AN ABSTRACT OF THE THESIS OF

Michael J. Lamb for the degree of Master of Science in Horticulture presented on December 20, 1990.

Title: Influence of Nitrogen Form Ratio and Calcium on Greenhouse and Field Performance of Watermelon.

Abstract approved: _____
George H. Clough

_____
Delbert D. Hemphill

Watermelon (*Citrullus lanatus* (Thunb.) Matsum. & Nakai var. Crimson Sweet) was seeded in a commercial peat mix in multicell containers (72 cells·tray^{-1}, 40 cm^3·cell^{-1}) in July 1989 and April 1990. In 1989, the medium was amended with $CaCO_3$ at 10% w:v. In 1990, no $CaCO_3$ amendment was made. Watermelon seedling growth and mineral composition response to a factorial treatment combination of 5 nitrogen form ratios and 5 levels of supplemental calcium applied within a 100-31-265 mg·liter^{-1} NPK pretransplant nutrition regime were analyzed. In 1990 seedlings were transplanted in the field to determine pretransplant treatment effects on seedling establishment and yield.

In 1989 shoot growth decreased with increasing NH_4-N; in 1990, N ratio had varying effects on shoot growth parameters. In 1989, $CaCO_3$ amendment ameliorated N ratio effects on plant mineral composition; in 1990, increasing NH_4-N depressed cation uptake. In 1989, plants given N ratios with greater than 50% NO_3-N had greater N content and total uptake. In 1990, increasing NH_4-N produced greater shoot % N.

Reduction in plant growth with increasing Ca was greater in 1990

than 1989, due to higher medium EC. Increasing Ca did not affect shoot N in 1989, but in 1990 N accumulation was greatest with 4 to 8 $mmol \cdot liter^{-1}$ Ca. Increasing supplemental Ca reduced K and Mg uptake in 1989, and Mg in 1990.

In the field, seedling establishment and early yield were greater with 100% NH_4-N and supplemental Ca at 8 and 16 $mmol \cdot liter^{-1}$. Late yield was not affected by treatments. Total yield was not affected by N ratio; however, total yield was greater with supplemental Ca than without. Differences in yields were due to an increase in fruit number, and not fruit size. Although yield and fruit number increased with increasing shoot N concentration, shoot N was not the primary factor affecting yield.

It was concluded that NH_4-N at 100 ppm and Ca level of 8 and 16 $mmol \cdot liter^{-1}$ in the pretransplant fertilization regime were optimal for watermelon transplant production.

In an additional experiment, supplemental Ca was applied within an NH_4-N based NPK (100-31-265 $mg \cdot liter^{-1}$) pretransplant fertilization regime with and without calcium carbonate amendment to the medium (10% w:v).

Supplemental Ca had no effect on dry weight, leaf area, or shoot N content 4 weeks after seeding. Calcium carbonate amendment decreased shoot dry weight and plant height, while increasing shoot N concentration. Shoot N accumulation was not affected by $CaCO_3$ medium amendment. Medium pH increased with $CaCO_3$ addition.

No net nitrification was observed in response to any treatment over the duration of the experiment.

Influence of Nitrogen Form Ratio and Calcium on Greenhouse and Field Performance of Watermelon

by

Michael J. Lamb

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Completed December 20, 1990

Commencement June 1991

APPROVED:

Assistant Professor of Horticulture in charge of major

Professor of Horticulture in charge of major

Head of the Department of Horticulture

Dean of the Graduate School

Date thesis presented December 20, 1990.

Typed by Michael J. Lamb

ACKNOWLEDGEMENTS

I express my gratitude to Dr. George H. Clough for his unconditional support and friendship along the way. I am indebted to my committee members Drs. Del Hemphill and Mary Powelson for their guidance and their continuous challenge that made me grow.

At the Hermiston AREC I thank Elaine Urban for her help in the greenhouse and the field. I also extend my thanks to Dr. Gary Reed and the rest of the staff for their assistance, patience, and humor.

Recognition is expressed to Drs. Anita Miller and Bill Mansour for their counsel and assistance.

In the most difficult moments the presence of Elzbieta Krzesinska provided the incentive and motivation to persevere.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Influence of Nitrogen Form Ratio and Calcium on Greenhouse and Field Performance of Watermelon

Chapter 1

INTRODUCTION

Increases in vegetable crop production costs have stressed the need for better crop production efficiency. For some crops, an increase in production efficiency can be attained by using vegetable transplants grown in multicell containers as opposed to direct-seeding or using bare-root transplants. Some of the advantages of their use include improved stand establishment (Haber, 1941; Kahn and Motes, 1989; Schultheis and Cantliffe, 1988), earlier and more uniform crop maturity (Haber, 1941; Kahn and Motes, 1988, 1989; Liptay et al., 1982; Olson, 1989; Schultheis and Cantliffe, 1988), and higher crop yields (Kahn and Motes, 1988, 1989; Liptay et al., 1982; Overman and Jones, 1975; Schultheis and Cantliffe, 1988).

Multicell container pretransplant practices affect seedling establishment and field performance. Varying cell size, transplant age, and pretransplant nutritional conditioning have influenced yields of vegetable crops (Adler, 1983; Dufault, 1985, 1986, 1987; Knavel, 1977; Tremblay et al., 1987; Weston and Zandstra, 1989; Widders, 1989; Wurr et al., 1986).

Several pretransplant nutritional conditioning studies have tested the effect of nitrogen rate on seedling growth and yield (Adler et al., 1984, Dufault, 1985; Kratky and Mishima, 1981; Tremblay and Senecal, 1988); however, the effect of nitrogen-form on seedling growth and field

performance has received little attention (Tremblay and Gosselin, 1989a, b).

Nitrogen-form can have a dramatic effect on plant growth. Generally, plant growth is greater with NO_3-N, as compared to NH_4-N, as the predominant nitrogen source (Alan, 1989; Barker and Maynard, 1972; Barker et al., 1966; Elamin and Wilcox, 1986a, b; Kirkby, 1968; Kirkby and Mengel, 1967; Magalhaes and Wilcox, 1983a, b). Ammonium nitrogen uptake acidifies rhizosphere pH (Barker et al., 1966a, b; Mengel et al., 1983), and depresses the uptake of other essential cations (Mengel and Kirkby, 1987). This may result in an ammonium toxicity which is characterized by stunted plant growth, interveinal necrosis, necrotic lesions, wilting, brown discolored roots, and, eventually, death of the entire plant (Barker et al., 1966; Maynard and Barker, 1969).

The degree to which NH_4-N can be utilized is affected by the pH buffering capacity of the growing medium. With a high pH buffer capacity near pH 7.0, growth with NH_4-N may equal that of NO_3-N (Cox and Seeley, 1984; Marcus-Wyner, 1983; Mengel et al., 1983; Morris and Giddens, 1963; Peet et al., 1985). Maintenance of medium pH near neutral alleviates the harmful effects of ammonium uptake. The addition of copious amounts of calcium to NH_4-N based fertilizer solutions has also been shown to ameliorate the detrimental effects of NH_4-N (Fenn et al., 1987; Horst et al., 1985; Taylor et al., 1985). Supplemental calcium in NH_4-N based fertilizer solutions has increased plant growth in both calcareous (pH-buffered) and non-calcareous media, suggesting a synergistic effect on plant growth above that of buffering medium pH near neutral (Fenn et al., 1987; Taylor et al., 1985).

Typical growing media for vegetable transplant production consist of a 50:50 or 60:40 (v:v) mixture of peat moss and vermiculite (Bunt, 1976). While vermiculite is regarded as being inert, peat moss typically is well pH-buffered at pH 3.5-4.0. Most commercial media are supplemented with $CaCO_3$ or $MgCO_3$, or both, to raise pH buffer capacity to near neutral.

Standard recommendations on fertilizer regimes for greenhouse production include Hoagland's Solution 1 and 2 (Lorenz and Maynard, 1980). These solutions have NO_3:NH_4 ratios of 100:0 and 75:25, respectively (Hoagland and Arnon, 1950). Nitrification in peat-based media has been shown to be depressed as compared to typical soil (Elliott, 1986).

Since peat-based media are pH-buffered, growth with ammonium nitrogen may equal that of nitrate nitrogen. Supplemental calcium may improve NH_4-N utilization, resulting in greater shoot dry weight, and greater total and percent nitrogen.

This investigation tested the effect of various NO_3:NH_4 ratios, with increasing levels of supplemental calcium, on watermelon seedling growth, plant field performance, and nitrification in soilless media.

Chapter 2

LITERATURE REVIEW

Transplant Production

Transplanting seedlings into the field has been widely used for centuries. The use of transplants over direct seeding is becoming more advantageous for some crops as production costs rise necessitating increased crop production efficiency. Some advantages of using transplants over direct seeding include improved stand establishment (Haber, 1941; Kahn and Motes, 1989; Schultheis and Cantliffe, 1988), earlier and more uniform crop maturity (Haber, 1941; Kahn and Motes, 1988, 1989; Liptay et al., 1982; Olson, 1989; Schultheis and Cantliffe, 1988), and higher crop yields (Kahn and Motes, 1988, 1989; Liptay et al., 1982; Overman and Jones, 1975; Schultheis and Cantliffe, 1988).

Recently, the use of seedlings grown in multicell containers, or flats, has gained popularity over traditional bare-root transplants for some vegetables. "Plug plants" are better suited for mechanical transplanting, may require less greenhouse space, and can delay the onset of symptoms caused by nematodes (Overman and Jones, 1975; Rogers, 1983).

Typically, plug plants are produced by sowing seeds in a flat (multicell container, 5-50 $cm^3 \cdot cell^{-1}$) in growing medium composed of 1 part sphagnum peat moss:1 part vermiculite (v:v). They are grown in a greenhouse with nutrients provided through the irrigation system. After

the seedlings have reached adequate size they are transplanted into the field, either manually or with the aid of a mechanical transplanter.

From 1974 to 1979, the containerized vegetable transplant nursery industry in Florida tripled in size (Smith and Miller, 1979). In 1974 a combined sales estimate from twelve vegetable transplant growers exceeded $2,904,000. In 1979 sales were estimated at $6,254,000 from twenty nurseries. Presently in California there are over 30 commercial vegetable transplant nurseries (personal communication, John Inman and Robert Brendler, Farm Advisors for Salinas and Ventura Counties, respectively), the largest producing over 500,000,000 transplants annually (personal communication, Donald Bahl, General Manager, Greenheart Farms, Inc.).

Pretransplant Conditioning

Early experiments on the effects of pretransplant treatments on field performance were conducted in the southern United States using bare-root tomato transplants produced for northern areas. Plants often were ready for field transplanting when weather conditions were unfavorable and had to be held in storage. Transplants also tended to vary in size and development, thereby negating some of the advantages of their use. Investigations centered upon number of marketable transplants, transplant survival, and yields as affected by plant clipping, pretransplant nutrition, and storage techniques. In one study transplant storage (5-10 days) and clipping decreased transplant survival and total yield (Jaworski and Webb, 1966). Different NPK pretransplant regimes produced variable results on seedling survival, number of marketable transplants, and total yields (Jaworski and Webb,

1966; Jaworski et al. 1966). Tomato transplants grown in multicell containers have been shown to be larger and more uniform at transplanting, set fruit earlier, and produce larger yields than bare-root transplants (Long and Cantliffe, 1975). There is less root damage at transplanting which may decrease establishment time. In treated soil, symptoms of disease caused by nematodes were delayed longer with plug plants than bare-root plants (Overman and Jones, 1975).

Depending on the crop, pretransplant practices can manipulate the growth rate and influence yield of plants grown in multicell containers. These practices include the use of different plug cell sizes (Knavel, 1965; Marsh and Paul, 1988; Weston, 1986, 1988), varying transplant age (Weston, 1988, 1989; Wurr, 1986), and pretransplant nutrition (Adler, 1983; Dufault, 1985, 1986, 1987; Knavel, 1977; Kratky and Mishima, 1981; Precheur and Maynard, 1983; Tremblay and Gosselin, 1989a, b; Tremblay and Senecal, 1988; Tremblay et al., 1987; Weston and Zandstra, 1989; Widders, 1989; Wurr et al., 1986).

Larger transplant cells produced the greatest early yields of tomato and pepper but did not affect total yield (Knavel, 1965; Weston and Zandstra, 1986; Weston, 1988). Tomato transplants 4 and 5 weeks old had greater early and total yields than 3 and 6 week old seedlings (Weston and Zandstra, 1989). Early yield of pepper was also influenced by transplant age with 60-day old transplants outperforming 30 to 50-day old seedlings (Weston, 1988). However, total yield of watermelon was not influenced by either transplant cell size or transplant age (from 3 to 5 weeks old) (Olson, 1989).

Dufault (1986) tested pretransplant nutrient regimes for their effect on muskmelon seedling growth and yield. Seedling growth treatments were factorial combinations of N from urea at 10, 50, or 250 $mg \cdot liter^{-1}$; P from phosphoric anhydride at 5, 25, or 125 $mg \cdot liter^{-1}$; and K from K_2SO_4 at 10, 50, or 250 $mg \cdot liter^{-1}$. Seedlings from 9 treatments were selected to test pretransplant fertilization effects on plant field performance. Seedling growth and early yield were greatest with a pretransplant nutrient regime of 250-125-250 NPK ($mg \cdot liter^{-1}$).

Tremblay and Gosselin (1989a) evaluated 3 NO_3:NH_4 ratios (1:1, 2:1, and 3:1) at rates of 150, 250 and 350 $mg \cdot liter^{-1}$ for their effects on celery seedling growth. Plant dry weight, leaf area, and root:shoot ratio were greatest with a 3:1 NO_3:NH_4 ratio at 350 $mg \cdot liter^{-1}$ (Tremblay and Gosselin, 1989a).

