T H E S I S

THE EFFECTS OF CERTAIN SOIL AND NUTRIENT FACTORS ON THE QUALITY OF CARNATIONS

Submitted by

Norvald C. Gomness

In partial fulfillment of the requirements
for the Degree of Master of Science
Colorado
Agricultural and Mechanical College
Fort Collins, Colorado

February, 1952

COLORADO AGRICULTURAL AND MECHANICAL COLLEGE

February 1 1952

WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY NORVALD C. GOMNESS

ENTITLED THE EFFECTS OF CERTAIN SOIL AND NUTRIENT FACTORS OF THE QUALITY OF CARNATIONS

BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

Committee on Graduate Work

W D Holley — Major Professor
W.R. Schmehl
Geo. Beach

A. M. Binkley — Head of Department

Examination Satisfactory

Committee on Final Examination

W D Holley
A. M. Binkley
W. R. Schmehl
Geo. Beach

D. A. Peterson — Chairman

COLORADO AGRICULTURAL AND MECHANICAL COLLEGE

February 1 1952

WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY NORVALD C. GOMNESS ENTITLED THE EFFECTS OF CERTAIN SOIL AND NUTRIENT FACTORS OF THE QUALITY OF CARNATIONS BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

Committee on Graduate Work

[redacted]

Major Professor

[redacted]

Head of Department

Examination Satisfactory

Committee on Final Examination

[redacted]

[redacted]

[redacted]

Chairman

ACKNOWLEDGMENT

The author wishes to take this opportunity to express his thanks to the following members of the faculty of Colorado Agricultural and Mechanical College, Fort Collins, Colorado, for their assistance in the preparation of this thesis:

W. D. Holley, Associate Professor of Horticulture, for his supervision of the investigation.

O. W. Olsen, Professor of Zoology and Head of Department, W. R. Schmehl, Associate Professor of Agronomy (Soils), and G. A. Beach, Professor of Horticulture, for their suggestions and criticisms of the text.

A. G. Clark, Professor of Mathematics and Head of Department, and A. C. Ferguson, Associate Professor of Horticulture, for their aid in the statistical analysis of the study.

The author also wishes to acknowledge his indebtedness to L. C. Taylor and John Malloy, Denver Wholesale Florists Company, for their aid in conducting the tests.

TABLE OF CONTENTS

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter I

INTRODUCTION

A conservative estimate of the value of the 1948-1949 carnation crop in the United States was placed by Fossum (20) at 20 million dollars. Of these flowers approximately 25 per cent, or 5 million dollars worth, were grown in Colorado. This sum represented a vast number of cut flowers, a high percentage of which were of inferior quality. Besides those of inferior quality that were sold at a reduced price, as compared with prices received for top quality blooms, millions were discarded, because their quality was so low as to render them unsaleable. This discard made a heavy reduction of income to the grower.

It is believed by the writer that if more of the factors affecting the quality of growth of the carnation could be determined and controlled, a higher percentage of top quality blooms could be grown. This would eliminate the production of so many low grade and unsaleable flowers.

Background.--There has been noted in the Denver, Colorado, area a great difference in the quality of single varieties of carnations as grown in the various greenhouses.

This difference in quality is common even within one range, where several different levels of quality are cut. The difference cannot be explained entirely by position in house, temperature, climatic conditions, light, or presence or absence of disease or insects.

Greenhouses under investigation in this study are under the supervision of field men from the wholesale houses. Growers send soil samples to these men monthly. Chemical tests are run on these samples, testing for the various nutrients. Suggestions as to feeding practices, based on the results of the tests, are made to the growers. It is assumed these suggestions are followed. This, then, should eliminate variations in feeding practices as a cause for different levels of quality of blooms cut.

It was believed that a study of certain soil, and nutrient factors and their relationship to the quality of growth of carnations, would reveal at least a partial answer to the problem. It was also hoped that this study would point out paths for future studies on soil factors affecting the quality of growth.

In light of the foregoing discussion, it was decided to set the problem up in the following manner.

Problem

What effect do certain soil and nutrient factors have on the quality of growth of carnations?

Problem analysis.--Before attempting to answer the major question, it will be necessary to divide it into its component parts and answer each part separately. The following questions suggest themselves:

1. What is the quality of growth of William Sim carnations in each of 40 greenhouses?
2. What is the relationship between proportion of sand, silt and clay in the soil and quality of growth of carnations?
3. What is the relationship between soil aeration and quality of growth of carnations?
4. What relationship exists between the amount of organic matter in the soil and quality of growth of carnations?
5. What is the relationship between amount of available potassium in the soil and quality of growth of carnations?
6. What is the relationship between amount of available calcium in the soil and quality of growth of carnations?
7. What is the relationship between amount of available sodium in the soil and quality of growth of carnations?

8. What evidence is there to show the effect of improper balance of these factors on the quality of growth of carnations?

Delimitation.--This investigation has been restricted to the William Sim carnation as grown in 40 commercial greenhouses in the Denver, Colorado, area. Samples were taken from April 1 to May 12, 1951.

Definition of terms.--1. Quality of growth.--The factor, weight per inch, includes stem and bloom. This was used to designate quality of growth and was obtained as described in Chapter III, Methods and Materials.

2. Available--those amounts of potassium, calcium, and sodium that are soluble in Spurway's acetic acid extracting solution are considered to be available to the plants.

3. Pinched plants--those plants whose primary growing points have been removed to stimulate axillary growth.

Chapter II

REVIEW OF LITERATURE

Little work has been done to determine the effect of various soil and nutrient factors on the quality of growth of carnations. The body of this review will of necessity deal with the effect of these factors on other crops which have been under investigation. To make more comprehensive reading, each factor under consideration is reviewed separately.

Mechanical analysis

In his text on soil physics, Baver (4) gave a complete account of the earlier work done on the physical structure of the soil as affected by the percentages of sand, silt, and clay. This has long been recognized as one of the most important factors contributing to crop growth and crop response to fertilizers. As Baver pointed out, the percentage of sand, silt, and clay and their arrangement into aggregates affect many physical properties of the soil. Among these are base exchange capacity, air supply, water holding capacity, water permeability, and availability of nutrients.

According to Baver (4), early workers in the field of soil physics were Schubler, Schumaker, Wollny, Hilgard, Johnson, King and others. Many of the concepts set forth by these men are being proved today.

More recent investigations of soil colloids have been carried on by Bray (10). In his work, soil colloids below one micron in size were fractionated into three fractions and the base exchange of each determined. His conclusions were that the exchange of the finer fractions increased markedly with decreasing particle size.

Whitt and Baver (44), working with the colloidal fraction of Putnam clay, also found that exchange capacity of colloids increased with decreasing particle size.

Baver (4) pointed out that the exchange capacity of soils is due mainly to the colloidal fraction of the soil, including colloidal organic matter. He also indicated that it is this exchange phenomenon that aids in the formation of soil aggregates and improves the soil structure. It is also the exchange complex that causes adsorption of ions or nutrients, thus preventing them from leaching out of the root zone and running off in the drainage water.

Reporting the work of Hager, Baver (2) stated there was definite evidence found in Hager's work that sodium and potassium tended to harden argillaceous soils and reduced their workability, aeration, water permeability and water holding capacity. In his own work, Baver (2) found this to be true. He found also that calcium had the opposite effect, e.g., tended to aid in the aggregation of soils containing a high percentage of clay.

Hoffer (26) working on corn response to fertilizers, found an increase in yield in some cases, and a decrease in yield in others. This was true even though all plots fertilized were considered low in available nutrients at the time of fertilizer application. In seeking the reason for the variation in response, Hoffer concluded that the negative response was due to poor aeration as a result of water logged soil. He determined that the poor aeration caused a subsequent contest for oxygen by the increase of microorganisms and plants. This condition coupled with the release of CO_2 and its subsequent build-up in a poorly aerated soil, caused a reduction in plant yield.

Soil organic matter

This constituent of the soil performs several very important functions in the soil. Among them are:

1. To cement soil particles to form stable aggregates.
2. To adsorb and release mineral nutrients as needed by the plants through base exchange.
3. To supply nutrients to the plants and microorganisms by undergoing decomposition.
4. To increase the water holding capacity of the soil.

From a study of the effect of organic matter on four different soils, Baver (3) concluded that the absorption capacity of the soil for cations due to organic matter varied from 30 to 60 per cent and that there is a base exchange of one milliequivalent for every gram of organic matter. He concluded further that oxidation of the organic matter produced a marked lowering of both the upper and lower plastic limits with a slight tendency towards decreasing the plastic number.

Feustel and Byers (19) reported a 40 to 50 per cent increase in the water holding capacity of soils when mixed with equal volumes of peat. However, they believed that due to the increased moisture percentage at the wilting coefficient, the admixture of peat to heavy soils reduced the benefits of the increased water holding capacity. Only in sandy soils would maximum benefits from additional water holding capacity be evident.

In work on colloidal humus, Baver and Horner (5) found that humus systems saturated with lithium, sodium and potassium ions were completely dispersed, and could be flocculated only with difficulty. They suggested also that the importance of calcium in the nutrition of plants for the production of vegetation is a more significant factor in organic matter accumulation than has been recognized. They observed further that the stable structural formation of soil is more dependent upon total organic matter content than its percentage saturation with calcium.

In a study of the influence of various soil mixtures on production and growth of roses, Link and Culvert (29) reported a significant increase in production of flowers from the half humus - half sand mixture over all other mixtures tried. They suggested this difference could be due to a more uniform moisture content and aeration.

In a study similar to the one above, Post and Howland (34) found no significant differences between mixtures of 50 per cent peat and 50 per cent Genesee silt loam which had been composted with manure (25 per cent by volume) for nine months, and other soil mixtures. These differences were observed: the soils used, especially the compost soil, packed considerably during the study; the soil containing peat remained loose and friable, even at the end of the experiment (three years). The root zone in the 25 per cent or 50 per cent peat was completely ramified by a mass of fibrous roots, while in the composted soil there were relatively few small roots.

Ray and Shanks (35) conducted an experiment with carnations and roses in which soil alone and also different mixtures of soil and manure, hay, stover, blue grass sod, sand, and cinders were used as a growing medium.

The amount of aggregation was determined as was the air supply and oxygen content of the soil. They reported better aeration with the mixtures than with soil alone. In one plot sucrose was added with the result that the oxygen content of the soil was reduced considerably. No beneficial or detrimental effects on the plants were noted.

<u>Soil aeration</u>

This is rather a two-fold problem. The first part is concerned with the amount of air or gas a soil will hold, the second part with the rate of diffusion of these gases from the soil into the atmosphere above the soil in an effort to remain at equilibrium with gases in the atmosphere. Soil air is affected by many things. They are as follows:

1. Soil structure or the amount of, or lack of water-stable aggregates. It is generally true that as the per cent of aggregation increases, the per cent of soil air increases.
2. The water holding capacity of the soil, or the amount of water in the soil at any time. As the water in the soil increases, the pores left for air obviously must decrease.

