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A Study of the Effect of Three Nutrients on the Growth of Tomatoes

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GROWTH OF TOMATOES - STONE

A STUDY OF THE EFFECT OF THREE NUTRIENTS ON THE GROWTH OF TOMATOES

By

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CHAPTER I

INTRODUCTION

Studies of the various phases of plant growth are becoming more and more important to plant physiologists. Many such studies have been conducted for economic reasons to obtain increased production. In this investigation, fruit production and quality have been considered important, but have been placed second in interest to the effect certain nutrients may have on plant development during growth.

Most experiments of this type have been concerned with nutrient deficiencies. The writer has attempted in this experiment to use nutrient elements in excess and observe the effects produced during progressive phases of plant growth. Single elements, nitrogen, phosphorous, and iron were tried in excess above the recommended amounts and a balanced solution using all three elements in excess was also used.

The plant chosen for this experiment was the Ball F_1 variety of tomato. The method of culture used was hydroponics. This method was chosen because the technique eliminates many sources of error such as may occur in soil where bacteria and other micro-organisms may alter the medium and interfer with the absorption of elements by the plant under investigation.

CHAPTER II

SURVEY OF LITERATURE

The technique of growing plants in soil-less media is referred to as nutriculture, chemi-culture, or hydroponics and has been practiced for centuries in various parts of the Orient. Modern hydroponic technique, however, date from the experiments by Sachs in 1860.

Sachs' solution formula includes potassium acid phosphate as a source for phosphorous. Shives (1915, p. 445) used different gram weights of the elements in Sachs' formula and supplied iron in the form of ferrous phosphate. Shives' formula was further improved by Hoagland (1936, p. 31). He substituted ammonia acid phosphate for the potassium acid phosphate and used iron tartrate as a source of iron.

Another very important addition to the formula was made by the two workers, Haas (1932, p. 490), and Reed (1938, p. 175) with their "A-Z" solution. This solution contained all of the minor elements known to be required by plants. The work of Haas and Reed in determining the nature and extent of plant reactions to deficiencies of the minor elements was very important to the development of chemi-culture solutions.

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Plant-tissue analysis as a means of determining the elements necessary for plant nutrition was first used

by de Saussure in 1804. In his investigation, de Saussure demonstrated, through analysis of plant ash, that different plant parts varied in amounts of elements present. This variation was found to depend on the age of the plant and the soil in which the plant grew. Since 1804, some prominent workers such as von Liebig (1852) and Hall (1905) have applied the technique of plant-tissue analysis to nutritional demands on the root media. Fertilizer recommendations for plants were made on the basis of plant-tissue analyses and the fertility of the soil in which they grew.

More recent investigators in the field of plant-tissue analysis have developed accurate chemical short cuts in the analytical procedure. This work has resulted in the so-called "Quick Tests" or "Rapid Determinations", and in some techniques employ photoelectric colorimeters and flame photometers. Wolf (1943, p. 248) has contributed much to the development and use of the photoelectric colorimeter in the commercial agriculture of New Jersey. Berry (1946) and his co-workers, in working primarily with flame photometers, have also added a great deal of information to the field of plant-tissue analyses and soil fertilization on the basis of "Quick Tests".

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As a result of the interest and development of "Quick Test" techniques (Wolf and Ichisaka, 1947, p. 227), simplified colorimetric kits have been devised which do not use either expensive laboratory instruments or elaborate chemical techniques (La Motte, 1951). These handy, portable kits are used in field work as well as in the laboratory.

The various state agricultural experiment stations over the United States are responsible for much of the information available today in the fields of plant nutrition and plant culture. There are three stations more prominent than the rest in the field of greenhouse culture and hydroponic growth of tomatoes. These three state experiment stations, whose circulars and bulletins have been used in this paper, are California, Ohio, and Kentucky. Briefly, The California station contributed information on solution formulae; the Ohio station gave information on management, disease control, and environment for greenhouse tomatoes; and the Kentucky station provided comparisons in production of tomatoes in different nutrient solutions.

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CHAPTER III

METHODS AND MATERIALS

Eighty tomato seedlings (Ball F_1) were transplanted from flats, when 4½ weeks old, to 20, 2-gallon, porcelain jars containing sterile, white quartz sand. The amount of sand in each jar was adjusted so that 2 liters of solution would reach ½ inch below the surface level of the sand in each jar. The 80 seedlings, planted 4 to a jar, were selected for uniformity on the basis of size, vigor, and color. The 20 jars were then divided into 5 groups (A, B, C, D, and E) and nutrient solutions added as listed in Table 1.

The control solution used was Hoagland's #2 which is listed in the California Experiment Station Circular 347, on page 31. The excesses of nitrogen and phosphorus, and the excess of nitrogen, phosphorus, and iron together were adjusted according to Emmert (1942, pp. 46 and 47). The group given excess iron was grown in a solution similar to that used for the controls with the exception that the experimental solution contained 4 times the amount of iron.

The trace element formula (Table 1) was the same for all 5 groups. The pH of each different solution was as near neutral as could be obtained (Table 4). Compressed air was bubbled through the sand media for 2½ to 3 hours each day.

