The Influence of Calcium on the Growth, Yield, Quality, and Chemical Composition of Watermelons, *Citrullus vulgaris* Schrad.

By

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INTRODUCTION

The watermelon is one of the most extensively grown vegetables in the United States, yet little is known about the nutrition of this plant. Florida alone produced 95,000 acres of watermelons during the 1957 and the 1958 seasons, which comprised 31 per cent of the southern acreage or 21 per cent of the acreage of the United States (80). Relatively few basic nutrient experiments have been conducted with watermelons, mainly because the extensive type of vine growth limits the feasibility of greenhouse culture techniques. However, extensive experimentation has been conducted in the field on the rates, sources, and methods of application of the major fertilizer elements.

In the South watermelons are planted on light sandy soils, which often have inherently low calcium supplies and pH. Watermelons have generally been considered to tolerate relatively acid conditions, and thus the liming of watermelon fields is not normally a recommended practice. However, from a literature review, it is obvious that very little research has been conducted on the effects of differential calcium levels and soil pH on the yield and quality of watermelons.

The objective of this study was to evaluate the effects of the calcium supply on growth responses; yield;

quality; sex expression and fruit set; and the concentrations of calcium, potassium, and magnesium in the tissues of the Charleston Gray variety of watermelon. The study was conducted in two parts: (1) a greenhouse phase involving eight calcium levels in nutrient cultures and (2) a field phase designed to study three levels of calcium in combination with three levels of nitrogen.

The results of this study may be beneficial in explaining the occurrence of certain physiological disorders and poor yields often obtained from watermelon fields receiving apparently adequate fertilizer. It also emphasizes the need for additional research on the nutrition of the watermelon.

REVIEW OF LITERATURE

Mineral Nutrition of Cucurbits

Effects on yield

The extent to which the major nutrient elements affect the yield of watermelons (*Citrullus vulgaris* Schrad.) is variable, depending upon the element, the environment, and the chemical properties of the soil. Hartwell and Damon (34) reported in 1914 that the best yields of watermelons were obtained on plots made very acid by the application of sulfate of ammonia. Examination of their data indicated that liming had no effect on yield. Hartman and Gaylord (33) reported no significant difference in yield or average weight of watermelons grown on Princeton or Elk fine sand ranging in pH from 4.7 to 7.5. However, there was a trend toward greater yields at the higher pH levels. The pH range was obtained by the application of up to 1,000 pounds of elemental sulfur or up to 9,000 pounds of limestone.

Hall, Nettles, and Dennison (28) found no significant differences in yields in a factorial experiment on Arredonda fine sand containing three levels of calcium (0, 80, and 160 pounds per acre supplied as calcium sulfate in the row) and three levels of magnesium (0, 20, and 40 pounds per acre of magnesium oxide applied in the row). Hall, Nettles, and Dennison (29) in later work were unable to show benefits from

the application of gypsum alone in the row. Jamison and Nettles (40) reported that the application of soluble magnesium with all inorganic nitrogen increased the yields of watermelons.

Eisenmenger and Kucinski (20) observed that calcium hastened maturity of both watermelons and cantaloupes by nearly two weeks over no-lime treatments. Apparently the application of lime augments cantaloupe production on soils with low pH. Carolus and Lorenz (14) concluded that the application of lime to light acid soils promotes early maturity and increases yields of muskmelons. Hartman and Gaylord (32) obtained an increase of cantaloupes from 160 bushels to 350 bushels per acre by increasing the soil pH from 4.7 to 7.2 with limestone. Other cucurbits including cucumbers, squash, and pumpkins apparently yield more when grown on soils moderately supplied with calcium and within the pH range of 5.5 to 7.0 (42, 83).

Considerable research relative to the effect of N-P-K fertilizers on yields has been reported. Hall, Nettles, and Dennison (29) concluded after five years of experimentation at several locations in Florida that 60 pounds per acre each of potassium and nitrogen were ample to give maximum yields in seasons with reasonably favorable rainfall. This is, in general, supported by data presented by Nettles and Halsey(53) in 1958. Bradley and Fleming (10) observed similar results on Norfolk fine sand in Arkansas. They stated that 60 pounds

each of nitrogen, potassium, and phosphorus was adequate for good yields. In a somewhat drier area in Texas, Smith and Mohr (70) concluded after four years tests on Hockley fine sand that 20 pounds of nitrogen, 40 pounds of phosphorus, and 40 pounds of potassium produced maximum yields. However, Patterson and Smith (57) reported significant increases in yield from up to 200 pounds of potassium on Hockley fine sand in Texas. According to Brantley (11) nitrogen increased early marketable, total marketable, and total yield of watermelons in Indiana on Princeton fine sand in a season of heavy rainfall but not in a moderately dry season. Potassium did not affect yields in either season.

Effects on quality

It has long been known that the quality of watermelons, especially the soluble solids, is influenced by both heredity and environmental factors (60, 85). The effects of these factors have been established; however, research relative to the true influence of different nutrient elements is less apparent. Hartman and Gaylord (33) reported that the application of up to 9,000 pounds of ground limestone did not significantly increase the percentage of sucrose. Hall, Nettles, and Dennison (28, 29) observed that neither calcium sulfate nor magnesium oxide had any significant effect on the percentage of soluble solids, hollow-heart, or white-heart. However, Eisenmenger and Kucinski (20) stated that cantaloupes and watermelons grown on land treated with calcium were considerably higher

in sugar content, although no data were presented. Mazaeva (47) observed that magnesium increased the sugar content of watermelons grown in pots of light sodpodzolized soil. According to Morazov (52) the application of sodium chloride or sodium sulfate to the soil decreased the monosaccharides and the total sugar content of both watermelons and muskmelons.

Work by Brantley (11) and by Kimbrough (41) indicated that up to 250 pounds of elemental nitrogen had no significant effect on the percentage of soluble solids in watermelons. Bradley and Fleming (10) reported a significant increase in soluble solids as a result of an interaction between nitrogen and phosphorus and an interaction between phosphorus and potassium, but other quality measurements such as hollow-heart, white-heart, and rind thickness were not affected by any fertilizer treatment. When yields were not affected by fertilizer treatments, soluble solids were not affected; therefore, they concluded that providing adequate fertilizer assures good quality. In contrast to this, Hall, Nettles, and Dennison (28) concluded after several experiments that neither potassium nor nitrogen had any significant effect on soluble solids, white-heart, or hollow-heart. Brantley (11) found no effect from differential levels of potassium on the quality of watermelons or cantaloupes. Woodard (85) demonstrated that the occurrence of white-heart of watermelons was associated with heredity and not with nitrogen source.

Effects on sex expression and fruit set

The nature of the effect, if any, of the cations on sex expression and fruit set has not been clearly defined. Hasler and Maurizio (35) reported that insufficient amounts of potassium as well as nitrogen and phosphorus resulted in both poor flowering and seed set in winter rape (Brassica napus). According to Mazaeva (47), magnesium acts on reproductive organs, tending to increase female flowers in many crops. Stark and Haut (72) found that flower production in cantaloupes was inhibited when the potassium level was dropped to 0.25 milliequivalents per liter (9.15 ppm). There was a positive response of fruit set to high levels of calcium: 10 and 15 milliequivalents per liter (200, 300 ppm). A concentration of 0.2 milliequivalents per liter (2.4 ppm) of magnesium was inadequate for normal fruit set.

After comprehensive literature reviews on the physiological aspects of sex expression, Loehwing (45) and Heslop (36) concluded that, with the exception of carbohydrates and nitrogen, general nutrition is not a major factor in sex expression in monoecious and dioecious species. Furthermore, Loehwing (45) stated that highly localized compositional differences are much more significant than general composition, not only in relation to flowering but also in determining sexes in various floral parts.

There are numerous reports in the literature to the effect that increased nitrogen concentrations in the substrate

enhanced female sex expression in plants. Thompson (76) working with spinach, Tibeau (77) with hemp, and Sabinin (64) with corn observed that high levels of nitrogen stimulated the production of pistillate flowers while low nitrogen levels favored staminate flower formation. Similar observations have been reported by Tiedjens (78) and Dearborn (18) for cucumbers (Cucumis sativus), by Hall (30) for gherkins (Cucumis anguria), by Sabinin (64) and Minina (51) for cucumbers and watermelons, and by Brantley (11) for cantaloupes and watermelons.

The influence of nitrogen on fruit set is similar to its effect on yields. In general, increasing increments of nitrogen up to a critical maximum enhances fruit set while additional increments tend to decrease fruit set (11, 17). Work by Jamison and Nettles (40) and by Cunningham (17) indicates that late side-dressing with nitrogen delays and decreases fruit set.

Effects on blossom-end rot

The precise cause of watermelon blossom-end rot has not been determined. Blossom-end rot first appears as a water-soaked area at the blossom-end, later turning brown, and often invaded by saprophytic and parasitic fungi (56, 73). The disease has been attributed to many factors--including pathogenic organisms, disarrangement of internal nutrition, improper moisture supply, poor pollination and/or fertilization. Pathologists (56, 75) have shown that a large number

of both saprophytic and parasitic organisms have been associated with blossom-end rot. Parris (56) reported that Pythium debaryanum and P. aphanidermatum started the infection. Taubenhaus (75) in 1921 concluded that Diplodia tubericola caused blossom-end rot of watermelons. However, Blodgett (8) was unable to control the disease by use of fungicides.

Stuckey (73) postulated in 1924 that blossom-end rot is probably a physiological disturbance brought on by rapid changes in soil moisture as the young fruit start to grow. He reported it is of little consequence in low-lying loamy sands where the water table is near the surface. Walker (82) in 1931 noted that blossom-end rot had been observed in connection with pollination work and that defective pollination appeared to be the most important factor in initiating it. He pointed out that considerable decline of the melon occurred before fungi appeared. Nettles and Halsey (53) were unable to associate the incidence of blossom-end rot with fertilizer rates of up to 2,000 pounds of 6-8-8 or with plant spacings of 3, 6, 9, and 12 feet. Everett and Geraldson (22) obtained a lower percentage of melons exhibiting blossom-end rot from plots receiving one-half ton of hydrated lime or gypsum per acre plus two tons of dolomite than from plots receiving dolomite alone.

Geraldson (27) has shown similar blossom-end disorders in tomatoes and peppers may be produced by insufficient calcium in the substrate or by high concentrations of soluble salts. Taylor and Smith (74) reported significant increases

in blossom-end rot of tomatoes as a result of high nitrogen levels.

Brantley (11) associated the occurrence of blossom-end rot of watermelons with high nitrogen levels; however, no data were presented.

Calcium in Plant Nutrition

Role in the soil

Soil scientists have vividly demonstrated that the application of lime affects not only the chemical properties of the soil but also the biological and physical properties as well. The beneficial chemical effects of liming acid soils result from: (1) increased availability of calcium and possibly certain other nutrient elements and (2) pH changes which influence the solubility of other elements, both essential and non-essential.

In work reported by Marshall (46) a considerable part of the absorbed calcium in kaolinitic type clays became active at calcium saturation percentages of 39 to 59 while 70 to 80 per cent calcium saturation was necessary in montmorillonitic type clays. According to Sharples and Foster (66) maximum growth of cantaloupes on Arizona desert soil occurred between 50 to 60 per cent calcium saturation with growth decreasing rapidly on either side of this range. Fried and Peech (25) in several field and greenhouse experiments have demonstrated that increasing the calcium supply with gypsum, in contrast to limestone, failed to increase plant growth of such crops

as barley, alfalfa, and perennial ryegrass.

Many workers have shown that the solubility of aluminum, manganese, iron, boron, copper, and zinc increases with increasing acidity (25, 38, 61, 65, 71, 86). Toxic concentrations of such elements as aluminum, manganese, and iron may develop below pH 5.5; moreover, such elements as manganese, iron, and boron may become deficient above pH 6.5.

The soil biological population is influenced by calcium directly as an essential element for metabolism and indirectly through alterations in the soil reaction (1, 4, 13, 83). Microbiologists have demonstrated that, in general, fungi thrive when the pH is below 6 and bacteria and actinomycetes prefer media above pH 6 (1, 13, 48, 81). This points out the necessity for liming acid soils to obtain maximum benefits from nitrifying bacteria as well as from other biological processes involving principally bacteria.

Baver and Hall (5) and Meyers (49) have shown that calcium ions do not affect the physical properties of organic or inorganic colloids any more than do hydrogen ions. After reviewing the literature on this subject Baver (4) concluded the main effect of lime on the soil physical properties, especially aggregation, resulted indirectly from its effect on the production and decomposition of organic matter.

Role in plants

Calcium enters into several important physiological processes within the plant. One of its most important roles

is the reaction with pectic acids to form calcium pectate, a constituent of the middle lamella of the cell wall (9, 48, 50). Pectic acid is composed of long chains of galacturonic acid residues which possess the 6-membered pyranose ring structure with a carboxyl group on the number five carbon. This carboxyl group is free to combine with available cations such as calcium, potassium, and magnesium thereby forming pectates.

Calcium reacts with certain organic acids, especially oxalic and malic, to form relatively immobile oxalate compounds (6, 9, 79). According to Meyer and Anderson (48) these oxalate compounds occur in the cell vacuoles in large quantities.

Plant physiologists point out that it was once believed that organic acids were toxic; therefore, calcium and other cations were absorbed to precipitate these acids. However, according to Meyer and Anderson (48) and Shear, Crane, and Meyers (68) cell sap must be electrostatically neutral; therefore, if greater absorption of cations than anion occurs the plant cells produce certain organic acids to precipitate the cations.

Nightingale (54) reported that in the absence of calcium some species are unable to absorb nitrates.

It is generally believe that calcium is necessary for the continued growth of meristematic tissue. This is apparent by the symptoms of calcium deficient plants. The leaves of plants grown in media low in calcium, especially the

young leaves, often are distorted, dark green in color, and the margins pointed downward or cupped under (48, 50). In severe cases a deficiency is manifested by cessation of terminal growth and the development of chlorosis and necrotic areas even in the older growth.

Calcium plays another important role in plant growth by its antagnostic effects on the absorption of other ions (21, 44, 48, 50, 56, 79). The antagonism apparently works in at least two ways. First, less toxic ions may depress the uptake or accumulation of more toxic ions. For example, sodium, potassium, or magnesium may be toxic in single-salt solutions; however, this toxic effect is eliminated by the addition of calcium. Second, proteins may become saturated with a single salt thereby changing their normal composition. The addition of other salts tends to balance the protein colloidal system.

Cations in Plant Tissue

Cation accumulation

It has been demonstrated many times that the concentration and type of nutrient elements occurring in plant tissue is dependent upon a number of interrelated environmental conditions as well as the plant species in question. Numerous literature reviews point out that the ratio or balance of the various ions in the substrate has a direct effect on the chemical composition of the tissue (6, 13, 21, 63, 65, 74). In a refinement and extension of nutritional theories proposed

by earlier workers, Shear and co-workers (67, 68, 69) state that plant growth is a function of two nutritional variables, intensity and balance, which are reflected in the composition of leaves when the plants are in the same stage of growth and development. Intensity refers to the total equivalent concentration of all functional nutrient elements in the plant. They pointed out that there is a definite cation: anion ratio within the plant; therefore, an accumulation of one or more cations must be accompanied by an equivalent decrease in one or more cations at any given anion level. Likewise, an accumulation of one or more anions at a given cation level must be accompanied by a decrease in one or more anions. The simultaneous accumulation of both cations and anions, either organic or inorganic, in plant tissue has been observed by many authors (3, 13, 26, 63, 68, 69, 79).

Cooper (16) concluded that the relative rate of absorption and accumulation of nutrients by plants is proportional to the relative activity (energy properties) of the nutrients as measured by such means as standard electrode or ionization potential. This conclusion has been subjected to extensive criticism. Geraldson (27) explained the occurrence of blossom-end rot of tomatoes as a calcium deficiency when the plants were grown in high concentrations of soluble salts on the basis that as the soluble salt concentrations increase, the relative activities (effective concentration) of the divalent salts decrease at a more rapid rate than monovalent salts. Also, the calcium to soil soluble salts ratio (actual

concentration) varies inversely with concentration.

Shear, Crane, and Meyers (69) working with young tung nut trees found that increasing the magnesium or potassium in the substrate generally resulted in increased concentrations in the tissue; however, the total accumulation of potassium+magnesium+calcium was generally decreased. Moreover, increasing calcium in the substrate not only increased the calcium in the tissue but also increased the total accumulation of the three cations. This was explained on the basis that since a large percentage of the absorbed calcium in many species is inactivated by oxalate precipitation and no longer able to affect the entrance of other cations, the increased calcium accumulation would result in an increasod total cation accumulation. Pierre and Bower (59) pointed out that potassium absorption is usually decreased in the presence of high concentrations of other cations such as calcium and magnesium. However, under relatively high levels of potassium, increasing the concentration of other cations, especially calcium, may increase potassium absorption and accumulation in many crops. After a critical literature review Peech and Bradfield (58) concluded that the addition of lime to soils may have no effect, may increase, or decrease the availability of potassium to plants depending upon the degree of initial soil saturation. They indicated that calcium may have little effect on the absorption of the available potassium, at least at the concentrations found in most soils. Meanwhile, Geraldson (26) indicated that the

application of excessive amounts of ammonium, potassium, magnesium, or sodium to sandy soils of Florida limited the uptake of calcium by tomatoes.