3. The soil microbiological activity. This activity depends on the amount of organic matter available for decomposition by the organisms and the resultant decomposition in turn effects the composition of the soil air.
4. The type and number of plants growing in a given area. This affects the composition of the gases and also the amount of organic matter available to microorganisms.

Durell (18) grew tomato plants in nutrient solutions with forced aeration and found that the growth of these plants increased markedly when air was bubbled through the solution at regular times throughout the growing period.

From results of experiments on forced aeration of plants growing in various soil and sand mixtures, Cannon (14) and Clements (16) reported that moist air forced through the growing medium greatly increased the growth; increased the number and length of root hairs; increased the top to root ratio; and in general, gave the plants a healthier appearance. These favorable results occurred only in those plots considered inadequately aerated, and were deemed to occur because the oxygen was resupplied to the soil air, and the carbon dioxide was brought into equilibrium with the atmosphere above the soil.

Cannon (14) worked with several varieties of plants and found that at different oxygen levels, the soil temperature greatly affected the growth response of the plants. By growing plants at one temperature and varying the oxygen level, growth increased as the oxygen concentration increased. By growing plants at one oxygen level and varying the temperature, he found that growth decreased as the temperature increased.

Other results obtained by Cannon in this rather extensive experiment were as follows:

1. When working with carbon dioxide levels of 10, 25, 50, 75, and 90 per cent and corresponding oxygen levels of 90, 75, 50, 25, and 10 per cent, it was found that growth was depressed in some cases or ceased entirely in others, but in all cases growth was resumed again within one to six hours after normal aeration.
2. In certain species of plants which have marked aerobic traits, root hairs did not develop in cases of great oxygen deficiency.
3. It was the rate of supply rather than the partial pressure "per se" of oxygen that influenced growth.

In other experiments, Cannon (13) studied the effects of the rate of evaporation on the oxygen requirements of plants. It was well known at that time that the evaporation power of the air had a direct influence on the rate of photosynthesis. As the dryness of the air increased, photosynthesis proceeded at a very slow rate or ceased entirely. In this event, the evolution of oxygen ceased also. Cannon reasoned that partial aeration of the plant tissues may come from the oxygen evolved in photosynthesis. Working on this hypothesis, he set up an experiment in which the plants were grown in direct sunlight but the evaporation rate from plant surfaces was speeded alternately by an electric fan and by the natural movement of the air. It was found that the rate of oxygen absorption by roots during the active period of evaporation was from 50 to 100 per cent more rapid than during those periods in which the air was quiet. It was concluded that under conditions of rapid evaporation the rate of photosynthesis was less rapid than during quiet periods; less oxygen was evolved, and accordingly less available to plant tissues, including those of the roots. Thus a relatively heavy drain was placed on the oxygen in the soil air.

Other conclusions drawn by Cannon from this series of experiments were that there is probably a different critical concentration of oxygen for each species at different temperatures, and that there is a specific response to parallel amounts of oxygen and carbon dioxide in the soil air.

In an extensive article on the effect of soil aeration on plant growth, in which he reviewed the work of others as well as his own, Loehwing (30) presented the following conclusions:

1. Plants in aerated soils were heavier and taller than those in check plots. Plants receiving supplemental aeration made an earlier and more rapid growth.
2. Plants in aerated cultures had larger, more fibrous root systems and root cells were heavier and higher in reserve carbohydrates.
3. Aerated plants were able to absorb nutrients more rapidly as shown by higher content of ash, calcium, potassium and phosphorous.
4. Aerated plants were higher in total weight of crude fibers, starch, total sugars, and nitrogen.
5. The expressed sap of the tops and roots of aerated plants was more alkaline; a higher buffer capacity against alkali and acid was shown by the tops but the roots showed a lower buffer capacity against alkali and acid.

6. There was smaller top to root ratios in terms of fresh weight of aerated plants as compared to those in control plots.

Loehwing's (30) conclusions were that moderate rates of continuous soil aeration with moist air increased size and growth rate of plants, but very rapid aeration had the opposite effect. Species differed in their tolerance of soil aeration.

Bryant (12), Boynton (7), and Boynton, DeVillers, and Reuther (8) found results in their work on soil aeration that substantiated the work of the men mentioned previously.

Potassium, calcium, and sodium; their interactions

It is impossible to investigate the effects of these nutrients separately since their effects on one another and subsequent reactions on plant growth are just as important as their individual effects on plant growth.

The bulk of potassium absorbed by plants ordinarily moves into it in the early stages of its life cycle. Unlike all other ash constituents required by plants in appreciable amounts, potassium is not definitely known to be built into organic compounds of fundamental significance. It occurs in plants mostly as soluble inorganic salts. Potassium salts of organic acids also occur in plant cells. Nevertheless, potassium is essential to plant growth and cannot be replaced entirely by such chemically similar elements as sodium or lithium. Potassium, when available to the plant, is generally abundant in young meristematic tissue such as buds, young leaves, root tips, etc. Since older tissue contains comparatively little potassium, it is assumed that it is translocated to the younger, more rapidly growing sections.

Although the exact role of potassium is obscure, its chief role is considered to be a regulatory or catalytic one and it may exert many of its effects by influencing enzymatic activity. Potassium is considered necessary for the normal maintenance of the following processes:

1. Synthesis of simple sugars and starch.
2. Translocation of carbohydrates.
3. Reduction of nitrates.
4. Synthesis of proteins, particularly in meristems.
5. Normal cell division.

Study by Nightingale, Schermerhorn, and Robbins (32) showed that potassium deficient plants grown with ammonium nitrogen developed leaf breakdown symptoms totally dissimilar to potassium deficient plants grown with nitrate nitrogen. Chemical evidence attributed this breakdown to toxic concentrations of high internal ammomium. Chemical tests showed also potassium deficient plants in both the ammonium and the nitrate series accumulated ammonia, and amide and amino nitrogen, while the protein concentration decreased. At the same time the plants showed a high initial increase in carbohydrates, which finally decreased and fell below those plants supplied with adequate potassium.

In an extensive experiment designed to determine the effects of one nutrient or lack of it on the uptake of other nutrients, Bartholomew, Watts, and Janssen (1) drew the following conclusions:

1. The milligrams of nitrogen, phosphorous and potassium absorbed by plants receiving all nutrients essential to growth was controlled to a great extent by the concentration of those elements in the medium.
2. A deficiency of potassium in the nutrient medium increased absorption of nitrogen and phosphorous by the leaves, and an abundant supply of potassium increased the absorption of phosphorous by the stem.

He suggested that Liebigs "Law of the Minimum" was not applicable to fertilization with potassium salts, since potassium deficient plants showed an increase in the milligrams of nitrogen and phosphorous absorbed.

Hartt (22) grew sugar cane with varying amounts of potassium and with sodium instead of potassium and made the following observations:

1. The growth of sugar cane was proportional to the amount of potassium supplied.
2. The addition of potassium to plants deficient in that element resulted in a rapid absorption of potassium and a considerable increase in growth. The absorption of phosphorous and magnesium was decreased in those plants to which potassium was added.
3. Since equal amounts of potassium were absorbed by day and by night, it was concluded that the absorption of potassium was not affected by light.
4. Plants deficient in potassium absorbed more phosphosous, iron, calcium, magnesium and silicon than the controls.
5. In potassium deficient plants, there was an accumulation of iron in the roots and nodes, but when potassium was added some of the iron moved up into the blades. This was possibly due to an increase of turgor in the leaves, and to the upward movement of the transpiration stream.
6. Potassium deficient plants had a lower moisture content than the control plants.

7. Ash analysis showed potassium migrated from dying leaves to the living top of sugar cane. No other element did this.

8. There was some evidence that the transpiration rate of potassium deficient plants was less than that of the controls.

9. The effect of potassium deficiency upon the relative amounts of protein and amino nitrogen in the plants varied with their age.

   a. After two months there was a higher percentage of amino nitrogen and a lower percentage of protein nitrogen in the blades and stems of potassium deficient plants than in the controls.

   b. After seven months, there was a higher percentage of amino, protein and total nitrogen found in the blades of potassium deficient plants than in controls, while in the stems the opposite was true.

10. Conclusions from above results were that both synthesis and the translocation of proteins were diminished by potassium starvation; and that potassium deficiency resulted in a derangement in the transformation of hexoses to sucroses.

Regarding the controversial sodium for potassium substitution, Hartt found no evidence to indicate that sodium could substitute for potassium in any way in the nutrition of sugar cane.

In an attempt to study the effect of potassium, calcium and light on photosynthesis, protein synthesis, and translocation in the pea plant, Hibbard and Grigsby (25) found no evidence that increases in potassium or calcium were paralleled by increases in nitrogen and protein. Potassium and calcium absorption were found to be more rapid in light. Total ash was highest in those plants growing in a calcium deficient solution. The percentage of calcium was higher in plants deficient in potassium than in check plants or those grown in solutions devoid of calcium. The percentage of potassium was higher in plants growing in solutions lacking calcium than in the checks or in plants growing in solutions without potassium.

In studying the effect of potassium on plant growth and on the ability of different plants to absorb potassium from the soil, Drake and Scarseth (17) found that the best quality leaves on tobacco were obtained when the ratio of magnesium to potassium was 1 to 5.9. The response of various plants to potash fertilization was almost inversely proportional to the abilities of the plants to absorb native potash from the soil. Plants differed greatly in their ability to absorb potassium from soils low in exchangeable and soluble forms of this element.

Working on the effects of lack of potassium on transpiration rates of sunflowers, tobacco, and beans, Snow (39) made the following observations:

1. Transpiration decreased significantly in plants growing in solutions lacking potassium.
2. In solutions where sodium was substituted for potassium, there was either no significant difference between those plants and the checks, or the difference became apparent only in the last 45 hours of the experiment. The length of the experiment was nine days.

Reporting results obtained from work on potato discs, Sommer (40) gave the following: respiratory rates were increased by additions of potassium bromide, potassium chloride and potassium nitrate, and decreased by additions of calcium chloride, and calcium bromide, as compared with additions of distilled water. In aerated solutions potassium stimulated and calcium depressed water absorption.

Nightingale (31) found potassium to be necessary for nitrate absorption and suggested that potassium, with other elements, must be intimately associated with synthesis of protein from nitrates. He also gave evidence to show that potassium was important in carbon dioxide assimilation. Plants adequately supplied with potassium were materially higher in reserve carbohydrates than others deficient in this element.

Calcium.--This element plays a very important role in plant metabolism. It is a structural component of plant cell walls. Calcium ions have pronounced effects upon the permeability of cyto-plasmic membranes and upon the hydration of colloids. Lack of calcium interferes with the translocation of carbohydrates and amino acids. Calcium may occur in plant cells as calcium proteinate or insoluble crystals of calcium oxalate. It also forms salts by reactions with organic acids, thus preventing the accumulation of organic acids within the cells.

Concerning calcium-potassium ratios and their effects on growth of tomatoes and cucumbers, Tiedjens and Schermerhorn (42) reported that as long as calcium was abundant no detrimental effects from high potassium were noted. When calcium dropped below optimum concentrations and potassium remained high, the latter element had a pronounced depressive action on the uptake of calcium.