At the end of each week, starting from the date of transplanting, all jars were drained. The pH of the week-old solutions were determined at this time, and the jars were refilled with the appropriate fresh nutrient solutions. Each week growth measurements were taken and recorded.

A daily log of observations and actions was kept through the course of this problem in addition to daily and weekly work sheets. On these daily work sheets were recorded the water (distilled) addition in cubic centimeters, jar solution temperature, air temperature of the greenhouse, humidity of the greenhouse, general weather conditions, and supplementary feeding toward the end of the problem.

On the weekly work sheets for each jar were recorded the amount of growth during the week, the average daily moisture consumption, the pH of the old nutrient solution, and the pH of the fresh solution. The averages for greenhouse temperature and humidity, jar solution temperatures, and the total sunlight and cloudy hours resulting from weather were also recorded on the weekly sheets.

Water was added daily to each container so the jar solution was maintained $\frac{1}{2}$ inch below the surface level of the sand. Jar tops were covered with notched cardboard to reduce evaporation.

All aqueous tissue extractions were made with one gram of macerated tissue soaked for 5 minutes in 10 milliliters of distilled water. The nutrient element identification

and quantity were determined using the method of La Motte (1951). The pH's of the tissue extractions were run in samples of 4 with each of the following indicators: Bromcreosol Green, Chlorophenol Red, and Bromthymol Blue. The pH readings which fell midway in an indicator range were used. The nutrient determinations and pH's were each taken under two different light conditions as Tables 2 and 3 indicate.

Plants to be used for tissue extractions were chosen as to uniformity of size, color and exposure to light. All of the extractions were made during the fourth, fifth, and sixth weeks when the plants were growing vigorously. The pH's and the element extractions of the leaves were run first. The plant was then removed from the culture and the main stem and root determinations were run immediately.

The averages in the weekly work sheet were obtained in the following manner: (1) For moisture; the daily additions were added for each container, divided by 7 and recorded for the particular jar. The sum of these 4 averages were then obtained, divided by 4, and the results placed on a graph (Figure 1). (2) pH (Table 4); these were obtained by adding the pH of each jar in the separate nutrient levels and dividing by 4 in all 5 cases. This entry was made in the record and compared with the pH of the nutrient solution

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at the beginning of the week. (3) Air temperature, humidity, and temperatures of jar solutions; these daily readings were added each week and divided by 7. Entries were made in the record the same for all nutrient levels. The total hours of sun and cloudy skies were recorded.

The numbers of buds, flowers, and fruit sets were counted each day and recorded for the week in each group.

In judging the quality of fruit, care had to be taken to make sure that judges had as uniform a standard as possible upon which to judge. The judging standards and results for this study are recorded in Table 8. Numerical equivalents and descriptions were given superior, average, and poor fruits. Twenty judges gave opinions which were averaged for each group and recorded.

During the 9th week, ordinary tap water was used in place of distilled water for daily moisture replenishment.

Toward the end of the problem, from the 9th week on, the root masses in all groups had grown to such an extent that the jars would not hold the alloted amounts of nutrient liquid in one feeding. The liquid was divided in 2 equal parts; half was added at mid-week in place of the regular moisture addition, and half was added at the regular time of drainage and refilled at the end of each week.

CHAPTER IV

RESULTS

Group A (Controls)

The control plants of Group A developed the least growth in height, the smallest number of leaves and consumed the lowest total amount of water. The total weight of the fruit was the lowest of all groups, but the quality of fruit was judged the highest.

The root systems of these plants were smaller in overall length, size of tap root and branching than any other group. These systems when air dried lost 81% of their fresh weight.

Group B (Excess Iron)

Plants cultured with an excess of iron produced the highest vegetative growth of all groups. The moisture consumption was 14% more than the control plants. The total weight of fruit produced was 1165.4 gms. This group was 2nd among the groups for quantity of production. Group B plants were also rated 2nd in quality of fruit.

The root systems of this group were consistent in appearance and development. They were stringy, uncompacted, and had developed many long roots. These root systems lost 78% of their moisture when air dried.

Group C (Excess Phosphate)

Plants cultured with an excess of phosphorous had a greater vegetative growth than that produced in the control Group A, but less than any of the other groups. Their total moisture consumption was 12% more than Group A. With a total fruit production of 957.9 grams, they rated 4th of all groups. In quality of fruit these plants were also rated 4th.

The root systems of this group were also consistent in appearance and development. They were compact, massive and produced few long roots. The roots lost 74% of their moisture when air dried.

Group D (Excess Nitrogen)

Plants cultured with an excess of nitrogen were similar to those of Groups B and E in vegetative growth, but were still rated 3rd. The total moisture consumption was 66 % more than the control plants. In total fruit production they rated 3rd with 991.5 grams. The quality of fruit of this group was rated least desirable of all groups.

The root systems were very consistent in their appearance and development. They were stringy, not closely bunched, and had many long roots. The loss of water when air dried was 71%.

