NH_4 than with 100% NO_3 but was unaffected by N level, while in the fall shoot dry weight was lower with 100% NH_4 than with 0 or 50% NH_4 , and was reduced at 16 rather than 8 meq N liter⁻¹. In the summer, shoot dry weight did not vary with N source or concentration when treatment solutions were collected and reused for 1 week. Flower bud count at harvest did not vary with N source in the winter but was reduced at 100% NH_4 in the fall and summer. Time to flower bud set was unaffected by N source, but was increased by applying 16 rather than 8 meq N liter⁻¹. In the winter, leaves of plants receiving 75-100% NH_4 were dark green early in the studies, but became chlorotic, twisted and quilted before plants matured; in the summer and fall these symptoms of NH_4 toxicity

were absent. Leaf chlorophyll content was greater for plants grown in quartz sand when given 100% NH_4 rather than 100% NO_3 .

In related studies, gloxinias were treated at every watering with a soluble 20N-8.7P-16.7K fertilizer. Shoot dry weight was greater and time until flower bud set shorter at 200 than at 0, 400 or 600 ppm N in the summer; shoot dry weight and flower bud count were greater at 100 than at 200-400 ppm N in the winter. Days until flowering in the summer and days until bud set in the winter were unaffected by fertilizer levels.

Tissue composition varied with N source and level and $\text{Ca}(\text{OH})_2$ treatment although lime application did not affect any external plant characteristics.