Results of their study on a calcium-sodium ratio were reported by them as follows:

1. The higher the proportion of calcium to sodium, the greater the percentage of dry matter in plants. They explained this by pointing

out the difference in affinity for water of sodium and calcium. They suggested that, since potassium has a similar affect to sodium, it is entirely possible that one of the functions of potassium is to counteract the effect of an over abundance of calcium.

2. There was an accumulation of protein in plants receiving high calcium.

As a general conclusion, Tiedjens and Schermerhorn suggested that one very important function of calcium is to hold the cell protoplasm in an equilibrium conducive to the synthetic processes that build up proteins rapidly.

From a study of the physicochemical relations of calcium, Bradfield (9) stated that this element is extremely important in flocculating soil colloids and thus preventing their leaching from the root zone. He showed also that as the carbon dioxide content of soil air increased, the percentage saturation of clay by calcium decreased. Bradfield considered the action of calcium in increasing the pH of the soil as one of its most valuable contributions.

Shear, Crane, and Myers (37) substantiated the findings of other workers regarding calcium and potassium and suggested some points not brought out by others. They observed that the most pronounced relationship was between the $\frac{Ca - K}{mg}$ ratio and boron. A high ratio of $\frac{Ca - K}{mg}$

consistently resulted in boron toxicity. A high $\frac{Ca - Mg}{K}$ ratio also increased boron toxicity, but high $\frac{K - Mg}{Ca}$ ratios had alittle effect on the appearance of boron toxicity. They also observed that definite relationships existed between the accumulation in the leaves of the three bases, namely, calcium, potassium, and magnesium, and the accumulation of manganese, zinc, copper, and iron. They pointed out that symptoms of manganese deficiency were found to be associated with a high accumulation of any one of the three bases, and were most severe when all three were high in proportion to manganese. Thus conditions promoting increased accumulation of these three bases worked in two ways to produce manganese deficiency; first, by depressing the accumulation of manganese, and second, by increasing the concentration of manganese required in the leaf to create a proper balance with the other elements.

Sodium.--From an experiment on millet, wheat, oats, barley, and rye seedlings to test the theory that sodium could act as a partial substitute for potassium, Hartwell and Pember (23) gave the following observations:

1. When potassium was withheld to such an extent that the growth of the seedlings was depressed, an addition of sodium resulted in

an increase in the production of seedlings tops.

2. When potassium was increased or the sodium added, the increase of transpiration was usually less than the increase of green weight.
3. An excess ratio of magnesium to calcium markedly reduced transpiration and root growth.
4. During a given time less potassium was absorbed by the seedlings when the potassium was supplemented by sodium. Sodium was a conserver of potassium.

These workers concluded that some of the functions of potassium in some plants could be performed by sodium. They stated also that there were certain principal functions of potassium which could not be performed by any other element. If the amount of potassium was insufficient for these functions, maximum growth could not be secured with any amount of sodium.

Work by Lehr (28) gave evidence that in the event of a potassium shortage, sodium was translocated to the foliage, releasing certain amounts of potassium for use in other parts of the plant. He supported other investigations in stating that because the effects of sodium depend on special circumstances and crops, the importance of sodium and potassium change with the crop.

Harmer and Benne (21) divided plants into two groups; those benefited by sodium when potassium was low, and those benefited when potassium was abundant. They concluded that sodium served no definite function in those plants benefited only when potassium was low, but that it did substitute for or assist with the functions of potassium.

When Harmer and Benne added sodium to a nutrient solution containing abundant potassium, some plants showed improved vigor and color of foliage. These plants also showed increased disease resistance, decreased wilting in hot weather, and their foliage continued growing for a longer period. It was in these plants that these men assumed sodium had a definite function it alone could fulfill.

Absence of sodium in sodium-responsive plants resulted in increased absorption of potassium. Absence of potassium in sodium responsive plants resulted in physiological breakdown because sodium could not serve all the functions of potassium.

Shear, Crane and Meyers (37) inferred that one of the principal effects of sodium in sodium accumulating plants resulted from its differential depressing effect on other bases. Thus, at times sodium caused a more favorable calcium-magnesium-potassium ratio in the plant in which case beneficial effects resulted from its accumulation. Under other conditions, accumulation of sodium produced a less favorable ratio between these elements and subsequent detrimental effects.

Chapter III

METHODS AND MATERIALS

In setting up this experiment, tests for sand, silt, clay, aeration, organic matter, potassium, calcium, and sodium were selected on the basis of their potential adaptability to commercial use.

General procedure

In this investigation a ten foot section of a bench of the carnation variety William Sim was selected in each of 40 commercial greenhouses. Special effort was made to select a section in each house that was representative of the type of growth in that house. This section was watered thoroughly, then allowed to drain for one hour. Measurements were made at the end of that hour to determine the air supply in the soil. Ten samples were taken at random throughout the bench and their average air content was considered representative of that section.

All normal flowers at approximately the same stage of maturity in each test section were cut and the quality of growth determined by average weight per inch of stem length. Each flower was cut to its point of origin and measured in inches. Side branches were removed and the flowers were then weighed on a dietary scale in grams and the weight divided by the length to give a quality index in grams per inch. All flowers from one section were then averaged. This average or index was considered to be indicative of the quality of the flowers found in that section.

Ten soil samples were taken at random from each test section. After removal of loose mulch, complete cores were taken with a sampling tube and mixed to give one composite sample for each test section. The samples were brought back to the laboratory, air dried, and screened through a 0.5 mm. screen. They were then analyzed for the desired factors.

All tests were run in duplicate, and results agreed closely.

A questionnaire pertinent to the treatment of the soil in the chosen section was submitted to the growers and answered by them as far as possible. (See Appendix). Notes also were made by the author regarding temperatures, light and other factors which might have affected the quality of growth in each section. The answers to the questionnaire and observations by the author were used as aids in interpreting results obtained.

<u>Mechanical analysis</u>

The Bouyoucos method (6) for determining the percentage of sand, silt, and clay in a soil sample by the hydrometer was used. Sodium silicate and sodium oxalate were added to the soil suspensions to precipitate the calcium and also to aid in dispersing the soil particles. The suspensions were then stirred for 20 minutes with a mechanical stirrer to insure complete dispersion. The new type hydrometer with the stream-lined bulb was used and was removed at the end of every reading. The temperature of the solution was taken at every reading and corrections were made for temperature changes. The extremes of temperatures at which readings were taken ranged from 78.8^{o}F to 88.8^{o}F. Two readings were taken; one at 40 seconds and one two hours after shaking the suspension.

This method of mechanical analysis was chosen because it is rapid, cost of materials is low, and results are comparable to those by other empirical methods. As pointed out by Bouyoucos and also by Keen (27) the experimental errors are approximately nullified or compensate one another.

Organic matter

Comparison of the methods of organic matter determination, their speed and accuracy of results showed the Walkley-Black method (43) is comparable to others in results, is faster, and requires less expensive equipment.

In this method the organic carbon of the soil is digested with chromic and sulphuric acids, making use of the heat of dilution of the sulphuric acid. The excess of chromic acid not reduced by the organic matter of the soil is then determined by titration with standard ferrous sulphate. To prevent interference from chlorides likely to be present in the soil, 1.25 g of silver sulphate were dissolved in each 100 ml of sulphuric acid used. By precipitating the chlorine as silver chloride, this prevented the reduction of chromic acid by the chlorine present. The end point in every test was very sharp. The amount of carbon oxidized was determined by the formula:

$$\frac{V_1 - V_2}{W} \times 0.003 \times 100 = \text{Carbon oxidized}$$

V_1 = volume of N potassium dichromate (ml)

V_2 = volume of N ferrous sulphate (ml)

W = weight of soil taken

The percentage recovery of organic matter by this method for the majority of agricultural soils lies between 75 and 80 per cent. They are reported as "Organic Carbon, Walkley-Black values".

Air supply

A new instrument for determining the percentage of soil volume occupied by air has been devised by Russell (36). This instrument, called the air picnometer, has given results very similar to those obtained by other methods. It is very rapid and the results are easily duplicated.

A soil sample of known volume is placed in an air tight system in which the gas pressure is known. The volume of the system is then changed by a known amount and the resultant pressure is measured. From this data and comparison with a curve calibrated with a series of brass discs of known size, the percentage of the sample volume that is filled with air can be calculated. The curve calibrated from brass discs of sizes varying from 5 to 100 per cent of total volume of cylinder is shown in Fig. 1.

As was stated in the general procedure, the percentage of air-filled pores was determined at the greenhouses, one hour after thorough watering of the section.

Nutrient tests

The extraction solution for use in testing for potassium, calcium, and sodium was made according to Spurway (41).

Potassium.--Bray's test (11) for potassium was used. This is known as the sodium cobaltinitrite test in which potassium is precipitated as potassium cobaltinitrite. The amount of precipitation was measured by using the Cenco photolometer. The photolometer reading was converted to parts per million by comparison with a curve established with known solutions, Fig. 2.