Group E (Excess Nitrogen, Phosphorous and Iron)

These plants produced vegetative growth second only to that of group B. In moisture consumption these plants consumed less than group D but 44% more than the control plants in group A. Group E plants produced the highest total fruit production with 1402.1 grams. However, the fruits produced were only rated 3rd in quality when compared to the fruit of the other groups.

The root systems of this group displayed some variation in appearance and development but were not as inconsistent as those in group A. Generally, the whole group developed root systems which were strongly bunched and compact but still produced a few long roots. These roots lost the least amount of water when air dried. Their water loss was 63%.

Relationships in Growth, Moisture Uptake, and Media pH

There occurred in all groups an increased moisture uptake with every surge of growth. An increase in vegetative growth and an increase in number of buds, blooming flowers, and fruit sets on all plants was accompanied by an increase in moisture uptake except during the 10th and 11th week. The average moisture uptake increased with the general increase in size but periodic rapid growth increases caused fluctuations of moisture uptake throughout the growth of the plants.

Accompanying these periodic fluctuations of growth and moisture uptake were pH changes in the solutions of all groups. The extent of the fluctuations varied among the groups without any apparent consistency as to nutritional concentration of the solution (Table 4). The major factor contributing to the observed fluctuation appeared to be rate of growth.

CHAPTER V

DISCUSSION

A. Iron

In making the addition of iron to all of the different group solutions, the writer used the local Soil Conservation Service recommendations as a guide (Abaskin, 1954). These general recommendations state that available iron should be present in the soil for normal plant growth in the amount of 10 to 15 parts per million. Therefore, iron tartrate was added in the amount of 14 parts per million to the nutrient solution for the control group and where required in excess was added in the amount of 56 parts per million.

These amounts of iron, when considering the standard ratio of 2/5 with manganese, were in excess. The manganese added to all of these solutions was in the rate of .5 parts per million (Table 1). Yet, no chlorosis was produced in any of the 80 plants grown in this experiment.

The amounts of available iron and the interrelated effects of iron with other metals required in plant nutrition is discussed by Hewitt (1951, p. 25). In his discussion, Hewitt has linked potassium with iron in chlorophyl formation. He states that the effect of high potassium is to maintain limited supplies of iron and that perhaps manganese competes with magnesium rather than iron in chlorophyl

formation. The high levels of potassium and iron, the low levels of manganese, and the large ratio of magnesium to manganese (12/.5) in this problem seem to bear out Hewitt's findings.

In connection with chlorosis being produced in an unbalanced iron to manganese ratio, the writer has done some other experimentation (Stone, 1955, p. 8). This experimentation was also under hydroponic culture with group B nutrient solution and employed both Oxhart Late, and Marglobe tomatoes. No manganese chlorosis was produced although leaf inoculations were made periodically with iron solutions as high as 28 parts per million.

The excess iron levels of nutrition were undoubtedly an aid in growth, production, and quality of fruit as can be seen from the development of the plants in group B. This excess iron in the nutrition formulae used, aided in economy of moisture consumption and increased plant utility of the major elements, nitrogen and phosphorous.

The nutrient solution for group B, together with the control solution in group A, had the least buffered solution of all groups. Howell, (1932, p. 666) has discussed ionized solutions in relation to buffer compounds and has concluded that the acid influence in Hoagland's water culture formulae is negligible. Therefore, the sharp alkaline rise of the group B pH curve in Figure 2 during

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The excess iron levels of solution were undoubtedly an aid in growth, production, and quality of fruit as can be seen from the development of the plants in group A. This excess iron in the nutrition formulae used, aided in economy of moisture consumption and increased plant utility of the major elements, nitrogen and phosphorus.

The nutrient solution for group C, together with the control solution in group A, had the least buffered solution of all groups. Howell (1932, p. 566) has discussed ionized solutions in relation to buffer compounds and has concluded that the acid influence in Shive's water culture formulae is negligible. Therefore, the sharp alkaline rise of the group B pH curve in Figure 2 during

the 9th week is attributed to the use of tap water.

Growth of the plants in group B is presented in its general trend in Figure 2 and Table 5. During the 2nd week these plants increased their height 12.6%. In the 4th week the average number of leaves was increased 90.5% for each plant. During the 6th and 7th weeks the vegetative growth remained at a steady increase but the plants were setting and maturing flower buds. The group B plants opened and matured a total of 18 flowers during the 8th week.

Due to the use of tap water over the 9th week, both vegetative growth and development of flowers was slowed. When distilled water was resupplied, the flower development increased but the vegetative growth never reached its former rate.

All 18 of the flowers produced in the 7th and 8th weeks began to set fruit in the 10th week. It was not until the 12th week that flowers which developed in the 8th and 9th week began to set fruit.

The majority of the fruit set during the 10th and 12th weeks produced ripe fruit. There were a few late flowers which set fruit during the 16th week but these never matured and were left on the plants at the end of the problem (Table 7).

The moisture consumption of these plants (Figure 1) followed very closely the growth pattern as set forth in

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The moisture consumption of these plants (Figure 3) followed very closely the growth pattern as set forth in

Table 5 and the discussion above. Peak demands for water occurred during the 7th week, the 9th week, and the 13th week. The decline in moisture demand which culminated in the 11th week occurred at a time when there was very little vegetative increase in growth and after the plants had set the first large numbers of fruit. After the 13th week there was a steady decline in moisture demand until the end of the problem.