Reports on the specific cation nutrition of cucurbits, especially watermelons, are limited. Bradley and Fleming (10) observed that the potassium content of watermelon leaves was influenced primarily by the addition of potassium to the soil. The difference in potassium content of the leaves between treatments grew smaller as the season progressed. The application of 60 pounds of potassium in the row significantly reduced the calcium content of the watermelon leaves early in the season but had no effect toward the end of the season. In one of two seasons potassium applications significantly reduced the magnesium content of the leaves early in the season but had no effect on samples collected toward the end of the growing season.

Sharples and Foster (66) grew cantaloupes in Arizona desert sand cultures with calcium saturation percentages of 2.9, 11.9, 36.2, 63.7, 72.5, and 86.6. They found that extremely high and low saturation percentages tended to restrict potassium uptake while leaf calcium varied directly and magnesium inversely with the calcium saturation percentages. Stark and Haut (72) reported that the calcium content of cantaloupe leaves increased in a geometric proportion to the calcium concentration in the substrate, while potassium and magnesium increased in arithmetic proportions to the concentration of these respective elements in the substrate.

Concentrations of 4 to 5 milliequivalents per liter (200-300 ppm) appeared to produce the best growth. When calcium was supplied at 4, 8, or 16 milliequivalents (80, 160, 220 ppm), Reynolds and Stark (62) obtained maximum top, root, and fruit yields of cucumbers at the lowest calcium level, and growth decreased as the calcium level increased.

Effects of nitrogen on the cation content

It has been established that not only the concentration of nitrogen in the substrate but also the source (nitrate or ammonium) will have a profound effect on the cation content of the tissue (3, 13, 48, 63, 67, 84).

It has been shown repeatedly that increasing the proportion of nitrate to ammonium nitrogen in the substrate increases the production of organic acids, especially oxalic (13). Since oxalic acid precipitates much of the absorbed calcium, plants growing under high nitrate levels may utilize more calcium (3, 13, 48, 63, 67, 68).

Shear and co-workers (67, 68, 69), Geraldson (26), and Burrus (13) pointed out that the activity of the ammonium ion is very similar to the activity of the potassium ion and will greatly affect the uptake of other cations. Shear and Crane (67), by supplying the nitrogen as ammonium in contrast to nitrate, reduced the cation content of tung leaves by the following percentages: potassium--18 per cent, magnesium--25 per cent, and calcium--46 per cent.

Bradley and Fleming (10) indicated that the soil

application of ammonium nitrate had no consistent effect on the potassium, calcium, and magnesium content of watermelon leaves. Sharples and Foster (66) reported that the application of ammonium nitrate in sand cultures of cantaloupes significantly increased the potassium, calcium, and magnesium content of the leaves and decreased the phosphorus content under varying calcium and magnesium ratios.

Distribution of cations in plants

Numerous studies have been conducted on the distribution of cations in plant tissue employing both chemical analyses and radio-isotopes (3, 7, 31, 43, 63). The following generalizations may be drawn: (1) a large part of the calcium is located in the leaves with considerably smaller amounts occurring in the roots, stem, seeds, and meristematic areas, (2) potassium is distributed more uniformly throughout the plant than calcium with relatively large quantities occurring in regions of meristematic division, translocation, and storage, and (3) magnesium is present in somewhat smaller amounts than calcium or potassium with relatively large concentrations occurring in the leaves and in the seeds of some plants.

Hardh (31) showed with radiographs that calcium accumulates in cucumbers in clearly separated pits occurring more frequently in the leaves than in the stems. Wilkins (83) reported that cucurbit vines, namely, pumpkins, preserving citrons, two types of squash, cucumbers, and cantaloupes, contained large amounts of calcium ranging from 5

to 8.5 per cent calcium oxide, while the fruits at no time contained over 0.75 per cent calcium oxide. The vines contained up to 5.9 per cent potassium oxide and the fruit up to 5.4 per cent depending upon the species. The magnesium content of the vines was much less variable, ranging from 0.46 per cent to 1.30 per cent magnesium oxide, and the fruit consistently contained even less magnesium than calcium. Wilkins (83) also found an increase in the percentage of calcium in the cucurbit vines toward maturity, and the calcium content of the fruit decreased slightly toward maturity. The opposite trends were true for both potassium and magnesium.

METHODS AND PROCEDURES

The watermelon industry in North Central Florida was surveyed by making field observations and soil analyses in 30 melon fields during the 1958 growing season. This aided in familiarization with the fertility problems involved in watermelon production.

The literature indicated that certain physiological disorders of watermelons resulted from adverse chemical or physical conditions of the soil. Therefore, profile examinations were made and soil samples were obtained from plots devoted to watermelon fertility experiments as described by Nettles and Halsey (53) in the spring of 1958. Chemical analyses of the soil samples were made to observe any possible correlation between the chemical constituents and the presence of blossom-end rot.

In the spring of 1958 samples of watermelon tissue were obtained from mature field-grown plants to determine the distribution of calcium, potassium, magnesium, and sodium in the various plant parts and the variation of these elements from plant to plant. The samples for analyses were taken from six plants grown under similar environmental conditions and were bearing mature fruits. Samples for analyses from each plant included the following locations: basal leaves, mid-leaves, vine tips, basal stem, mid-stem, and fruit.

Each tissue sample was analyzed for calcium, potassium, magnesium, and sodium on the Beckman model DU flame spectrophotometer by using procedures outlined by Breland (12). In order to evaluate the effect of interfering anions in the watermelon tissue on the calcium determinations, each sample was analyzed for calcium, with and without these ions present. The method of removing the interfering anions from the samples is given under the heading "Chemical Analyses."

Preliminary experiments with nutrient solutions and quartz sand were conducted to determine the feasibility of these techniques for greenhouse culture of watermelons.

In addition to the major study reported below, simultaneous exploratory work was conducted in the greenhouse and field to observe the effects of foliar applications of calcium chloride on watermelons. Plants grown in field soil in greenhouse benches were sprayed with 0.25, 0.10, 0.08, 0.06, and 0.04 molar concentrations of calcium chloride to determine optimum levels for foliar applications. Severe leaf burning occurred at the 0.25 level and slight burning was evident at the 0.10 molar concentration. The 0.04 through 0.08 molar levels appeared satisfactory for treatment. A greenhouse sand culture experiment with 8 replications was established to observe the effects of bi-weekly applications of 0.04 molar calcium chloride spray versus no spray on the watermelon plants. Adequate amounts of a basic nutrient solution containing 16 ppm calcium was supplied to each pot. A field experiment containing three levels of a calcium chloride

foliar spray arranged in a randomized block design was conducted during the 1959 season. The spray levels were no spray, 0.04, and 0.08 molar concentrations of calcium chloride applied every five days.

The major study consisted of two parts--a greenhouse phase and a field phase. The greenhouse phase was organized to study the effects of various calcium levels in nutrient solutions on growth responses; sex expression; fruit set and quality; and the accumulation of calcium, potassium, and magnesium in the various plant parts. The field phase was designed to investigate the effects of three levels of nitrogen and three levels of calcium on growth, yield, quality, and cation composition of the watermelon plant. The Charleston Gray variety of watermelons was used in all experiments.

Greenhouse Phase

A randomized block experiment with four replications was initiated on April 15, 1959, to study the influence of eight progressive levels of calcium on watermelon responses. This test was conducted using a solution culture procedure in which the calcium levels were supplied by the addition of calcium chloride to a basic nutrient solution. Young watermelon seedlings were produced by germinating seeds on wet filter paper. Two of these seedlings constituted an experimental unit when suspended by a wooden support in a four-gallon glazed crock. The solution levels in the crocks were maintained at 13 liters by daily application of deionized

water with a complete change of solution each week. Adequate aeration was supplied to each crock by means of a centrally located pump.

The concentration of calcium in the different treatments is given in Table 1. Since it was necessary to use large volumes of solutions, the concentration is given in both parts per million(ppm) and milliequivalents per liter (m.e./L).

TABLE 1

CALCIUM LEVELS IN GREENHOUSE SOLUTION CULTURES

Greenhouse Treatment Number	Calcium ppm	Calcium m.e./L
1	0	0.0
2	4	0.2
3	8	0.4
4	16	0.8
5	32	1.6
6	64	3.2
7	128	6.4
8	256	12.8

The composition of the basic nutrient solution is shown in Table 2. The iron solution was prepared by dissolving 100 grams of sodium-iron versenol (12 per cent iron) per 2.5 liters of deionized water, and 1/10 millileter of this solution was used per liter of nutrient solution. The other elements were prepared by the procedure outlined by Hoagland and Arnon (37).

The pH of all newly prepared solutions, regardless of calcium level, was approximately 5.2. At the end of the

seven-day period the pH of the solutions ranged from 6.0 to 6.8 depending on the size of the vines; therefore, no pH adjustments were necessary.

TABLE 2

THE COMPOSITION OF THE BASIC NUTRIENT SOLUTION FOR GREENHOUSE EXPERIMENT

Element	Source	Concentration (ppm)
Nitrogen	KNO_3	70
Phosphorus	KH_2PO_4	32
Potassium	KNO_3, KH_2PO_4	234
Magnesium	$MgSO_4$	48
Boron	H_3BO_3	0.5
Manganese	$MnCl_2$	0.5
Iron	NaFeEDTA	0.5
Molybdium	H_2MoO_4	0.05
Zinc	$ZnSO_4$	0.05
Copper	$CuSO_4$	0.02

Fifteen days after transplanting one plant per pot was harvested and dry weights were obtained as an early growth measurement. All flowers were hand-pollinated in the early morning and the number of both pistillate and staminate flowers produced per experimental unit was recorded daily. All fruits developed blossom-end rot in this experiment and were harvested individually and oven-dried as soon as the rot was obvious. Continuous records on growth responses were maintained throughout the experiments.

The experiment ended June 15 and the following obtained from each experimental unit: leaf, tip, and root samples and dry weight of frui , roots, and vines. The leaf

samples were composed of eight mature leaves per plant. The tip samples were composed of eight actively growing lateral tips two inches in length. The root samples were composed of the entire root system from each experimental unit. All tissue samples were washed twice in deionized water before drying, with each washing lasting approximately 10 seconds.

Field Phase

Description of soil type and soil test

The area used in this experiment was located on the Horticulture Unit of the University of Florida near Gainesville, Florida. The soil was classified as Kanapaha fine sand (2). The surface layer is medium gray, loose, acid, fine sand and underlain by yellowish white, loose, strongly acid, fine sand. This is underlain by a phosphatic lime material. Kanapaha fine sand is relatively low in organic matter, moderately to imperfectly drained, level to slightly undulating with poor physical structure, and often located near ponds or lakes.

Two soil samples were taken from each plot on April 1. One sample was taken in the bed and consisted of 5 cores taken at four locations across the bed. The other sample was taken from the calcium-treated area on each side of the bed and consisted of 20 cores. The samples were analyzed for available CaO, MgO, K_2O, P_2O_5, NO_3, and pH by the University of Florida Soil Testing Laboratory.

Field methods

An experiment containing three levels of calcium and three levels of nitrogen arranged factorially in a balanced-lattice design was conducted in the spring of 1959 on Kanapaha fine sand. The calcium levels tested were at the rate of 0, 500, and 1,000 pounds of hydrated lime ($Ca(OH)_2$)per acre. The nitrogen levels tested were at the rate of 60, 120, and 180 pounds per acre applied as ammonium nitrate. The individual plot size was 15 by 80 feet with each calcium treatment being broadcast in a 10-foot band throughout the length of each plot on February 20. This left an untreated area of 2.5 feet on both sides of each plot. An untreated area of 10 feet was left between the ends of the plots to serve as a buffer area.

A single bed approximately 8 inches high and 18 inches wide was prepared in the center of each plot. One half of the total nitrogen and a uniform application of 80 pounds of P_2O_5 and 80 pounds of K_2O per acre was placed in two bands in the row on March 12. The remaining half of the nitrogen was plowed into both sides of the bed May 1, when the vines began to develop.

Sixteen hills of watermelons were planted per plot on March 26, and an excellent stand of plants was obtained. Two weeks after emergence the melons were thinned to two plants per hill. The methods used for cultivation, insect, and disease control were in accordance with recommended practices for the North Central Florida area. The melons were

harvested four times (June 17, 22, 26, and July 3) and the following data obtained on all fruits from each plot: number and weight of early marketable yield; number and weight of total marketable yield; mean thickness of rind of each fruit measured at the top center and bottom center; thickness of rind at blossom-end; percentage soluble solids; percentage blossom-end rot; and cutting quality including data on hollow-heart, white-heart, and other abnormalities. The first three harvests were considered to represent the early yield, and all normally shaped melons over 16 pounds in weight were considered as U. S. number 1. Soluble solids were determined on a Carl Zeiss water-cooled refractometer.

The amount of rainfall recorded in the immediate area of the experiment is presented in Table 3.

TABLE 3

TOTAL BI-MONTHLY RAINFALL RECORDED AT THE HORTICULTURE UNIT MARCH 1 TO JUNE 30, 1959

Date	Inches of rain
March 1-14	3.22
March 15-31	8.01
April 1-14	1.73
April 15-30	2.07
May 1-14	0.70
May 15-31	5.93
June 1-14	1.53
June 15-30	2.32
Total	25.51

Since there was an extremely large amount of rainfall following the first fertilizer application early in March, an attempt was made to estimate the fertilizer loss from the upper 8 inches of soil as a result of more than 8 inches of rain. An extra row was fertilized on April 1 at the rate of 90 pounds of nitrogen and 80 pounds each of P_2O_5 and K_2O per acre. This was located beside a row which received the same fertilizer treatments before the rains. Six soil samples were taken on April 1 from each of these two rows, as well as from a third row receiving no fertilizer, and analyzed for CaO, MgO, P_2O_5, K_2O, NO_3, and pH.

Tissue samples

On May 1, just prior to the second application of nitrogen, every other hill of the young watermelon plants from each plot was harvested and pooled into one composite sample, and the oven-dry weight was obtained. Prior to drying, tip and leaf samples were taken from each composite sample for chemical analyses. Additional leaf and tip samples were obtained from each plot for chemical analyses one week prior to the first harvest of fruit. At this time the plants were in a vigorous state of growth with little apparent disease or insect damage. The leaf sample from each plot was composed of the first two normal leaves, including the petiole, from each plant. The tip samples consisted of four actively growing vine tips from each plant located in each plot. These tips were 2 inches in length and included

very young leaves and a small end portion of the stem. The leaf and tip samples were oven-dried and stored.

The fruits exhibiting blossom-end rot were removed from the vines at the beginning of the harvest period and a composite fruit sample was obtained from six representative fruits from each plot. Three cores, one inch in diameter, were taken through the center of each fruit by use of a soil sampling tube. These cores were then cut into sections one-half inch long and mixed thoroughly; after which, four 90-gram subsamples were weighed from each plot sample. Two of these were frozen at 0° F. for subsequent chemical analyses. The remaining two samples were used for moisture determinations. Similar subsamples for analyses were obtained from the first six normal fruits harvested from each plot.

Chemical Analyses

All tissue samples were dried in a forced air oven for 48 hours at 70°C. After which all leaf, tip, root, and greenhouse fruit samples were ground in a Wiley Mill and stored in one-pound paper bags. One-gram samples of the oven dried tissue were ashed in a muffle furnace at 450°C., dissolved in 15 milliliters (ml.) of 40 per cent hydrochloric acid (HCl), evaporated to dryness, reheated in the muffle furnace at 450°C. for 30 minutes to 3 hours (depending on the amount of black carbon present), dissolved in 1 ml. of

concentrated HCl, evaporated to dryness, and diluted to volume with 0.1 normal HCl.

Fruit samples collected from the field experiment were dried in 250 ml. beakers and ashed in the same manner as the other tissue samples. The entire sample was ashed and calculations were based on the oven dry weight of the sample less beaker weight.

All samples were analyzed for potassium, calcium, and magnesium on a Beckman model DU flame spectrophotometer following the procedure outlined by Breland (12). Before the calcium and magnesium determinations were made, 10 ml. aliquots of each sample were passed through a six-inch column of anion exchange resin (Dowex 1-8X, 50-100 mesh, medium porosity) to remove interfering anions (39).

Statistical Methods

The data were analyzed by the analysis of variance methods described by Cochran and Cox (15). Probability statements of comparisons among means are based on the Duncan Multiple Range Test (19). Count data were transformed by the square root method and percentage data by the arcsin transformation before statistical analyses were made. All growth response data presented from the field experiment were derived from the adjusted treatment totals of the balanced-lattice design.

RESULTS OF EXPERIMENTS

Examination of soil test data obtained from the field survey indicated that, in general, low yields and a high percentage of blossom-end rot were associated with low nutrient levels, especially calcium and magnesium.