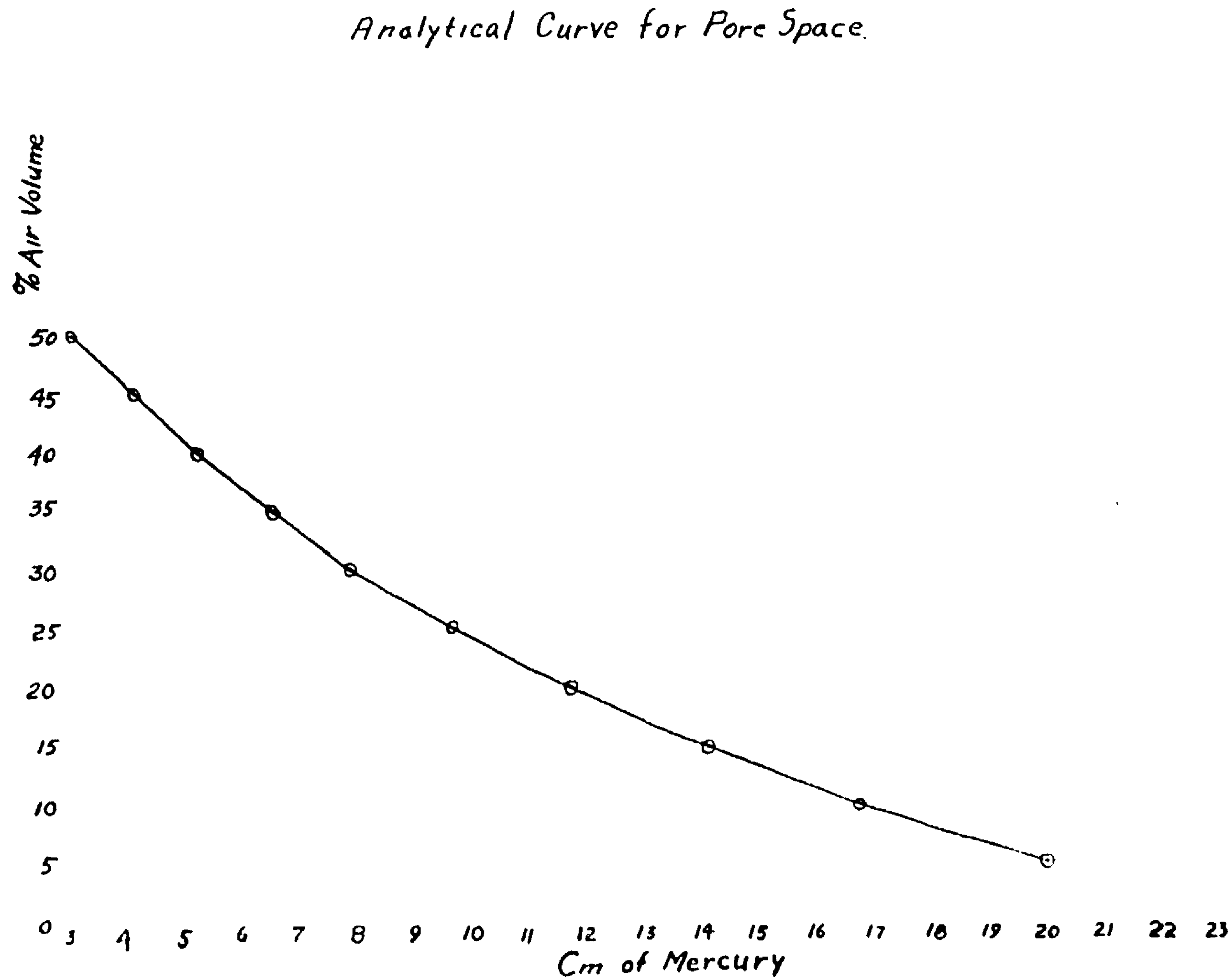


Fig. 1.--Analytical curve for converting air picnometer mercury readings of soils to per cent of soil occupied by air.

Fig. 2.--Analytical curve for converting photolometer reading to parts per million of potassium in solution.

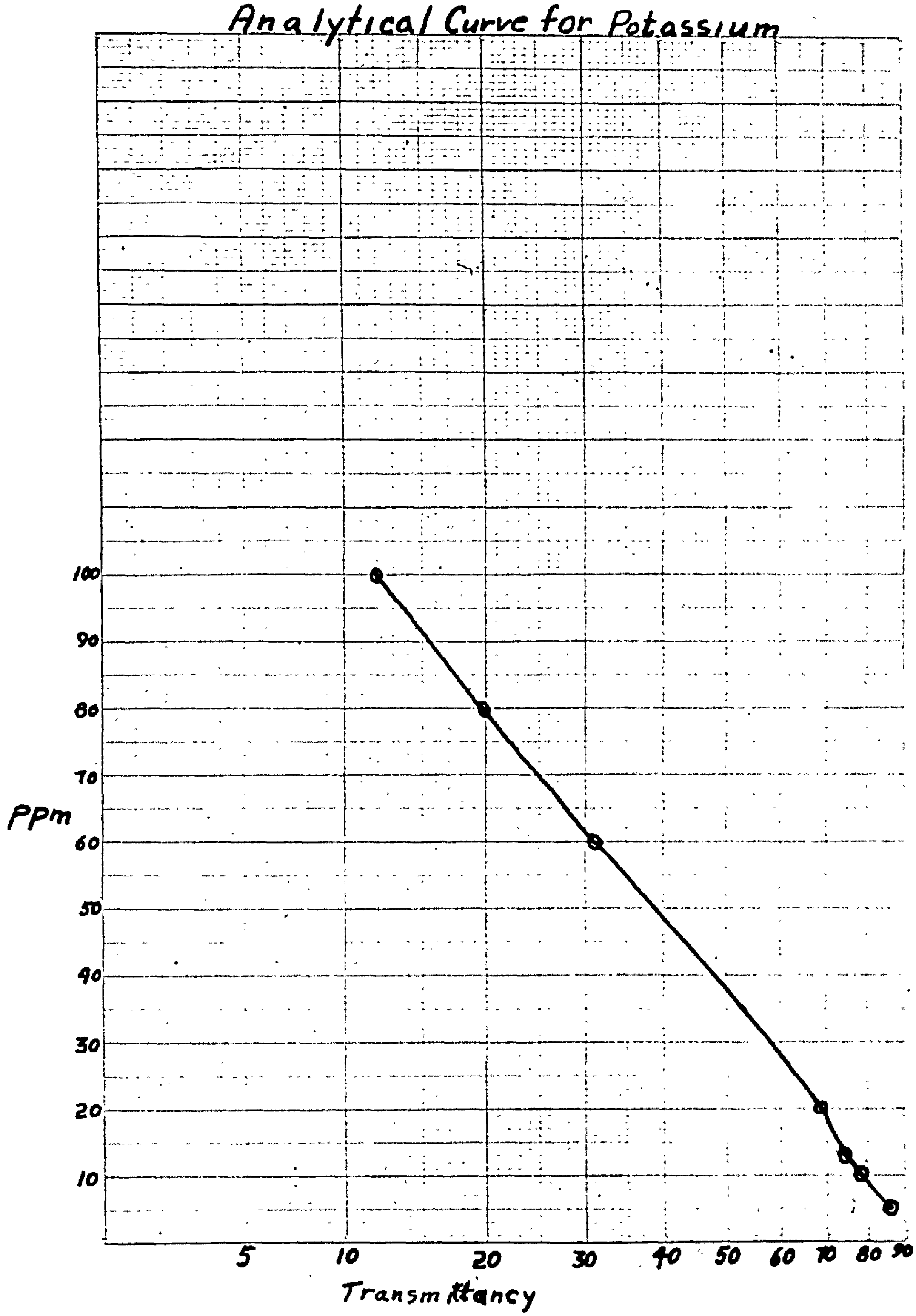
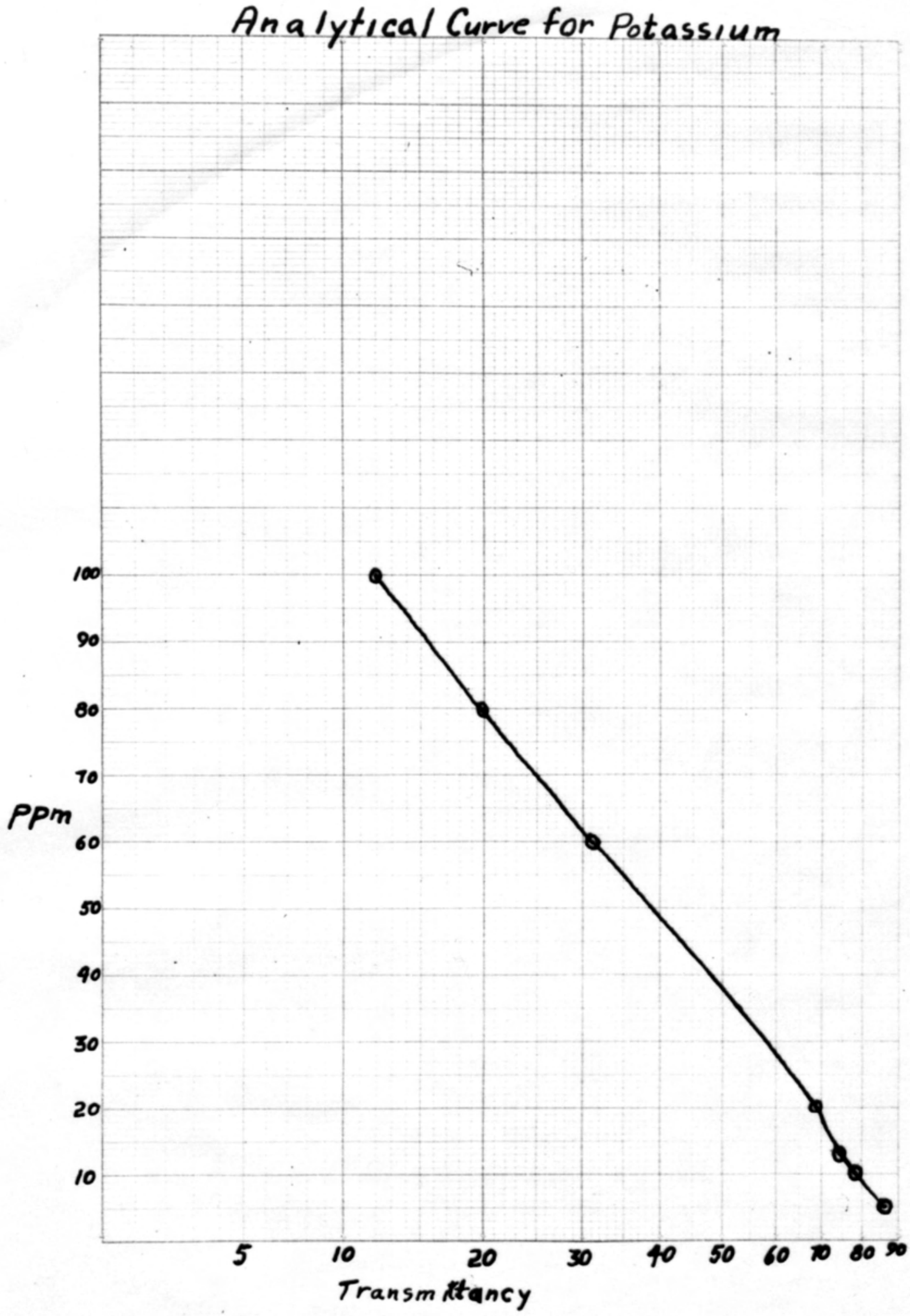


Fig. 2.--Analytical curve for converting photolometer reading to parts per million of potassium in solution.



Inasmuch as temperature affects the amount of precipitate formed, the tests were run at a constant temperature of 70°F. Reagents were made up fresh for the tests.

Calcium.--Peech's ammoniacal-soap solution test (33) for calcium was used. In this test, as in the one for potassium, the precipitate formed was measured by the Cenco photolometer and was converted to parts per million by comparison with a curve made up from known solutions, Fig. 3.

Sodium.--Spurway's magnesium uranyl acetate test (41) was used to determine sodium. The sodium present was precipitated as sodium uranyl acetate, and was estimated as blank, low, medium, or high in quantity.

Supplemental experiment on potassium, calcium, sodium ratios

In addition to testing the 40 greenhouse soils for potassium, calcium and sodium and their effect on the quality of the carnation, a sand-nutrient solution experiment was set up in the Colorado A & M research greenhouses to test the effects of varying proportions of these three elements on the quality of growth of carnations.

The experiment was set up in the form of a triangle with a total of 21 one-gallon glazed crocks. There were six crocks to a side. (See Fig. 4). The nutrient

Fig. 3.--Analytical curve for converting photolometer readings to parts per million calcium in solution.