B. Nitrogen

Nitrogen was supplied all solutions in the forms of ammonia and nitrate. Of the two, nitrate is more readily available by plants. In the group receiving excess nitrogen, or group D, there were 18 parts per million ammonia and 992 parts per million nitrate. In group C (excess phosphate) there were 36 parts per million ammonia and 620 parts per million nitrate. In group E, there were 36 parts per million ammonia and 1,240 parts per million nitrate. In groups A and B there were 18 parts per million ammonia and 620 parts per million nitrate. The approximate ratios of ammonia nitrogen to nitrate in all groups were: group D, 1:54; group C, 1:18; Group E, 1:35; groups A and B, 1:34.

Emmert's (1942, pp. 46-47) method was used in balancing the amounts of nitrogen and phosphorous in this investigation. However, in view of the different amounts

and kinds of nitrogen supplied, it is seen that group D had the greatest amount of readily available nitrogen in the solution while group C had the smallest proportion of this readily available nitrogen. Although groups A and B had the same total amount of nitrate as group C, they had a larger proportion of it than of the ammonia. Group E, of course, had a larger total amount of nitrate but a smaller proportion of nitrate than of the ammonia used in group D.

There is some doubt as to how much nitrogen was actually made available from the ammonia in a week-old hydroponic solution. Bacteria normally required for the process in soil media seem to be lacking in a hydroponic situation. Hoagland (1949, p. 7) has discussed the absence of bacteria in a hydroponic situation due to the lack of organic matter.

On the basis of nitrate supplied the different cultures, groups D and E were similar while groups A, B, and C were similar. Table 5 shows the growth increase each week compared percentagewise to growth already established.

Table 7 shows a much greater difference between groups D and E in total amount of ripe fruit. Although both had adequate nutrition, the production of group E was greater where larger amounts of elements were present and phosphorous was in larger proportion to available nitrate.

Plants in group D showed the most rapid growth of all groups up to the 6th week, especially in height. After the 6th week these plants were surpassed by those of group E. During the 9th week they were outgrown by the plants in group B which outgrew all others from the 14th week to the end of the problem.

Apparently, the plants in group D took longer to establish themselves for it was not until the 3rd week that these plants demonstrated the growth effect of abundant nitrate in the culture solution. In the 3rd week the vegetative increase was 100% in number of leaves and 20.0% in height. During the 4th week, however, these plants increased 119.3% in height and only 22.2% in number of leaves. In the 5th week they showed no such rapid increase nor was there any during the 6th week. During the 7th week, however, these plants initiated a total of 27 flower buds. These flowers bloomed and were pollinated during the 8th and 9th weeks and 19 set fruit during the 10th week. It was during the 13th week when some later appearing flowers set fruit. Only a few of the latter matured and ripened. No further significant increase occurred in these plants, although they did continue to grow in height until the end of the problem and set fruit in a few very late flowers during the 16th week.

The moisture consumption of these plants (Figure 1)

reached maximum and diminished peaks in accordance with growth except during the 8th week when the first early group of buds was flowering. After the 13th week when some late flowers set fruit, there was a gradual decrease in moisture consumption until the end of the problem. These plants retained 3 fruit in the ripening process 3 days longer than the other groups. This retention of fruit is probably the reason for the delay of the sudden increase in moisture uptake at the end of the problem.

Because the nutrient concentration of group E was considered "excess" over the optimum for growth and production (group A solution), increased growth and production over those of group A were expected. Workers at Ohio State (Keirns, 1954, pp. 9-11) have reported that under "luxury consumption" vegetative parts of tomato plants will contain more nutrient elements but the yield will not be influenced. The different concentration of the nutrient solution between "minimum for growth and production" and "luxury consumption", was not an object of this problem. As Ulrich (1948, p. 158) states this situation, "luxury consumption.... is a condition in which nutrient concentrations increase but yields remain constant" and progressive increments of nutrient combinations were not attempted here.

The object of this investigation was to determine the effects on plant growth and production of an "excess"

of the nutrient elements in the culture solution. Groups A and E present examples of a balanced minimal concentration and a balanced "excess" concentration respectively. The balanced concentrations referred to here were according to Emmert (1942, pp. 46-47).

Group E plants outgrew those of group A during the 2nd week and remained taller with more leaf surface until the end of the problem (Table 5). In the 3rd week group E increased the leaf surface 107.7% and group A 18.5%. The height increase for the same period was 24.4% for group E and 5.32% for group A. During the 4th week the height increase for group E was 107.8% while for group A it was 81.3%. In leaf surface group E increased 44.8% and group A 75% for the same period. During the 5th week group A increased height and number of leaves in greater percentages than group E but were still smaller plants. It was during the 7th week that group A started setting flower buds with the majority setting during the 8th week. At this time group A set 28 buds and group E set 14. Group E buds appeared all in the 8th week but was the smallest number of flower buds for any group. During the 9th week growth was somewhat slowed both in height and in numbers of leaves but this was true in all groups and is assumed to reflect the use of tap water for that period. During the 10th week both groups set fruit (group A, 19; group E, 13) and produced a much

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lower percentage increase in height and number of leaves. During the 11th week the lack of increased vegetative growth was again evident in both groups. However, during the 12th and 13th weeks both groups again set fruit in a few late flowers and produced some late flower buds. During the 14th week group E produced more flowers and set some fruit, but these were scattered and never matured. Group A, during the 14th week, produced flowers but they were much fewer in number. There was no growth change from the 15th week on in either group beside an occasional flower or fruit set. Group A continued to increase height and leaf surface longer than group E, but the percentage increase was hardly significant.