Data obtained from fruit counts and soil studies from fertility experiments described by Nettles and Halsey (53) revealed that significant differences in the percentage of blossom-end rot could not be attributed to fertility treatments of differential levels of available soil nutrients. In two of the three fertility experiments significant differences in the percentage of blossom-end rot did result from replications. Further examination of the data showed that in one of the experiments the percentage of blossom-end rot decreased significantly from the higher to the lower elevation of the field. Examination of the soil profile revealed that the soil in the upper portion of the field was slightly compact for the first 18 inches then was very loose to a depth of over 6 feet. The compactness of this upper portion of the soil decreased from the higher to the lower elevation of the field. From field examination of the profile, at the lower elevation the soil appeared to have a more desirable texture, more organic matter, and was darker in color. Examination of the data from a second experiment

indicated that replications located on a soil with a loose porous profile produced significantly more blossom-end rot than replications located on a soil with a hard-pan 12 to 24 inches below the surface. In the third experiment no significant differences resulted from replications. Examination of this soil profile revealed a uniform, relatively loose profile with no observable textural or structural differences throughout the experimental area.

The distribution of calcium, potassium, magnesium, and sodium in the various parts of mature watermelon plants grown under similar environmental conditions during the spring of 1958 is shown in Table 4. By passing the sample solutions through an anion exchange resin, calcium determination values were, in general, from 20 to 35 per cent greater than those obtained from samples in which this step was eliminated. The greatest concentration of calcium, irrespective of analytical methods, and of magnesium occurred in the older leaves with the percentages decreasing at the various sampling locations in the following order: basal leaves, mid-leaves, tips, stems, and fruits.

Statistical comparisons of the percentage of potassium, calcium, and magnesium present at different locations in the plants are shown in Table 5. The concentration of potassium was significantly less in the leaves than in other plant parts with the largest concentrations occurring in the stems and fruits. There was no significant difference between the calcium content of the stem sampling positions; however, the

TABLE 4

THE PERCENTAGE OF CALCIUM, POTASSIUM, MAGNESIUM, AND SODIUM AT SIX LOCATIONS WITHIN MATURE WATERMELON PLANTS, 1958[a]

Locations	Ca[b]	Ca[c]	K	Mg	Na
Basal leaves	5.34	4.02	1.87	1.18	0.040
Mid-leaves	4.21	3.03	1.78	1.00	0.032
Tips	2.92	1.95	2.35	0.79	0.034
Basal stems	0.65	0.47	2.40	0.66	0.024
Mid-stems	0.61	0.44	2.83	0.67	0.038
Mature fruits	0.21	0.18	2.58	0.29	0.032

[a]Each percentage is average of six determinations on the oven-dry weight basis.

[b]Samples passed through an anion exchange column.

[c]Samples not passed through an anion exchange column.

calcium percentages of all other sampling locations within the plant were significantly different from each other. This was true for the samples passed through the anion exchange columns as well as for those not passed through the columns. The magnesium content of the sampling positions in the stems did not differ significantly; however, the magnesium content of all other sampling locations within the plants differed significantly.

TABLE 5

TEST OF SIGNIFICANCE FOR THE PERCENTAGE OF POTASSIUM, CALCIUM, AND MAGNESIUM AT SIX LOCATIONS WITHIN MATURE WATERMELON PLANTS[a]

Potassium percentage						
Locations	Mid-leaves	Basal leaves	Tips	Basal stem	Mature fruits	Mid-stem

Calcium[b] and magnesium					
Locations	Mature fruit	Mid-stem	Basal stems	Tips	Mid-leaves	Basal leaves

[a]Any two locations underlined by the same line were not significantly different. Any two locations not underlined by the same line were significantly different at the 5 per cent level (See Table 33 for A.O.V.).

[b]Significance table for calcium analyses both with and without anion exchange resins.

There was far greater variation in the sodium content from one plant to another than from sampling locations within any one plant; consequently, sodium analyses were eliminated in later work.

Results from exploratory foliar spray experiments were inconclusive. Vine growth in the greenhouse was not affected by foliar application of 0.04 molar calcium chloride. When each plant was allowed to set one fruit, all eight of the vines receiving no spray produced fruits with obvious blossom-end rot. Two of the eight plants receiving bi-weekly sprays of 0.04 molar calcium chloride produced fruit with obvious blossom-end rot. The remaining six plants produced fruits with no external symptoms of rot; however, examination of the internal tissues revealed that three of the fruits had a semi-dehydrated, whitish, leathery type of tissue at the blossom-end. There were no significant differences in vine growth, yield, or percentage of blossom-end rot obtained from the foliar spray treatments of the field experiment. However, it should be pointed out that the plants in this experiment were injured considerably by excessive rains.

Greenhouse Phase

Growth responses

All plants grown in solutions void of calcium became stunted, chlorotic and all but one plant died within two

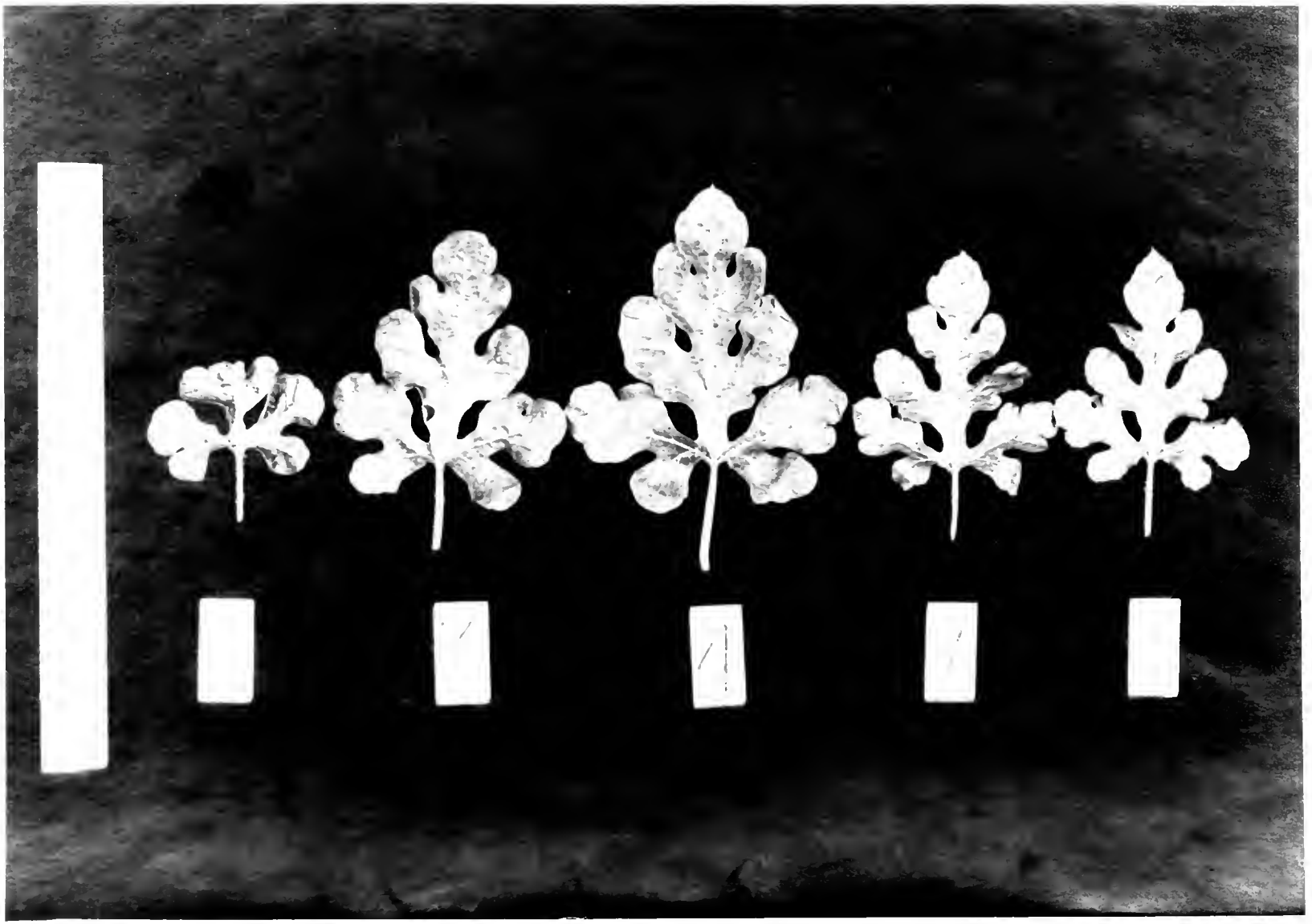
weeks after transplanting. One plant per experimental unit was harvested from the seven remaining treatments 18 days after transplanting. The analysis of variance of the data revealed no significant differences in the dry weights of roots or tops.

Slight calcium deficiency symptoms became apparent on newly developing leaves of plants grown in 4 ppm calcium (treatment 2) on May 8. By May 15, these deficiency symptoms were very pronounced in both the tops and the roots, and the symptoms became increasingly more severe as the season progressed. The leaves of deficient plants were dark green in color, moderately cupped under at the margins, and severely restricted especially at the apex forming a more circular type leaf (Fig. 1, No. 2).

The vine laterals of plants in treatment 2 were shorter and much more numerous than those of the other treatments. Frequently terminal growth of these short laterals would cease and more short laterals would appear which would in turn often produce other short laterals. This type of growth pattern suggested a retardation or cessation of the activity of the merstimatic tissue at the apex of each vine lateral. There were no observable differences in either vine laterals or leaf formation of plants in treatments 3 through 8. However, the leaves of treatments 7 and 8 were lighter green in color and appeared to be smaller in size (Fig. 1).

The root systems of plants grown in treatment 2 exhibited a growth pattern similar to the vine laterals with

Fig. 1.--The twelfth leaf from the base of the plants in treatments 2, 3, 4, 7, and 8 of the greenhouse experiment. Treatments 5 and 6 were eliminated to conserve space, because they did not appear to be different from 4.



the roots being short, dense, very numerous, and often dark at the apex indicating death (Fig. 2). Root systems of treatment 3 showed these symptoms in a very limited degree. The root systems of treatments 4 through 8 appeared to be normal.

Since the calcium levels used in this experiment were 4, 8, 16, 32, 64, 128, and 256 ppm, that is, increased in the ratio of 2 to 1, statistical analyses and interpretations of the data were facilitated by considering all responses as measured against the logarithms of the calcium concentrations. Thus, in the analysis of variance of all data pertaining to the greenhouse experiment and to the discussion of linear and non-linear effects, the independent variable is always the logarithm of the amount of calcium added to the nutrient solutions.

The dry weights of vines, roots, fruits, and the total dry weight of plants are presented in Table 6. When the vine growth was measured against the increasing calcium levels, it was found to decrease in a highly significant linear trend, while the root growth responded in a significant cubic fashion. There were no significant differences in the dry weight of the entire plants (vines, roots, and fruits), although it appeared to be curvilinear. Statistical analysis was not made on the dry weight of the fruits, because they were harvested whenever external blossom-end rot became evident.

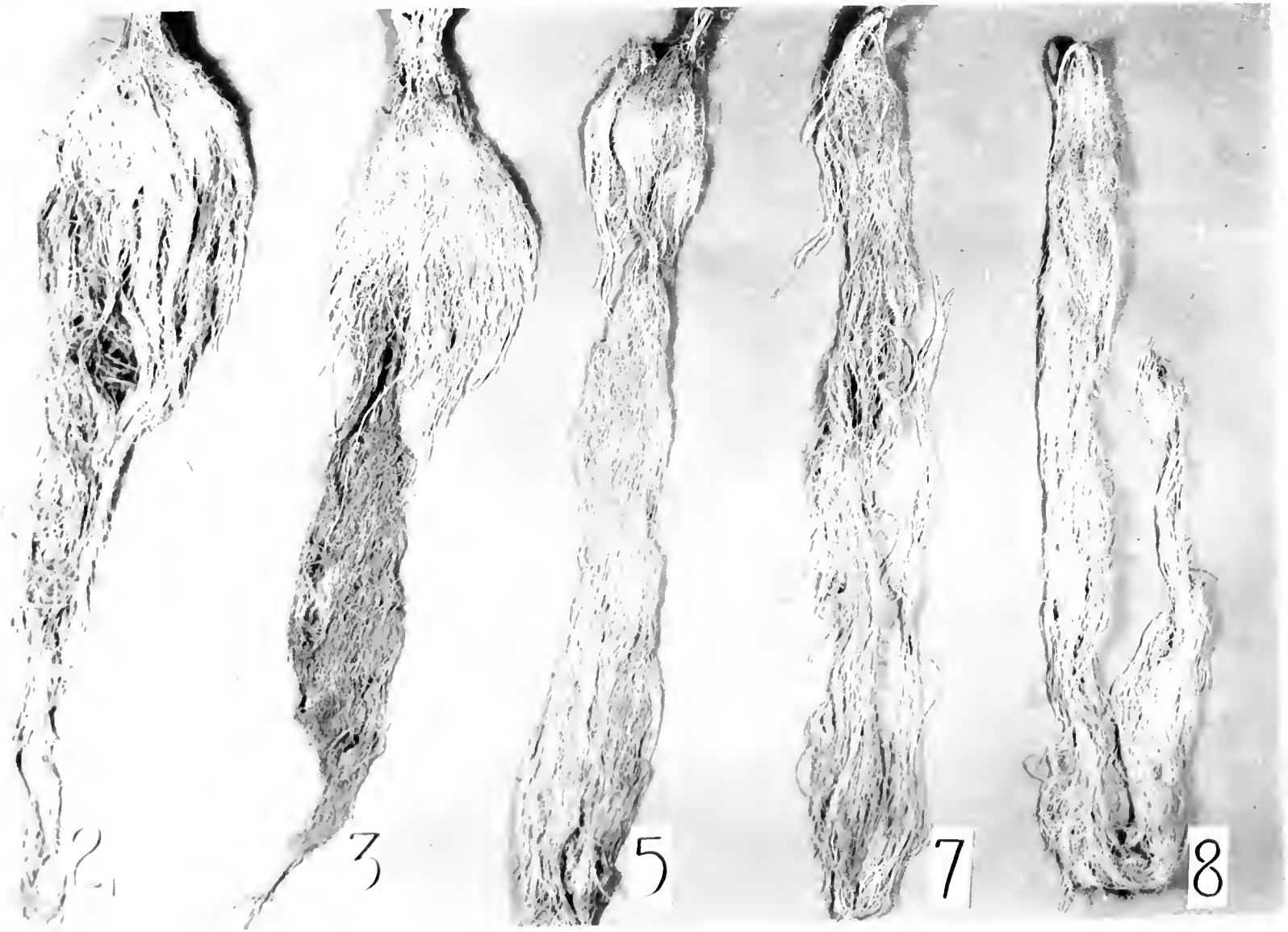

2
3
5
7
8

Fig. 2.--Representative root systems from treatments 2, 3, 5, 7, and 8 of the greenhouse experiment. Treatments 4 and 6 did not appear to be different from 5.

TABLE 6

THE EFFECTS OF CALCIUM TREATMENTS ON THE DRY WEIGHT OF VINES, ROOTS, FRUITS, AND TOTAL WEIGHT IN THE GREENHOUSE EXPERIMENT

Treatment		Dry weight in grams			
Number	Ca Levels ppm	Vines	Roots	Fruits	Total
2	4	79.60	5.84	0.00	85.44
3	8	91.10	5.80	1.76	98.66
4	16	81.60	5.95	33.23	120.79
5	32	61.13	3.80	39.84	104.76
6	64	60.80	4.12	26.86	91.79
7	128	66.82	3.72	26.91	97.45
8	256	60.05	5.15	32.84	98.16
	Effect:[b]				
	Linear	**	*	---	N. S.
	Quadratic	N. S.	N. S.	---	N. S.
	Cubic	N. S.	*	---	N. S.

* Significant at the 0.05 level
** Significant at the 0.01 level
N.S. Not significant

[a]Each figure is the average of four replications measured in grams.

[b]The linear, quadratic, and cubic effects were determined by using log x as the independent variable, where x is the concentration of calcium in ppm in the nutrient solution (see Table 34 for A.O.V.)

Sex expression and fruit set

The number of pistillate and staminate flowers, the ratio of staminate to pistillate flowers, and the number of fruits set are given in Table 7, and the comparisons of the square root of the means are given in Table 8.

TABLE 7

THE EFFECTS OF CALCIUM TREATMENTS ON FLOWER PRODUCTION AND FRUIT SET IN THE GREENHOUSE EXPERIMENT

Treatment		Ave. No. of flowers produced			Total number of fruits set
Number	Ca levels ppm	Staminate	Pistillate	Ratio S:P	
2	4	155.1	5.80	27.79	0
3	8	247.2	28.42	8.74	1
4	16	182.4	22.78	8.16	9
5	32	119.3	14.92	8.10	11
6	64	152.6	17.93	8.54	12
7	128	184.7	18.70	10.21	11
8	256	155.4	15.62	11.68	12

Treatment 3 produced significantly more and treatment 5 produced significantly fewer staminate flowers than any other treatments. Treatment 2 produced the least number of pistillate flowers while treatment 3 produced the largest number. The ratio of staminate to pistillate flowers was significantly greater in treatment 2 than in any of the other treatments. No fruit was set on plants in treatment 2 (4 ppm calcium) and only one fruit was set by plants in treatment 3 (16 ppm calcium). There were no significant differences in the number of fruit set from treatments 4 through 8.