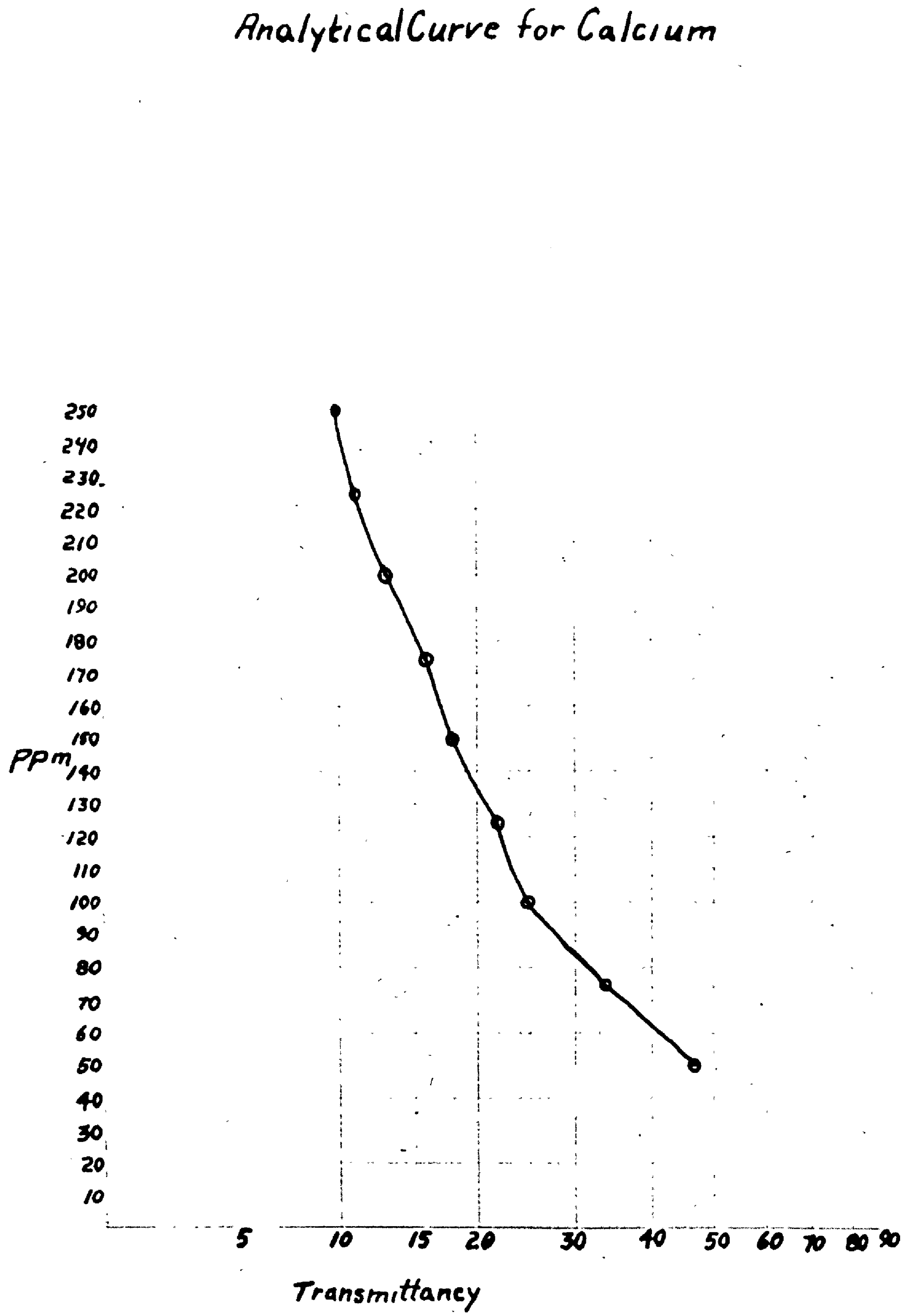


Fig. 3.—Analytical curve for converting photolometer readings to parts per million calcium in solution.

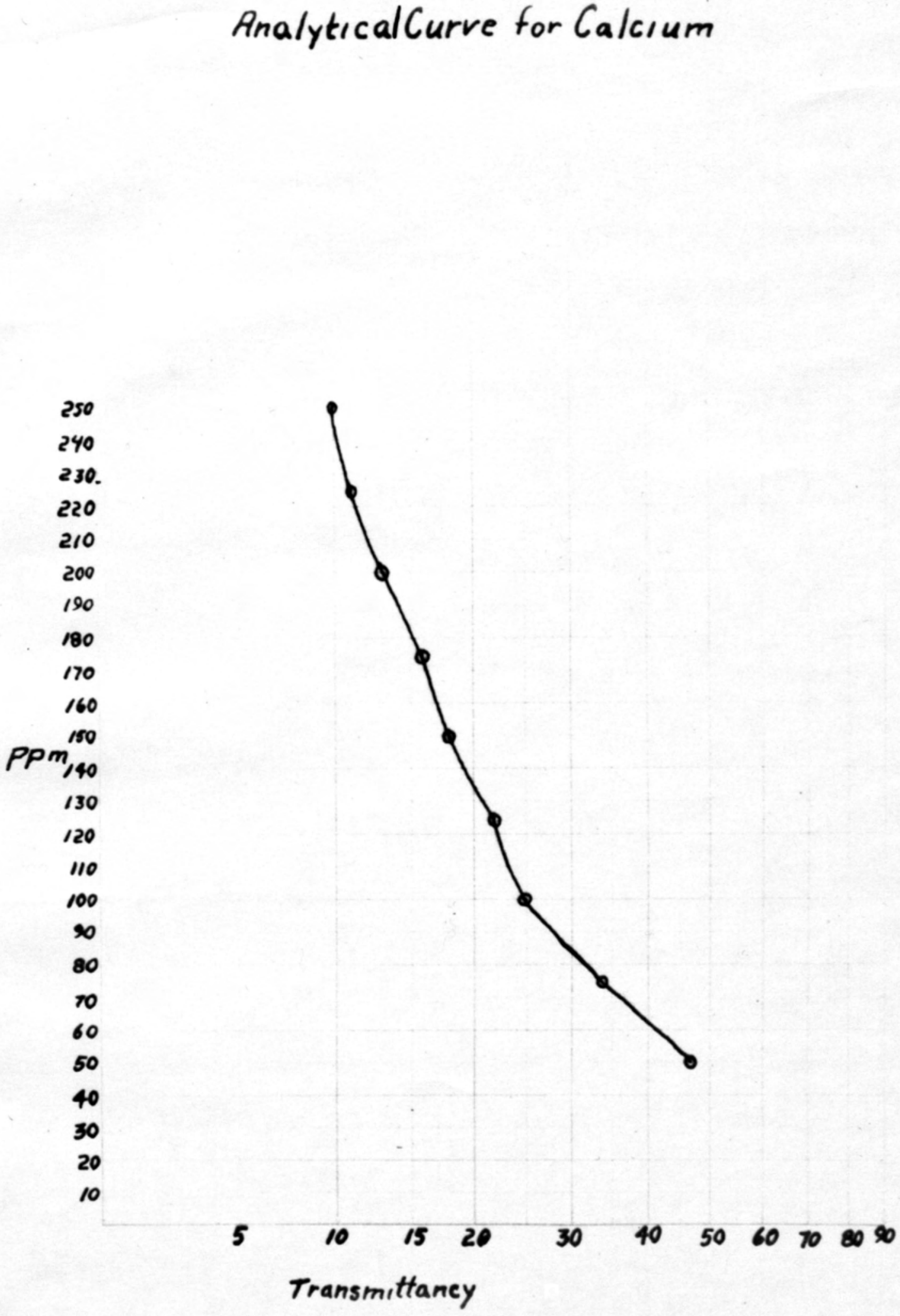
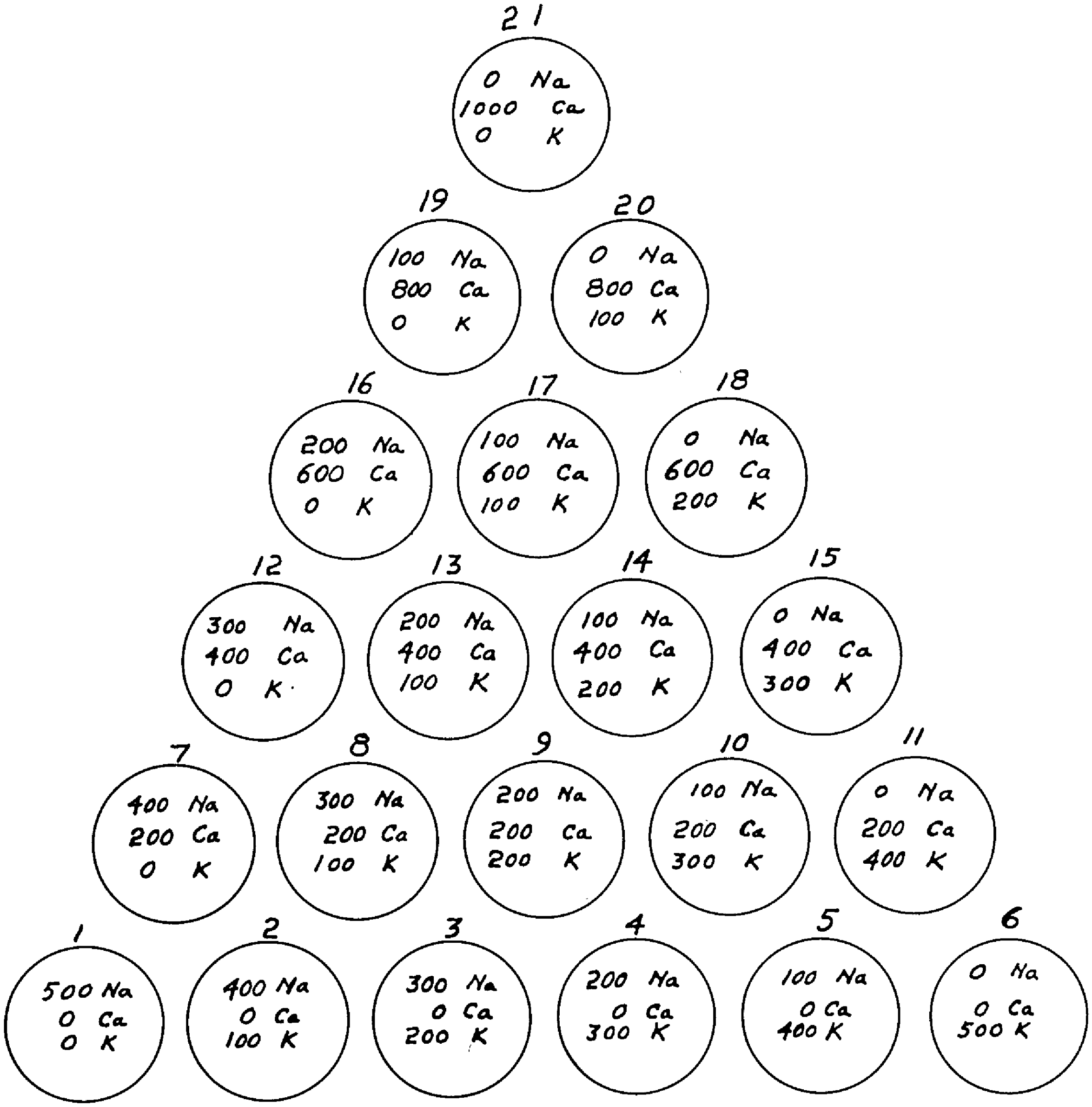


Fig. 4.--Schematic diagram of potassium, calcium, sodium experiment.



solutions used for the plants were complete with the exception of potassium which varied from 500 ppm. to 0 ppm., calcium from 1,000 ppm. to 0 ppm., and sodium from 500 ppm. to 0 ppm. These were made up as shown on pages 71 - 75 Appendix, and replicated twice.