The moisture consumption of these two groups compared favorably as to peak demands of the plants during the 7th, 9th, and 13th weeks but were vastly different in the amount consumed (Figure 1). The point of reduced demand during the 11th week was also the same for both groups. The sharp rise in moisture uptake at the end of the problem after all ripe fruit were picked from both groups was also similar.

During the 8th week of growth group E plants displayed a more continuous uptake of moisture than did the other groups. This week was the period when other groups were setting large numbers of flower buds while group E

set only 14 buds. During this general period too, group E was the fastest growing group of plants and showed most obviously the effects of the high temperatures of the greenhouse.

Tissue tests were made for nitrogen in all groups according to the method of La Motte (1951). The results are presented in Table 3. In some cases there is evidence that leaf tissues contained more detectable nitrate during sunlight than they contained during cloudy weather. The figures in Table 3 represent 3 analyses each. As light intensities were not measured by a meter no conclusions are drawn. There did not seem to be any correlation as to growth rate and the amount of this element in the tissues of any of the groups.

C. Phosphorous

Among the single excesses of nitrogen, phosphate and iron tried in this problem, excess phosphate produced the least effect in growth, production and quality of fruit. In fact, the excess phosphate plants, or group C, produced growth and total amount of fruit very little better than those of the control plants in group A (Table 7 and Figure 1).

Tomato plants are not known to be heavy phosphate users as are alfalfa plants. Therefore, the 95 parts per million of phosphate supplied by the minimal formula for all plants (Hoagland, 1950, p. 31) to be raised in water cultures, is somewhat in excess of the minimal requirement

set only 14 buds. During this general period too, group E was the fastest growing group of plants and showed most obviously the effects of the high temperatures of the greenhouse.

Tissue tests were made for nitrogen in all groups according to the method of la Motte (1951). The results are presented in Table 3. In some cases there is evidence that leaf tissues contained more detectable nitrate during sunlight than they contained during cloudy weather. The figures in Table 3 represent 3 analyses each. As light intensities were not measured by a meter no conclusions are given. There did not seem to be any correlation as to growth rate and the amount of this element in the tissues of any of the groups.

C. Phosphorous

Among the single excesses of nitrogen, phosphate and iron tried in this problem, excess phosphate produced the least effect in growth, production and quality of fruit. In fact, the excess phosphate plants, or group C, produced growth and total amount of fruit very little better than those of the control plants in group A (Table 7 and Figure 1).

Tomato plants are not known to be heavy phosphate users as are alfalfa plants. Therefore, the 93 parts per million of phosphate supplied by the minimal formula for all plants (Hoagland, 1956, p. 31) to be raised in water cultures, is somewhat in excess of the minimal requirement

for tomatoes. When the single element phosphate is doubled, there is only a slight increase in growth and production. When phosphate is doubled in conjunction with iron and nitrogen excesses, a decided increase is received.

In the 2nd week of growth, group C plants grew better than any other group. During this week they produced a 14.8% increase in height and a 38% increase in the number of leaves. This initial growth increase was not maintained however, and the group at the end of the problem had outgrown and outproduced the control group only.

In the 3rd week group C plants produced only 16.5% increase in height but a rapid increase of 90% in leaf surface. In the 4th week height was increased 91.1% and leaves increased only 43.7%. For the period of the 5th week only nominal growth was produced, but during the 6th week height increased 68.9% and leaves, 12.7%. In the 7th week the plants slowed their growth again. In the 8th week growth in height and leaves was still slowed but the plants produced 17 flower buds. During the 9th week growth was still slowed from the previous rate of the first 7 weeks. It was over the 10th week period when the plants set fruit in 14 of the 17 flower buds. Diminished growth again occurred during the 11th and 12th weeks, but the plants again set fruit in some late flowers during the 12th week. There was a spurt of growth with an increase in height during the 13th week, but the plants never recovered a

steady growth increase.

The moisture consumption of the plants in group C followed the characteristic peak demands and fluctuations established by the other groups in correlation with growth increases (Figure 1). Group C was comparable in moisture uptake to both groups A and B.

Tissue tests for detectable phosphate were made according to the method of La Motte (1951) on plants from all groups and the results are presented in Table 3. Phosphate was generally present in greater amounts in the tissues tested than was nitrogen. There was also some fluctuation in the amounts of detectable phosphate in the plant tissue due to the effect of light intensity.