Almost all the ovaries produced by plants grown in treatment 2 turned dark brown to black in color beginning at the blossom-end, even before the flower parts opened. This also occurred rather frequently in the plants in treatment 3, but it was not observed in any of the other treatments.

TABLE 8

TEST OF SIGNIFICANCE FOR THE EFFECTS OF CALCIUM TREATMENTS ON FLOWER PRODUCTION IN THE GREENHOUSE EXPERIMENT

Staminate flowers

Treatment	5	6	2	8	4	7	3
Mean (sq. root)	10.92	12.35	12.45	12.46	13.50	13.59	15.75

Pistillate flowers

Treatment	2	5	8	6	7	4	3
Mean (sq. root)	2.41	3.86	3.95	4.24	4.32	4.77	5.33

Ratio of staminate to pistillate flowers

Treatment	5	4	6	3	7	8	2
Mean (sq. root)	2.85	2.86	2.92	2.96	3.20	3.42	5.27

Notes:

Any two means underlined by the same line are not significantly different. Any two not underlined by the same line are significantly different at the 5 per cent level (see Table 35 for the A.O.V.).

Chemical composition

The effects of varying levels of calcium in the substrate on the percentage of calcium, potassium, and magnesium in the leaves, tips, roots and fruits are presented in Tables 9 and 10. Statistical analyses revealed that as the logarithms of the calcium concentrations were increased by equal amounts in substrate the calcium content of the leaves increased in quadratic fashion, the potassium content decreased in a highly significant linear trend, and the magnesium content decreased in a highly significant quadratic manner.

The calcium content of the plant tips increased linearly, the magnesium content decreased in a curvilinear fashion, and the potassium content was not significantly affected by increasing increments of calcium in the nutrient solutions.

As the calcium levels were increased, the percentage of calcium in the root tissue increased in a highly significant cubic manner, and both the potassium and magnesium percentages decreased linearly.

Analyses of the fruit from treatments 4 through 8 indicated that the potassium content of the fruit was not affected by varying the calcium concentration of the substrate. However, there was a highly positive linear regression in the calcium content and a highly negative linear response in the magnesium content of the fruits when measured against increasing calcium concentrations in the nutrient solutions.

TABLE 9

THE EFFECTS OF CALCIUM TREATMENTS ON THE PERCENTAGE OF CALCIUM, POTASSIUM, AND MAGNESIUM IN THE LEAVES AND TIPS OF PLANTS GROWN IN THE GREENHOUSE[a]

Treatment		Leaves			Tips		
Number	Ca levels (ppm)	Ca	K	Mg	Ca	K	Mg
2	4	0.32	5.19	2.07	0.088	4.16	0.557
3	8	0.48	4.79	1.45	.117	3.54	.490
4	16	1.04	4.14	1.89	.270	3.81	.603
5	32	3.12	4.02	2.06	.285	4.04	.575
6	64	3.90	3.54	1.41	.347	3.59	.460
7	128	4.95	3.72	0.89	.303	3.77	.345
8	256	5.01	3.36	0.53	0.385	3.76	0.322
Effect:[b]							
Linear		**	**	**	**	N.S.	**
Quadratic		N.S.	N.S.	**	N.S.	N.S.	**
Cubic		**	N.S.	N.S.	N.S.	N.S.	N.S.

* Significant at 0.05 level
** Significant at 0.01 level
N.S. Not significant

[a]Each percentage is the average of four replications on the dry weight basis.

[b]Linear, quadratic, and cubic effects were determined by using log x as the independent variable, where x equals the concentration of calcium in the nutrient solution in ppm (see Table 36 for A.O.V.).

TABLE 10

THE EFFECTS OF CALCIUM TREATMENTS ON THE PERCENTAGE OF CALCIUM, POTASSIUM, AND MAGNESIUM IN THE ROOTS AND FRUITS OF PLANTS GROWN IN THE GREENHOUSE[a]

Treatment		Roots			Fruits		
Number	Ca levels (ppm)	Ca	K	Mg	Ca	K	Mg
2	4	0.19	5.33	0.525	---	---	---
3	8	0.25	4.92	.415	---	---	---
4	16	0.38	4.69	.420	0.095	4.87	0.370
5	32	0.41	3.80	.315	.105	4.40	.320
6	64	0.55	4.01	.312	.175	4.73	.295
7	128	1.39	3.79	.302	.265	4.72	.273
8	256	4.85	3.76	0.253	0.313	4.53	0.235
Effect:[b]							
	Linear	**	**	**	**	N.S.	**
	Quadratic	**	N.S.	N.S.	N.S.	N.S.	N.S.
	Cubic	**	N.S.	N.S.	N.S.	N.S.	N.S.

* Significant at 0.05 level.

** Significant at 0.01 level.

N.S. Not significant

[a]Each percentage is the average of four replications on the dry weight basis.

[b]Linear, quadratic, and cubic effects were determined by using log x as the independent variable, where x equals the concentration of calcium in the nutrient solution in ppm (see Tables 36 and 37 for A.O.V.).

Field Phase

Soil tests

The results of the analyses of soil samples taken within the beds are presented in Table 11. In general, the results show good correlation with the amount of hydrated lime applied. The variability within treatments may be partially attributed to at least two factors: (1) at the time of sampling small particles of hydrated lime were still visible in some of the soil samples and (2) replication number 3 was abnormally high in the various elements; this tended to increase the average values of all tests (see Appendix Table 31).

TABLE 11

THE pH AND POUNDS PER ACRE OF AVAILABLE NUTRIENTS OF SAMPLES TAKEN FROM THE WATERMELON BEDS ON APRIL 1, 1959[a]

Treatments[b]	pH	CaO	MgO	P_2O_5	K_2O	NO_3[c]
Ca_0N_0	4.9	234	101	93	263	VL
Ca_0N_1	5.0	147	85	90	227	L
Ca_0N_2	4.8	145	98	86	247	L
Ca_1N_0	5.3	373	73	77	226	L
Ca_1N_1	5.4	653	90	89	267	L
Ca_1N_2	5.4	629	87	90	226	L
Ca_2N_0	5.8	1316	86	97	262	L
Ca_2N_1	5.8	1511	65	99	231	M
Ca_2N_2	5.8	1967	116	91	228	L

[a]Each value is the average of four replications.

[b]Ca_0=none, Ca_1=500, and Ca_2=1,000 lbs. of $Ca(OH)_2$ per acre; N_0=60, N_1=120, and N_2= 180 lbs. of N per acre.

[c]M=medium, L=low, VL=very low.

The data in Table 12 are from soil samples collected from each side of the bed within the calcium treated area. There was little difference in the pH and calcium content of the various treatments. This may be explained by the fact that the beds were prepared following the lime applications which tended to concentrate the lime in the beds. The data in Table 12, excluding calcium, represent the native fertility of the plots (see Appendix Table 32).

TABLE 12

THE pH AND POUNDS PER ACRE OF AVAILABLE NUTRIENTS OF SAMPLES TAKEN FROM EACH SIDE OF THE MELON BEDS ON APRIL 1, 1959[a]

Treatments	pH	CaO	MgO	P_2O_5	K_2O	NO_3
Ca_0N_0	4.9	188	94	50	69	VL
Ca_0N_1	4.8	85	71	55	69	L
Ca_0N_2	4.8	94	93	51	77	VL
Ca_1N_0	5.0	94	58	49	58	L
Ca_1N_1	5.0	188	90	48	53	L
Ca_1N_2	4.9	102	75	51	52	L
Ca_2N_0	5.0	154	62	52	49	L
Ca_2N_1	5.1	146	57	51	37	L
Ca_2N_2	5.0	186	80	48	58	VL

[a]Each value is the average of four replications.

The effects of heavy rains on the removal of fertilizer from the upper eight inches of soil are shown in Table 13. It is apparent from examination of the data that all of the nitrates and approximately 50 per cent of the K_2O were leached from the upper eight inches of the soil.

The excessive rainfall had very little effect on the levels of CaO, MgO, and P_2O_5.

TABLE 13

THE INFLUENCE OF MORE THAN EIGHT INCHES OF RAINFALL ON THE REMOVAL OF FERTILIZER NUTRIENTS IN POUNDS PER ACRE FROM THE UPPER EIGHT INCHES OF SOIL IN WATERMELON BEDS[a]

Treatments[b]	pH	CaO	MgO	P_2O_5	K_2O	NO_3[c]
Fertilizer plus no rain	4.8	109	86	80	426	VH
Ferlitizer plus 8" rain	5.0	80	65	90	228	L
No fertilizer plus 8" rain	4.8	45	43	51	45	L

[a]Each figure is the average of six determinations.

[b]The fertilizer rate was 90 lbs. N/acre as NH_4NO_3, 80 lbs. K_2O/acre as KCl, and 80 lbs. of P_2O_5/acre as triple superphosphate.

[c]VH-very high, L-low.

Growth responses

The dry weight of plants from eight hills per plot harvested May 1 is given in Table 14. There was a significant linear increase in dry weight as the calcium levels were increased. Nitrogen did not significantly affect early vine growth or any other growth response measured in this experiment.

The number of U. S. Number 1 watermelons harvested early is given in Table 15. There was a highly significant

TABLE 14

THE EFFECTS OF CALCIUM AND NITROGEN ON EARLY VINE GROWTH AS INDICATED BY THE DRY WEIGHT OF EIGHT HILLS PER PLOT

Pounds of hydrated lime per acre	Pounds of nitrogen per acre			Total
	60	120	180	
0	196.30	204.00	193.75	594.05
500	214.05	206.35	237.25	657.65
1,000	208.20	212.35	251.50	672.05
Total	618.55	622.70	682.50	

Effect (from A.O.V. in Table 38):
Calcium linear-significant at 0.05 level.
Nitrogen-not significant.

TABLE 15

THE EFFECTS OF CALCIUM AND NITROGEN ON THE NUMBER OF EARLY U. S. NUMBER 1 WATERMELONS

Pounds of hydrated lime per acre	Pounds of nitrogen per acre			Total
	60	120	180	
0	25	23	18	66
500	30	32	31	93
1,000	37	28	44	109
Total	92	83	93	

Effect (from A.O.V. in Table 38):
Calcium linear-singificant at 0.01 level.
Nitrogen-not significant.

linear increase in the number of early watermelons as a result of the calcium treatments.

The total weight of U. S. Number 1 watermelons which was harvested early are presented in Table 16. There was a significant linear increase in the early yield, in pounds, as a result of increasing increments of calcium.

TABLE 16

EFFECTS OF CALCIUM AND NITROGEN ON THE TOTAL WEIGHT IN POUNDS OF U. S. NUMBER 1 WATERMELONS HARVESTED EARLY

Pounds of hydrated lime per acre	Pounds of nitrogen per acre			Total
	60	120	180	
0	576.4	568.3	428.6	1573.3
500	765.6	725.8	779.5	2270.9
1,000	872.9	626.1	1148.5	2647.5
Total	2214.9	1920.2	2356.6	

Effect (from A.O.V. in Table 38):
Calcium linear-significant at the 0.05 level.
Nitrogen-not significant.

The total number of U. S. Number 1 watermelons harvested is given in Table 17. The total number of watermelons produced increased in a significant fashion in response to the calcium treatments.

The total weight in pounds of U. S. Number 1 watermelons, reported in Table 18, increased in a significant linear manner in response to the calcium treatments.

TABLE 17

EFFECTS OF CALCIUM AND NITROGEN ON THE TOTAL NUMBER OF U. S. NUMBER 1 WATERMELONS

Pounds of hydrated lime per acre	Pounds of nitrogen per acre			Total
	60	120	180	
0	39	35	35	109
500	52	53	47	152
1,000	58	45	59	162
Total	149	133	141	

Effect (from A.O.V. in Table 38):
Calcium linear-significant at the 0.05 level.
Nitrogen-not significant.

TABLE 18

EFFECTS OF CALCIUM AND NITROGEN ON THE TOTAL WEIGHT IN POUNDS OF U. S. NUMBER 1 WATERMELONS

Pounds of hydrated lime per acre	Pounds of nitrogen per acre			Total
	60	120	180	
0	851.8	755.4	778.0	2385.2
500	1167.0	1140.4	1118.6	3426.0
1,000	1267.8	938.3	1444.7	3650.8
Total	3286.6	2834.1	3341.3	

Effect (from A.O.V. in Table 38):
Calcium linear-significant at the 0.05 level.
Nitrogen-not significant.

The average of soluble solids as per cent sucrose of all marketable fruit from each plot is reported in Table 19. The average percentage of soluble solids was not significantly affected by either the nitrogen or the calcium treatments.

TABLE 19

THE EFFECTS OF CALCIUM AND NITROGEN ON THE AVERAGE SOLUBLE SOLIDS AS PER CENT SUCROSE FROM ALL MARKETABLE MELONS PER PLOT

Pounds of hydrated lime per acre	Pounds of nitrogen per acre 60	120	180	Mean
0	9.97	9.65	10.24	9.95
500	9.78	9.94	10.12	9.95
1,000	9.48	9.46	9.72	9.55
Mean	9.74	9.68	10.03	

Effect (from A.O.V. in Table 39): Not significant.

The average thickness of the rinds measured at the top and bottom center of all marketable fruits is shown in Table 20. The average thickness of the rind at these locations was not affected significantly by any treatment combination.

The average thickness of the rind at the blossom-end of all marketable fruits per plot is given in Table 21. A linear reduction in the thickness of the rind at the blossom-end was associated with increasing increments of calcium.

TABLE 20

THE EFFECTS OF CALCIUM AND NITROGEN ON THE AVERAGE THICKNESS OF THE RIND IN CENTIMETERS AT THE TOP CENTER AND BOTTOM CENTER OF ALL MARKETABLE FRUITS

Pounds of hydrated lime per acre	Pounds of nitrogen per acre 60	120	180	Mean
0	2.006	1.712	1.883	1.867
500	1.797	1.818	1.722	1.779
1,000	1.722	1.709	1.957	1.796
Mean	1.842	1.746	1.854	

Effect (from A.O.V. in Table 39):
Not significant.

TABLE 21

THE EFFECTS OF CALCIUM AND NITROGEN ON THE AVERAGE THICKNESS OF THE RIND IN CENTIMETERS AT THE BLOSSOM-END OF ALL MARKETABLE FRUITS

Pounds of hydrated lime per acre	Pounds of nitrogen per acre 60	120	180	Mean
0	1.548	1.512	1.641	1.567
500	1.008	1.365	0.979	1.117
1,000	0.982	1.053	1.300	1.112
Mean	1.179	1.310	1.307	

Effect (from A.O.V. in Table 39):
Calcium linear-significant at the 0.05 level.
Nitrogen-not significant.

The average percentage of blossom-end rot of the watermelon fruits associated with each treatment combination is given in Table 22. The analysis of variance of this data revealed no significant difference among treatments.

TABLE 22

THE EFFECTS OF CALCIUM AND NITROGEN ON THE PERCENTAGE OF BLOSSOM-END ROT

Pounds of hydrated lime per acre	Pounds of nitrogen per acre 60	120	180	Mean
0	46.52	47.27	39.93	44.57
500	48.83	46.46	51.55	48.95
1,000	44.64	49.56	42.10	45.43
Mean	46.66	47.76	44.53	

Effect (from A.O.V. in Table 39): Not significant.

All fruits were examined for hollow-heart, white-heart, and other abnormalities; however, these disorders were very limited in occurrence and of no importance in this experiment.

Fruit set

The total number of fruits set per treatment is shown in Table 23. There was a significant positive quadratic response to the increasing calcium levels. Nitrogen treatments had no significant effect on the total number of fruits set.

TABLE 23

THE EFFECTS OF CALCIUM AND NITROGEN ON THE TOTAL NUMBER OF FRUITS SET

Pounds of hydrated lime per acre	Pounds of nitrogen per acre			Total
	60	120	180	
0	136.6	124.6	92.2	353.4
500	148.2	160.9	186.4	495.5
1,000	136.8	163.2	163.5	463.5
Total	421.6	448.8	442.1	

Effect (from A.O.V. in Table 39):
Calcium linear-significant at 0.05 level.
Calcium quadratic-significant at 0.05 level.
Nitrogen-not significant.

Chemical composition

The percentage of calcium, potassium, and magnesium in the tips of young watermelon plants on May 1 is presented in Table 24. There was a highly significant linear increase in the calcium content of the tips as the calcium supply was increased in the soil. The calcium content of the tips was not affected by the nitrogen treatments. Neither the potassium nor magnesium content of the young tips was influenced by the application of nitrogen or calcium to the soil.