Nitrogen-form Utilization

Generally, most vegetable species utilize NO_3-N, as opposed to NH_4-N, as the predominant nitrogen source (Alan, 1989; Barker and Maynard, 1972; Barker et al., 1966; Elamin and Wilcox, 1986a, b; Kirkby, 1968; Kirkby and Mengel, 1967; Magalhaes and Wilcox, 1983a, b; Marcus-Wyner, 1983; Mengel et al., 1983; Morris and Giddens, 1963). However, some plants utilize NH_4-N more efficiently as the primary nitrogen source. This is reflected in the calcifuge-calcicole classification scheme which separates plants on the basis of nitrogen source better utilized (Marschner, 1986). Calcifuge growth is optimal with NH_4-N as the predominant nitrogen source. Calcifuges are generally found in acidic soils or soils with a low redox potential (Ismunadji and Dijkshoorn, 1971). Examples include wetland rice and *Vaccinium* species such as

blueberry and cranberry. Calcicoles better utilize NO_3-N and are found in calcareous soils with neutral to high pH (Kirkby, 1967). Examples include tomato, pea, cucumber, bean, corn, and muskmelon (Alan, 1989; Marcus-Wyner, 1983; Barker et al., 1966a, b; Barker and Maynard, 1972; Elamin and Wilcox, 1986a, b). The degree to which calcicoles can utilize NH_4-N as the predominant nitrogen source is affected by the pH buffering capacity of the soil or medium. Soils or media with a pH near 7.0 and with a high pH buffering capacity best enable ammonium utilization by calcicoles (Barker et al., 1966a, b; Cox and Seeley, 1984; Marcus-Wyner, 1983; Mengel et al., 1983; Morris and Giddens, 1963; Peet et al., 1985). A high pH buffering capacity neutralizes rhizosphere acidification caused by ammonium uptake (Barker and Maynard, 1972; Kirkby, 1967, 1968; Kirkby and Armstrong, 1980; Kirkby and Mengel, 1967; Pierpont and Minotti, 1977; Pill and Lambeth, 1977; Precheur and Maynard, 1983). The uptake mechanism is not completely understood; however, the evidence that NH_4^+ is taken up in exchange for H^+ or is deprotonated at the plasma membrane is corroborated by the decrease in rhizosphere pH (Munn and Jackson, 1978).

Ammonium also "competes" with other cations for ionophores, carriers that transport cations across membranes, causing a reduction in the uptake of other essential cations (Mengel and Kirkby, 1987). This imbalance in cation uptake can be exacerbated at low substrate pH, where NH_4^+ uptake is not as depressed as that of other cations. This results in an ammonium toxicity which is characterized by stunted plant growth, interveinal necrosis, necrotic lesions, wilting, brown discolored roots, and, eventually, death of the entire plant (Barker et al., 1966; Maynard

and Barker, 1969). At high substrate pH ammonium is converted to ammonia according to the equilibrium $NH_4^+ + OH^- \langle = \rangle NH_4OH \langle = \rangle NH_3\uparrow + H_2O$ and creates an ammonia toxicity with symptoms similar to ammonium toxicity (Bennett and Adams, 1970 a, b).

Cation uptake acidifies the rhizosphere, while anion uptake increases rhizosphere pH (Kirkby, 1967, 1968; Kirkby and Armstrong, 1980; Kirkby and Mengel, 1967; Pill and Lambeth, 1977; Precheur and Maynard, 1983). Uptake of NO_3^- or other anions occurs in exchange for HCO_3^- or is 'accompanied' by a cation (Kirkby and Armstrong, 1980). These mechanisms are thought to maintain an electrochemical balance both in root cells and the external solution (Kirkby, 1968; Kirkby and Mengel, 1967; Marschner, 1986). Evidence of an electrochemical balance is seen by the cation-anion ratios of plants grown with either NH_4-N or NO_3-N (Kirkby, 1968; Kirkby and Mengel, 1967). Nitrate uptake causes more cation uptake than does ammonium. With ammonium as the predominant nitrogen source, more anions are taken up while other cations required for plant growth may be deficient (Alan, 1989; Barker and Maynard, 1972; Elamin and Wilcox, 1986a, b; Kirkby, 1968; Kirkby and Knight, 1977; Kirkby and Mengel, 1977; Magalhaes and Wilcox, 1983; Pill and Lambeth, 1977). Calcium deficiency is quite common (Alan, 1989; Barker and Maynard, 1972; Barker et al., 1966; Kirkby, 1968; Kirkby and Mengel, 1967; Maynard and Barker, 1969; Murtadha et al. 1988; Pill and Lambeth, 1977).

Calcium Deficiency and the Viets Effect

At low pH Ca^{2+} must be present in the external (soil) solution at a concentration of at least 0.005 mmol·liter^{-1} to counteract the adverse

effect of H^+ on root growth (Fawzy et al., 1953; Marschner et al., 1966; Mengel and Kirkby, 1987). Growth of the root tip, which is the main site of calcium uptake, is reduced at low substrate pH, resulting in reduced Ca^{2+} uptake by the plant (Murtadha et al., 1988).

Low substrate pH increases cell membrane permeability, resulting in damage to cellular organelles and ionic efflux through the cell membrane (Fawzy et al., 1953; Marinos, 1962; Marschner et al., 1966). The presence of Ca^{2+} or other polyvalent cations in the soil solution decreases ionic efflux regardless of the Ca^{2+} content of the cell. This effect is most pronounced at pH 6.0 or below, while at higher pH values ionic efflux is negligible (Marschner et al., 1966). Early work reported this as an acceleration of monovalent ion uptake due to the presence of polyvalent cations in solution, later termed the Viets effect (Viets, 1944). More recent interpretations attribute this to a decrease in cell membrane permeability caused by the presence of Ca^{2+} (Mengel and Kirkby, 1987).

Different ammonium salts have been shown to precipitate calcium from the soil solution or on the exchange complex by the formation of relatively insoluble compounds. Diammonium phosphate, $(NH_4)_2HPO_4$, precipitates calcium by the formation of either $Ca_4H(PO_4)_3$ or $Ca_5OH(PO_4)_3$, resulting in a calcium deficiency separate from an ammonium or ammonia toxicity (Bennett and Adams, 1970b).

When urea is used as the nitrogen source, calcium can be precipitated as $CaCO_3$ (Fenn, 1975; Fenn and Kissell, 1973; Fenn and Matocha, 1981; Fenn and Taylor, 1981). Urea hydrolyzes to form ammonium carbonate, an unstable compound. The products of disassociated ammonium

carbonate are two NH_4^+ ions and one CO_3^{2-} ion. The carbonate ion causes a brief, localized rise in soil solution pH seen when urea is used as the nitrogen source. This ion reacts with calcium to form calcium carbonate. The ammonium ions form either a soluble ammonium salt, or are volatilized as NH_3, depending on soil solution pH.

The addition of soluble calcium fertilizer to urea prevents ammonia volatilization by depressing solution pH, which is accomplished by ensuring enough Ca^{2+} in the soil solution to precipitate $CO_3^=$ as $CaCO_3$.

This effect has been demonstrated in both acidic and calcareous soils (Fenn, 1975; Fenn and Kissell, 1973; Fenn and Matocha, 1981; Fenn and Taylor, 1981).

Supplemental Calcium

Increases in growth of plants given ammoniacal fertilizer plus calcium over ammoniacal nitrogen alone have been reported using several plant species in both acidic and basic (calcareous) soils. This effect has been demonstrated using supplemental calcium levels from 5 to 16 $mmol \cdot liter^{-1}$. Increased shoot and root dry weights, plant total nitrogen, and decreased leachate ammonium were attributed to a synergistic ammonium absorption and assimilation response beyond that expected from calcium control of ammonia volatilization and the nutritive effect of calcium (the Viets effect) (Fenn et al., 1987; Horst et al., 1985; Taylor et al., 1985). However, a study by Hons and Aljoe, (1985) failed to demonstrate this effect with corn in either an acidic or basic soil.

Soilless Media

Typical commercial soilless media consist of sphagnum peat moss and vermiculite at 50:50 or 60:40 ratio (v:v). Perlite is sometimes added at 10 to 20% on a volume basis. Perlite and vermiculite are used to alter medium water-holding capacity and air porosity. Perlite, composed of silicon dioxide and aluminum oxide, is regarded as being inert. Vermiculite is an aluminum-iron-magnesium silicate with a high cation exchange capacity (100-150 meq·100 g^{-3}) similar to peat moss. Vermiculite contains little to no nitrogen, 5-8% available potassium and 9-12% available magnesium (Bunt, 1976).

Sphagnum peat moss has a high pH buffering capacity at pH 3.5 to 4.0. In commercial media, amendments of calcium carbonate or dolomitic limestone (or both) are made to raise pH and provide a pH buffer capacity near neutral. Elevating medium pH increases the cation exchange capacity (CEC) of peat, as peat CEC is pH-dependent (Bunt, 1976). The addition of cations from salts without CO_3^- or OH^- may decrease medium pH by displacing H^+ on the exchange complex (Bunt, 1976). The use of ammonium nitrogen fertilizer may decrease medium pH by this mechanism in addition to plant H^+ extrusion from ammonium uptake.

Many of the physical and chemical properties of soilless media differ from those of typical mineral soils. This restricts comparing nutrient availability and nitrogen dynamics between the two.

Soilless media have bulk densities of approximately 0.1 to 0.2 g·cm^{-3} and a total nitrogen content of 0.5 to 2.5% dry weight (Bunt, 1976). Mineral soils typically have a bulk density of 1 g·cm^{-3} and

total nitrogen content of 0.05 to 0.2% dry weight (Black, 1968). If analyzed on a weight basis for total nitrogen, as is done with mineral soils, soilless media would appear to have greater total nitrogen. However, the volume of soilless medium required to obtain a specific weight is greater than that of mineral soils. Therefore, analytical results for soilless media are reported on a volume basis. Also, soilless media contain little to no nutrients available for plant uptake. While nitrogen content is high, it is not in a readily available form.

Compared to soil, release of nutrients by decomposition of peat in soilless media occurs slowly due to reduced numbers of microorganisms. Populations of nitrifying bacteria such as *Nitrosomonas* and *Nitrobacter* are depressed due to low peat pH. Many soilless media are steam sterilized or pasteurized, thereby further reducing microbial populations (Bunt, 1976). In one study comparing nitrification rates of two non-sterilized sphagnum peats and one sedge peat, nitrification was first detected in the sedge peat after 10 days and in the sphagnum peats after 50 and 75 days (Bunt, 1976). In another study, nitrification rates of 14 commercial media were determined from cropped and uncropped media fertilized with ammonium nitrogen. No significant net nitrate formation was observed at 8 weeks after fertilization from either sample type (Elliott, 1986).

Chapter 3

NITROGEN-FORM RATIO AND SUPPLEMENTAL CALCIUM EFFECT ON WATERMELON TRANSPLANT GROWTH, MINERAL COMPOSITION, AND FIELD PERFORMANCE

ABSTRACT

Watermelon (*Citrullus lanatus* (Thunb.) Matsum. & Nakai var. Crimson Sweet) was seeded in a commercial peat mix in multicell containers (72 cells·tray^{-1}, 40 cm^3·cell^{-1}) in July 1989 and April 1990. In 1989, the medium was amended with $CaCO_3$ 10% w:v; in 1990 no amendment was made. Five N-form ratios and 5 levels of supplemental Ca were applied in factorial combination in a 100-31-265 mg·liter^{-1} NPK pretransplant nutrition regime.

Increasing NH_4-N affected seedling growth more in 1989 than 1990. In 1989, medium amendment with $CaCO_3$ alleviated NH_4^+-induced depression of cation uptake, however, growth decreased with increasing NH_4^+. In 1990, increasing NH_4-N depressed cation uptake, increased shoot percent N, and had varying results on shoot growth parameters.

Reduction in plant growth with increasing Ca was greater in 1990 than 1989. Increasing Ca did not affect shoot N in 1989, but in 1990 N accumulation was greater at 4 to 8 mmol·liter^{-1} Ca. Increasing supplemental Ca reduced K and Mg uptake in 1989, and Mg in 1990.

In the field, increasing pretransplant NH_4-N increased seedling establishment. Early marketable fruit yield was greater with 100%

NH_4-N. Supplemental calcium at 4 to 8 mmol·liter^{-1} increased seedling establishment, early, and total marketable fruit yield. Differences in yields were due to an increase in fruit number, and not fruit size. Enhanced field performance, as affected by pretransplant N and Ca, was partially due to increased transplant percent N.

It was concluded that NH_4-N at 100 ppm and Ca level of 8 mmol·liter^{-1} in the pretransplant fertilization regime was optimal for watermelon transplant production.

INTRODUCTION

Pretransplant nutrition has been shown to influence transplant quality, seedling establishment, and yield for some crops (Adler et al., 1984; Dufault, 1985, 1986, 1987; Knavel, 1977; Precheur and Maynard, 1983; Tremblay and Gosselin, 1989a, b; Weston and Zandstra, 1989; Widders, 1989). Several studies have shown the importance of nitrogen rate within the pretransplant nutrition regime (Adler et al., 1984; Dufault, 1985, 1986, 1987; Knavel, 1977), however, nitrogen-form within the regime has not received much attention (Tremblay and Gosselin, 1989a, b).

Ammonium nitrogen as the predominant nitrogen source in fertilization regimes can be detrimental (Alan, 1989). Ammonium acidifies rhizosphere pH and depresses the uptake of other important cations (Alan, 1989; Barker and Maynard, 1972). Ammonium toxicity is ameliorated in growing media with a high pH-buffer capacity near pH 7.0 (Barker et al., 1966a, b). Addition of copious amounts of calcium to NH_4-N based fertilizers has been shown to decrease NH_3 volatilization

(Fenn, 1975; Fenn and Kissel, 1973, 1974, 1976), to alleviate NH_4-N toxicity symptoms, and produce a synergistic plant growth response in both calcareous and noncalcareous growing media (Fenn et al., 1987; Horst, et al., 1985; Taylor et al., 1985).

Nitrate-nitrogen sources are recommended for soilless media and hydroponic production (Lorenz and Maynard, 1980). Typical commercial soilless media are well pH-buffered near pH 7.0 (Bunt, 1976). It was hypothesized that the use of NH_4-N should be comparable to that of NO_3-N for watermelon transplant production, especially with the addition of supplemental calcium.

The purpose of this experiment was to test NO_3:NH_4 ratio and supplemental calcium effects on transplant growth, mineral composition, and plant field performance.

MATERIALS AND METHODS

Greenhouse experiments were conducted in 1989 and 1990 at the Agricultural Research and Extension Center in Hermiston, Oregon to determine the effects of pretransplant NO_3:NH_4 ratio and supplemental calcium on watermelon transplant growth and mineral composition. In 1990 pretransplant NO_3:NH_4 ratio and supplemental calcium effects on watermelon field performance and yield were evaluated, and in an additional greenhouse trial, nitrification in watermelon transplant media was investigated.