D. Environmental Temperature and Humidity

Workers at both Ohio State (Kierns, 1954, p. 6 and p. 15) and California State (Hoagland, 1950, p. 19) Agricultural Experiment Stations agree that in growing greenhouse tomatoes optimum temperature should be between 70°-75°F for bright, sunny days and around 60°F at night. The plants in this problem were grown under weekly average temperatures of 82°-90°F and were believed to have been adversely affected as a result.

According to Kierns (1954, p. 15), higher than optimum temperatures break down carbohydrates faster than they can be built up in the plant and stored in the fruit.

Borders (1953, p. 465), in working with garden vegetable transplants grown in the south and shipped north, has corroborated this finding. Emmert (1942, pp. 38-40) also states that higher than optimum temperatures will reduce production in tomatoes.

The temperatures of the nutrient solutions fell within the recommended optimum as stated by Hester (1941, p. 19) in varying from 75°F to 82°F.

Humidities of the greenhouse ran high during the extent of this problem ranging from a weekly average of 63.4 to 75.4. There was no apparent relationship with any other factor of growth.

E. pH of the Nutrient Solutions (Table 6 and Figure 2)

Initially, the nutrient solutions were formulated with as near neutral pH as the excesses would permit. The fresh nutrient solutions each week were generally in the range of pH 6.9 to 7.1 for all groups. This pH range guaranteed the availability of nutrients particularly phosphorous and iron.

For the first 10 weeks each group produced an acid solution from the original neutral solution every week. The amount of the change did not seem to fluctuate with the nutrient concentration, but it did fluctuate with the degree of growth of the plants in each group.

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In the 11th week all groups of plants produced a definite alkaline nutrient solution. There was no relationship with nutrient concentration but rather with growth for it was immediately before in the 10th week when all groups set the first large number of fruit. All group solutions remained alkaline after the 11th week and fluctuated in an alkaline range with the growth of the plants rather than with any other factor.

The particular points of relationship among groups and in response to growth were the 2nd, 4th, 8th, 10th, 11th, 12th, 14th, and 16th weeks.

The acid effect of plants on the root media has been reported in the literature. Hoagland (1949, p.7), the most prominent investigator in this field, sums up his previous work on this subject by stating categorically that there are two acid influences in soil: plant root cells, and soil bacteria and other soil micro-organisms.

In hydroponic cultures the effect of soil organisms is eliminated, leaving only plant root cells as an acid influence. Howell (1932, p. 666) in working with the pH factor as a growth influence on Yellow Pine seedlings investigated and discarded the acid effect of the exuded carbon dioxide of the roots. Erickson (1946, p. 556) also found that carbon dioxide accumulated to the insignificant amount of .2% of an unaerated and undrained solution

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In hydroponic cultures the effect of soil organisms is eliminated, leaving only plant root cells as an acid influence. Howell (1932, p. 556) in working with the pH factor as a growth influence on Yellow Pine seedlings investigated and discussed the acid effect of the exuded carbon dioxide of the roots. [illegible] (1936, p. 395) also found that carbon dioxide contributed to the insignificant amount of .2% of an unaerated and untreated solution

in a 5 week period.

Therefore, it was necessary to look elsewhere for other possible acid influences in the nutrient solution. Plants are known to exchange ions with the soil medium. This could alter the pH value in a highly ionized solution such as the nutrient liquid. Howell (1932, p. 666, Table IV) also investigated and disproved the acid effect of this reaction.

These cited investigations leave the only strong acid influence on the nutrient solution to be an actual acid secretion by the root cells. Robertson (1951, p. 1), in reviewing the work done in this field, compares this plant root acid secretion to that of the hydrochloric acid secretion of the gastric mucosa in animals. From the evidence presented by this problem, it can be said, at least, that the more acid influenced media solutions occurred during periods of accelerated growth.

CHAPTER VI

SUMMARY AND CONCLUSIONS

The effects of excess nitrogen, phosphorous, iron, and the effect of the excess of all three of these elements in one solution were observed in 80 tomato plants. The plants given excess nutrients were compared to a control group grown in a balanced nutrient solution of Hoagland's No. 2 formula. The 80 plants were divided into 4 jars of 4 plants each totaling 16 plants to each of 5 groups.

These groups (A, B, C, D, and E) were given nutrient solutions listed in Table 1. The results of the growth and production over a 17 week period are summarized below.

1. Group A (Control)

Group A plants produced the least vegetative growth, consumed the least water, produced the least total weight of fruit, but grew the best quality of fruit of all groups.

2. Group B (Excess Iron)

Group B plants produced the greatest amount of vegetative growth, consumed the 3rd lowest amount of water, produced next to the highest total weight of fruit and grew the second best quality fruit of all groups.

3. Group C (Excess Phosphate)

Group C plants produced next to the least vegetative growth, consumed next to the least amount of water, grew

next to the least total weight of fruit, and their fruit was rated 4th in quality in all groups.

4. <u>Group D (Excess Nitrate)</u>

Group D plants produced the 3rd largest amount of vegetative growth, consumed the highest total amount of water, grew the 3rd highest total weight of fruit, and produced fruit which was rated least desirable in quality of all groups.