The nutrient solutions were made up in concentrated form, (20 x that used on the plants) and diluted 190 cc H_2O to 10 cc of the concentrate at feeding time.

Pinched plants that had been grown in sand without nutrients were planted two to a crock on July 23, 1951. They were watered on the same day and were given the nutrient solution on the following day and every sixth day thereafter.

On November 28, 1951, the experiment was terminated. Photographs were taken to show the differences in growth and the plants were then cut off at the soil line. The tops were weighed green then dried in a circulating oven at 125°F for 48 hours and weighed again. The dry weight and moisture content of the tops were determined for each plant given each nutrient solution.

Chapter IV

ANALYSIS OF DATA

The results of the tests for the various factors under consideration are given in Table 1. Since the tests for calcium were consistently high, around 250 p.p.m., and the tests for sodium were consistently low, with little or no variation for either nutrient, the results for these two factors were discarded.

Total correlation

Total correlation of each factor was calculated by the formula recommended by Snedecor (38), presented below.

$$r = \frac{N\ S(xy) - S(x)\ S(y)}{\sqrt{\left[N\ Sx^2 - S(x)^2\right]\left[N\ S(y^2) - S(y)^2\right]}}$$

Table 2 includes the calculated total correlation coefficients between all factors as well as between each factor and quality alone.

Table 1.--RESULTS OF SOIL TESTS OF 40 COMMERCIAL GREENHOUSE SOILS AND THE QUALITY OF GROWTH OF CARNATIONS FOUND FOR EACH SOIL.

Soil Number	Quality Index	Percent Pore Space	Percent Sand	Percent Silt	Percent Clay	Percent Organic Matter	ppm. Potassium	ppm Calcium	Sodium
1	1.305	19	69	25	6	2.56	19	250	Trace
2	1.193	10	68	23	8	2.60	21	250	"
3	1.128	13	71	21	8	2.66	48	250	"
4	1.110	21	49	36	15	2.68	50	250	"
5	1.062	14	61	29	10	2.73	37	250	"
6	1.062	12	53	41	6	2.04	44	250	"
7	1.053	15	73	20	7	2.58	44	250	"
8	1.045	17	60	22	18	2.69	31	250	"
9	1.043	14	62	27	11	3.19	45	250	"
10	1.036	20	69	22	9	2.86	45	250	"
11	1.034	20	79	15	6	2.36	3	175	"
12	1.014	18	71	23	6	2.62	21	250	"
13	1.011	38	76	18	6	2.87	38	250	"
14	1.008	17	42	37	21	3.20	38	250	"
15	1.008	18	81	13	6	2.35	3	220	"
16	.996	12	68	21	11	2.62	48	250	"
17	.982	11	78	13	9	2.23	45	250	"
18	.961	8	59	40	1	2.40	50	250	"
19	.945	8	84	14	2	1.84	20	250	"
20	.939	5	64	24	12	2.74	45	250	"
21	.936	17	46	28	26	3.13	50	250	"
22	.931	14	60	26	14	2.32	42	250	"
23	.929	36	77	15	8	2.23	38	195	"
24	.924	11	74	21	5	1.96	50	250	"
25	.923	9	72	21	7	1.86	12	250	"
26	.912	15	44	34	22	2.64	35	190	"
27	.912	11	65	20	15	2.16	46	250	"
28	.904	6	48	32	20	2.38	50	250	"
29	.893	10	86	10	4	1.90	31	250	"
30	.883	19	62	21	17	2.73	37	250	"
31	.882	19	66	22	12	2.49	42	250	"
32	.871	16	62	32	6	1.96	23	250	"
33	.869	7	60	24	16	2.56	32	250	"
34	.860	22	58	26	16	2.31	8	250	"
35	.853	14	42	39	19	2.22	34	250	"
36	.786	15	66	21	13	2.07	40	250	"
37	.780	29	50	45	5	2.90	50	250	"
38	.761	6	83	12	5	2.02	25	250	"
39	.758	4	78	17	5	1.23	21	250	"
40	.744	17	62	32	6	2.04	27	250	"

Table 2.--TOTAL CORRELATION COEFFICIENTS FOR ALL INTER-RELATIONSHIPS BETWEEN FACTORS B TO G AND THE RELATIONSHIPS BETWEEN EACH OF THESE FACTORS AND QUALITY OF GROWTH OF CARNATIONS.

	A Quality	B Per cent Pore Space	C Per cent Sand	D Per cent Silt	E Per cent Clay	F Per cent Organic Matter	G Potassium ppm
A Quality	0						
B Per cent Pore Space	.0133	0					
C Per cent Sand	.0406	-.0537	0				
D Per cent Silt	-.0130	.0690	-.8682**	0			
E Per cent Clay	-.0682	.0092	-.7207**	.2944	0		
F Per cent Organic Matter	.4332**	.3859*	-.4617**	.3217*	.0045	0	
G ppm Potassium	.0135	-.0061	-.3998*	.3633*	.2685	.3764*	0

* Significant at .05 level
** Significant at .01 level

r values necessary to show significance are .313 at the .05 level and .403 at the .01 level

Factors which should be pointed out at this time are as follows:

1. The effect of organic matter on quality was significant at the one per cent level.
2. The effect of organic matter on pore space was significant at the five per cent level.
3. The effect of sand on organic matter content was significant at the one per cent level.
4. There was no apparent effect of sand on the pore space.
5. The effects of silt on organic matter and silt on potassium content were significant at the five per cent level.
6. The effect of organic matter on the potassium content was significant at the five per cent level.

Multiple correlation

To determine the total effects of the factors studied on the quality of growth of carnations, multiple-correlation was calculated using a method recommended by Hayes and Immer (24). In this method the standard partial-regression coefficients are determined, Table 3, and these in conjunction with the total correlation coefficients are used to determine the total effect.

Table 3.--PARTIAL-REGRESSION COEFFICIENTS OF THE INTER-RELATIONSHIPS BETWEEN GROWTH QUALITY OF CARNATIONS (A), AND PORE SPACE (B), SAND (C), SILT (D), CLAY (E), ORGANIC MATTER (F), POTASSIUM (G), OF THE SOIL.

* $\beta_{AB.CDEFG}$	=	0.0407
* $\beta_{AC.BDEFG}$	=	-2.0207
* $\beta_{AD.BCEFG}$	=	-1.4400
* $\beta_{AE.BCDFG}$	=	-1.1150
* $\beta_{AF.BCDEG}$	=	-0.0662
* $\beta_{AG.BCDEF}$	=	0.0533

*Factors to the left of the decimal point are correlated while the factors to the right are held constant.

The multiple-correlation coefficient measures the degree to which the dependent variable is influenced by the other factors studied and is calculated from the formula given below.

$$R^2_{A.BCDEFG} = r_{AB} \times \beta_{AB.CDEFG} + r_{AC} \times \beta_{AC.BDEFG} + r_{AD} \times \beta_{AD.BCEFG} + r_{AE} \times \beta_{AE.BCDFG} + r_{AF} \times \beta_{AF.BCDEG} + r_{AG} \times \beta_{AG.BCDEF}.$$

The multiple correlation $R = 0.122$. Squaring this factor and multiplying by 100 gave 1.49 per cent of the quality of growth of carnations that was affected by the factors studied.

Supplemental experiment

As was stated in Chapter III, a supplemental sand-nutrient experiment was undertaken to determine the effects of different levels of potassium, calcium, and sodium on the growth of carnations. The results of this experiment are included in Table 4.

Attention should be directed at this point to the decrease in percentage of weight lost on drying of green plant tissue. The water content of the plants decreased significantly as the calcium level was increased. High sodium treatment plants had significantly more water than did high potassium plants.

Using the analysis of variance given by Snedecor (38) to determine the significance of differences in per cent weight lost on drying by the different treatments, an "F" value of 14.335 was obtained. The required "F" value to show significance at the one per cent level was 8.10. The LSD at this level was 1.71.

Fig. 5 is a photograph of four of the sets of plants receiving different treatments. The differences in degree of maturity should be noted.

Table 4.--RESULTS OF MOISTURE PERCENTAGE DETERMINATIONS FOR POTASSIUM, CALCIUM, SODIUM TREATMENTS.*

Treatment Number	A				B				Mean % Loss
	Green Weight(g)	Dry Weight(g)	Loss of Weight(g)	% Loss Green Weight	Green Weight(g)	Dry Weight(g)	Loss of Weight(g)	% Loss Green Weight	
1	59.5	10.5	49.0	82.4	62.0	11.0	51.0	82.3	82.35
2	68.5	12.5	56.0	81.8	59.5	11.5	48.0	80.7	81.25
3	55.5	11.0	44.5	80.2	72.5	14.5	58.0	80.0	80.1
4	75.0	15.5	59.5	79.3	58.0	11.0	47.0	81.0	80.15
5	66.5	13.5	53.0	79.7	68.0	14.0	54.0	79.4	79.55
6	64.0	12.5	51.5	80.5	70.0	13.0	57.0	81.4	80.95
7	66.0	12.0	54.0	81.8	51.0	10.0	41.0	80.4	81.1
8	51.5	10.0	41.5	80.6	66.0	12.5	53.5	81.1	80.85
9	69.5	14.0	55.5	79.9	56.0	10.5	45.5	81.3	80.6
10	60.0	12.0	48.0	80.0	74.0	15.0	59.0	79.7	79.85
11	51.5	10.5	41.0	79.6	51.5	11.0	40.5	78.6	79.1
12	63.5	13.5	50.5	79.1	60.0	12.5	47.5	79.2	79.15
13	59.0	12.5	46.5	78.8	60.5	13.5	47.0	77.7	78.25
14	53.0	11.0	42.0	79.2	56.5	11.5	45.0	79.6	79.40
15	68.0	14.5	53.5	78.7	75.0	16.0	59.0	78.7	78.70
16	75.0	16.0	59.0	78.7	52.0	11.5	40.5	77.9	78.30
17	55.0	12.0	43.0	78.2	58.0	13.0	45.0	77.8	78.00
18	65.0	14.0	51.0	78.5	67.5	14.5	53.0	78.5	78.50
19	58.0	13.0	45.0	77.6	53.0	12.5	40.5	76.4	77.00
20	53.0	12.5	40.5	76.4	55.0	13.0	42.0	76.4	76.4
21	56.0	13.5	42.5	75.9	69.0	16.0	53.0	76.8	76.35

*For key to treatments see appendix and for key to experimental design see Fig. 4.