Greenhouse NO_3:NH_4 Ratio + Supplemental Calcium Study

Watermelon was seeded in multicell containers (72 cell TLC plastic trays, 40 $cm^3 \cdot cell^{-1}$) using a commercial peat mix (Fison's Sunshine Mix

#3) on 17 July 1989 and 16 April 1990. Maximum daily greenhouse temperatures are shown in Figure 3.1 and 3.2. After leaching, the medium contained low nutrient levels (3-1-7 mg·liter^{-1} NPK). In 1989 $CaCO_3$ was added to the medium at 10% w:v; in 1990 no amendment was made.

NPK solutions with 5 NO_3:NH_4 ratios and 5 levels of supplemental calcium added in factorial combination were applied beginning 1 week after seeding and continued for 3 weeks (Table 3.1). Treatments were replicated 4 times, with one 72-cell tray per replicate. Solutions were prepared using tap water (6-1-7 mg·liter^{-1} NPK), applied 6 days per week to runoff for the first 2 application weeks, and every other day during the last application week. In 1989 plugs were leached in between application days during the last week of treatment applications to reduce excessive plant growth. Treatment solution pH ranged from 6.1 to 6.4. Treatment solution concentrations and element sources are given in Table 3.2.

Experimental design for 1989 was a randomized complete block with 2 blocks and 2 replicates per block. In 1990 there were 4 blocks with 1 replicate per block. Each sample consisted of 8 plants per replicate. Statistical analysis was performed using SAS Proc GLM with treatment effects determined using orthogonal contrasts (SAS Institute, Cary, N.C.).

Twenty-one days after seeding plant dry weight, stem length, plant height, leaf area (Model LI 3000, Li-Cor), medium pH (Fisher Scientific, model #13-620-3 and #13-621-1) and EC (Fisher Scientific, model #09-328) were measured. Medium extracts for pH and EC measurements were prepared using a saturated media extraction method (Warnke, 1986). Measurements

were repeated at day 28, except for medium pH and EC. Plant samples at 4 weeks were dried in a forced-air oven at 65°C for 24 hours and ground in a Wiley mill to pass through a 40-mesh screen (Lockman, 1980). One-half gram dried plant subsamples for total mineral analysis were ashed for 8 hours at 500°C and solubilized in 1N HCl. The solubilized ash was filtered through Whatman No. 42 filter paper and the solution was diluted to 50 ml with 1N HCl (Gaines and Mitchell, 1979). Mineral content was determined with an inductively-coupled plasma spectrometer (Jerrell-Ash ICAP 9000) at the O.S.U. Plant Analysis Laboratory, Corvallis, Ore. Total nitrogen was determined by acid digestion of 1 g samples. Diluted digests were analyzed using an Alpkem rapid-flow analyzer (RF-300) (Gaines and Mitchell, 1979).

Field NO_3:NH_4 Ratio + Supplemental Calcium Study

On 14 May 1990 seedlings from 9 treatments were hand-transplanted in the field to determine the influence of pretransplant NO_3:NH_4 ratio and supplemental calcium on seedling survival, plant vining, flowering, and yield. Treatments were factorial combinations of 3 NO_3:NH_4 ratios (100:0, 50:50, and 0:100) and 3 levels of supplemental calcium (0, 8, and 16 mmol·liter^{-1}) arranged in a randomized complete block design. There were 4 blocks with 12 plants per plot.

Soil tests from field plots prior to planting indicated 13N-22P-220K kg·ha^{-1} and 0.9% organic matter. Plots were established on 2 April 1990 by rototilling 1.8 m-wide strips in a wheat cover crop, leaving 15 cm-wide windbreaks between rows. Fertilizer was broadcast and rototilled on 4 April in 0.6 m-wide bands. Nitrogen, phosphorous, potassium, and sulfur rates were 112, 108, 149, and 45 kg·ha^{-1},

respectively. Micronutrients copper, zinc, and boron were included at 4.5, 3.4, and 1.7 $kg \cdot ha^{-1}$. On 30 April a single drip irrigation line (Chapin turbulent wall, 4 mil, 0.23 m emitter spacing, 3.35 $liters \cdot hr^{1} \cdot 100\ m^{-1}$ at 51.6 Pa) was buried 5 cm deep in the middle of the bed. Carbofuran (0.225 kg. a.i.$\cdot$1000 m row^{-1}) and Plastigon 19B black plastic mulch (1.25 m wide) were applied over the bed. Plants were spaced 0.71 m between plants, 2.13 m between rows with 1 $row \cdot bed^{-1}$ (6585 $plants \cdot ha^{-1}$). On 15 June and 5 July additional N and Ca were applied through the drip line at 28 and 35 $kg \cdot ha^{-1}$, respectively.

Drip irrigation was applied daily to the mulched bed area at a rate of $ET_{crop} = K_c \cdot kp \cdot E_{pan}$ (Doorenbos and Pruitt, 1975). ET_{crop} is watermelon evapotranspiration in $mm \cdot day^{-1}$, K_c is the watermelon crop coefficient, kp is the pan coefficient, and E_{pan} is pan evaporation in $mm \cdot day^{-1}$.

Plant vining, number of female flowers, and plant stand measurements were made on 29 May, 21 June, and 21 July, respectively. Two plants per plot were destructively harvested on 18 June for dry weight and leaf area determinations.

Plots were harvested 3, 9, and 17 August. Marketable melon weight and fruit number per plot were analyzed as early (first harvest), late (second plus third harvests), and total yield. Non-marketable fruit were not subjected to an analysis of variance, as very few melons were evaluated as being non-marketable.

RESULTS AND DISCUSSION

1989 Greenhouse Study

NO_3:NH_4 Ratio

Increasing NH_4-N in the NO_3:NH_4 ratio significantly decreased shoot dry weight 3 and 4 weeks after seeding (Table 3.3). At both sampling dates, nitrogen-form ratios with either 100% or 75% NO_3-N produced significantly greater shoot dry weights than did the mean of the other ratios. The effect of nitrogen-form ratio on shoot dry weight concurs with the findings of Barker and Maynard, (1972), Kirkby (1967), Kirkby and Knight (1977), Pierpont and Minotti, (1977), and Precheur and Maynard (1983), who reported growth with NH_4-N being slightly less than, or approximately equal to, growth with NO_3-N in a well pH-buffered growing medium.

The trend of decreasing growth with increasing NH_4^+ is seen also in the leaf area results (Table 3.3). Three weeks after seeding, the 100% NH_4-N treatment had significantly less leaf area than the average of the other ratios. At 4 weeks, the 100% NO_3-N treatment produced significantly greater leaf area than did the aggregate of the others, which included NH_4-N.

Nitrogen-form ratio did not significantly affect stem length or plant height at week 4 (Table 3.4).

Decreasing NO_3:NH_4 ratio decreased medium pH and increased medium EC (Table 3.5). Hydrogen ion extrusion into the soil solution caused by NH_4^+ uptake has been reported to decrease medium pH (Kirkby, 1967; Kirkby and Armstrong, 1980; Kirkby and Mengel, 1967; Pill and Lambeth,

1977; Precheur and Maynard, 1983). An additional mechanism by which NH_4^+ depressed medium pH is by displacing H^+ on the medium exchange complex (Bunt, 1976).

Increasing medium EC may explain the decrease in plant growth. High soil solution EC has been shown to decrease plant growth and reduce yield (Maas, 1986). Although medium EC was less than 1.2 $dS \cdot m^{-1}$, high greenhouse temperatures may have decreased plant salt tolerance. High temperatures increase transpiration causing solute accumulation around roots (Marschner, 1986), resulting in decreased water potential in the rhizosphere due to an increase in osmotic potential. Plant uptake of water from the rhizosphere would be reduced, and growth decreased. Since EC measurements were performed on medium solution extracts from the entire medium solution and not on the rhizosphere solution only, medium solution EC values may be lower than rhizosphere EC.

Shoot nitrogen concentration was less than 2% for all nitrogen-form ratios, indicating a general nitrogen deficiency (Table 3.6). There was a slight decrease in percent nitrogen values from 25 to 100% NH_4-N. Both dry matter accumulation (Table 3.3) and nitrogen concentration decreased with increasing NH_4-N, pointing to either loss of available NH_4+ or a decrease in NH_4^+ uptake. Ammonium may have volatilized as NH_3, since medium pH values were above 7.0 and greenhouse temperatures were high; or NH_4^+ was adsorbed on the exchange complex and removed when the medium was leached.

High medium pH may have suppressed NH_4^+ uptake. Ammonium uptake has been shown to decrease with increasing ambient pH (Munn and Jackson, 1978).

Nitrogen-form ratio did not affect shoot concentrations of phosphorous, potassium, calcium, or magnesium (Table 3.6). Since the medium was amended with $CaCO_3$, the decrease in uptake of other cations usually associated with NH_4^+ uptake was alleviated (Alan, 1989; Barker and Maynard, 1972; Kirkby and Mengel, 1967). Differences in shoot mineral content reflect shoot dry weight differences, since shoot mineral concentrations were not significantly different.

Since the synergistic response on shoot growth and nitrogen content caused by the interaction of supplemental calcium and NH_4-N was not demonstrated, it was decided not to add $CaCO_3$ to the medium in 1990. It was considered that the medium $CaCO_3$ amendment may have resulted in solubilized Ca levels in the medium above the 10 mmol·liter^{-1} Ca level reported by Fenn et al. (1987) and Taylor et al. (1985) needed to produce the effect.

Supplemental Calcium

Twenty-one days after seeding, shoot dry weight decreased linearly with increasing level of supplemental calcium, but at day 28 dry weight was not significantly affected by supplemental calcium (Table 3.8).

Leaf area response was similar to shoot dry weight. At day 21 a linear decrease occurred, but one week later no significant effect was detected (Table 3.8).

Neither stem length nor plant height were affected by increasing supplemental calcium (Table 3.9).

Medium pH responded quadratically to increasing calcium by day 21, while medium EC increased linearly with increasing supplemental calcium (Table 3.10). Supplemental calcium depressed medium solution pH by

displacing H^+ adsorbed on the peat exchange complex as reported by Bunt (1976).

The decrease in plant growth with increasing calcium at week 3 could have been due to a decrease in water potential (high medium EC). Decrease in dry matter accumulation and leaf area caused by high EC was alleviated in week 4 when the medium was leached and frequency of treatment applications were reduced.

Nitrogen concentration was not affected by supplemental calcium (Table 3.11). With increasing levels of supplemental calcium, concentration of shoot potassium and magnesium decreased linearly while calcium increased linearly. Similar effects occurred for shoot mineral accumulation (Table 3.12). With increasing supplemental calcium levels, nitrogen accumulation was not affected, magnesium accumulation decreased linearly, and calcium accumulation increased linearly. The shoot mineral concentration and shoot mineral accumulation data together, suggest that increasing supplemental calcium depressed the uptake of potassium and magnesium. This demonstration of cation antagonism, where increasing the supply of one cation lowers the concentrations of other cation species, is a basic principle of plant nutrition.

1990 Greenhouse Study

NO_3:NH_4 Ratio

Increasing NH_4-N in the pretransplant nutrient regime significantly decreased shoot dry weight 3 weeks after seeding (Table 3.13). However, at week 4, no significant differences were detected at the 5% level.

Leaf area was not affected by NO_3:NH_4 ratio 3 weeks after seeding,

but, at week 4, differences were found (Table 3.13). The 0:100 NO_3:NH_4 treatment produced significantly greater leaf area than did the other treatments.

Stem length decreased with increasing proportion of NH_4-N in the nitrogen-form ratio (Table 3.14). While statistically significant differences were detected for plant height, both the 100% NO_3-N and the 100% NH_4-N ratio produced plants of approximately equal height.

Medium EC increased with increasing proportion of NH_4-N (Table 3.15). At week 3, decreased shoot growth coincided with increased NH_4-N in the NO_3:NH_4 ratio, and increased medium EC. At week 4, growth responses were not significantly different or were variable. (Treatments were applied once every other day during week 4.) Although medium EC was not measured after week 4, it is reasonable to assume that medium EC decreased over all treatments. Either the decrease in medium EC, or the reduced amount of NH_4-N applied, negated the growth differences which occurred at week 3.

Nitrogen-form ratio and supplemental calcium interacted to affect medium solution pH (Table 3.20). Increasing NH_4-N decreased medium solution pH. Within each NO_3:NH_4 ratio, increasing levels of supplemental calcium also decreased medium solution pH. At 100 and 75% NO_3-N, solution pH decreased quadratically with increasing Ca, while at 50, 25 and 0% NO_3-N the response was linear. Ammonium nitrogen uptake acidifies rhizosphere pH, while NO_3-N increases rhizosphere pH (Alan, 1989; Barker and Maynard, 1972). Cations displace H^+ on the peat exchange complex decreasing rhizosphere pH (Bunt, 1976). Calcium and NH_4^+ jointly affected a decrease in medium pH. Nitrate uptake (OH^-

extrusion) acted to buffer medium pH at pH values above that of treatments with NH_4-N as the predominant N-form.

Shoot N concentration with 100% NH_4-N was significantly greater than the mean of the other ratios (Table 3.16). Decreasing NO_3:NH_4 ratio decreased potassium and calcium concentration.

Nitrogen accumulation increased from 25 to 100% NH_4-N; however, the 75 and 100% NO_3-N ratios were not significantly different than the mean of the other treatments (Table 3.17). Phosphorous accumulation was similar for all nitrogen-form ratios; however, potassium, calcium, and magnesium content decreased with increasing NH_4-N.

Increasing NH_4-N depressed the uptake of other cations resulting in higher nitrogen concentration and accumulation, and lower concentration and accumulation of other cations.

Supplemental Calcium

Shoot dry weight 3 weeks after seeding responded quadratically to increasing levels of supplemental calcium (Table 3.18). At week 4, the response was cubic, with greatest shoot dry weight at 4 mmol·liter^{-1}.

Leaf area at day 21 decreased linearly with an increase in Ca, but no significant differences were detected at day 28 (Table 3.18).

Increasing Ca level decreased stem length linearly at day 28, while plant height had a significant cubic response (Table 3.19). The shortest plants were obtained with the 12 mmol·liter^{-1} Ca level.