The cation composition of the leaves from young watermelon plants is shown in Table 25. The calcium content of the leaves gave a curvilinear response to calcium treatments, increasing with increasing amounts of lime per acre. In response to nitrogen treatments, however, the

TABLE 24

THE EFFECTS OF CALCIUM AND NITROGEN ON THE PERCENTAGE OF CALCIUM, POTASSIUM, AND MAGNESIUM IN THE TIPS OF YOUNG WATERMELON PLANTS

Pounds of hydrated lime per acre	Pounds of nitrogen per acre			Mean
	60	120	180	
Calcium Content				
0	0.545	0.385	0.340	0.423
500	0.555	0.630	0.713	0.633
1,000	0.713	0.937	0.722	0.791
Mean	0.604	0.651	0.594	
Potassium Content				
0	5.61	4.69	5.11	5.14
500	5.19	5.02	5.55	5.25
1,000	5.26	5.00	5.51	5.26
Mean	5.35	4.90	5.39	
Magnesium Content				
0	0.340	0.285	0.300	0.308
500	0.285	0.323	0.298	0.302
1,000	0.292	0.308	0.288	0.296
Mean	0.306	0.305	0.295	

Effect (from A.O.V. in Table 40):
Calcium content-calcium linear (Ca_L) significant at 0.01 level.
Potassium content-not significant.
Magnesium content-not significant.

TABLE 25

THE EFFECTS OF CALCIUM AND NITROGEN ON THE PERCENTAGE OF CALCIUM, POTASSIUM, AND MAGNESIUM IN THE LEAVES OF YOUNG WATERMELON PLANTS

Pounds of hydrated lime per acre	Pounds of nitrogen per acre			Mean
	60	120	180	
Calcium Content				
0	2.73	2.41	1.96	2.37
500	4.15	3.81	3.59	3.85
1,000	4.21	4.31	4.06	4.19
Mean	3.70	3.51	3.20	
Potassium Content				
0	5.75	5.80	5.90	5.82
500	5.23	5.42	5.35	5.33
1,000	5.24	5.21	5.67	5.37
Mean	5.41	5.48	5.64	
Magnesium Content				
0	0.623	0.600	0.457	0.560
500	0.450	0.485	0.428	0.454
1,000	0.410	0.385	0.472	0.422
Mean	0.494	0.490	0.452	

Effect (from A.O.V. in Table 40):
Calcium content-Ca_L, calcium quadratic (Ca_Q), and nitrogen linear (N_L) significant at 0.01 level.
Potassium content-Ca_L significant at 0.05 level.
Magnesium content-Ca_L significant at 0.01 level; Ca_L X N_L significant at 0.05 level.

calcium content showed a highly significant linear regression, decreasing as the nitrogen levels were increased. Potassium content also showed a significant linear regression, decreasing as the calcium levels were increased in the soil. The magnesium content of the leaves similarly decreased in a highly significant linear trend as a result of increasing the calcium levels. However, a significant linear interaction was discovered between the linear responses of calcium and nitrogen, $Ca_L \times N_L$, on the magnesium content of the leaves of young plants (Fig. 3). The effect of increasing nitrogen on the linear response to the calcium treatments was to change the regression from negative to slightly positive as the nitrogen levels increased from 60 to 180 pounds per acre.

The effect of the calcium and nitrogen treatments on the cation composition of the tips from the mature watermelon plants is presented in Table 26. The calcium treatments had no significant effect on the cation composition of the mature tips. The potassium and magnesium content of the tips, however, responded in a significant negative linear fashion to the increasing nitrogen levels.

The cation composition of the leaves from mature plants is given in Table 27. Nitrogen treatments had no significant effect on the percentage of potassium, calcium, or magnesium in the mature leaves. The calcium content of the leaves was increased in a highly significant quadratic

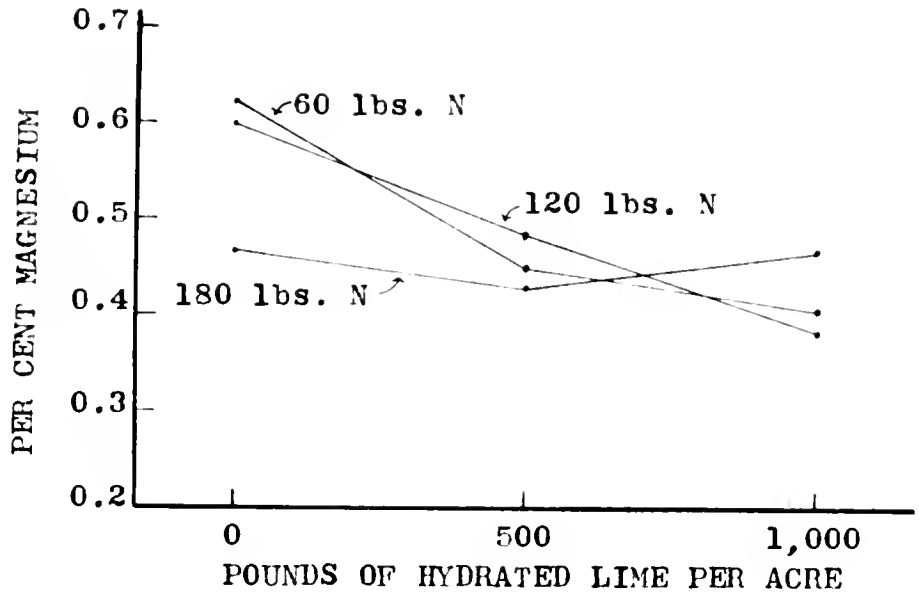


Fig. 3.--The interaction of calcium and nitrogen (Ca_L X N_L) on the magnesium content of the leaves of young watermelon plants

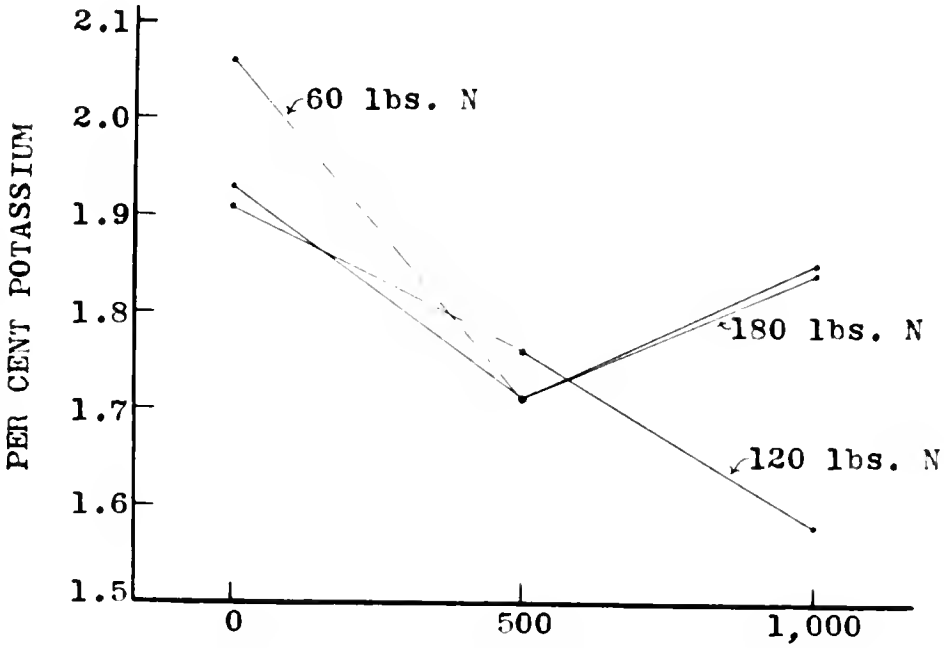


Fig. 4.--The interaction of calcium and nitrogen (Ca_Q X N_Q) on the potassium content of U. S. Number 1 watermelons.

TABLE 26

THE EFFECTS OF CALCIUM AND NITROGEN ON THE PERCENTAGE OF CALCIUM, POTASSIUM, AND MAGNESIUM IN THE TIPS OF MATURE WATERMELON PLANTS

Pounds of hydrated lime per acre	Pounds of nitrogen per acre			Mean
	60	120	180	
Calcium Content				
0	0.285	0.230	0.325	0.280
500	0.370	0.300	0.325	0.332
1,000	0.365	0.325	0.300	0.330
Mean	0.340	0.285	0.317	
Potassium Content				
0	3.85	3.84	3.75	3.81
500	4.06	3.35	3.35	3.59
1,000	3.84	3.26	3.56	3.55
Mean	3.92	3.48	3.55	
Magnesium Content				
0	0.460	0.367	0.380	0.402
500	0.385	0.355	0.333	0.358
1,000	0.400	0.345	0.390	0.378
Mean	0.415	0.356	0.368	

Effect (from A.O.V. in Table 41):
Calcium content-not significant.
Potassium content-N_L significant at 0.05 level.
Magnesium content-N_L significant at 0.05 level.

TABLE 27

THE EFFECTS OF CALCIUM AND NITROGEN ON THE PERCENTAGE OF CALCIUM, POTASSIUM, AND MAGNESIUM IN THE LEAVES OF MATURE WATERMELON PLANTS

Pounds of hydrated lime per acre	Pounds of nitrogen per acre 60	120	180	Mean
	Calcium Content			
0	4.21	4.50	4.63	4.45
500	8.16	8.88	8.72	8.59
1,000	9.90	8.23	9.15	9.09
Mean	7.42	7.20	7.50	
	Potassium Content			
0	3.21	2.79	2.81	2.94
500	1.96	2.19	1.83	1.99
1,000	1.96	1.79	2.08	1.94
Mean	2.38	2.26	2.24	
	Magnesium Content			
0	1.070	1.111	0.947	1.040
500	1.020	1.050	0.902	0.991
1,000	0.942	0.850	0.968	0.920
Mean	1.010	1.003	0.939	

Effect (from A.O.V. in Table 41):
Calcium content-Ca_L, Ca_Q significant at 0.01 level.
Potassium content-Ca_L, Ca_Q significant at 0.01 level.
Magnesium content-not significant.

fashion and the potassium content was decreased in a highly significant quadratic manner as the calcium levels were increased in the soil.

The results of the analyses of the mature marketable fruit for calcium, potassium, and magnesium are shown in Table 28. The calcium content increased in a highly significant manner as a result of the calcium applications, and it decreased in a highly significant quadratic fashion as a result of the nitrogen treatments. The potassium content showed significant quadratic regressions as a result of both calcium and nitrogen treatments. However, these relationships are complicated by a quadratic interaction (Ca_Q X N_Q) shown in Fig. 4. The quadratic regression on calcium changed drastically from "concave upward" for 60 and 180 pounds of nitrogen to "concave downward" for the 120 pounds of nitrogen applied per acre. The magnesium content responded to nitrogen only, and this was a quadratic relationship.

The composition of the fruits exhibiting blossom-end rot is shown in Table 29. The calcium content of the fruit showed a strong linear regression, increasing in response to increasing increments of applied calcium. The potassium content responded negatively to the calcium treatments and positively to the nitrogen treatments. However, a significant interaction (Ca_L X N_Q) is quite evident in Fig. 5. Here the shape of the linear regression of

TABLE 28

THE EFFECTS OF CALCIUM AND NITROGEN ON THE PERCENTAGE OF CALCIUM, POTASSIUM, AND MAGNESIUM IN U.S. NUMBER 1 WATERMELON FRUITS

Pounds of hydrated lime per acre	Pounds of nitrogen per acre			Mean
	60	120	180	
Calcium Content				
0	0.106	0.095	0.101	0.101
500	0.163	0.135	0.131	0.143
1,000	0.185	0.135	0.162	0.161
Mean	0.151	0.122	0.131	
Potassium Content				
0	2.06	1.91	1.93	1.97
500	1.71	1.76	1.71	1.73
1,000	1.85	1.58	1.84	1.76
Mean	1.87	1.75	1.83	
Magnesium Content				
0	0.143	0.134	0.146	0.141
500	0.127	0.120	0.134	0.127
1,000	0.125	0.108	0.143	0.125
Mean	0.132	0.121	0.141	

Effect (from A.O.V. in Table 42):
Calcium content-Ca_L significant at 0.01 level; N_L, N_Q significant at 0.05 level.
Potassium content- Ca_L, Ca_Q singificant at 0.01 level; N_Q, $Ca_Q \times N_Q$ significant at 0.05 level.
Magnesium content-N_Q significant at 0.05 level.

TABLE 29

THE EFFECTS OF CALCIUM AND NITROGEN ON THE PERCENTAGE OF CALCIUM, POTASSIUM, AND MAGNESIUM IN WATERMELON FRUITS EXHIBITING BLOSSOM-END ROT

Pounds of hydrated lime per acre	Pounds of nitrogen per acre			Mean
	60	120	180	
Calcium Content				
0	0.199	0.180	0.226	0.202
500	0.243	0.255	0.219	0.239
1,000	0.321	0.233	0.291	0.282
Mean	0.254	0.223	0.245	
Potassium Content				
0	2.15	2.92	3.01	2.69
500	2.36	2.54	2.49	2.46
1,000	2.34	1.98	2.48	2.27
Mean	2.28	2.48	2.66	
Magnesium Content				
0	0.180	0.218	0.238	0.212
500	0.184	0.154	0.181	0.173
1,000	0.159	0.124	0.156	0.146
Mean	0.174	0.165	0.192	

Effect (from A.O.V. in Table 42):
Calcium content-Ca_L significant at 0.01 level.
Potassium content-Ca_L significant at 0.01 level; N_L, Ca_L X N_Q significant at 0.05 level.
Magnesium content-Ca_L significant at 0.01 level; Ca_L X N_L significant at 0.05 level.

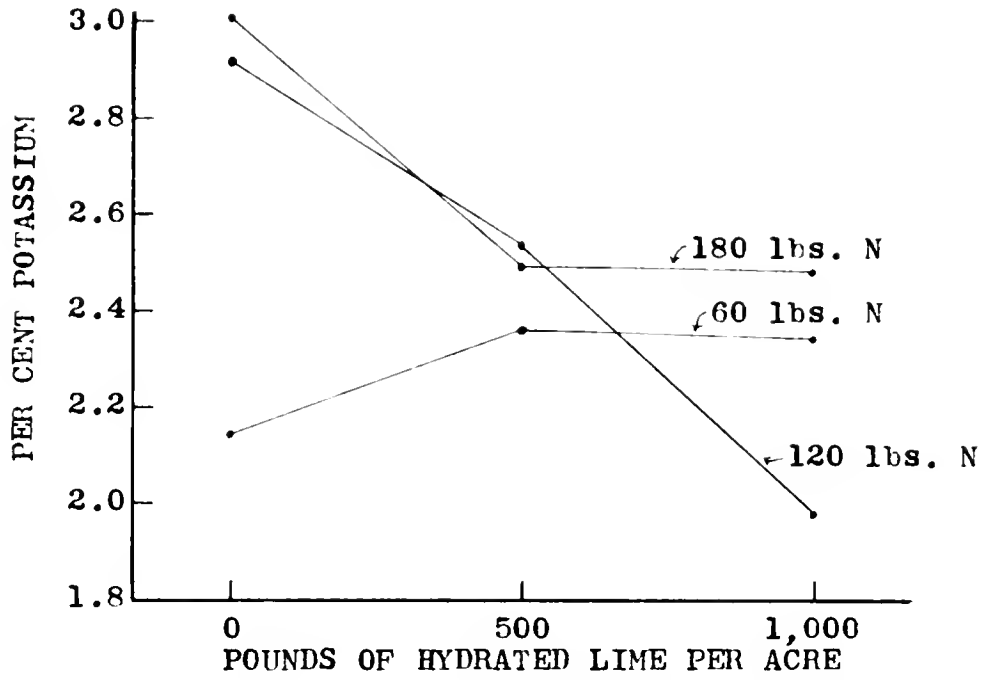


Fig. 5.--The interaction of calcium and nitrogen (Ca_L X N_Q) on the potassium content of watermelon fruits exhibiting blossom-end rot.