Chapter V

DISCUSSION

The total correlation-coefficients, Table 2, employed to test significance of the effect of pore space, sand, silt, clay, organic matter, potassium, calcium, and sodium on the quality of growth of the William Sim carnation, showed that only organic matter had a significant effect and that effect was significant at the one per cent level. This concurs with the results of Link and Culvert (29) in their work on Briarcliff roses. They found that organic matter increased stem length and stem diameter as well as production of flowers.

The significant effect of organic matter on quality obtained in this experiment is readily discernible when the beneficial effects of organic matter on soils in general are reviewed. One of the principal effects is to increase the aggregation of the soil thereby increasing the air supply or pore space of the soil. Total correlation between organic matter and pore space was significant at the five per cent level. Increasing the organic matter of a soil increases its water holding capacity, thereby making a more uniform moisture supply available to plants over longer periods.

Colloidal humus (organic residue) acts as an adsorbing surface for nutrients in the soil and prevents their leaching from the root zone. This may be shown by the total correlation between potassium and organic matter which was significant at the five per cent level.

The highly significant negative correlation-coefficient between sand and organic matter was interesting. It might be assumed that increasing the sand content of a soil would increase the macro-pores thereby increasing the air supply of the soil to the point where the increased air would increase the rate of decomposition of organic matter. This would decrease the amount of organic matter remaining in the soil. That this apparently is not the case can be shown by the lack of correlation between sand and pore space. Another and more probable answer could lie in the organic matter content of the original soil as influenced by the soil forming processes. A soil originally high in sand would have little chance to build up organic matter due to the low nutrient level of sandy soils and their low water holding capacity. If organic matter were not added to a sandy soil at the time it was placed in the bench, it would of necessity be low in organic matter at testing time. Another probable reason could be that soil is composed of four fractions; sand, silt, clay, and organic matter. An increase of any of these would result in the decrease of the other three fractions.

There was significance at the five per cent level between silt and organic matter, and silt and potassium. The effect of silt on potassium content of the soil may be explained in part by the fact that silt approaches colloids in size and in so doing exhibits small powers of attractions on the elements or nutrients in the soil, thus holding them in the root area.

Silt also greatly inhibits the movement of water through a soil and in so doing would tend to reduce the leaching of the nutrients from the root zone. It is the general belief of most investigators that the over-all effect of silt is detrimental to good soil structure and to quality of growth, therefore its effect would be negative. A tendency toward this is shown by the slight negative correlation between silt and quality.

The correlation between silt and organic matter may be explained in part by a reduction in the air supply of the soil caused by increased amounts of silt. There is no evidence in this experiment of the detrimental effect of silt on pore space.

Lack of correlation between clay content of the soil and other factors studied is rather puzzling. Although the correlation between clay and potassium approached significance it did not show as high a correlation as that between silt and potassium. This could be explained partially by showing that the clay was a type with a low exchange complex. Facilities were not available to determine the types of clay in the soils studied. Much more work needs to be done on effects of clay on growth qualities and other factors in the soil under greenhouse conditions.

Multiple correlation indicated that only 1.49 per cent of the quality of growth of carnations was affected by all the factors studied. This was disappointingly low but served to point out that there were many factors not under control, all of which exerted some influence upon quality of growth.

Supplemental experiment

Pointed out in the review of literature were the effects that potassium, calcium, and sodium have on the growth of plants other than carnations. The purpose of this experiment was to determine the effects of different levels of these three nutrients on the growth of carnations.

The evidence that calcium increases the amount of dry weight produced by the plants substantiated the work of other investigators. Both potassium and sodium increased the water content of the plants as shown by increased loss of weight on drying. The differences were highly significant, with sodium causing the greatest increase in water content.

High calcium and low potassium and sodium treatments caused an apparent delay in maturity of carnations in this experiment, Fig. 5. In spite of all efforts to keep the nutrients under strict control, soil tests at the end of the experiment showed traces of all three nutrients present in all the treatments. It is probable that the sand used contained very small amounts of these nutrients. This would account for the absence of extreme deficiency symptoms on the treatments.

It is assumed from the results of this experiment that sodium can substitute, at least in part, for potassium in the metabolism of the carnation plant. When sodium was abundant, no detrimental effects were noted in the treatments where the potassium level was considered to be far below that required for normal plant growth.

Suggestions for further study

1. Under controlled conditions, an experiment may be designed to test the effects of various percentages of sand, silt, and clay on plant growth in the greenhouse.
2. An experiment should be established to test the effects of soils with various base exchange capacities on feeding practices and

Fig. 5--. Photograph showing different stages of growth caused by varying levels of potassium, calcium, and sodium.

subsequent plant growth. The base exchange capacities of these soils could be varied by using different types and amounts of clay, and by varying the amount of organic matter.

3. An investigation to determine the adverse effects of silt on water movement, air supply, and nutrients in greenhouse soils should yield valuable information.
4. An investigation into the effects of different calcium, sodium, and potassium levels on the keeping quality of carnation blooms would be of great interest.

Chapter VI

SUMMARY

An attempt was made to correlate the effects of per cent pore space, sand, silt, clay, organic matter, potassium, calcium and sodium content of the soil with the quality of carnation growth. The inter-relationships of these soil factors also were studied.

1. Total correlation-coefficients showed that only organic matter had a significant effect on quality. This effect was significant at the one per cent level.
2. Total correlation-coefficients found in the inter-relationships between factors studied were as follows:
   a. Significance at the five per cent level between organic matter content and pore space.
   b. Significance at the five per cent level between potassium and organic matter.
   c. Significance at the five per cent level between silt and organic matter.

d. A negative correlation significant at the one per cent level between the percentage of sand in the soil and organic matter content.

e. A negative correlation significant at the five per cent level between sand and potassium.

f. Significance at the one per cent level between silt and potassium.

3. Multiple correlation indicated that only 1.49 per cent of the quality of growth was affected by the factors studied.

4. A supplemental sand-nutrient experiment to test the effects of different levels of potassium, sodium, and calcium on the growth of carnations indicated that:

   a. A high calcium, low sodium-potassium ratio produced greater dry weight per plant than did a high potassium-sodium, low calcium ratio. Plants receiving high sodium contained significantly more water than those receiving high potassium.

b. A high calcium, low sodium-potassium ratio delayed maturity. The most rapidly maturing plants were those receiving 400 p.p.m. calcium, 200 p.p.m. sodium, and 100 p.p.m. potassium in solution.

B I B L I O G R A P H Y

BIBLIOGRAPHY

1. Bartholomew, R. P., V. M. Watts, and G. Janssen. Effect of variations in the nutrient media upon the N, P, and K contents of plants with special reference to tomato. Arkansas Agr. Exp. Sta. Bul, 288, 1933.

2. Baver, L. D. The relation of exchangeable cations to the physical properties of soils. J. Amer. Soc. Agron., 20:921-941, 1928.

3. Baver, L. D. The effect of organic matter upon several physical properties of soils. J. Amer. Soc. Agron., 22:703-708, 1930.

4. Baver, L. D. Soil Physics. John Wiley and Sons, Inc., 1948.

5. Baver, L. D. and G. M. Horner. Colloidal properties of soil organic matter. Missouri Agr. Exp. Sta. Res. Bul., 267, 1937.

6. Bouyoucos, G. J. Directions for making mechanical analyses of soils by the hydrometer method. Soil Sci., 42:225-229, 1936.

7. Boynton, D. Soil atmosphere and the production of new rootlets by apple root systems. Proc. Amer. Soc. Hort. Sci., 37:19-26, 1940.

8. Boynton, D., J. I. DeVilliers, and W. Reuther. Are there different critical oxygen concentrations for the different phases of root activity? Science, 88:569-570, 1938.

9. Bradfield, R. Calcium in the soil. I Physico-chemical relations. Soil Sci. Soc. Amer. Proc., 6:8-15, 1941.

10. Bray, R. H. Chemical and physical changes in soil colloids with advancing development in Illinois soils. Soil Sci., 43:1-14, 1937.

BIBLIOGRAPHY.--Continued

11. Bray, R. H. Photometric methods for determining available potassium in the soil. Illinois Agr. Exp. Sta. Agron. Dept. pamphlet A G 1275, 1945.

12. Bryant, A. E. Comparison of anatomical and histological differences between roots of barley grown in aerated and non-aerated culture solutions. Plant Physiol., 9:389-391, 1934.

13. Cannon, W. A. On the relation between the rate of root growth and the oxygen of the soil. Carnegie Inst. of Wash. Yearbooks, 15:74-75, 1916; 16:82-83, 1917; 17:81-83, 1918; 31:294-296, 1931-1932.

14. Cannon, W. A. Physiological features of roots with special reference to the relation of roots to aeration of the soil. Carnegie Inst. of Wash. Pub., 368, 1925.

15. Chang, H. T. <u>and</u> W. E. Loomis. Effect of carbon dioxide on absorption of water and nutrients by plants. Plant Physiol., 16:327-341, 1916.

16. Clements, F. E. Aeration and air content, the role of oxygen in root activity. Carnegie Inst. of Wash. Pub., 315, 1927.

17. Drake, M. <u>and</u> G. D. Scarseth. Relative abilities of different plants to absorb potassium and the effects of different levels of potassium on the absorption of calcium and magnesium. Soil Sci. Soc. Amer. Proc., 4:201-204, 1939.

18. Durell, W. D. Effect of aeration on growth of tomato plants in nutrient solutions. Plant Physiol., 16:327-341, 1916.

19. Feustel, I. C. <u>and</u> H. G. Byers. The comparative moisture absorbing and moisture retaining capacities of peat and soil mixtures. U. S. Dept. Agri. Tech. Bul., 532, 1936.

20. Fossum, M. T. Floricultural and Ornamental Horticultural Economics. Soc. Amer. Florists, 1950.

BIBLIOGRAPHY.--Continued

21. Harmer, P. M. and E. J. Benne. Sodium as a crop nutrient. Soil Sci., 60:137-148, 1945.

22. Hartt, C. E. Some effects of potassium on the growth of sugar cane and upon the absorption and migration of ash constituents. Plant Physiol., 9:399-452, 1934.

23. Hartwell, B. L. and F. R. Pember. Sodium as a partial substitute for potassium. Rhode Island Agr. Exp. Sta. Ann. Rpt., 243-285, 1908.

24. Hayes, H. K. and F. R. Immer. Methods of Plant Breeding. McGraw-Hill Book Co., 1942.

25. Hibbard, R. P. and B. H. Grigsby. Relations of light, potassium, and calcium deficiencies to photosynthesis, protein syntehsis, and translocation. Michigan Agr. Exp. Sta. Tech. Bul., 141, 1934.

26. Hoffer, G. N. Fertilized corn plants require well ventilated soils. Better Crops with Plant Foods, 29(1):6-9, 1945.

27. Keen, B. A. Some comments on the hydrometer method for studying soils. Soil Sci., 26:261-263, 1928.

28. Lehr, J. J. The importance of sodium for plant nutrition. Soil Sci., 52:237-244, 1941.

29. Link, C. B. and J. R. Culvert. The effect of soil mixtures on production and growth of Briarcliff roses. Proc. Amer. Soc. Hort. Sci., 42:635-640, 1942.