5. <u>Group E (Excess All Three)</u>

Group E plants produced the 2nd greatest amount of vegetative growth, were rated 2nd also in total consumption of water, had the greatest total amount of fruit weight, and this fruit was rated 3rd in quality of all groups.

6. <u>All Groups</u>

The plants of all groups demonstrated a distinct relationship in growth, moisture consumption, and pH of the solutions. This relationship was evident among the plants of each group as well as among the groups themselves.

7. The results of this investigation indicated that excess quantities of the single elements, nitrogen and phosphate, do not increase plant growth, fruit production, or fruit quality to any appreciable extent. The single excess of iron, apparently, does have an appreciable effect on growth, production, and moisture uptake while the excess of all the elements in combination only affects these factors in

increasing magnitude if greater amounts of moisture are available to the plants.

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APPENDIX

TABLE 1

MAJOR ELEMENT COMPOSITION OF NUTRIENT GROUPS

Group	Nitrogen (NO_3 ppm)	Phosphorous (PO_4 ppm)	Iron (Fe ppm)	Potassium (K ppm)	Magnesium (Mg ppm)	Sulphate (SO_4 ppm)	Calcium (Ca ppm)
*A (Control	638	95	14	235	12	49	40
B (Excess Iron)	638	95	56	235	12	49	40
C (Excess Phosphate)	656	190	14	235	12	40	40
D (Excess Nitrate)	1010	95	14	470	12	49	40
E (Excess All Three)	1276	190	56	470	12	49	80

Trace Element Composition For All Nutrient Groups

Boron	.5 ppm
Manganese	.5 ppm
Zinc	.05 ppm
Copper	.02 ppm
Molybdenum	.01 ppm

* Taken from Hoagland and Arnon, Solution 2 (1950, p. 31)

TABLE 2

PLANT TISSUE pH'S DURING DAY AND NIGHT

(Average of 3 analyses)

Tissue Tested	Group A		Group B		Group C		Group D		Group E	
	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night
Apical Leaves	5.8	4.2	4.0	3.8	4.4	3.8	6.4	5.0	6.5	6.4
Main Stem	4.4	3.8	4.4	3.8	6.0	4.0	4.8	4.0	5.9	4.2
Center Leaves	6.3	4.0	6.5	5.0	4.4	4.2	6.0	5.2	4.7	---
Lower Leaves	6.4	4.0	---	---	6.6	4.8	6.2	4.4	---	---
Root	4.6	4.0	6.7	4.0	4.4	3.8	4.6	4.2	5.1	4.6

Group A ....Control
Group B ....Excess Iron
Group C ....Excess Phosphate
Group D ....Excess Nitrate
Group E ....Excess All Three

TABLE 3

PLANT TISSUE NUTRIENTS IN DIFFERENT LIGHT INTENSITIES

(Average of 3 Analyses)

Tissue Tested	Nitrate (NO_3 ppm) Group A	B	C	D	E	Phosphate (PO_4 ppm) Group A	B	C	D	E
Apical Leaves-sun	5	12	5	5	5	12	47	10	10	10
-cloud	5	10	5	-	-	10	31	94	-	-
Main Stem -sun	75	75	55	60	60	94	47	190	94	94
-cloud	75	-	-	-	-	24	-	-	-	-
Center Leaves-sun	10	12	5	5	5	12	17	10	10	10
-cloud	5	10	5	-	-	10	31	10	-	-
Root -sun	50	50	31	40	41	190	72	140	144	24
-cloud	35	50	50	-	-	140	94	190	-	-

TABLE 4

NUTRIENT SOLUTION pH'S

Age in	Group A		Group B		Group C		Group D		Group E	
Weeks	Refill	7Days	Refill	7Days	Refill	7Days	Refill	7Days	Refill	7Days
1	7.0	6.8	7.1	6.9	7.2	6.92	7.0	7.0	7.0	6.75
2	7.0	6.8	7.1	6.8	7.2	6.70	7.0	7.1	7.1	6.81
3	7.0	6.9	7.1	6.97	7.2	6.85	7.0	7.1	7.0	6.92
4	7.0	6.75	7.0	6.77	7.1	6.62	7.0	6.77	7.1	6.40
5	7.0	6.72	6.9	6.75	6.9	6.62	6.1	6.82	6.9	6.45
6	7.0	6.77	6.9	6.72	6.9	6.60	6.9	6.72	6.8	6.40
7	7.0	6.75	7.0	6.80	6.9	6.67	7.1	6.77	6.9	6.55
8	6.9	6.45	6.8	6.45	6.8	6.52	7.0	6.65	6.7	6.30
9	6.7	6.95	6.7	6.92	6.8	6.50	6.9	6.67	6.8	6.55
10	7.1	6.67	6.9	6.62	6.8	6.42	6.9	6.65	6.7	6.45
11	7.0	7.45	7.0	7.20	6.9	6.05	7.0	7.07	6.7	7.15
12	6.9	7.2	7.0	7.12	6.9	6.95	6.8	7.15	6.7	7.00
13	7.0	7.22	6.9	7.20	6.7	7.10	6.9	7.15	6.9	7.07
14	7.0	7.97	7.0	8.15	6.9	7.85	6.9	8.02	6.8	8.20
15	7.0	8.15	7.0	8.32	6.9	8.00	6.9	8.25	6.9	8.20
16	6.9	8.12	7.0	8.30	6.9	8.10	6.9	8.25	6.9	8.20
17	6.9	8.22	7.0	8.35	6.9	8.20	6.9	8.35	6.9	8.32