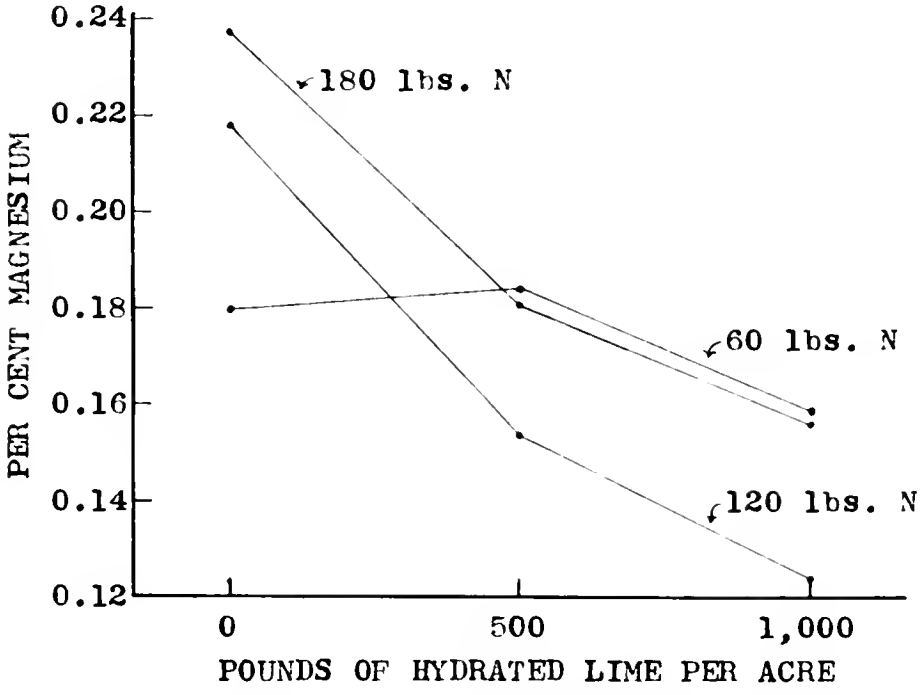


Fig. 6.--The interaction of calcium and nitrogen (Ca_L X N_L) on the magnesium content of watermelon fruits exhibiting blossom-end rot.

potassium on calcium changed markedly from positive to negative in a curvilinear fashion for different levels of nitrogen. The highly significant linear reduction in the magnesium content in response to calcium treatments appeared to be influenced by the nitrogen levels. It is evident by the linear interaction (Ca_L X N_L) of the magnesium content on calcium shown in Fig. 6. The graph clearly shows how the negative slope of the regression becomes steeper as the nitrogen is increased above 60 pounds of nitrogen per acre.

DISCUSSION

Growth Responses

In the greenhouse experiments with watermelons, any level of calcium in the nutrient solution from 4 to 256 ppm appeared to produce normal growth of plants the first two weeks after transplanting. After this, plants grown in solutions containing 4 ppm of calcium began to develop deficiency symptoms in the leaves, vines, and roots, and these symptoms grew increasingly more pronounced as the season progressed. Within three days all watermelon plants placed in solutions containing no calcium began developing deficiency symptoms which resulted in death of the plants in approximately two weeks. These visible symptoms appeared to be characteristic of a severe calcium deficiency rather than toxicity of any other element or elements. No deficiency symptoms were apparent in the tops of plants grown in 8 ppm calcium; however, the roots did show obvious deficiency symptoms at the 8 ppm level but not at 16 ppm of calcium. Research reported by Biddulph et al. (7) indicated that Red Kidney bean plants survived in nutrient solutions containing as low as 0.05 millimoles (2 ppm) of calcium. Below this level, the beans developed a severe deficiency or chlorosis which resulted in death.

The negative linear relationships existing between the dry weight of vines or the dry weight of the roots and the calcium concentrations, when expressed logarithmically, may be explained by the fruit yields (Fig. 7). In solutions containing 16 through 256 ppm of calcium a considerable part of the total plant weight was represented by the dry weight of the fruits. This is apparent by observation of the non-significant quadratic trend in total weight. The curvilinear response of root growth is unquestionably mainly a response to treatments; however, it may be partially attributed to the amount of the base portion of the main stem harvested with the root systems. Therefore, the negative linear pattern appears to describe the data adequately (Fig. 7).

The positive linear response of early vine growth to calcium treatments in the field (Table 14) is in general agreement with data obtained from a preliminary sand-pot experiment. Pots of Leon fine sand receiving 600 pounds of hydrated lime per acre produced significantly more vine growth than pots receiving no lime, but vine growth was not significantly different in pots receiving 600; 1,200; 1,800; or 2,400 pounds of hydrated lime per acre. Field application of nitrogen did not influence the early vine growth significantly. This may be explained on either of the following assumptions: (1) the excessive rains following application partially eliminated the nitrogen variable or (2) sufficient

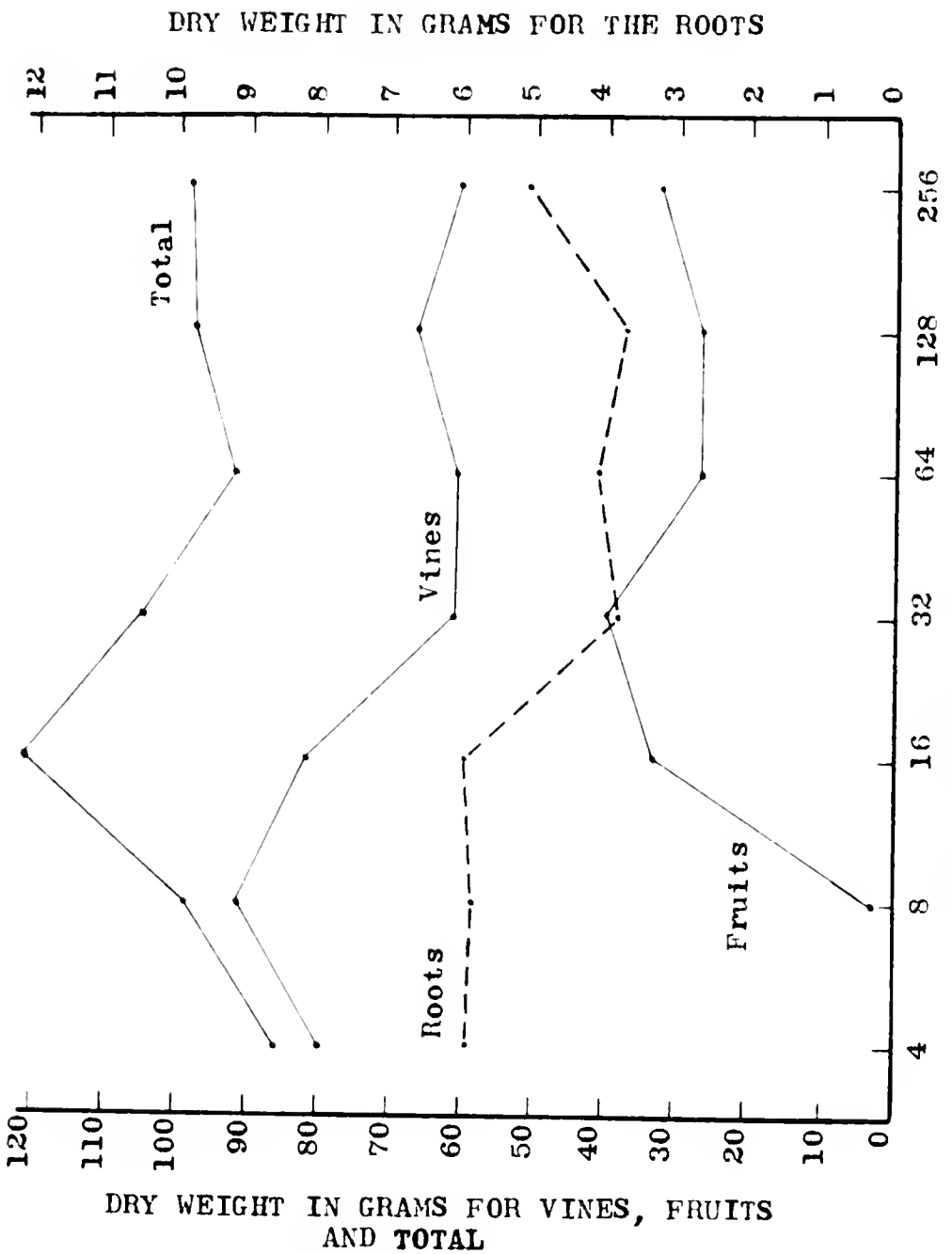


Fig. 7.--The influence of calcium on the dry weight of fruits, roots, vines, and total weight per experimental unit in the greenhouse.

nitrogen remained at all nitrogen levels after the excessive rains to give maximum growth in the early stages.

The percentage increase in early and total yields both in pounds and numbers are shown in Fig. 8. On an acre basis the application of 500 and 1,000 pounds of hydrated lime increased the number of early harvested watermelons by 80 and 129 respectively. These figures represent a percentage increase over the no lime treatment of 40 and 60 per cent respectively. On an acre basis the application of 500 and 1,000 pounds of hydrated lime increased the pounds of watermelons harvested early by 2,092.8 and 3,222.6 or 44 and 68 per cent respectively over the no lime treatment. The percentage increase in the number of pounds was slightly larger than the percentage increase in the actual number of watermelons. This indicates that the average weight per melon was slightly greater as a result of the lime treatments; however, statistical analysis based on the average weight per plot showed no significant difference.

When the total yield of U.S. Number 1 watermelons per acre is considered, the application of 500 and 1,000 pounds of hydrated lime increased the yields by 127 and 156 watermelons (39 and 48 per cent) respectively. A comparison of the percentage increase in the total number with the percentage increase in total pounds again indicates that the melons were larger in size, and this is supported by statistical significance based on the average weight per plot. It should be pointed out, however, that the average weight per

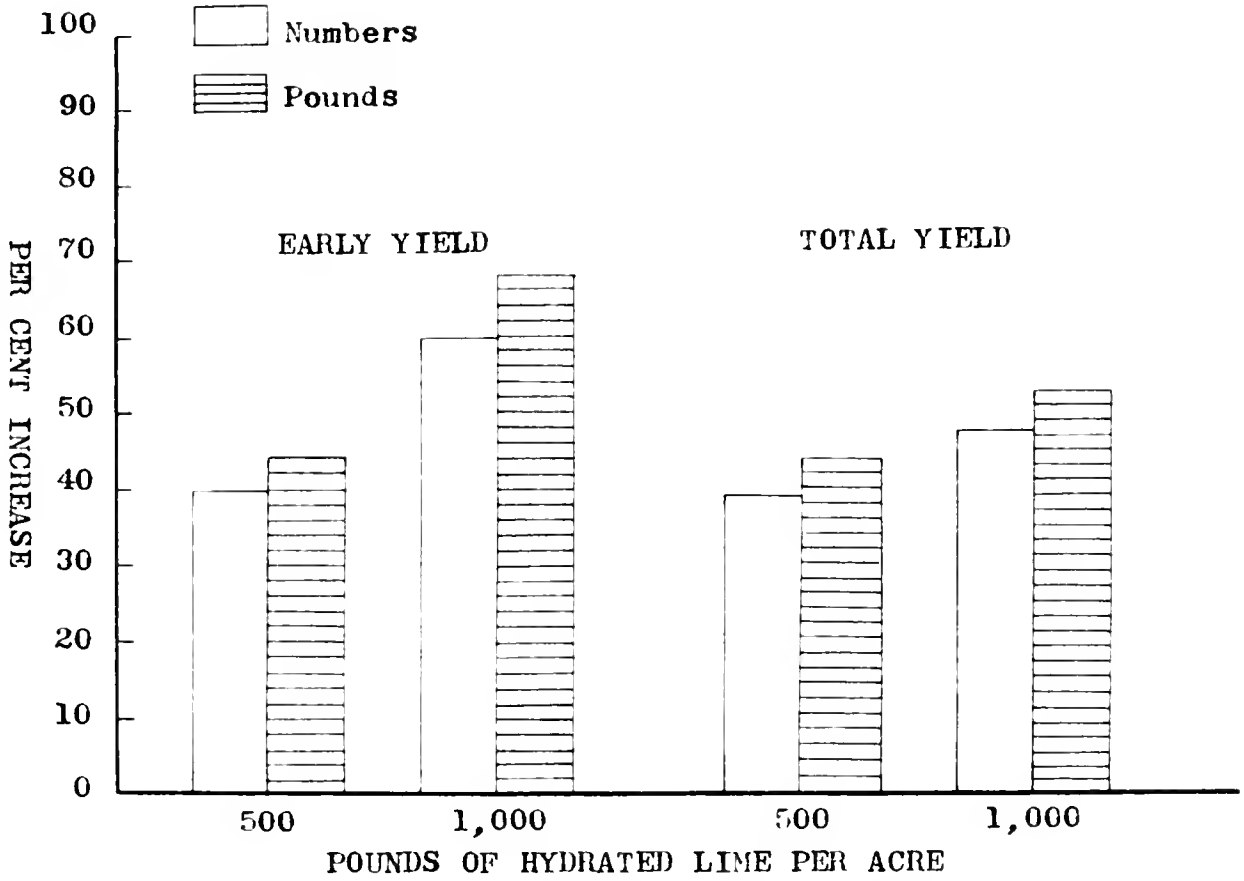


Fig. 8.--The percentage increase in early and total yield of U.S. Number 1 watermelons from plots receiving 500 and 1,000 pounds of hydrated lime over plots receiving no lime.

plot was based on unequal numbers; therefore, the analysis of variance may be biased.

Since these yield increases were obtained from rows spaced 15 feet apart and the hills 10 feet apart in the row, even greater total yields were probable by spacing the rows or the hills closer together. In commercial watermelon fields rows are usually spaced 8 to 10 feet apart. Nettles and Halsey (53) reported significant increases in the number of watermelons produced as the number of hills per row were increased. Plants spaced 3 feet apart in rows 10 feet apart produced 1,260 marketable watermelons per acre, and plants spaced 12 feet apart in 10-foot rows produced 660 marketable watermelons per acre. The average weight did not differ significantly, but it tended to be greater at the wider spacings.

From the literature review and from examination of all soil and tissue analytical data it appears that the beneficial effects of calcium resulted from both an increased supply of calcium and pH changes, which may have directly or indirectly affected the availability of certain other elements. In general, investigators agree that the calcium to magnesium ratio in the soil should be in the range 6 to 10:1. Data in Table 11 and 31 indicate the calcium to magnesium ratios associated with the three treatments (0, 500, and 1,000 pounds of hydrated lime per acre) were approximately 1:1, 6:1, and 15:1, respectively. Likewise, more favorable calcium to potassium ratios existed in the

plots receiving lime. The importance of these ratios is exemplified by the data on the cation composition of the plants shown in Tables 24 through 30. In general, the calcium content of the plant increased from 50 to 100 per cent in response to added calcium, and the potassium and magnesium content generally decreased. Moreover, Wilkins (83) pointed out that cucurbits accumulate large quantities of calcium, and suggested that it may be desirable to plant these crops on soils containing an abundant supply of calcium.

Another undoubtably important factor contributing to the increased yields is the soil pH. From data in Table 11, it may be seen that the average pH corresponding to the three calcium levels were 4.9, 5.4, and 5.8. Fiskell and co-workers (23, 24) have shown that toxic concentrations of aluminum ions are present in many of the Florida soils, including Kanapaha, with a low pH. Furthermore, it has been established that the rate of nitrification as well as organic matter decomposition is greatly influenced by the soil pH (13, 81).

Nitrogen had no significant effect on any of the yield data from the field experiment. This may be attributed in part to excessive rainfall following both nitrogen applications. Over eight inches of rain fell the first 15 days following the initial application of nitrogen. Over seven inches of rain fell the first 30 days following the second application of nitrogen. Data in Table 13 indicated

that almost all of the nitrates and approximately 50 per cent of the potassium was leached from the upper eight inches of the soil by slightly more than eight inches of rainfall. Since ammonium occupies a lower position in the lyotrophic series than potassium it follows that at least 50 per cent of the ammonium nitrogen also was lost.

No definite relationship was established between blossom-end rot and calcium treatments in the greenhouse or the field. In all greenhouse work using nutrient cultures, all the fruits set developed blossom-end rot. Geraldson (26) observed that black-heart of celery, a calcium deficiency, occurred in nutrient solutions in the greenhouse regardless of the calcium levels. Black-heart was controlled by foliar applications of 0.04 molar calcium chloride. A similar control has been developed for blossom-end rot of tomatoes (27).

In the exploratory work in the greenhouse with watermelons, a lower incidence of blossom-end rot was observed with treatments receiving foliar sprays of 0.04 molar calcium chloride than from pots receiving no spray. This does not necessarily establish the disorder as a calcium deficiency; however, it does support the theory that blossom-end rot is a physiological disorder. This is further substantiated by the fact that a large percentage of the ovaries of plants grown in four and eight ppm calcium decayed beginning at the blossom-end even before the floral parts opened. It is suggested, therefore, that future examinations into the

causes of blossom-end rot of watermelons may be more profitable if attempted under controlled environmental conditions.

The differential calcium treatments tested in the field did have an effect on the rind thickness at the blossom-end of the watermelon but not on the average thickness of the top and bottom center of the rind. At the blossom-end the rind thickness decreased as the calcium levels were increased. At least two possible explanations exist for this: it is possible that calcium enhanced maturity; however, this is not supported by a significant increase in the soluble solids, and observations have shown that fruits affected with blossom-end disorders tend to have a thick whitish rind at the blossom-end; therefore, increasing the calcium supply may have reduced these disorders. It should also be pointed out that the calcium content of the fruit generally increased linearly in response to calcium treatments.