30. Loehwing, W. F. Physiological aspects of the effect of continuous soil aeration on plant growth. Plant Physiol., 9:567-583, 1934.

31. Nightingale, G. T. Physiological-chemical functions of potassium in crop growth. Soil Sci., 55:73-78, 1943.

BIBLIOGRAPHY.—Continued

32. Nightingale, G. T., L. G. Schermerhorn, and W. R. Robbins. Some effects of potassium deficiency on histological structure and nitrogenous and carbohydrate constituents of plants. New Jersey Agr. Exp. Sta. Bul., 499, 1930.

33. Peech, M. and L. English. Rapid micro-chemical soil tests. Soil Sci., 57:167-195, 1944.

34. Post, K. and J. E. Howland. The influence of various soil amendment materials on the growth and flower production of greenhouse roses. Proc. Amer. Soc. Hort. Sci., 47:465-468, 1946.

35. Ray, S. H. and J. B. Shanks. Aggregation and aeration of some greenhouse soil mixtures for roses and carnations. Proc. Amer. Soc. Hort. Sci., 49:420-426, 1947.

36. Russell, M. B. A simplified air picnometer for field use. Soil Sci. Soc. Amer. Proc., 14:73-76, 1949.

37. Shear, C. B., H. L. Crane, and A. T. Myers. Nutrient element balance: a fundamental concept in plant nutrition. Proc. Amer. Soc. Hort. Sci., 47:239-248, 1946.

38. Snedecor, G. W. Statistical Methods. The Iowa State College Press, 1940.

39. Snow, A. G., Jr. Transpiration as modified by potassium. Plant Physiol., 11:583-594, 1936.

40. Sommer, A. L. Mineral nutrition of plants. Ann. Rev. Biochem., 10:471-490, 1941.

41. Spurway, C. H. Soil fertility control for greenhouses. Michigan Agr. Exp. Sta. Tech. Bul., 132, 1944.

42. Tiedjens, V. A. and L. B. Schermerhorn. Calcium-sodium ratio and growth of tomato in sand culture. Soil Sci., 42:419-435, 1936.

BIBLIOGRAPHY.--Continued

43. Walkley, A. and I. A. Black. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Sci., 37:29-38, 1934.

44. Whitt, D. M. and L. D. Baver. Particle size in relation to base exchange and hydration properties of Putnam clay. J. Amer. Soc. Agron. 29:905-916, 1937.

A P P E N D I X

Greenhouse ______________________________ Date __________

Soil

1. Where did soil come from?

2. How long has soil been in bench?

3. Treatment of soil before benching crop.

   a. Type organic matter added.

   b. How sterilized.

   c. Anything special done to it.

4. If soil has been in bench for more than one crop, how was it treated for the next crop? Roto tilled? Turned by hand? All the way to the bottom of the bench?

5. Is soil mulched and, if so, with what?

6. Fertilizers used.

7. Type of bench. (Solid bottom or wooden.)

8. Type of greenhouse - old - new - dirty?

9. Temperatures

   Night -

   Day -

   If day was cloudy and cold, was heat run to keep day temperature above night temperature?

FORMULA FOR POTASSIUM, CALCIUM, SODIUM SOLUTIONS

Crock and solution	Weight grams	Compound	ppm/liter	Concentrated 20 times (grams/l)
I	.680	$NaNO_3$	500 ppm NO_3	13.6
			184 ppm Na -	
	.8190	NaCl	316 ppm Na -	16.38
			500 ppm Cl -	
II	.680	$NaNO_3$	500 ppm NO_3	13.6
			184 ppm Na -	
	.5265	NaCl	216 ppm Na -	10.53
			321 ppm Cl	
	.194	KCl	100 ppm K -	3.88
			91 ppm Cl -	
III	.680	$NaNO_3$	500 ppm NO_3	13.6
			184 ppm Na -	
	.2925	NaCl	116 ppm Na -	5.85
			178 ppm Cl -	
	.373	KCl	200 ppm K -	7.46
			175 ppm Cl -	
IV	.808	KNO_3	500 ppm NO_3 -	16.16
			311 ppm K -	
	.509	NaCl	200 ppm Na -	10.18
			310 ppm Cl -	
V	.808	KNO_3	500 ppm NO_3 -	16.16
			311 ppm K -	
	.171	KCl	89 ppm K -	3.42
			119 ppm Cl -	
	.256	NaCl	100 ppm Na	5.12
			153 ppm Cl -	
VI	.808	KNO_3	500 ppm NO_3 -	16.16
			311 ppm K -	
	.356	KCl	189 ppm K -	7.12
			167 ppm Cl -	

FORMULA FOR POTASSIUM, CALCIUM, SODIUM SOLUTIONS (con't.)

Crock and solution	Weight grams	Compound	ppm/liter	Concentrated 20 times (grams/l)
VII	.944	$Ca(NO_3)_2 \cdot 4H_2O$	500 ppm NO_3 - 160 ppm Ca --	18.88
	.222	CaCl	40 ppm Ca -- 142 ppm Cl -	4.44
	1.04	NaCl	400 ppm Na - 612 ppm Cl -	2.08
VIII	.944	$Ca(NO_3)_2 \cdot 4H_2O$	500 ppm NO_3 - 160 ppm Ca --	18.88
	.222	$CaCl_2$	40 ppm Ca-- 142 ppm Cl	4.44
	.77	NaCl	300 ppm Na - 469 ppm Cl -	15.4
	.191	KCl	100 ppm K - 90 ppm Cl	3.82
IX	.944	$Ca(NO_3)_2 \cdot 4H_2O$	500 ppm NO_3 - 160 ppm Ca --	18.88
	.222	$CaCl_2$	40 ppm Ca -- 142 ppm Cl	4.44
	.512	NaCl	200 ppm Na - 312 ppm Cl -	10.24
	.380	KCl	200 ppm K - 179 ppm Cl	7.60
X	.944	$Ca(NO_3)_2 \cdot 4H_2O$	500 ppm NO_3 - 160 ppm Ca --	18.88
	.222	$CaCl_2$	40 ppm Ca-- 142 ppm Cl	4.44
	.256	NaCl	100 ppm Na - 216 ppm Cl -	5.12
	.574	KCl	300 ppm K - 269 ppm Cl -	11.48

FORMULA FOR POTASSIUM, CALCIUM, SODIUM SOLUTIONS (con't.)

Crock and solution	Weight grams	Compound	ppm/liter	Concentrated 20 times (grams/l)
XI	.944	$Ca(NO_3)_2 \cdot 4H_2O$	500 ppm NO_3 –	18.88
			160 ppm Ca ––	
	.222	$CaCl_2$	40 ppm Ca ––	4.44
			142 ppm Cl	
	.75	KCl	400 ppm K –	15.0
			352 ppm Cl –	
XII	.944	$Ca(NO_3)_2 \cdot 4H_2O$	500 ppm NO_3 –	18.88
			160 ppm Ca ––	
	.816	$CaSO_4$	240 ppm Ca ––	
			609 ppm SO_4	
	.77	NaCl	300 ppm Na –	15.40
			469 ppm Cl –	
XIII	.944	$Ca(NO_3)_2 \cdot 4H_2O$	500 ppm NO_3 –	18.88
			160 ppm Ca ––	
	.816	$CaSO_4$	240 ppm Ca ––	
			609 ppm SO_4	
	.191	KCl	100 ppm K –	3.82
			90 ppm Cl	
	.512	NaCl	200 ppm Na –	10.24
			312 ppm Cl –	
XIV	.944	$Ca(NO_3)_2 \cdot 4H_2O$	500 ppm NO_3 –	18.88
			160 ppm Ca ––	
	.816	$CaSO_4$	240 ppm Ca ––	
			609 ppm SO_4	
	.256	NaCl	100 ppm Na –	5.12
			216 ppm Cl –	
	.380	KCl	200 ppm K –	7.60
			179 ppm Cl	

FORMULA FOR POTASSIUM, CALCIUM, SODIUM SOLUTIONS (con't.)

Crock and solution	Weight grams	Compound	ppm/liter	Concentrated 20 times (grams/l)
XV	.944	$Ca(NO_3)_2 \cdot 4H_2O$	500 ppm NO_3 - 160 ppm Ca	18.88
	.816	$CaSO_4$	240 ppm Ca 609 ppm SO_4	
	.574	KCl	300 ppm K - 269 ppm Cl -	11.48
XVI	.944	$Ca(NO_3)_2 \cdot 4H_2O$	500 ppm NO_3 - 160 ppm Ca --	18.88
	.952	$CaSO_4$	280 ppm Ca-- 676 ppm SO_4	
	.444	$CaCl_2$	160 ppm Ca-- 284 ppm Cl -	8.88
	.512	NaCl	200 ppm Na - 312 ppm Cl	10.24
XVII	.944	$Ca(NO_3)_2 \cdot 4H_2O$	500 ppm NO_3 - 160 ppm Ca	18.88
	.952	$CaSO_4$	280 ppm Ca 676 ppm SO_4	
	.444	$CaCl_2$	160 ppm Ca 284 ppm Cl -	8.88
	.191	KCl	100 ppm K - 90 ppm Cl	3.82
	.256	NaCl	100 ppm Na - 216 ppm Cl -	5.12
XVIII	.944	$Ca(NO_3)_2 \cdot 4H_2O$	500 ppm NO_3 - 160 ppm Ca	18.88
	.952	$CaSO_4$	280 ppm Ca 676 ppm SO_4	
	.444	$CaCl_2$	160 ppm Ca 184 ppm Cl	8.88
	.191	KCl	100 ppm K 90 ppm Cl	3.82

FORMULA FOR POTASSIUM, CALCIUM, SODIUM SOLUTIONS (con't.)

Crock and solution	Weight grams	Compound	ppm/liter	Concentrated 20 times (grams/1)
XIX	.944	$Ca(NO_3)_2\cdot$ $4H_2O$	500 ppm NO_3 160 ppm Ca	18.88
	.952	$CaSO_4$	280 ppm Ca 676 ppm SO_4	
	1.0	$CaCl_2$	360 ppm Ca 640 ppm Cl -	20.0
	.256	NaCl	100 ppm Na - 153 ppm Cl -	5.12
XX	.944	$Ca(NO_3)_2\cdot$ $4\ H_2O$	500 ppm NO_3 160 ppm Ca	18.88
	.952	$CaSO_4$	280 ppm Ca 676 ppm SO_4	
	1.0	$CaCl_2$	360 ppm Ca 640 ppm Cl -	20.0
	.191	KCl	100 ppm K 90 ppm Cl	3.82
XXI	.944	$Ca(NO_3)_2\cdot$ $4H_2O$	500 ppm NO_3 160 ppm Ca	18.88
	1.0	$CaCl_2$	360 ppm Ca 640 ppm Cl -	20.0
	1.66	$CaSO_4$	480 ppm Ca 1178 ppm SO_4	