Medium EC increased linearly (P=0.001) with increasing Ca at week 3 (Table 3.21). High soluble salts probably depressed growth as shoot dry weight and leaf area generally decreased with increasing medium EC. Maas (1986) classified watermelon as being moderately sensitive for

tolerance to soil salinity. Watermelon growth was estimated to decrease above saturated extract EC of 1.5. Medium EC probably decreased during week 4 when treatments were applied once every other day, resulting in variability in shoot dry weight and leaf area results at week 4.

With increasing Ca level, N and Ca concentrations increased linearly, while percent P and Mg decreased linearly (Table 3.22). The same general trend was seen in the mineral accumulation results. However, a linear decrease in K accumulation also occurred (Table 3.23). The mineral concentration and accumulation results, in combination with the dry weight data, suggest a concentration effect with N. Shoot dry weight began to decrease at 8 to 12 mmol·liter^{-1} Ca, while N accumulation decreased only slightly at these levels. Increasing Ca depressed the uptake of Mg. (Both Mg concentration and accumulation decreased with increasing Ca.) Potassium concentration was not affected by increasing Ca, but K accumulation decreased with increasing Ca, due to the decrease in dry matter accumulation. Phosphorous concentration and uptake decreased with increasing Ca. Calcium does not directly depress phosphorous uptake. Phosphorous accumulation was reduced at the higher Ca levels by high soluble salts which can cause poor root growth. Decreasing root surface area reduces P uptake (Mengel and Kirkby, 1987; Marschner, 1986). Phosphorous is transported to the root surface from only a few millimeters away from the root by diffusion along a concentration gradient.

Greenhouse Study Conclusions

NO_3:NH_4 Ratio

Plant growth was greater in 1989 than in 1990 due to higher

greenhouse temperatures. Increasing NH_4-N affected plant growth more in 1989 than in 1990. In 1989, medium amendment with $CaCO_3$ alleviated the usual NH_4^+-induced depression of cation uptake, however, dry matter accumulation and leaf area decreased with increasing NH_4^+. Loss of available N from NH_4^+, reduced N uptake, or increasing medium EC with increasing NH_4^+ probably limited growth.

In 1990, increasing NH_4-N depressed the uptake of other cations, but increased shoot nitrogen concentration. Reduction in frequency of treatment applications after week 3 ameliorated the decrease in growth associated with increasing NH_4^+.

Although statistically significant differences were detected for plant growth and mineral composition between N ratios, either N-form, in any of the ratios tested, proved to be satisfactory for transplant production.

Supplemental Calcium

Reduction in plant growth with increasing Ca was greater in 1990 than in 1989. Greater plant cation accumulation may account for lower medium EC in 1989 as compared to 1990. In 1989, leaching of the medium after week 3 probably negated Ca effect on plant growth.

Increasing Ca appeared to reduce K and Mg uptake in 1989, and Mg in 1990. Calcium did not affect N in 1989; however in the following year, increasing Ca produced a concentration effect with N. In 1990, increasing Ca caused a decrease in P concentration and accumulation. This may have been caused by restricted root growth at higher Ca levels.

The synergistic effect of supplemental Ca on NH_4-N nutrition as reported by Fenn et al. (1987) and Taylor et al. (1985) was not detected

in either 1989 or 1990.

Calcium at 4 to 8 mmol·liter^{-1} was optimal for transplant production based on shoot growth and shoot nitrogen content.

Field NO_3:NH_4 Ratio + Supplemental Calcium Study

Two weeks after transplanting, increasing NH_4-N in the pretransplant nutrient regime increased the number of plants which had begun to produce vines (Table 3.24). A similar trend was seen at week 4; both plant dry weight and leaf area increased with decreasing NO_3:NH_4 ratio (Table 3.24).

Supplemental calcium had no effect on plant vining. However, plant dry weight and leaf area were greatest 4 weeks after transplanting with 8 mmol·liter Ca^{-1} (Table 3.25).

Neither N-form ratio nor supplemental Ca affected number of female flowers or plant stand (Tables 3.26 and 3.27). Although number of female flowers was not affected by the treatments, treatments may have affected ovule survival or fertilization. While pollen tube growth has been shown to be dependent on extracellular Ca^{2+}, this does not seem a likely explanation as the 100% NH_4-N ratio depressed Ca^{2+} uptake (Mascarenhas and Machlis, 1964).

Early yield (first harvest) of marketable watermelon fruit was greatest with 100% NH_4-N (Table 3.28). Fruit number did not differ at the 5% significance level; however, at the 6% level, the 100% NH_4-N ratio produced significantly more fruit than the mean of the others. Early average fruit weight was not affected by pretransplant N-form ratio. Late and total marketable yield, fruit number, and average fruit weight were not affected by N-form ratio.

The addition of Ca at 8 and 16 mmol·liter^{-1} significantly increased early and total marketable fruit number and yield over the 0 Ca control (Table 3.29) Early harvest average fruit weight was greater with the 0 Ca control due to the reduced number of fruit produced. Late marketable fruit number, average fruit weight, and yield were not affected by pretransplant supplemental Ca.

Shoot N concentration at transplanting, as affected by N-form ratio and supplemental Ca, appeared to correlate with plant field performance. (Field performance enhanced with greater transplant N concentration.) Covariate analysis using N concentration as a covariable produced a small decrease in unadjusted to adjusted F values for the effect of N-form ratio and supplemental Ca on yield and fruit number. This suggests that shoot nitrogen concentration may have partially affected fruit number and yield. Another factor or factors were primarily responsible for yield increase.

Conclusions

In the greenhouse, either NO_3-N or NH_4-N in any ratio, and Ca at 4-8 mmol·liter^{-1} were optimal for watermelon transplant production. However, in the field, nitrogen-form ratio with 100% NH_4-N improved field performance by enhancing early growth (plant vining, dry weight, and leaf area), which hastened maturity and produced more fruit. Supplemental Ca at 8 mmol·liter^{-1} increased dry weight and leaf area and Ca at 8 and 16 mmol·liter^{-1} increased early and total yields. Based on the field results, pretransplant fertilization of watermelon should include 100% NH_4-N at 100 mg·liter^{-1} N, and Ca at 8-16 mmol·liter^{-1}.

Table 3.1 Treatment NO_3:NH_4 ratios and supplemental calcium levels.

NO_3:NH_4 ratio	Supplemental calcium (mmol·liter^{-1})
100:0	0
75:25	4
50:50	8
25:75	12
0:100	16

Table 3.2 Treatment mineral sources and concentrations.

Element	Source	Concentration (mmol·liter^{-1})
Nitrogen	KNO_3	0 to 7.5
	$(NH_4)_2SO_4$	0 to 7.5
Phosphorous	H_3PO_4	1
Potassium	KNO_3	0 to 6.5
	KCl	0 to 6.5
Calcium	$CaCl_2$	0, 4, 8, 12, 16

Table 3.3 Nitrogen-form ratio effect on shoot dry weight and leaf area 3 and 4 weeks after seeding, 1989[z].

NO_3:NH_4 ratio	Dry weight (g)		Leaf area (cm^2)	
	Day 21	Day 28	Day 21	Day 28
100:0	2.69	5.47	372	517
75:25	2.63	4.96	360	470
50:50	2.61	4.91	373	465
25:75	2.55	5.12	371	491
0:100	2.51	4.72	339	464
	contrasts			
100% NO_3 vs others	***	***	NS	*
> 50% NO_3 vs others	***	**	NS	NS
> 50% NH_4 vs others	***	NS	NS	NS
100% NH_4 vs others	***	**	**	NS

[z]Means of twenty 8-plant samples.

[NS],[*],[**],[***]Nonsignificant or significant at P=0.05, 0.01, or 0.001, respectively.

Table 3.4 Nitrogen-form ratio effect on stem length and plant height 4 weeks after seeding, 1989[z].

NO_3:NH_4 ratio	Stem length (cm)	Plant height (cm)
100:0	7.5	14.6
75:25	7.4	14.5
50:50	7.4	14.5
25:75	7.4	14.6
0:100	7.5	14.6
	contrasts	
100% NO_3 vs others	NS	NS
> 50% NO_3 vs others	NS	NS
> 50% NH_4 vs others	NS	NS
100% NH_4 vs others	NS	NS

[z]Means of 160 single plant samples.

[NS]Nonsignificant.

Table 3.5 Nitrogen-form ratio effect on medium pH and electrical conductivity (EC) three weeks after seeding, 1989[z].

NO_3:NH_4 ratio	pH	EC ($dS \cdot m^{-1}$)
100:0	8.08	0.88
75:25	7.92	0.92
50:50	7.85	1.01
25:75	7.70	1.02
0:100	7.67	1.12
contrasts		
100% NO_3 vs others	***	NS
> 50% NO_3 vs others	***	*
> 50% NH_4 vs others	***	*
100% NH_4 vs others	***	*

[z]Means of twenty 8-plant samples.

[NS],[*],[***]Nonsignificant or significant at P=0.05 or 0.001, respectively.

Table 3.6 Nitrogen-form ratio effect on shoot mineral concentration, 1989[z].

NO_3:NH_4 ratio	Concentration (% dry wt)				
	N	P	K	Ca	Mg
100:0	1.64	0.57	4.32	4.30	0.82
75:25	1.65	0.58	4.36	4.30	0.82
50:50	1.53	0.58	4.11	4.12	0.77
25:75	1.64	0.57	4.14	4.24	0.79
0:100	1.54	0.55	4.01	4.16	0.78
	contrasts				
100% NO_3 vs others	NS	NS	NS	NS	NS
> 50% NO_3 vs others	*	NS	NS	NS	NS
> 50% NH_4 vs others	NS	NS	NS	NS	NS
100% NH_4 vs others	NS	NS	NS	NS	NS

[z]Means of twenty 8-plant samples.

[NS],[*]Nonsignificant or significant at P=0.05, respectively.

Table 3.7 Nitrogen-form ratio effect on shoot mineral accumulation, 1989[z].

NO_3:NH_4 ratio	Accumulation (mg)				
	N	P	K	Ca	Mg
100:0	90	31	237	235	45
75:25	82	29	206	213	41
50:50	75	29	200	202	37
25:75	84	29	212	218	40
0:100	73	26	190	197	37
	contrasts				
100% NO_3 vs others	**	*	***	***	**
> 50% NO_3 vs others	**	*	**	**	**
> 50% NH_4 vs others	NS	*	*	NS	NS
100% NH_4 vs others	**	**	**	**	*

[z]Means of twenty 8-plant samples.

[NS],[*],[**],[***]Nonsignificant or significant at P=0.05, 0.01, or 0.001, respectively.

Table 3.8 Supplemental calcium effect on shoot dry weight and leaf area 3 and 4 weeks after seeding, 1989[z].

Calcium (mM)	Dry weight (g)		Leaf area (cm^2)	
	Day 21	Day 28	Day 21	Day 28
0	2.61	5.05	378	479
4	2.54	5.01	366	474
8	2.56	4.95	365	475
12	2.50	5.02	353	476
16	2.47	5.16	351	492
	contrasts			
0 vs others	NS	NS	NS	NS
linear	*	NS	*	NS
quadratic	NS	NS	NS	NS
cubic	NS	NS	NS	NS

[z]Means of twenty 8-plant samples.

[NS],[*]Nonsignificant or significant at P=0.05, respectively.

Table 3.9 Supplemental calcium effect on stem length and plant height 4 weeks after seeding, 1989[z].

Calcium (mM)	Stem length (cm)	Plant height (cm)
0	7.47	14.57
4	7.44	14.61
8	7.46	14.60
12	7.45	14.62
16	7.48	14.62
	contrasts	
0 vs others	NS	NS
linear	NS	NS
quadratic	NS	NS
cubic	NS	NS

[z]Means of 160 single plant samples.

[NS]Nonsignificant.

Table 3.10 Supplemental calcium effect on medium pH and electrical conductivity (EC) 3 weeks after seeding, 1989[z].

Calcium (mM)	pH	EC ($dS \cdot m^{-1}$)
0	8.06	0.70
4	7.96	0.79
8	7.76	1.03
12	7.71	1.25
16	7.73	1.18
	contrasts	
0 vs others	***	***
linear	***	***
quadratic	***	NS
cubic	NS	*

[z]Means of twenty 8-plant samples.

[NS],[*],[***]Nonsignificant or significant at P=0.05 or 0.001, respectively.

Table 3.11 Supplemental calcium effect on shoot mineral concentration, 1989[z].

Calcium (mM)	Concentration (% dry wt)				
	N	P	K	Ca	Mg
0	1.56	0.58	4.37	3.52	0.82
4	1.60	0.57	4.18	3.87	0.82
8	1.63	0.57	4.15	4.22	0.77
12	1.62	0.57	4.03	4.54	0.79
16	1.60	0.56	4.02	4.96	0.78
	contrasts				
0 vs others	NS	NS	*	***	***
linear	NS	NS	**	***	***
quadratic	NS	NS	NS	NS	NS
cubic	NS	NS	NS	NS	NS

[z]Means of twenty 8-plant samples.

[NS],[*],[**],[***]Nonsignificant or significant at P=0.05, 0.01, or 0.001, respectively.

Table 3.12 Supplemental calcium effect on shoot mineral accumulation, 1989[z].

	Accumulation (mg)				
Calcium (mM)	N	P	K	Ca	Mg
0	79	29	222	179	49
4	80	29	208	194	45
8	81	28	206	209	39
12	81	29	203	228	34
16	83	29	206	255	32
		contrasts			
0 vs others	NS	NS	*	***	***
linear	NS	NS	NS	***	***
quadratic	NS	NS	NS	NS	NS
cubic	NS	NS	NS	NS	NS

[z]Means of twenty eight-plant samples.

[NS],[*],[***]Nonsignificant or significant at P=0.05 or 0.001, respectively.

Table 3.13 Nitrogen-form ratio effect on shoot dry weight and leaf area 3 and 4 weeks after seeding, 1990[z].

NO_3:NH_4 ratio	Dry weight (g)		Leaf area (cm^2)	
	Day 21	Day 28	Day 21	Day 28
100:0	2.10	3.92	182	324
75:25	2.05	3.94	180	314
50:50	2.00	3.93	180	321
25:75	1.92	3.82	183	320
0:100	1.81	3.83	182	357
	contrasts			
100% NO_3 vs others	***	NS	NS	NS
> 50% NO_3 vs others	***	NS	NS	*
> 50% NH_4 vs others	***	NS	NS	**
100% NH_4 vs others	***	NS	NS	***

[z]Means of twenty 8-plant samples.