Sex Expression and Fruit Set

Calcium treatments had a profound effect on sex expression in nutrient solutions containing relatively low amounts of calcium (Table 7). Plants grown in 13 liters of a solution containing 4 ppm calcium had an average ratio of staminate to pistillate flowers of 27.79:1. When the calcium level was raised to 8 ppm the ratio dropped to 8.74:1 and did not differ significantly as the calcium level was increased

from 4 to 256 ppm; however, at the higher calcium levels the ratio tended to increase. From data presented in Tables 9 and 10 it may be assumed that this drastic increase in the flower ratio was due to either a deficiency of calcium, an excess of potassium and magnesium in the nutrient solution, or any combination of the latter with a calcium deficiency.

Apparently calcium concentrations greater than 8 ppm are necessary for fruit set. Since a large number of the ovaries of plants in solutions containing 4 and 8 ppm calcium decayed, it is assumed that insufficient quantities of calcium were present for normal cellular development. The parabolic response in the number of fruits set to calcium treatments in the field may be explained on the basis that the liming applications enhanced vine growth thereby increasing the actual numbers of fruits set (Table 23).

Chemical Analyses

In the greenhouse experiment, the increase in the calcium content of the tips and fruits was linear as the logarithms of the calcium treatments increased, however, a positive curvilinear response occurred in the leaves and roots. It is generally agreed that increasing the concentration of any element in the substrate usually results in increased absorption of that element by the plant (44, 59). The linear decrease in the potassium content of the leaves and roots probably was produced by a cation antagonism

resulting from an increase in the calcium content. The failure of potassium to decrease significantly in the tips and fruits may be explained on the basis that potassium is a very mobile element and occurs in relatively large quantities in areas of high metabolic activity (48, 50). Apparently cation antagonism between calcium and magnesium resulted in a linear decrease in the magnesium content of the leaves and roots and a quadratic decrease in the tips and fruits.

Conversion of the data in Table 10 to equivalents per 100 grams indicated that the calcium-equivalent increase in the plants at the various treatments was considerably greater than the accumulative equivalent decrease of potassium and magnesium. This may be attributed to inactivation of much of the absorbed calcium by organic acid precipitation thereby causing a continuous build-up of the total cation equivalents in the tissue as calcium increased in the substrate.

The influence of calcium and nitrogen on the average percentage of calcium, potassium, and magnesium of tissue samples from the field experiment is shown in Table 30. The linear increase in the calcium content in response to calcium applications occurred in the leaves of both young and mature plants. The significant decrease in the calcium content of the leaves at the first sampling date as a result of nitrogen treatments failed to occur at the second sampling date. This may be the consequence of

TABLE 30

THE AVERAGE PERCENTAGE OF CALCIUM, POTASSIUM, AND MAGNESIUM ASSOCIATED WITH EACH CALCIUM AND EACH NITROGEN LEVEL IN BOTH VINES AND FRUITS FROM THE FIELD EXPERIMENT[a]

Treatment levels	Composition of young plants (May 1, 1959)			Composition of mature plants (June 10, 1959)		
	Leaves			Leaves		
	Ca	K	Mg	Ca	K	Mg
Calcium						
0	2.37	5.82	0.560	4.45	2.94	1.04
500	3.85	5.33	.454	8.59	1.99	0.99
1,000	4.19	5.37	.422	9.09	1.94	0.92
Nitrogen						
60	3.70	5.41	.494	7.42	2.38	1.01
120	3.51	5.48	.490	7.20	2.26	1.00
180	3.20	5.64	.452	7.50	2.24	0.94
	Tips			Tips		
	Ca	K	Mg	Ca	K	Mg
Calcium						
0	0.423	5.14	0.308	0.280	2.81	0.402
500	.633	5.25	.302	.332	3.59	.358
1,000	.791	5.26	.296	.330	3.55	.378
Nitrogen						
60	.604	5.35	.306	.340	3.92	.415
120	.651	4.90	.305	.285	3.48	.356
180	0.594	5.39	0.295	0.317	3.55	0.368
	Composition of U. S. number 1 fruits			Composition of fruits exhibiting blossom-end rot		
	Ca	K	Mg	Ca	K	Mg
Calcium						
0	0.101	1.97	0.141	0.202	2.69	0.212
500	.143	1.73	.127	.239	2.46	.173
1,000	.161	1.76	.125	.282	2.27	.146
Nitrogen						
60	.151	1.87	.132	.254	2.28	.174
120	.122	1.75	.121	.223	2.48	.165
180	0.131	1.83	0.141	0.245	2.66	0.192

[a]Oven dry weight basis.

retardation in growth and less antagonism between ammonium and calcium through leaching and oxidation of the ammonium. The concentration of calcium in the leaves, regardless of treatments, approximately doubled from the first to the second sampling date. This is probably due to the precipitation of a large percentage of the calcium by certain organic acids.

The potassium content of the leaves at both sampling dates decreased in response to calcium applications; although, nitrogen had no effect on the potassium percentage of the leaves at either sampling period. The leaf samples taken early in the season contained more than twice as much potassium on a percentage basis as those collected late in the season. Perhaps the best explanation of this is a combination of the mass action effect of the potassium applied early in the season with luxury consumption by the plant, and a dilution effect later in the season induced by heavy vine growth.

The interaction between calcium and nitrogen on the magnesium content of the leaves at the first sampling may be attributed to varying degrees of antagonism between the applied calcium and ammonium nitrogen when the level of either was changed along with differential growth responses. At maturity this decrease in the magnesium percentage of the leaves was not statistically significant. The relative increase in the magnesium percentage of the leaves as the season progressed, regardless of treatment, was approximately

proportional to the relative increase in the calcium percentage.

The equivalent shift of the cation composition of the leaves in response to treatments at either sampling time is in agreement with the greenhouse findings. That is, the calcium-equivalent increase in the tissue in response to calcium applications is much greater than the total magnesium and potassium equivalent decrease in the tissue.

The linear increase in the calcium content of the tips at the first sampling date in response to the calcium levels had disappeared by the second sampling date (Tables 21, 26, 30). Perhaps the best explanation of this is that the young plants were in a more vigorous state of growth and assimilation than the mature plants. Also, this would account for the greater percentage of calcium in the tips of young plants.

Neither the potassium nor the magnesium content in the tips at the first sampling date was significantly influenced by any treatment. However, nitrogen treatments decreased the potassium and magnesium content of the tips at the second sampling time. This may be attributed to a combination of a number of factors, including a retardation of the physiological activity of the merstimatic tissues, differential build up of ammonium ions in the tissue, and a dilution effect resulting from differential vine growth and fruit yields.

In general, the normal fruits contained considerably less calcium, potassium, and magnesium than fruits exhibiting blossom-end rot. The most logical explanation of this is a dilution effect, since the mature fruits were approximately four to five times larger than the ones exhibiting blossom-end rot (Table 28, 29, 30).

The calcium content of both types of fruit samples increased linearly in response to calcium treatments. The curvilinear response of calcium in the mature fruits to nitrogen may be attributed to antagonism between ammonium and nitrogen and differential vine growth.

The curvilinear interactions of the calcium and nitrogen treatments on the potassium content of both types of fruits may have resulted from mass action effect of the hydrated lime, antagonism between ammonium and potassium, and dilution due to differential growth responses (Figs. 4 and 5). The same explanation may be given for the interaction of treatments on the magnesium content of fruits showing blossom-end rot (Fig. 6).

SUMMARY AND CONCLUSION

Research was conducted in both the greenhouse and the field to evaluate the effects of varying calcium levels on vine growth, yields, quality, sex expression and fruit set, and the calcium, potassium, and magnesium content of plant tissues of the Charleston Gray variety of watermelons. In the greenhouse, plants grown in a basic nutrient solution containing no calcium developed severe calcium deficiency symptoms and died within two weeks following transplanting. Plants grown in 4 ppm calcium began to develop calcium deficiency symptoms in both the tops and roots three weeks following transplanting, and they grew increasingly more severe as the season progressed. Plants grown in 8 ppm calcium showed no deficiency symptoms in the tops, although slight deficiency symptoms were present in the roots. Plants grew normally in nutrient solutions ranging from 16 to 256 ppm calcium.

The leaves of deficient plants were dark green in color, moderately cupped under at the margins, and severely restricted especially at the apex forming a more circular type leaf, and the vine laterals were short and very numerous. The root systems of calcium deficient plants were short, dense, very numerous, and often dark at the apex indicating death.

The dry weight of the vines and the roots, when analyzed separately, decreased linearly as the logarithms of the calcium concentration increased in the nutrient solution. However, total dry weight (vines, roots and fruit) did not differ significantly among calcium levels.

In the field experiment testing three levels of calcium (0, 500, and 1,000 pounds of hydrated lime per acre) and three levels of nitrogen (60, 120, and 180 pounds per acre), the dry weight of early vine growth increased significantly in a linear pattern in response to increasing calcium levels. Nitrogen did not affect early vine growth or any other growth measurements taken in this experiment. Explanations are suggested based on soil test and rainfall data.

There was a significant linear increase in early and total yield in both pounds and numbers of marketable watermelons as a result of increased calcium levels. The average weight per melon of the early yield was not affected by treatments; however, the average weight per melon of the total yield was increased significantly by increasing the calcium levels. The environmental factors possibly responsible for these yield increases are discussed. It appeared that the beneficial effects of calcium resulted from both an increased supply of calcium and pH changes which may have directly or indirectly affected the availability of other elements.

Calcium levels in the greenhouse nutrient solutions had a profound effect on sex expression and fruit set at the lower concentrations. The ratio of staminate to pistillate flowers in solutions containing 4 ppm calcium was 27.79:1. When the calcium concentration was increased to 8 ppm the flower ratio dropped to 8.74:1, and it did not differ significantly as the calcium levels were increased to 256 ppm. At least 16 ppm of calcium in the nutrient solutions were necessary for fruit set. In the field the total number of fruits set increased in a quadratic fashion as the calcium levels were increased. Nitrogen had no effect on the numbers of fruit set in the field. A large percentage of the ovaries produced by plants grown in nutrient solutions containing 4 or 8 ppm calcium turned dark brown to black in color beginning at the blossom-end, even before the floral parts opened. All fruits set in the greenhouse, regardless of the admixture of the nutrient solutions, developed blossom-end rot within three weeks after flowering. The percentage of blossom-end rot in the field experiments could not be associated with treatments. However, the rind thickness at the blossom-end of marketable fruits decreased linearly as the calcium treatments increased.

Analyses of data from three fertility experiments during the 1958 season revealed that the occurrence of blossom-end rot could be associated with the soil profile characteristics but not with the different fertility treatments.

In the field experiment, the different fertility treatments tested resulted in no significant influence on the soluble sugars, hollow-heart, white-heart, or average thickness of the rind measured at the center of the fruit.

Analyses of tissue samples from various plant parts indicated that watermelons absorb relatively large quantities of calcium, potassium, and magnesium. The greatest concentration of calcium or magnesium occurred in the older leaves with the percentages decreasing in the following order: basal leaves, mid-leaves, tips, stems and fruits. The potassium percentages decreased in the following order: fruits, stems, tips, leaves.

Analyses of the tips, leaves, roots and fruits from the greenhouse experiment indicated, in general, that as the calcium concentration was increased logarithmically in the nutrient medium the calcium content in the tissues increased and the potassium and magnesium content decreased. The increase in the percentage of calcium in the tips and fruits was linear and the increase in the calcium content of the leaves and roots was curvilinear, when measured against the logarithms of the calcium concentrations in the nutrient solution. Significant negative linear regressions in the potassium content occurred in the leaves and roots but not in the tips and fruits in response to calcium levels. The negative regression in the magnesium content induced by the calcium levels was linear in the roots and fruits and quadratic in the leaves and tips.

Analyses of tip and leaf samples from both young and mature watermelon plants from the field indicated that the calcium percentage generally increased, and the magnesium and potassium content decreased as the calcium supply was increased in the soil. The influence of nitrogen on the cation composition of the leaf and tip samples was at variance for the two sampling dates; however, any significant effect of nitrogen treatments on the cation composition of the tissues generally resulted in a decrease of the particular element as the nitrogen levels were increased in the soil.

On a percentage basis the calcium and magnesium content of the leaves of mature plants, regardless of treatment, was approximately double that of the leaves of the young plants, while the potassium content was approximately 50 per cent less in the older plants. The calcium or potassium percentage of the tips of mature plants was 50 per cent less, while the magnesium percentage remained fairly constant from the first to the second sampling.

Analyses of U. S. Number 1 watermelons and those exhibiting blossom-end rot revealed that the calcium content generally increased and the potassium and magnesium content generally decreased in response to increasing calcium levels. Increasing nitrogen levels, however, resulted in a reduction of both the calcium and magnesium content of the U. S. Number 1 watermelon fruits. The magnesium content of the fruits

exhibiting blossom-end rot and the potassium content of both types of fruits was influenced by calcium and nitrogen interactions.

The calcium, potassium, and magnesium content of the U. S. Number 1 fruits were generally lower than the concentration of these cations in the fruits exhibiting blossom-end rot.

It is believed that results of this study may be of value in evaluating and explaining the occurrence of certain physiological disorders and poor growth and yield often obtained in many of the commercial watermelon fields in North Central Florida.

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APPENDIX A

DETAILED SOIL TEST RESULTS BY PLOT

TABLE 31

THE pH AND THE POUNDS PER ACRE OF AVAILABLE NUTRIENTS FROM SOIL SAMPLES TAKEN IN WATERMELON BEDS FROM ALL FIELD PLOTS ON APRIL 1, 1959

Treatment	pH	CaO	MgO	P_2O_5	K_2O	NO_3
			Replication I			
Ca_0 N_0	4.9	103	73	85	229	L
Ca_0 N_1	5.1	34	52	85	210	L
Ca_0 N_2	5.0	137	97	93	296	M
Ca_1 N_0	5.4	434	73	88	191	L
Ca_1 N_1	5.2	562	97	83	296	L
Ca_1 N_2	5.7	652	62	83	223	L
Ca_2 N_0	5.9	1395	52	119	262	L
Ca_2 N_1	6.0	2000	52	99	210	L
Ca_2 N_2	5.8	1286	83	85	197	L
			Replication II			
Ca_0 N_0	4.8	68	52	99	216	VL
Ca_0 N_1	5.2	68	52	83	184	L
Ca_0 N_2	4.8	68	62	96	235	M
Ca_1 N_0	5.4	434	62	68	310	L
Ca_1 N_1	5.5	698	83	96	296	L
Ca_1 N_2	5.5	562	62	116	255	M
Ca_2 N_0	5.8	2000	124	76	296	L
Ca_2 N_1	5.9	1772	83	101	338	M
Ca_2 N_2	6.2	2224	73	90	216	L
			Replication III			
Ca_0 N_0	5.2	698	216	90	352	VL
Ca_0 N_1	4.8	350	152	83	269	L
Ca_0 N_2	4.8	308	182	78	248	VL
Ca_1 N_0	5.2	350	97	76	204	L
Ca_1 N_1	5.3	562	97	108	262	M
Ca_1 N_2	5.1	562	152	67	210	L
Ca_2 N_0	5.5	837	97	93	242	L
Ca_2 N_1	5.6	932	62	67	165	M
Ca_2 N_2	5.5	2910	199	96	262	VL
			Replication IV			
Ca_0 N_0	4.8	68	62	99	255	VL
Ca_0 N_1	4.8	137	83	108	242	L
Ca_0 N_2	4.7	68	52	76	210	L
Ca_1 N_0	5.1	273	62	76	197	VL
Ca_1 N_1	5.5	789	83	70	216	VL
Ca_1 N_2	5.2	741	73	96	216	L
Ca_2 N_0	5.9	1030	73	101	248	VL
Ca_2 N_1	5.8	1340	62	128	210	M
Ca_2 N_2	5.7	1449	111	93	235	L

TABLE 32

THE pH AND THE POUNDS PER ACRE OF AVAILABLE NUTRIENTS FROM SOIL SAMPLES TAKEN ON EACH SIDE OF THE BED FROM ALL PLOTS ON APRIL 1, 1959

Treatment	pH	CaO	MgO	P_2O_5	K_2O	NO_3
			Replication I			
$CaO\ N_0$	4.7	34	41	54	30	L
$CaO\ N_1$	4.9	68	52	55	47	L
$CaO\ N_2$	4.7	34	62	51	65	M
$Ca_1\ N_0$	5.1	137	62	46	65	M
$Ca_1\ N_1$	5.1	308	97	49	59	M
$Ca_1\ N_2$	4.8	68	52	52	59	M
$Ca_2\ N_0$	5.2	239	62	52	47	M
$Ca_2\ N_1$	5.3	239	73	61	24	M
$Ca_2\ N_2$	5.0	103	41	49	59	L
			Replication II			
$CaO\ N_0$	5.0	34	31	46	41	VL
$CaO\ N_1$	4.9	68	41	54	41	L
$CaO\ N_2$	4.8	34	31	45	47	VL
$Ca_1\ N_0$	5.0	68	41	46	35	L
$Ca_1\ N_1$	5.1	137	97	44	47	L
$Ca_1\ N_2$	4.9	68	41	51	35	M
$Ca_2\ N_0$	5.0	171	83	43	53	L
$Ca_2\ N_1$	5.0	137	62	46	53	L
$Ca_2\ N_2$	5.1	103	41	48	41	VL
			Replication III			
$CaO\ N_0$	5.2	652	253	44	152	L
$CaO\ N_1$	4.8	137	138	51	127	VL
$CaO\ N_2$	4.9	239	216	48	172	VL
$Ca_1\ N_0$	5.0	103	97	49	102	L
$Ca_1\ N_1$	5.0	171	83	51	47	VL
$Ca_1\ N_2$	4.9	205	166	45	77	VL
$Ca_2\ N_0$	4.8	103	62	54	65	VL
$Ca_2\ N_1$	4.8	103	41	48	41	VL
$Ca_2\ N_2$	4.9	434	166	44	90	L
			Replication IV			
$CaO\ N_0$	4.7	34	52	55	53	VL
$CaO\ N_1$	4.7	68	52	60	59	L
$CaO\ N_2$	4.8	68	62	60	24	VL
$Ca_1\ N_0$	4.9	68	31	55	30	VL
$Ca_1\ N_1$	4.9	137	83	49	59	VL
$Ca_1\ N_2$	5.0	68	41	55	35	VL
$Ca_2\ N_0$	5.1	103	41	57	30	VL
$Ca_2\ N_1$	5.1	103	52	49	30	VL
$Ca_2\ N_2$	4.9	103	73	51	41	VL

APPENDIX B

ANALYSES OF VARIANCE TABLES

TABLE 33

THE ANALYSES OF VARIANCE FOR THE PERCENTAGE OF CALCIUM, POTASSIUM, MAGNESIUM, AND SODIUM OF SIX LOCATIONS IN MATURE WATERMELON PLANTS, 1958

Source of variation	Degrees of freedom	Mean squares[c]				
		Ca[a]	Ca[b]	K	Mg	Na
Plants	5	0.11	0.06	0.28*	0.024*	0.0024*
Location in plants	5	27.83**	15.64**	1.00**	0.565**	0.0022
Error	25	0.06	0.04	0.10	0.008	0.0009
Total	35	---	---	---	---	---

*Significant at 0.05 level, **Significant at 0.01 level.