NS,*,**,***Nonsignificant or significant at P=0.05, 0.01, or 0.001, respectively.

Table 3.14 Nitrogen-form ratio effect on stem length and plant height 4 weeks after seeding, 1990[z].

NO_3:NH_4 ratio	Stem length (cm)	Plant height (cm)
100:0	5.6	12.3
75:25	5.4	11.9
50:50	5.4	11.9
25:75	5.0	11.3
0:100	5.1	12.1
	contrasts	
100% NO_3 vs others	***	***
> 50% NO_3 vs others	***	***
> 50% NH_4 vs others	***	***
100% NH_4 vs others	***	***

[z]Means of 160 single plant samples.

[NS],[*],[**],[***]Nonsignificant or significant at P=0.05, 0.01, or 0.001, respectively.

Table 3.15 Nitrogen-form ratio effect on medium electrical conductivity (EC) 3 weeks after seeding, 1990[z].

NO_3:NH_4 ratio	EC ($dS \cdot m^{-1}$)
100:0	2.20
75:25	2.45
50:50	2.75
25:75	3.25
0:100	3.26
contrasts	
100% NO_3 vs others	***
> 50% NO_3 vs others	***
> 50% NH_4 vs others	***
100% NH_4 vs others	***

[z]Means of twenty 8-plant samples.

[NS],[***]Nonsignificant or significant at P=0.001, respectively.

Table 3.16 Nitrogen-form ratio effect on shoot mineral concentration, 1990[z].

NO_3:NH_4 ratio	Concentration (% dry wt)				
	N	P	K	Ca	Mg
100:0	2.24	0.65	4.99	2.59	0.82
75:25	2.08	0.66	4.66	2.51	0.82
50:50	2.16	0.65	4.31	2.37	0.77
25:75	2.24	0.68	4.26	2.37	0.79
0:100	2.36	0.68	4.09	2.20	0.78
	contrasts				
100% NO_3 vs others	NS	NS	***	***	NS
> 50% NO_3 vs others	***	*	***	***	NS
> 50% NH_4 vs others	***	NS	***	***	NS
100% NH_4 vs others	***	NS	***	***	NS

[z]Means of twenty 8-plant samples.

[NS],[*],[***]Nonsignificant or significant at P=0.05 or 0.001, respectively.

Table 3.17 Nitrogen-form ratio effect on shoot mineral accumulation, 1990[z].

NO_3:NH_4 ratio	Accumulation (mg)				
	N	P	K	Ca	Mg
100:0	87	25	195	101	29
75:25	82	26	185	98	27
50:50	85	26	169	92	24
25:75	86	26	162	90	23
0:100	90	26	157	84	21
	contrasts				
100% NO_3 vs others	NS	NS	***	***	***
> 50% NO_3 vs others	NS	NS	***	***	***
> 50% NH_4 vs others	*	NS	***	***	***
100% NH_4 vs others	**	NS	***	***	***

[z]Means of twenty 8-plant samples.

[NS],[*],[**],[***]Nonsignificant or significant at P=0.05, 0.01, or 0.001, respectively.

Table 3.18 Supplemental calcium effect on shoot dry weight and leaf area 3 and 4 weeks after seeding, 1990[z].

Calcium (mM)	Dry weight (g)		Leaf area (cm^2)	
	Day 21	Day 28	Day 21	Day 28
0	1.98	3.90	183	328
4	2.00	4.11	182	333
8	2.05	3.95	191	334
12	1.98	3.81	179	322
16	1.88	3.68	172	319
	contrasts			
0 vs others	NS	NS	NS	NS
linear	*	***	**	NS
quadratic	**	**	NS	NS
cubic	NS	*	NS	NS

[z]Means of twenty 8-plant samples.

[NS],[*],[**],[***]Nonsignificant or significant at P=0.05, 0.01, or 0.001, respectively.

Table 3.19 Supplemental calcium effect on stem length and plant total height 4 weeks after seeding, 1990[z].

Calcium (mM)	Stem length (cm)	Plant height (cm)
0	5.3	12.2
4	5.5	12.3
8	5.2	12.0
12	5.4	11.8
16	5.0	12.2
	contrasts	
0 vs others	NS	***
linear	***	***
quadratic	NS	***
cubic	NS	***

[z]Means of 160 single plant samples.

NS,***Nonsignificant or significant at P=0.001, respectively.

Table 3.20 Interaction of supplemental calci m and nitrogen-form ratio on medium pH, 1990[z].

	NO_3:NH_4 ratio				
Calcium (mM)	100:0	75:25	50:50	25:75	0:100
			pH		
0	7.65	6.96	6.61	6.34	6.27
4	7.32	6.78	6.47	6.30	6.11
8	7.08	6.66	6.32	6.14	6.05
12	6.96	6.59	6.22	6.09	5.93
16	6.89	6.53	6.18	6.00	5.92
			contrasts		
linear	***	***	***	***	***
quadratic	**	***	NS	NS	NS
cubic	NS	NS	NS	NS	NS

[z]Means of four 8-plant samples.

NS,**,***Nonsignificant or significant at P=0.01 or 0.001, respectively.

Table 3.21 Supplemental calcium effect on medium electrical conductivity (EC) 3 weeks after seeding, 1990[z].

Calcium (mM)	EC ($dS \cdot m^{-1}$)
0	1.40
4	1.94
8	2.76
12	3.46
16	4.35
contrasts	
0 vs others	***
linear	***
quadratic	NS
cubic	NS

[z]Means of twenty 8-plant samples.

[NS],[***]Nonsignificant or significant at P=0.001, respectively.

Table 3.22 Supplemental calcium effect on shoot mineral concentration, 1990[z].

	Concentration (% dry wt)				
Calcium (mM)	N	P	K	Ca	Mg
0	2.14	0.70	4.58	1.80	0.74
4	2.15	0.66	4.37	2.00	0.70
8	2.24	0.68	4.54	2.42	0.66
12	2.25	0.65	4.39	2.73	0.58
16	2.30	0.64	4.44	3.09	0.52
	contrasts				
0 vs others	**	**	NS	***	***
linear	***	***	NS	***	***
quadratic	NS	NS	NS	NS	NS
cubic	NS	NS	NS	NS	NS

[z]Means of twenty 8-plant samples.

NS,**,***Nonsignificant or significant at P=0.01 or 0.001, respectively.

Table 3.23 Supplemental calcium effect on shoot mineral accumulation, 1990[z].

	Accumulation (mg)				
Calcium (mM)	N	P	K	Ca	Mg
0	83	27	178	70	29
4	88	27	180	82	29
8	88	27	179	95	26
12	86	25	167	104	22
16	84	23	163	113	19
	contrasts				
0 vs others	NS	*	NS	***	***
linear	NS	***	***	***	***
quadratic	*	*	NS	NS	***
cubic	NS	NS	NS	NS	***

[z]Means of twenty 8-plant samples.

[NS],[*],[***]Nonsignificant or significant at P=0.05 or 0.001, respectively.

Table 3.24 Nitrogen-form ratio effect on plant vining, dry weight, and leaf area.

NO_3:NH_4 ratio	Vining[z] %	Dry weight[y] (g)	Leaf area[y] (cm^2)
100:0	36.6	9.55	1000
50:50	56.6	12.69	1405
0:100	76.6	14.16	1641
	contrasts		
100% NH_4 vs others	*	*	*
100% NH_4 vs 100% NO_3	**	**	**

[z]Two weeks after transplanting.

[y]Four weeks after transplanting.

[NS],[*],[**]Nonsignificant or significant at P=0.05 or 0.01, respectively.

Table 3.25 Supplemental calcium effect on plant vining, dry weight, and leaf area.

Calcium (mM)	Vining[z] %	Dry weight[y] (g)	Leaf area[y] (cm^2)
0	48.3	10.26	1114
8	69.2	15.29	1729
16	52.5	10.88	1206
	contrasts		
0 vs 8,16	NS	NS	NS
8 vs 16	NS	*	*

[z]Two weeks after transplanting.

[y]Four weeks after transplanting.

[NS],[*]Nonsignificant or significant at P=0.05, respectively.

Table 3.26 Nitrogen-form ratio effect on female flowering and plant stand[z].

NO_3:NH_4 ratio	Female flowers (No.)	Plants·plot^{-1} (No.)
100:0	7.92	9.67
50:50	7.92	9.50
0:100	8.75	9.75
	contrasts	
100% NH_4 vs others	NS	NS
100% NH_4 vs 100% NO_3	NS	NS

[z]Mean of twelve 10-plant plots.

[NS]Nonsignificant.

Table 3.27 Supplemental calcium effect on female flowering and plant stand[z].

Calcium (mM)	Female flowers (No.)	Plants·plot^{-1} (No.)
0	7.66	9.33
8	8.75	9.83
16	8.17	9.75
	contrasts	
0 vs 8, 16	NS	NS
8 vs 16	NS	NS

[z]Mean of twelve 10-plant plots.

[NS]Nonsignificant.

Table 3.28 Nitrogen ratio effect on watermelon production.

NO_3:NH_4 ratio	Number ($1000 \cdot ha^{-1}$)	Weight (kg)	Yield ($Mg \cdot ha^{-1}$)
		Early	
100:0	4.6	8.5	38.3
50:50	5.2	7.7	40.3
0:100	5.9	8.4	49.2
	contrasts		
100% NH_4 vs others	NS	NS	*
100% NH_4 vs 100% NO_3	NS	NS	*
		Late	
100:0	3.5	6.2	21.1
50:50	3.3	6.6	21.7
0:100	3.0	5.9	17.4
	contrasts		
100% NH_4 vs others	NS	NS	NS
100% NH_4 vs 100% NO_3	NS	NS	NS
		Total	
100:0	8.1	7.6	59.4
50:50	8.6	7.3	61.9
0:100	8.8	7.3	66.6
	contrasts		
100% NH_4 vs others	NS	NS	NS
100% NH_4 vs 100% NO_3	NS	NS	NS

NS,*Nonsignificant or significant at P=0.05, respectively.

Table 3.29 Supplemental calcium effect on watermelon production.

Calcium (mM)	Number ($1000 \cdot ha^{-1}$)	Weight (kg)	Yield ($Mg \cdot ha^{-1}$)
		Early	
0	3.7	8.8	32.4
8	5.4	7.7	44.9
16	4.8	8.2	41.0
	contrasts		
0 vs 8 and 16	***	*	*
8 vs 16	NS	NS	NS
		Late	
0	2.7	6.3	19.2
8	2.6	6.4	16.9
16	2.4	6.5	15.6
	contrasts		
0 vs 8 and 16	NS	NS	NS
8 vs 16	NS	NS	NS
		Total	
0	6.4	8.0	51.5
8	8.0	7.7	61.7
16	7.2	7.9	56.6
	contrasts		
0 vs 8 and 16	**	NS	*
8 vs 16	NS	NS	NS

NS,*,**Nonsignificant or significant at P=0.05 or 0.01, respectively.

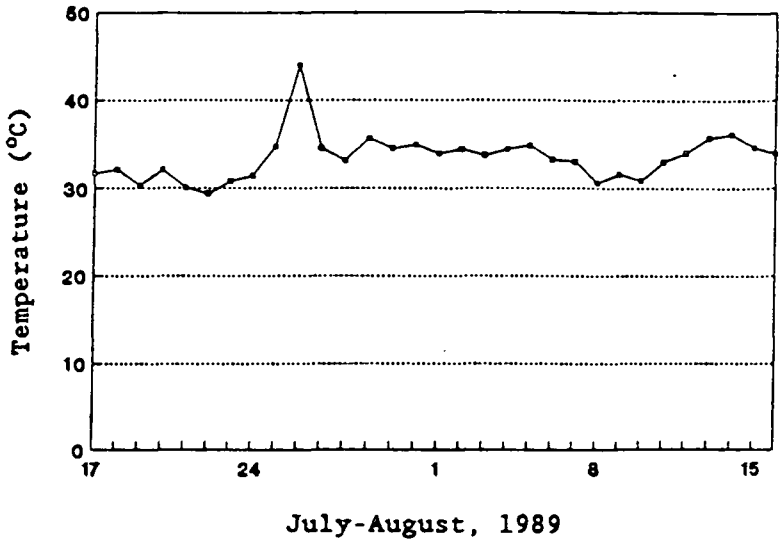

Figure 3.1 Greenhouse daily maximum temperature, 17 July to 17 August, 1989.

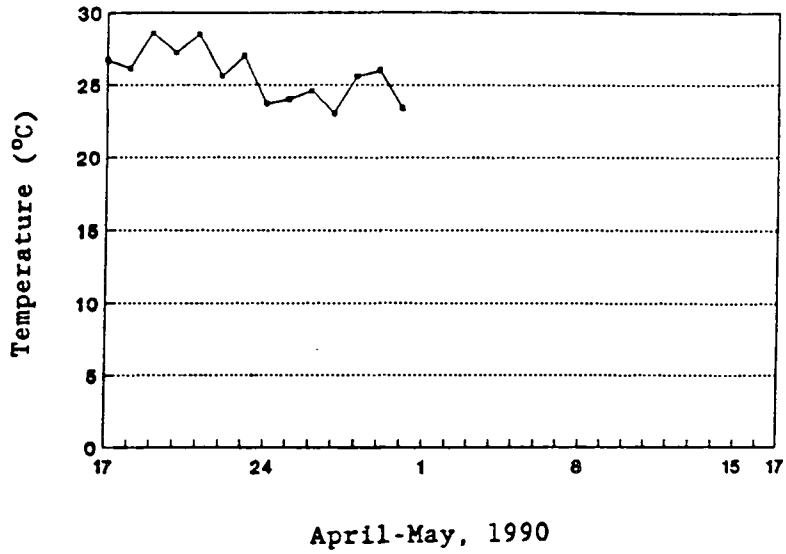

Figure 3.2 Greenhouse daily maximum temperature, 17 April to 17 May, 1990. (Instrument malfunction from 1 May to 17 May, 1990.)

LITERATURE CITED

Adler, P.R., R.J. Dufault, and L. Waters, Jr. 1984. Influence of nitrogen, phosphorous and potassium on asparagus transplant quality. HortSci. 19:565-566.

Alan, R. 1989. The effect of nitrogen nutrition on growth, chemical composition and response of cucumbers (*Cucumis sativus* L.) to nitrogen forms in solution culture. J. Hort. Sci. 64:467-474.

Barker, A.V. and D.N. Maynard. 1972. Cation and nitrate accumulation in pea and cucumber plants as influenced by nitrogen nutrition. J. Amer. Soc. Hort. Sci. 97:27-30.

Barker, A.V., R.J. Volk and W.A. Jackson. 1966a. Root environment acidity as a regulatory factor in ammonium assimilation by the bean plant. Plant Physiol. 41:1193-1199.

Barker, A.V., R.J. Volk and W.A. Jackson. 1966b. Growth and nitrogen distribution patterns in bean plants (*Phaseolus vulgaris* L.) subjected to ammonium nutrition: I. Effects of carbonates and acidity control. Soil Sci. Soc. Amer. Proc. 30:228-232.

Bunt, A.C. 1976. Modern Potting Composts. The Pa. State Univ. Press. Pittsburgh, Pa.

Doorenbos, J. and W.O. Pruitt. 1975. Guidelines for Predicting Crop Water Requirements. F.A.O. Irrigation and Drainage Paper 24.

Dufault, R.J. 1985. Relationship among nitrogen, phosphorous, and potassium fertility regimes on celery transplant growth. HortSci. 20:1104-1106.

Dufault, R.J. 1986. Influence of nutritional conditioning on muskmelon transplant quality and yield. J. Amer. Soc. Hort. Sci. 111:698-703.

Dufault, R.J. 1987. Use of slow-release nitrogen and phosphorous fertilizers in celery transplant production. HortSci. 22:1268-1270.

Fenn L.B. 1975. Ammonia volatilization from surface applications of ammonium compounds on calcareous soils: III. Effects of mixing low and high loss ammonium compounds. Soil Sci. Soc. Amer. Proc. 39:366-368.

Fenn, L.B. and D.E. Kissel. 1973. Ammonia volatilization from surface applications of ammonium compounds on calcareous soils: I. General theory. Soil Sci. Soc. Amer. Proc. 37:855-859.

Fenn, L.B. and D.E. Kissel. 1974. Ammonia volatilization from surface applications of ammonium compounds on calcareous soils: II. Effect of temperature and rate of ammonium nitrogen application. Soil Sci. Soc. Amer. Proc. 38:606-610.

Fenn, L.B. and D.E. Kissel. 1976. The influence of cation exchange capacity and depth of incorporation on ammonia volatilization from ammonium compounds applied to calcareous soils. Soil Sci. Soc. Amer. Proc. 40:394-398.

Fenn, L.B., R.M. Taylor and G.L. Horst. 1987. *Phaseolus vulgaris* growth in an ammonium based nutrient solution with variable calcium. Agron. J. 79:89-91.

Gaines, T.P and G.A. Michell. 1979. Chemical methods for soil and plant analysis. Univ. Ga. Coastal Plain Exp. Sta. Agron. Handbook No 1.

Horst, G.L., L.B. Fenn and N.B. Dunning. 1985. Bermudagrass turf responses to nitrogen sources. J. Amer. Soc. Hort. Sci. 110:759-761.

Kirkby, E.A. 1967. A note on the utilization of nitrate, urea, and ammonium nitrogen by *Chenopodium album*. Z. Pflanzenernaehr. Bodenkd. 117:204-209. (English summary.)

Kirkby, E.A. and A. H. Knight. 1977. Influence of the level of nitrate nutrition on ion uptake and assimilation, organic acid accumulation, and cation-anion balance in whole tomato plants. Plant Physiol. 60:349-353.

Kirkby, E.A. and K. Mengel. 1967. Ionic balance in different tissues of the tomato plant in relation to nitrate, urea, or ammonium nutrition. Plant Physiol. 42:6-14.

Kirkby, E.A. and M.J. Armstrong. 1980. Nitrate uptake by roots as regulated by nitrate assimilation in the shoot of castor oil plants. Plant Physiol. 65:286-290.

Knavel, D.E. 1977. The influences of nitrogen on pepper transplant growth and yielding potential of plants grown with different levels of nitrogen. J. Amer. Soc. Hort. Sci. 102:533-535.

Lockman, R.B. 1980. Review of soil and plant tissue preparation procedures. J. Assoc. Off. Anal. Chem. 63:766-769.

Lorenz, O.A. and D. N. Maynard. 1980. Knott's Handbook for Vegetable Growers. John Wiley & Sons, New York, N.Y. p. 129.

Maas, E. V. 1986. Salt tolerance of plants. Applied Agr. Res. 1:12-26

Marschner, H. 1986. Mineral Nutrition of Higher Plants. Academic Press, New York, N.Y. p.210-211,524.

Mascarenhas, J.P. and L. Machlis. 1964. Chemotropic response of the pollen of *Antirrhium majus* to calcium. Plant Physiol. 39:70-77.

Mengel, K. and E.A. Kirkby. 1987. Principles of Plant Nutrition. Intenational Potash Institute, Worblaufen-Bern, Switzerland. p.134-135, 141-143.

Munn, D.A. and W.A. Jackson. 1978. Nitrate and ammonium uptake by rooted cuttings of sweet potato. Agron. J. 70:312-316.

Pierpont, R.A. and P.L. Minotti. 1977. Effects of calcium carbonate on ammonium assimilation by tomato seedlings. J. Amer. Soc. Hort. Sci. 102:20-23.

Pill, W.G. and V.N. Lambeth. 1977. Effects of NH_4 and NO_3 nutrition with and without pH adjustment on tomato growth, ion composition, and water relations. J. Amer. Soc. Hort. Sci. 102:78-81.

Precheur, R.J. and D.N. Maynard. 1983. Growth of asparagus transplants as influenced by nitrogen form and lime. J. Amer. Soc. Hort. Sci. 108:169-172.

Taylor, R.M., L.B. Fenn and G.L. Horst. 1985. The influence of calcium on growth of selected vegetable species in the presence of ammonium nitrogen. J. Plant Nutr. 8:1013-1023.

Tremblay, N. and A. Gosselin. 1989a. Growth and nutrient status of celery seedlings in response to nitrogen fertilization and NO_3:NH_4 ratio. HortSci. 24:284-288.

Tremblay, N. and A. Gosselin. 1989b. Growth, nutrient status, and yield of celery seedlings in response to urea fertilization. HortSci. 24:288-291.

Warnke, D.D. 1986. Analyzing greenhouse growth media by the saturation extraction method. HortSci. 21:223-225.

Weston, L.A. and B.H. Zandstra. 1989. Transplant age and N and P nutrition effects on growth and yield of tomatoes. HortSci. 24:88-90.

Widders, I.E. 1989. Pretransplant treatments of N and P influence growth and elemental accumulation in tomato seedlings. J. Amer. Soc. Hort. Sci. 114:416-420.

Chapter 4

WATERMELON TRANSPLANT GROWTH AND MEDIUM NITRIFICATION RESPONSE TO $CaCO_3$ AMENDMENT AND SUPPLEMENTAL CALCIUM

ABSTRACT

Watermelon (*Citrullus lanatus* (Thunb.) Matsum. & Nakai var. Crimson Sweet) was seeded in a commercial peat mix in multicell containers (72 cells·tray^{-1}, 40 cm^3·cell^{-1}) in July 1990. Treatments included 3 levels of supplemental calcium (0, 8, and 16 mmol·liter^{-1}) applied within an NH_4-N based pretransplant nutritional regime (100-31-265 mg·liter^{-1} NPK), with and without $CaCO_3$ added at 10% w:v.

Three weeks after seeding, increasing supplemental Ca decreased shoot dry weight and leaf area due to high medium soluble salts. At week 4, supplemental Ca had no significant effect on shoot growth parameters or shoot nitrogen content, since frequency of treatment applications was reduced. In general, medium EC increased and medium pH decreased with increasing Ca level.

Calcium carbonate decreased shoot dry weight and plant total height but increased shoot nitrogen concentration. Total nitrogen uptake was not affected by $CaCO_3$ addition. Decrease in shoot growth may have been due to decreased nutrient availability with $CaCO_3$ addition.

No net nitrification occurred in response to any treatment over a period of 4 weeks.

INTRODUCTION

Soilless potting media are standard substrates for commercial transplant production (Bunt, 1976). To accurately assess the effects of pretransplant nutritional conditioning, a better understanding of media physical, chemical, and biological properties is needed. Since nitrogen-form may influence plant growth (Barker and Maynard, 1972; Barker et al. 1966a, b), the fate of different forms of nitrogen in soilless media is important for plant growth management.

Nitrogen rate in pretransplant nutritional conditioning affects both transplant quality and plant field performance (Dufault, 1985, 1986, 1987; Tremblay and Senecal, 1988). In many pretransplant nutrition studies, different forms of nitrogen have been used (Dufault, 1985, 1986). Lorenz and Maynard, 1980, recommend a 100% NO_3 or 75:25% NO_3:NH_4 ratio for greenhouse production.

A synergistic growth response to supplemental calcium addition to NH_4-N fertilizers has been reported in quartz sand and calcareous soil (Fenn et al., 1987; Horst et al., 1985; Taylor et al., 1985). However, there are contradictory studies (Hons and Aljoe, 1985). In those studies which demonstrated the synergistic response, a decrease in leachate NH_4^+ was given as partial evidence of increased NH_4^+ uptake. Conversion of NH_4^+ to NO_3^- was not measured.

Oxidation of NH_4^+ to NO_2^- or NO_3^- is variable in soilless media. The rate of nitrification in pine bark media increases with an increase in liming rate (Neimiera and Wright, 1986). In peat-vermiculite media, using urea as the nitrogen source, nitrification rate was very slow in

both cropped and uncropped samples (Elliott, 1986).

The study was conducted to evaluate watermelon seedling growth and nitrification in a commercial peat medium in response to 1) increasing levels of supplemental calcium in an NH_4-N based fertilization regime, and 2) medium amendment with $CaCO_3$.

MATERIALS AND METHODS

Watermelon was seeded in multicell containers (72-cell TLC plastic trays, 40 $cm^3 \cdot cell^{-1}$) in a commercial peat mix (Fison's Sunshine Mix #3) in July 1990. Mean weekly day and night greenhouse temperatures are shown in Table 4.1. After leaching, the medium contained low nutrient levels (3-1-7 $mg \cdot liter^{-1}$ NPK).

Experimental design was a randomized complete block, with four blocks. Treatments included medium with and without $CaCO_3$ (10% w:v) and three levels of supplemental calcium (0, 8, and 16 $mmol \cdot liter^{-1}$) from $CaCl_2$, applied in factorial combination, in an all NH_4-N based NPK fertilizer solution (100-31-265 $mg \cdot liter^{-1}$). Treatment solutions were prepared using tap water (6-1-7 $mg \cdot liter^{-1}$ NPK), applied 6 days a week to runoff during the first two application weeks, and every other day during the last application week. Statistical analysis was performed using SAS Proc GLM with treatment effects determined using orthogonal contrasts (SAS Institute, Cary, N.C.).

Plant dry weight, stem length, plant height, leaf area (Model LI 3000, Li-Cor), medium extract pH (Fisher Scientific, model #13-620-3 and #13-621-1), and medium EC (Fisher Scientific, model #09-328) were recorded 21 and 28 days after seeding. Plant samples were dried in a

forced air oven at 65°C for 24 hours and ground in a Wiley mill to pass through a 40 mesh screen (Lockman, 1980). Shoot N content was determined by digesting 0.4 g dried plant subsamples in acid (micro-Kjeldahl), and the diluted digest was analyzed using an Alpkem rapid-flow analyzer (RF-300) (Gaines and Mitchell, 1979).

Medium extract NO_3^- plus NO_2^- concentration was measured at 1, 21, and 28 days after seeding using an Alpkem rapid-flow analyzer (RF-300) with a cadmium reduction column (Gaines and Mitchell, 1979). Medium extracts were prepared using the saturated media extraction method (Warnke, 1986). Samples were kept frozen until analyzed.

RESULTS AND DISCUSSION

Supplemental Ca at 8 and 16 mmol·liter^{-1} significantly decreased shoot dry weight and leaf area 3 weeks after seeding as compared to the 0 Ca level (Table 4.2). At 4 weeks, dry weight and leaf area were not affected by supplemental Ca. Stem length was significantly shorter at the 16 mmol·liter^{-1} Ca level 3 and 4 weeks after seeding than with Ca at 0 or 8 mmol·liter^{-1} (Table 4.3). At week 3, plant height decreased with each increase in Ca level, but at week 4, plant height decreased only from 8 to 16 mmol·liter^{-1} Ca.

Medium pH decreased, and medium EC increased, with each increasing level of supplemental calcium 3 and 4 weeks after seeding (Table 4.4). From week 3 to 4, medium EC decreased and medium pH increased due to reduced fertilizer application.

In peat-based media, addition of cations in fertilizer solutions decrease medium solution pH by displacing H^+ on the peat cation exchange

complex (Bunt, 1976). Maas (1986) classified watermelon as being moderately sensitive to increasing soil solution salinity. Plant growth and/or fruit yield of moderately sensitive plants were reduced above EC values of 1.5 $dS \cdot m^{-1}$. High medium EC depressed shoot growth, particularly 3 weeks after seeding, when EC increased from 3.14 $dS \cdot m^{-1}$ to 6.00 $dS \cdot m^{-1}$ with increasing levels of supplemental Ca. At week 3, dry weight and leaf area decreased as supplemental calcium increased from 0 to 8 $mmol \cdot liter^{-1}$. As the frequency of treatment applications decreased during week 4, the effect on dry weight and leaf area was reduced. Stem length and plant height decreased as Ca increased from 8 to 16 $mmol \cdot liter^{-1}$ at both sampling times.

Shoot concentration and accumulation of nitrogen were not significantly affected by increasing levels of supplemental calcium (Table 4.5). This contradicts the findings of Fenn et al. (1987), Horst et al. (1985), and Taylor et al. (1985), who reported an increase in plant growth, N concentration, and N accumulation with increasing Ca in an NH_4-based fertilizer solution with bean, squash, cantaloupe, bermuda grass, and tomato grown in a calcareous soil.