[a]Samples passed through an anion exchange column.

[b]Samples not passed through an anion exchange column.

[c]Variance ratio for 5 and 25 degrees of freedom:
F at 0.05 level equals 2.60
F at 0.01 level equals 3.86

TABLE 34

THE ANALYSES OF VARIANCE OF THE OVEN DRY WEIGHTS OF VINES, ROOTS, AND TOTAL WEIGHT (VINES, ROOTS, AND FRUITS) OF GREENHOUSE EXPERIMENT

Source of variation	Degrees of freedom	Mean squares[a]		
		Vines	Roots	Total weight (vines, roots, fruits)
Replication	3	160.7	1.66	440.9
Ca levels[b]	6	617.9	4.05	496.5
Linear	1	2340.6**	9.29*	6.5
Quadratic	1	33.7	4.31	917.1
Cubic	1	434.4	6.93*	1229.1
Residual	3	224.6	1.26	277.8
Error	18	135.3	1.37	304.7
Total	27	---	---	---

*Significant at 0.05 level, **significant at 0.01 level.

[a]Variance ratio for 1 and 18 degrees of freedom:
F at 0.05 level equals 4.41
F at 0.01 level equals 8.28

[b]Effects were determined by using log x as the independent variable, where x equals the concentration of calcium in the nutrient solution in ppm.

TABLE 35

THE ANALYSES OF VARIANCE FOR THE NUMBER OF STAMINATE, PISTILLATE, AND RATIO OF STAMINATE TO PISTILLATE FLOWERS PRODUCED IN THE GREENHOUSE EXPERIMENT

Source of variation	Degrees of freedom	Mean squares		
		Staminate	Pistillate	S:P ratio
Replication	3	1.72	0.44	0.11
Ca levels	6	8.89**	3.23**	3.04**
Error	18	0.62	0.22	0.16
Total	27	---	---	---

**Significant at 0.01 level.

Variance ratio for 6 and 18 degrees of freedom:

F at 0.05 level equals 2.66
F at 0.01 level equals 4.01.

TABLE 36

THE ANALYSES OF VARIANCE FOR THE PERCENTAGE CALCIUM, POTASSIUM, AND MAGNESIUM, IN THE LEAVES, TIPS, AND ROOTS OF THE GREENHOUSE EXPERIMENT

Source of variation	Degrees of freedom	Mean squares for leaves			Mean squares for tips			Mean squares for roots		
		Ca	K	Mg	Ca	K	Mg	Ca	K	Mg
Replications	3	0.51	0.05	0.14	0.012	0.54	0.021	0.15	0.42	0.018
Ca levels[b]	6	16.96	1.79	1.40	0.505	0.20	0.049	11.35	1.65	0.035
Linear	1	95.85**	9.66**	5.53**	0.250**	0.13	0.185**	38.76**	8.31**	0.190**
Quadratic	1	0.10	0.64	1.22**	0.019	0.74	0.056*	20.52**	0.12	0.009
Cubic	1	4.62**	0.03	0.17	0.001	0.11	0.002	7.47**	0.39	0.002
Residual	3	0.43	0.03	0.50	0.011	0.08	0.017	0.45	0.46	0.004
Error	18	0.30	0.16	0.06	0.008	0.30	0.006	0.17	0.14	0.005
Total	27	---	---	---	---	---	---	---	---	---

**Significant at 0.01 level.

[a]Variance ratio for 1 and 18 degrees of freedom:
F at 0.05 level equals 4.41
F at 0.01 level equals 8.28

[b]Effects were determined by using log x as the independent variable, where x equals the concentration of calcium in the nutrient solution in ppm.

TABLE 37

THE ANALYSES OF VARIANCE FOR CALCIUM, POTASSIUM, AND MAGNESIUM IN THE FRUITS OF THE GREENHOUSE EXPERIMENT

Source of variation	Degrees of freedom	Mean squares[a]		
		Ca	K	Mg
Replications	3	0.001	0.10	0.002
Ca levels[b]	4	0.037	0.14	0.010
Linear	1	0.141**	0.05	0.040**
Quadratic	1	0.003	0.01	0.000
Cubic	1	0.000	0.38	0.001
Residual	1	0.004	0.04	0.000
Error	12	0.001	0.23	0.002
Total	19	---	---	---

**Significant at 0.01 level.

[a]Variance ratio for 1 and 12 degrees of freedom:

F at 0.05 level equals 4.75
F at 0.01 level equals 9.33

[b]Effects were determined by using log x as the independent variable, where x equals the concentration of calcium in the nutrient solution in ppm.

TABLE 38

THE ANALYSES OF VARIANCE SHOWING THE MEAN SQUARES FOR THE DRY WEIGHT OF YOUNG WATERMELON PLANTS; THE NUMBERS, WEIGHT AND AVERAGE WEIGHT OF BOTH EARLY AND TOTAL MARKETABLE YIELD OF U.S. NUMBER 1 WATERMELONS FROM THE FIELD EXPERIMENT

Source of variation	Degrees of freedom	Dry wt. young plants	No.early melons	Wt.early melons	Ave.wt. early melons	Total no. melons	Total wt. melons	Ave.wt. total melons
Replication	3	681.8	103.7	75935	22.5	12.1	83514	18.4
Blocks (adjusted)	8	20.5	20.0	13045	4.1	32.1	18069	4.5
Treatment	8	89.5	210.3	15237	9.5	30.6	19888	7.1
Calcium	2							
Linear	1	253.5*	76.5**	48079*	20.7	112.2*	66739*	17.7*
Quadratic	1	33.6	1.6	1431	13.1	15.2	9248	9.4
Nitrogen	2							
Linear	1	170.4	0.1	837	2.3	2.5	125	4.5
Quadratic	1	43.0	4.2	7424	14.8	8.0	12792	12.8
Interaction	4							
$Ca_L \times N_L$	1	131.3	10.6	11204	5.5	1.4	3928	7.7
$Ca_Q \times N_L$	1	0.7	0.0	208	0.0	0.8	833	0.9
$Ca_L \times N_Q$	1	58.4	16.4	1410	16.3	9.6	10707	3.5
$Ca_Q \times N_Q$	1	25.1	4.8	16905	3.6	15.8	6206	0.4
Intra block error	16	51.9	7.4	4889	5.6	14.4	7930	3.0
Effective error	16	51.9	8.9	5908	5.6	15.5	9414	3.3
Total	35	---	---	---	---	---	---	---

*Significant at 0.05 level, **significant at 0.01 level.
Variance ratio for 1 and 16 degrees of freedom:
F at 0.05 level equals 4.49
F at 0.01 level equals 8.53

TABLE 39

THE ANALYSES OF VARIANCE SHOWING THE MEAN SQUARES FOR PERCENTAGE SOLUBLE SOLIDS, AVERAGE RIND THICKNESS MEASURED AT THE TOP AND BOTTOM CENTER, RIND THICKNESS AT THE BLOSSOM-END, PERCENTAGE BLOSSOM-END ROT, AND THE TOTAL NUMBERS OF FRUIT SET IN THE FIELD EXPERIMENT

Source of variation	Degrees of freedom	% soluble solids	Ave. rind thickness (top-bottom)	Rind thickness (blossom-end)	% blossom-end rot	Total no. fruit set
Replication	3	1.07	0.07	0.38	109.5	407.7
Blocks (adjusted)	8	0.49	0.05	0.16	31.9	164.5
Treatment	8	0.26	0.06	0.28	53.6	213.1
Calcium	2					
Linear	1	0.96	0.03	1.24*	38.0	504.9*
Quadratic	1	0.31	0.02	0.40	122.9	420.7*
Nitrogen	2					
Linear	1	0.48	0.00	0.10	25.1	17.4
Quadratic	1	0.33	0.08	0.04	39.9	15.8
Interaction	4					
$Ca_L \times N_L$	1	0.00	0.13	0.05	16.4	315.0
$Ca_Q \times N_L$	1	0.01	0.02	0.07	71.2	201.9
$Ca_L \times N_Q$	1	0.14	0.01	0.00	5.0	0.7
$Ca_Q \times N_Q$	1	0.15	0.10	0.37	142.7	35.8
Intra block error	16	0.31	0.40	0.21	50.6	80.3
Effective error	16	0.35	0.04	0.21	50.6	94.0
Total	35	---	---	---	---	---

*Significant at 0.05 level.

Variance ratio for 1 and 16 degrees of freedom:
F at 0.05 level equals 4.49
F at 0.01 level equals 8.53

TABLE 40

THE ANALYSES OF VARIANCE FOR THE PERCENTAGE OF CALCIUM, POTASSIUM, AND MAGNESIUM IN THE LEAVES AND TIPS OF YOUNG WATERMELON PLANTS FROM THE FIELD EXPERIMENT

Source of variation	Degrees of freedom	Mean squares for leaves			Mean squares for tips		
		Ca	K	Mg	Ca	K	Mg
Replication	3	0.18	0.16	0.051	0.006	0.91	0.016
Treatment	8	3.10	0.30	0.027	0.136	0.36	0.001
Calcium	2						
Linear	1	19.98**	1.20*	0.115**	0.810**	0.09	0.001
Quadratic	1	2.62**	0.55	0.011	0.005	0.02	0.000
Nitrogen	2						
Linear	1	1.48**	0.33	0.010	0.001	0.01	0.001
Quadratic	1	0.03	0.02	0.002	0.022	1.76	0.000
Interaction	4						
$Ca_L \times N_L$	1	0.41	0.08	0.052*	0.046	0.55	0.001
$Ca_Q \times N_L$	1	0.01	0.04	0.001	0.087	0.31	0.002
$Ca_L \times N_Q$	1	0.02	0.06	0.019	0.103	0.10	0.004
$Ca_Q \times N_Q$	1	0.05	0.12	0.004	0.013	0.06	0.003
Error	24	0.16	0.20	0.007	0.034	0.63	0.002
Total	35	---	---	---	---	---	---

*Significant at 0.05 level, **significant at 0.01 level.

Variance ratio for 1 and 24 degrees of freedom:
F at 0.05 level equals 4.26
F at 0.01 level equals 7.82

TABLE 41

THE ANALYSES OF VARIANCE FOR THE PERCENTAGE OF CALCIUM, POTASSIUM, AND MAGNESIUM IN THE LEAVES AND TIPS OF MATURE WATERMELON PLANTS FROM THE FIELD EXPERIMENT

Source of Variation	Degrees of freedom	Mean squares for leaves			Mean squares for tips		
		Ca	K	Mg	Ca	K	Mg
Replication	3	2.5	0.78	0.444	0.001	0.80	0.008
Treatment	8	20.4	1.06	0.028	0.007	0.32	0.006
Calcium	2						
Linear	1	127.3**	5.93**	0.089	0.015	0.39	0.004
Quadratic	1	26.5**	1.59**	0.001	0.006	0.08	0.009
Nitrogen	2						
Linear	1	0.0	0.11	0.031	0.003	0.79*	0.014*
Quadratic	1	0.5	0.02	0.006	0.015	0.50	0.010
Interaction	4						
$Ca_L \times N_L$	1	1.4	0.29	0.021	0.011	0.03	0.005
$Ca_Q \times N_L$	1	0.7	0.00	0.007	0.001	0.38	0.000
$Ca_L \times N_Q$	1	2.5	0.00	0.057	0.006	0.31	0.000
$Ca_Q \times N_Q$	1	2.0	0.50	0.013	0.000	0.04	0.004
Error	24	1.0	0.16	0.052	0.006	0.18	0.003
Total	35	---	---	---	---	---	---

*Significant at 0.05 level, **significant at 0.01 level.

Variance ratio for 1 and 24 degrees of freedom:
F at 0.05 level equals 4.26
F at 0.01 level equals 7.82

TABLE 42

THE ANALYSES OF VARIANCE FOR THE PERCENTAGE OF CALCIUM, POTASSIUM, AND MAGNESIUM IN U.S. NUMBER 1 WATERMELON FRUITS AND IN FRUITS EXHIBITING BLOSSOM-END ROT FROM THE FIELD EXPERIMENT

Source of variation	Degrees of freedom	Mean sq. for No. 1 fruits			Mean sq. for B-E-R fruits		
		Ca	K	Mg	Ca	K	Mg
Replication	3	0.003	0.08	0.002	0.012	0.22	0.005
Treatment	8	0.008	0.17	0.001	0.015	0.87	0.010
Calcium	2						
Linear	1	0.043**	0.54**	0.003	0.078**	2.16**	0.051**
Quadratic	1	0.002	0.29**	0.001	0.000	0.00	0.001
Nitrogen	2						
Linear	1	0.005*	0.02	0.001	0.001	1.67*	0.004
Quadratic	1	0.006*	0.17*	0.004*	0.012	0.00	0.005
Interaction	4						
Ca_L X N_L	1	0.001	0.03	0.000	0.007	1.05	0.007*
Ca_Q X N_L	1	0.001	0.01	0.000	0.001	0.36	0.002
Ca_L X N_Q	1	0.002	0.07	0.001	0.004	1.59*	0.005
Ca_Q X N_Q	1	0.001	0.18*	0.000	0.020	0.10	0.001
Sampling Error	36	0.0004	0.01	0.0004	0.001	0.02	0.0011
Error	24	0.0010	0.03	0.0008	0.005	0.26	0.0016
Total	71	---	---	---	---	---	---

*Significant at 0.05 level, **significant at 0.01 level.

Variance ratio for 1 and 24 degrees of freedom:
F at 0.05 level equals 4.26
F at 0.01 level equals 7.82

BIOGRAPHICAL NOTES

Willie Estel Waters was born September 19, 1931, in Smithtown, McCreary County, Kentucky. He received his elementary education in the public school of Smithtown, Kentucky. He was graduated from McCreary County High School in 1950.

He entered Cumberland Junior College in September, 1950, and was graduated in May, 1952. He entered the University of Kentucky the same year and was graduated in June, 1954, with a Bachelor of Science Degree in Agriculture.

He married Mary Elizabeth Sumler of Sanford, Florida, in May, 1952.

From June, 1954, to December, 1954, he worked as an Assistant County Agricultural Agent in Perry County, Kentucky. He served with the United States Army Medical Corps from December, 1954, to September, 1956.

He entered the Graduate School of the University of Kentucky in 1956, and completed the requirements for the Master of Science Degree in Agriculture in January, 1958. He entered Graduate School of the University of Florida in February, where he has since been working toward the degree of Doctor of Philosophy.

He was employed as a research assistant by the University of Kentucky Agricultural Experiment Station from 1956

to 1958 and by the University of Florida Agricultural Experiment Station from 1958 to 1960.

He is a member of Alpha Zeta, Gamma Sigma Delta, Phi Kappa Phi, and an associate member of the Society of Sigma Xi.

This dissertation was prepared under the direction of the chairman of the candidate's supervisory committee and has been approved by all members of that committee. It was submitted to the Dean of the College of Agriculture and to the Graduate Council, and was approved as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

January, 1960

Dean, College of Agriculture

Dean, Graduate School

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