Medium NO_3^- plus NO_2^- concentration decreased from 1 to 21 and 28 days after seeding (Table 4.6). The 1 to 3 $mg \cdot liter^{-1}$ NO_3^- plus NO_2^- concentration 1 day after seeding may have been residual N from the light nutrient charge leached out of the medium. No difference in NO_3^- plus NO_2^- concentration was detected with increasing Ca at day 1, as treatments had yet to be applied. Although NO_3^- plus NO_2^- was detected 21 and 28 days after seeding, concentrations (less than 0.1 $mg \cdot liter^{-1}$) were below accurate detection limits of instrument

calibration, indicating little or no nitrification had occurred.

Nitrification is inhibited in soilless media due to reduced populations of nitrifying bacteria (e.g. *Nitrosolobus*, *Nitrosospirus* and *Nitrobacter*) caused by low pH and sterilization or pasteurization (Bunt, 1976). Bunt (1976) stated that nitrification in soilless media is optimal at pH 7.0. Rhizosphere pH, defined as the pH of the soil solution from the root surface to a few mm away from the root surface, can be less than the bulk soil solution pH by 1 pH unit with NH_4-N as the N source (Marschner, 1986). Medium solution pH 21 and 28 days after seeding was less than pH 5.75 for all Ca levels. The results for medium NO_3^- plus NO_2^- concentration concur with those of Elliott (1986) who reported no net nitrification in cropped and uncropped soilless medium samples 4 and 8 weeks after seeding.

Shoot dry weight was not affected by $CaCO_3$ amendment 3 weeks after seeding, but at week 4, dry weight was greater without $CaCO_3$ amendment than with (Table 4.7). Leaf area was not affected by $CaCO_3$ amendment 3 or 4 weeks after seeding.

Stem length 21 days after seeding was significantly greater with $CaCO_3$ than without (Table 4.8). However, 4 weeks after seeding, no difference due to $CaCO_3$ amendment was detected. Addition of $CaCO_3$ decreased plant height both 3 and 4 weeks after seeding.

Medium EC was not affected by $CaCO_3$ at either 21 or 28 days after seeding, but medium pH increased with $CaCO_3$ amendment on both sampling dates (Table 4.9).

Since medium EC was not affected by $CaCO_3$ amendment, differences in plant growth parameters between amended and non-amended medium may be

due to differences in medium solution pH. Peterson (1982) found a trend of decreasing availability of P, Fe, Mn, B, Zn, and Cu with increasing solution pH in a commercial soilless medium. Phosphorous availability decreased tenfold from pH 5.2 to 6.5. Medium solution pH from 5.2 to 5.5 was determined optimal for nutrient availability.

Shoot dry weight and plant height decreased with $CaCO_3$ amendment 4 weeks after seeding when medium pH was greater than pH 6.0. However, the same trend is seen in plant height at week 3, while stem length was greater at week 3 with $CaCO_3$.

Shoot N concentration increased with the addition of $CaCO_3$, however, shoot N accumulation was not affected (Table 4.10). Shoot dry weight, N concentration, and N accumulation results describe a concentration effect with N. With $CaCO_3$ addition, dry weight decreased while N accumulation remained unchanged, producing increased N concentration values.

Medium NO_3^- plus NO_2^- concentration decreased between 1 and 21 to 28 days after seeding (Table 4.11). No significant difference in NO_3^- plus NO_2^- concentration was found 1 day after seeding. Medium NO_3^- plus NO_2^- concentration fell below accurate detection limits 21 and 28 days after seeding, indicating little or no nitrification had occurred.

Conclusions

Supplemental Ca decreased shoot growth 3 weeks after seeding by increasing soluble salts. When frequency of treatment application was reduced, growth depression was alleviated. Contradicting the findings of Fenn et al. (1987), Horst et al. (1985), and Taylor et al. (1985), supplemental Ca had no synergistic effect of on either plant growth or

plant N accumulation.

Medium extract solution pH decreased and medium EC increased, with increasing cation content (Ca^{2+}) in the fertilizer solution.

Medium amendment with $CaCO_3$ decreased dry weight and plant height, while increasing shoot N concentration and medium pH. This suggests that nutrient availability may have been adversely affected by $CaCO_3$ amendment. Based on these results, medium amendment with $CaCO_3$ when using NH_4-N is not recommended.

No significant NO_3^- and NO_2^- concentration was detected in response to either supplemental Ca or $CaCO_3$ amendment at any of the 3 sampling dates. This corroborates Elliott (1986), who detected no significant NO_3^- formation in 14 cropped and uncropped media samples over an 8-week period.

Table 4.1 Greenhouse day and nighttime temperature means (°C).

Week beginning	Day	Night
7/6	--[z]	--[z]
7/13	30	24
7/20	28	23
7/27	29	23

[z]Instrument malfunction.

Table 4.2 Supplemental calcium effect on shoot dry weight and leaf area 3 and 4 weeks after seeding[z].

	Dry weight (g)		Leaf area (cm^2)	
Calcium (mM)	Day 21	Day 28	Day 21	Day 28
0	2.36	4.97	390	686
8	2.24	4.97	372	679
16	2.22	4.62	367	650
		contrasts		
0 vs 8, 16	**	NS	*	NS
8 vs 16	NS	NS	NS	NS

[z]Means of eight 8-plant samples.

[NS],[*],[**]Nonsignificant or significant at P=0.05 or 0.01, respectively.

Table 4.3 Supplemental calcium effect on stem length and plant height 3 and 4 weeks after seeding[z].

	Stem length (cm)		Plant height (cm)	
Calcium (mM)	Day 21	Day 28	Day 21	Day 28
0	5.0	7.5	12.3	17.4
8	5.1	7.5	11.9	17.5
16	4.8	6.3	11.5	16.5
		contrasts		
0 vs 8, 16	NS	NS	***	NS
8 vs 16	*	*	*	**

[z]Means of 96 samples.

[NS],[*],[**],[***]Nonsignificant or significant at P=0.05, 0.01, or 0.001 respectively.

Table 4.4 Supplemental calcium effect on medium electrical conductivity and pH 3 and 4 weeks after seeding[z].

	EC ($dS \cdot m^{-1}$)		pH	
Calcium (mM)	Day 21	Day 28	Day 21	Day 28
0	3.14	1.90	5.49	5.70
8	4.58	2.43	5.33	5.56
16	6.00	3.31	5.22	5.40
		contrasts		
0 vs 8, 16	***	**	***	**
8 vs 16	***	*	**	NS

[z]Means of eight 8-plant samples.

[NS],[*],[**],[***]Nonsignificant or significant at P=0.05, 0.01, or 0.001 respectively.

Table 4.5 Supplemental calcium effect on shoot nitrogen concentration and accumulation[z].

Calcium (mM)	N (% dry wt)	N (mg)
0	2.75	136
8	2.73	135
16	2.89	133
	contrasts	
0 vs 8, 16	NS	NS
8 vs 16	NS	NS

[z]Means of eight 8-plant samples.

[NS]Nonsignificant.

Table 4.6 Supplemental calcium effect on medium NO_3^- plus NO_2^- concentration[z].

	Days after seeding		
Calcium (mM)	1	21	28
	Concn ($mg \cdot liter^{-1}$)		
0	2	-[y]	-
8	2	-	-
16	1	-	-
	contrasts		
0 vs 8, 16	NS	-	-
8 vs 16	NS	-	-

[z]Means of eight 8-plant samples.

[y]Concentration below accurate detection limit.

[NS]Nonsignificant.

Table 4.7 Calcium carbonate amendment effect on shoot dry weight and leaf area 3 and 4 weeks after seeding[z].

	Dry weight (g)		Leaf area (cm^2)	
$CaCO_3$	Day 21	Day 28	Day 21	Day 28
none	2.27	5.05	376	688
10%	2.28	4.65	376	656
	NS	*	NS	NS

[z]Means of twelve 8-plant samples.

NS,*Nonsignificant or significant at P=0.05, respectively.

Table 4.8 Calcium carbonate amendment effect on stem length and plant height 3 and 4 weeks after seeding[z].

	Stem length (cm)		Plant height (cm)	
$CaCO_3$	Day 21	Day 28	Day 21	Day 28
none	4.7	7.1	12.1	17.5
10%	5.2	7.1	11.8	16.8
	***	NS	*	*

[z]Means of 96 samples.

NS,*,***Nonsignificant or significant at P=0.05 or 0.001, respectively.

Table 4.9 Calcium carbonate amendment effect on medium electrical conductivity and pH 3 and 4 weeks after seeding[z].

	EC ($dS \cdot m^{-1}$)		pH	
$CaCO_3$	Day 21	Day 28	Day 21	Day 28
none	4.79	2.49	4.88	4.98
10%	4.35	2.60	5.81	6.12
	NS	NS	***	***

[z]Means of twelve 8-plant samples.

[NS],[***]Nonsignificant or significant at P=0.001, respectively.

Table 4.10 Calcium carbonate amendment effect on shoot N concentration and accumulation[z].

$CaCO_3$	N (% dry wt)	N (mg)
none	2.68	135
10%	2.90	136
	*	NS

[z]Means of twelve 8-plant samples.

[NS],[*]Nonsignificant or significant at P=0.05, respectively.

Table 4.11 Calcium carbonate amendment effect on medium NO_3^- plus NO_2^- concentration[z].

	Days after seeding		
$CaCO_3$	1	21	28
	Concn (mg·liter^{-1})		
none	2	-[y]	-
10%	2	-	-
	NS	-	-

[z]Means of twelve 8-plant samples.

[y]Concentration below accurate detection limit.

[NS]Nonsignificant.

LITERATURE CITED

Barker, A.V. and D.N. Maynard. 1972. Cation and nitrate accumulation in pea and cucumber plants as influenced by nitrogen nutrition. J. Amer. Soc. Hort. Sci. 97:27-30.

Barker, A.V., R.J. Volk and W.A. Jackson. 1966a. Root environment acidity as a regulatory factor in ammonium assimilation by the bean plant. Plant Physiol. 41:1193-1199.

Barker, A.V., R.J. Volk and W.A. Jackson. 1966b. Growth and nitrogen distribution patterns in bean plants (*Phaseolus vulgaris* L.) subjected to ammonium nutrition: I. Effects of carbonates and acidity control. Soil Sci. Soc. Amer. Proc. 30:228-232.

Bunt, A.C. 1976. Modern Potting Composts. The Pa. State Univ. Press. Pittsburgh, Pa.

Dufault, R.J. 1985. Relationship among nitrogen, phosphorous, and potassium fertility regimes on celery transplant growth. HortSci. 20:1104-1106.

Dufault, R.J. 1986. Influence of nutritional conditioning on muskmelon transplant quality and yield. J. Amer. Soc. Hort. Sci. 111:698-703.

Dufault, R.J. 1987. Use of slow-release nitrogen and phosphorous fertilizers in celery transplant production. HortSci. 22:1268-1270.

Elliott, G.C. 1986. Urea hydrolysis in potting media. J. Amer. Soc. Hort. Sci. 111:862-866.

Fenn, L.B., R.M. Taylor and G.L. Horst. 1987. *Phaseolus vulgaris* growth in an ammonium based nutrient solution with variable calcium. Agron. J. 79:89-91.

Gaines, T.P and G.A. Michell. 1979. Chemical methods for soil and plant analysis. Univ. Ga. Coastal Plain Exp. Sta. Agron. Handbook No 1.

Hons, F.M. and K.D. Aljoe. 1985. Effects of applied calcium on growth and ammonium utilization by corn. Comm. Soil Sci. Plant Anal. 16:349-360.

Horst, G.L., L.B. Fenn and N.B. Dunning. 1985. Bermudagrass turf responses to nitrogen sources. J. Amer. Soc. Hort. Sci. 110:759-761.

Lockman, R.B. 1980. Review of soil and plant tissue preparation procedures. J. Assoc. Off. Anal. Chem. 63:766-769.

Lorenz, O.A. and D. N. Maynard. 1980. Knott's Handbook for Vegetable Growers. John Wiley & Sons, New York, N.Y. p. 129.

Maas, E. V. 1986. Salt tolerance of plants. Applied Agr. Res. 1:12-26

Marschner, H. 1986. Mineral Nutrition of Higher Plants. Academic Press, New York, N.Y. p.210-211,524.

Neimiera, A.X. and R.D. Wright. 1986. Effect of liming rate on nitrification in a pine bark medium. J. Amer. Soc. Hort. Sci. 111:713-715.

Peterson, J.C. 1982. Effects of pH upon nutrient availability in a commercial soilless root medium utilized for floral crop production. Ohio Agr. Res. Dev. Ctr vol. 268

Taylor, R.M., L.B. Fenn and G.L. Horst. 1985. The influence of calcium on growth of selected vegetable species in the presence of ammonium nitrogen. J. Plant Nutr. 8:1013-1023.

Tremblay, N. and M. Senecal. 1988. Nitrogen and potassium in nutrient solution influence seedling growth of four vegetable species. HortSci. 23:1018-1020.

Warnke, D.D. 1986. Analyzing greenhouse growth media by the saturation extraction method. HortSci. 21:223-225.

BIBLIOGRAPHY

Adler, P.R., R.J. Dufault, and L. Waters, Jr. 1984. Influence of nitrogen, phosphorous and potassium on asparagus transplant quality. HortSci. 19:565-566.

Alan, R. 1989. The effect of nitrogen nutrition on growth, chemical composition and response of cucumbers (*Cucumis sativus* L.) to nitrogen forms in solution culture. J. Hort. Sci. 64:467-474.

Barker, A.V. and D.N. Maynard. 1972. Cation and nitrate accumulation in pea and cucumber plants as influenced by nitrogen nutrition. J. Amer. Soc. Hort. Sci. 97:27-30.

Barker, A.V., R.J. Volk and W.A. Jackson. 1966a. Root environment acidity as a regulatory factor in ammonium assimilation by the bean plant. Plant Physiol. 41:1193-1199.

Barker, A.V., R.J. Volk and W.A. Jackson. 1966b. Growth and nitrogen distribution patterns in bean plants (*Phaseolus vulgaris* L.) subjected to ammonium nutrition: I. Effects of carbonates and acidity control. Soil Sci. Soc. Amer. Proc. 30:228-232.

Black, C.A. 1968. Soil-Plant Relationships. John Wiley & Sons, Inc. New York, N.Y. p.409.

Bennett, A.C. and F. Adams. 1970a. Concentration of NH_3(aq) required for incipient NH_3 toxicity to seedlings. Soil Sci. Soc. Amer. Proc. 34:259-263.

Bennett, A.C. and F. Adams. 1970b. Calcium deficiency and ammonia toxicity as separate causal factors of $(NH_4)_2HPO_4$ injury to seedlings. Soil Sci. Soc. Amer. Proc. 34:255-259.

Bunt, A.C. 1976. Modern Potting Composts. The Pa. State Univ. Press. Pittsburgh, Pa.

Cox, D.A. and J. Seeley. 1984. Ammonium injury to poinsetta: Effects of NH_4-N:NO_3-N and pH control in solution culture on growth, N absorption, and N utilization. J. Amer. Soc. Hort. Sci. 109:57-62.

Doorenbos, J. and W.O. Pruitt. 1975. Guidelines for Predicting Crop Water Requirements. F.A.O. Irrigation and Drainage Paper 24.

Dufault, R.J. 1985. Relationship among nitrogen, phosphorous, and potassium fertility regimes on celery transplant growth. HortSci. 20:1104-1106.

Dufault, R.J. 1986. Influence of nutritional conditioning on muskmelon transplant quality and yield. J. Amer. Soc. Hort. Sci. 111:698-703.

Dufault, R.J. 1987. Use of slow-release nitrogen and phosphorous fertilizers in celery transplant production. HortSci. 22:1268-1270.

Elamin, O.M. and G.E. Wilcox. 1986a. Manganese toxicity development in muskmelons as influenced by nitrogen form. J. Amer. Soc. Hort. Sci. 111:323-327.

Elamin, O.M. and G.E. Wilcox. 1986b. Nitrogen form ratio influence on muskmelon growth, composition and manganese toxicity. J. Amer. Soc. Hort. Sci. 111:320-322.

Elliott, G.C. 1986. Urea hydrolysis in potting media. J. Amer. Soc. Hort. Sci. 111:862-866.

Fawzy, H., R. Overstreet and L. Jacobson. 1953. The influence of hydrogen ion concentration on cation absorption by barley roots. Plant Physiol. 29:234-237.

Fenn L.B. 1975. Ammonia volatilization from surface applications of ammonium compounds on calcareous soils: III. Effects of mixing low and high loss ammonium compounds. Soil Sci. Soc. Amer. Proc. 39:366-368.

Fenn, L.B. and D.E. Kissel. 1973. Ammonia volatilization from surface applications of ammonium compounds on calcareous soils: I. General theory. Soil Sci. Soc. Amer. Proc. 37:855-859.

Fenn, L.B. and D.E. Kissel. 1974. Ammonia volatilization from surface applications of ammonium compounds on calcareous soils: II. Effect of temperature and rate of ammonium nitrogen application. Soil Sci. Soc. Amer. Proc. 38:606-610.

Fenn, L.B. and D.E. Kissel. 1976. The influence of cation exchange capacity and depth of incorporation on ammonia volatilization from ammonium compounds applied to calcareous soils. Soil Sci. Soc. Amer. Proc. 40:394-398.

Fenn, L.B. and J.E. Matocha. 1981. Ammonia losses from surface applied urea and ammonium fertilizers as influenced by rate of soluble calcium. Soil Sci. Soc. Amer. Proc. 45:883-886.

Fenn, L.B. and R.M. Taylor. 1981. Ammonia losses from surface applied nitrogen fertilizer as controlled by soluble calcium and magnesium: general theory. Soil Sci. Soc. Amer. Proc. 45:777-781.

Fenn, L.B., R.M. Taylor and G.L. Horst. 1987. *Phaseolus vulgaris* growth in an ammonium based nutrient solution with variable calcium. Agron. J. 79:89-91.

Gaines, T.P and G.A. Michell. 1979. Chemical methods for soil and plant analysis. Univ. Ga. Coastal Plain Exp. Sta. Agron. Handbook No 1.

Haber, E.S. 1941. Direct seeding of tomatoes vs. southern-grown plants. J. Amer. Soc. Hort. Sci. 38:515-516

Hoagland, D.R. and D.I. Arnon. 1950. The water-culture method for growing plants without soil. Calif. Agr. Expt. Sta. Cir. 347.

Hons, F.M. and K.D. Aljoe. 1985. Effects of applied calcium on growth and ammonium utilization by corn. Comm. Soil Sci. Plant Anal. 16:349-360.

Horst, G.L., L.B. Fenn and N.B. Dunning. 1985. Bermudagrass turf responses to nitrogen sources. J. Amer. Soc. Hort. Sci. 110:759-761.

Ismunadji, M. and W. Dijkshoorn. 1971. Nitrogen nutrition of rice plants measured by growth and nutrient content in pot experiments. I. Ionic balance and selective uptake. Neth. J. Agric. Sci. 19:223-236.

Jaworski, C.A. and R.E. Webb. 1966. Influence of nutrition, clipping and storage of tomato transplants on survival and yield. Proc. Fla. State Hort. Soc. 79:216-221.

Jaworski, C.A., R.E. Webb and J.J. Morton. 1966. Effects of storage and nutrition on tomato transplant quality, survival and yield. Hort. Res. 7:90-96.

Kahn, B.A. and J.E. Motes. 1988. Comparison of fluid drilling with conventional planting methods for stand establishment and yield of spring and fall broccoli crops. J. Amer. Soc. Hort. Sci. 113:670-674.

Kahn, B.A. and J.E. Motes. 1989. Comparison of fluid drilling with conventional planting methods for stand establishment and yield of spring and fall cauliflower crops. J. Amer. Soc. Hort. Sci. 114:200-204.

Kirkby, E.A. 1967. A note on the utilization of nitrate, urea, and ammonium nitrogen by *Chenopodium album*. Z. Pflanzenernaehr. Bodenkd. 117:204-209. (English summary.)

Kirkby, E.A. 1968. Influence of ammonium and nitrate nutrition on the cation-anion balance and nitrogen and carbohydrate metabolism of white mustard plants grown in dilute nutrient solutions. Soil Sci. 105:133-141.

Kirkby, E.A. and A. H. Knight. 1977. Influence of the level of nitrate nutrition on ion uptake and assimilation, organic acid accumulation, and cation-anion balance in whole tomato plants. Plant Physiol. 60:349-353.

Kirkby, E.A. and K. Mengel. 1967. Ionic balance in different tissues of the tomato plant in relation to nitrate, urea, or ammonium nutrition. Plant Physiol. 42:6-14.

Kirkby, E.A. and M.J. Armstrong. 1980. Nitrate uptake by roots as regulated by nitrate assimilation in the shoot of castor oil plants. Plant Physiol. 65:286-290.

Knavel, D.E. 1965. Influence of container, container size and spacing on growth of transplants and yields of tomato. Proc. Amer. Soc. Hort. Sci. 86:582-586.

Knavel, D.E. 1977. The influences of nitrogen on pepper transplant growth and yielding potential of plants grown with different levels of nitrogen. J. Amer. Soc. Hort. Sci. 102:533-535.

Kratky, B.A. and H.Y. Mishima 1981. Lettuce seedling and yield response to preplant and foliar fertilization during transplant production. J. Amer. Soc. Hort. Sci. 106:3-7.

Liptay, A., E.F. Bolton and V.A. Dirks. 1982. A comparison of field seeded and transplanted tomatoes grown on a clay soil. Can. J. Plant Sci. 62:483-487.

Lockman, R.B. 1980. Review of soil and plant tissue preparation procedures. J. Assoc. Off. Anal. Chem. 63:766-769.

Long, D.G. and D.J. Cantcliffe. 1975. Response of fresh market tomatoes to method of seeding or transplanting. Proc. Fla. State Hort. Soc. 88:211-213.

Lorenz, O.A. and D. N. Maynard. 1980. Knott's Handbook for Vegetable Growers. John Wiley & Sons, New York, N.Y. p. 129.

Maas, E. V. 1986. Salt tolerance of plants. Applied Agr. Res. 1:12-26

Mascarenhas, J.P. and L. Machlis. 1964. Chemotropic response of the pollen of *Antirrhium majus* to calcium. Plant Physiol. 39:70-77.

Magalhaes, J.R. and G.E. Wilcox. 1983. Tomato growth and mineral composition as influenced by nitrogen form and light intensity. J. Plant Nutr. 6:847-862.

Magalhaes, J.R. and G.E. Wilcox. 1983. Tomato growth and nutrient uptake patterns as influenced by nitrogen form and light intensity. J. Plant Nutr. 6:941-956.

Marcus-Wyner, L. 1983. Influence of ambient acidity on the absorption of NO_3^- and NH_4^+ by tomato plants. J. Plant Nutr. 6:657-666.

Marinos, N.G. 1962. Studies on submicroscopic aspects of mineral deficiencies. I. Calcium deficiency in the shoot apex of barley. Am. J. Botany 49:834-41.

Marschner, H. 1986. Mineral Nutrition of Higher Plants. Academic Press, New York, N.Y. p.210-211,524.

Marschner, H., R. Handley and R. Overstreet. 1966. Potassium loss and changes in the fine structure of corn root tips induced by H-ion. Plant Physiol. 41:1725-1735.

Marsh, D.A. and K.B. Paul. 1988. Influence of container type and cell size on cabbage transplant development and field performance. HortSci. 23:310-311.

Maynard, D.N. and A.V. Barker. 1969. Studies on the tolerance of plants to ammonium nutrition. J. Amer. Soc. Hort. Sci. 94:235-239.

Mengel, K. and E.A. Kirkby. 1987. Principles of Plant Nutrition. Intenational Potash Institute, Worblaufen-Bern, Switzerland. p.134-135, 141-143.

Mengel, K., P. Robin and Louis Salsac. 1983. Nitrate reductase activity in shoots and roots of maize seedlings as affected by the form of nitrogen nutrition and the pH of the nutrient solution. Plant Physiol. 71:618-622.

Morris, H.D. and J. Giddens. 1963. Response of several crops to ammonium and nitrate forms of nitrogen as influenced by soil fumigation and liming. Agron. J. 55:372-374.

Munn, D.A. and W.A. Jackson. 1978. Nitrate and ammonium uptake by rooted cuttings of sweet potato. Agron. J. 70:312-316.

Murtadha, H.M., J.W. Maranville and R.B. Clark. 1988. Calcium deficiency in sorghum grown in controlled environments in relation to nitrate/ammonium ratio and nitrogen source. Agron. J. 80:125-130.

Neimiera, A.X. and R.D. Wright. 1986. Effect of liming rate on nitrification in a pine bark medium. J. Amer. Soc. Hort. Sci. 111:713-715.

Olson, S.M. 1989. Watermelon transplant cell sizes and transplant age. Vegetarian 89-1:3-4.

Overman, A.J. and J.P. Jones. 1975. Effect of Furadan on yield and expression of Fusarium Wilt in tomato as bareroot and containerized transplants. Proc. Fla. State Hort. Soc. 88:214-217.

Peet, M.M., C.D. Raper, Jr., L.C. Tolley, and W.P. Robarge. 1985. Tomato responses to ammonium and nitrate nutrition under controlled root-zone pH. J. Plant Nutr. 8:787-798.

Peterson, J.C. 1982. Effects of pH upon nutrient availability in a commercial soilless root medium utilized for floral crop production. Ohio Agr. Res. Dev. Ctr vol. 268.

Pierpont, R.A. and P.L. Minotti. 1977. Effects of calcium carbonate on ammonium assimilation by tomato seedlings. J. Amer. Soc. Hort. Sci. 102:20-23.

Pill, W.G. and V.N. Lambeth. 1977. Effects of NH_4 and NO_3 nutrition with and without pH adjustment on tomato growth, ion composition, and water relations. J. Amer. Soc. Hort. Sci. 102:78-81.

Precheur, R.J. and D.N. Maynard. 1983. Growth of asparagus transplants as influenced by nitrogen form and lime. J. Amer. Soc. Hort. Sci. 108:169-172.

Rogers, H.T. 1983. Mechanical transplanting system begins commercial operation. Amer. Veg. Grower 31(11):26,28-30.

Schultheis, J.R. and D.J. Cantcliffe. 1988. Planting methods to improve stand establishment, uniformity, and earliness to flower in bell pepper. J. Amer. Soc. Hort. Sci. 113:331-335.

Smith, C.N. and M.N. Miller. 1979. Economic characteristics of the containerized vegetable transplant industry in Florida. Proc. Fla. State Hort. Soc. 92:122-123.

Taylor, R.M., L.B. Fenn and G.L. Horst. 1985. The influence of calcium on growth of selected vegetable species in the presence of ammonium nitrogen. J. Plant Nutr. 8:1013-1023.

Tremblay, N. and A. Gosselin. 1989a. Growth and nutrient status of celery seedlings in response to nitrogen fertilization and NO_3:NH_4 ratio. HortSci. 24:284-288.

Tremblay, N. and A. Gosselin. 1989b. Growth, nutrient status, and yield of celery seedlings in response to urea fertilization. HortSci. 24:288-291.

Tremblay, N. and M. Senecal. 1988. Nitrogen and potassium in nutrient solution influence seedling growth of four vegetable species. HortSci. 23:1018-1020.

Tremblay, N., S. Yelle and A. Gosselin. 1987. Effects of CO_2 enrichment, nitrogen and phosphorous fertilization on growth and yield of celery transplants. HortSci. 22:875-876.

Viets, F.G. Jr. 1944. Calcium and other polyvalent cations as accelerators of ion accumulation by excised barley roots. Plant Physiol. 19:466-480.

Warnke, D.D. 1986. Analyzing greenhouse growth media by the saturation extraction method. HortSci. 21:223-225.

Weston, L.A. 1988. Effect of flat cell size, transplant age, and production site on growth and yield of pepper transplants. HortSci. 23:709-711.

Weston, L.A. and B.H. Zandstra. 1983. Bigger transplants mean larger early yields. Amer. Veg. Grower 31(12):24,26,28.

Weston, L.A. and B.H. Zandstra. 1986. Effect of container size and location of production on growth and yield of tomato transplants. J. Amer. Soc. Hort. Sci. 111:498-501.

Weston, L.A. and B.H. Zandstra. 1989. Transplant age and N and P nutrition effects on growth and yield of tomatoes. HortSci. 24:88-90.

Widders, I.E. 1989. Pretransplant treatments of N and P influence growth and elemental accumulation in tomato seedlings. J. Amer. Soc. Hort. Sci. 114:416-420.

Wurr, C.E., E.F. Cox and J.R. Fellows. 1986. The influence of transplant age and nutrient feeding regime on cauliflower growth and maturity. J. Hort. Sci. 61:503-508.