TABLE 5

WEEKLY PERCENTAGE GROWTH INCREASE IN HEIGHT AND NUMBER OF LEAVES

Age in Weeks	Group	Height Increase					Number of Leaves				
		A	B	C	D	E	A	B	C	D	E
2		1.2	12.6	14.8	9.6	10.2	12.4	2.0	38.0	42.1	35.9
3		5.32	18.7	16.5	20.0	24.4	18.5	5.0	90.0	100.0	107.7
4		81.3	49.6	91.1	119.3	107.8	75.0	90.5	43.7	22.2	44.8
5		47 5	27.0	33.7	30.1	28 0	22.6	20.7	17.5	22 7	20.1
6		49.0	60.2	68.9	48.6	74.2	25.2	40.9	12.7	11.1	13.2
7		46.0	56.9	33.1	37.7	40.5	23.3	15.5	14.0	16.6	13.2
8		20.8	23.3	17.5	17.1	19.0	18.8	15.3	3.3	4.7	3.2
9		18.0	29.5	18.8	12.4	17.1	12.2	14.3	3.9	5.4	4.0
10		3.7	4.6	5.9	7.4	5.0	3.8	2.4	10.6	10.8	16.1
11		4.3	4.4	6.2	7.9	5.0	4.5	3.8	9.2	9.7	8.0
12		7.5	9.4	9.7	9.4	14.4	5.2	9.1	1.1	0.0	0.0
13		13.6	13.5	11.8	14.7	6.3	8.3	8.4	0.0	1.7	0.0
14		5.9	5.1	1.8	5.1	5.1	3.1	0.7	0.0	0.0	0.0
15		3.4	3.2	2.3	2.4	1.6	0.0	0.0	0.0	0.0	0.0
16		2.1	1.6	3.5	1.9	2.4	0.0	0.0	2.3	0.0	0.0
17		1.4	1.6	8.5	0.4	7.7	0.0	0.0	7.5	0.0	0.0

TABLE 6

EFFECTS OF DIFFERENT NUTRIENT SOLUTIONS ON ROOT SYSTEMS

Group	Growth Character	Root Weights	
		Fresh (gms)	Air Dry (gms)
A (Control)	Stringy, uncompacted, many long roots	142.5	27.3
B (Excess Iron)	Stringy, uncompacted, many, long roots	210.1	44.7
C (Excess Phosphate)	Compact, massive, few long roots	113.1	29.2
D (Excess Nitrate)	Stringy, uncompacted, many long roots	322.9	95.6
E (Excess All Three)	Strongly bunched, compact, few long roots	283.6	103.4

TABLE 7

NUTRIENT GROUP COMPARISONS AT END OF EXPERIMENT

Group	Flowers and Buds	Dried Buds	% Leaves Lost	Green Fruit (Total wt. gms.)	Ripe Fruit (Total wt. gms.)
A (Control)	9.0	3.25	32.4	286.6	890.0
B (Excess Iron)	6.5	2.75	25.8	215.9	1165.4
C (Excess Phosphate)	6.0	2.0	32.1	257.5	957.9
D (Excess Nitrate)	6.0	2.25	16.5	485.9	991.5
E (Excess All Three)	3.75	2.25	20.0	554.2	1402.1

TABLE 8

DESCRIPTIVE CHARACTERS AND NUMERICAL

EQUIVALENTS FOR JUDGING QUALITY OF FRUIT

Color
- 1.0 Pale, not true red with green or yellow cast
- 1.5
- 2.0 True, vine-ripened red
- 2.5
- 3.0 Rich, mellow, blood red

Skin
- 1.0 Rough, thick, tough
- 1.5
- 2.0 Smooth, tender, thin
- 2.5
- 3.0 Silky smooth, very tender, very thin

Shape
- 1.0 Lumpy, corrugated, Excessively cracked
- 1.5
- 2.0 Symmetrical
- 2.5
- 3.0 Sphere shaped

Wateriness
- 1.0 Excessively juicy, pithy, dry, excessive seeds, large air spaces
- 1.5
- 2.0 Normal juice and meat, very small air spaces, few seeds
- 2.5
- 3.0 Little juice, mostly meat, no air spaces

Firmness
- 1.0 Hard or extremely soft
- 1.5
- 2.0 Medium soft, resilient
- 2.5
- 3.0 Quickly resilient, capacity fullness

Flavor
- 1. Tart, flat, bitter
- 1.5
- 2.0 Characteristic, average blending
- 2.5
- 3.0 Very tasty, somewhat acid sweet, character taste is superior, succulent

Comparisons in Quality of Fruit

Group	Rating (6 characteristics, 20 judges)
A (Control)	2.02
B (Excess Iron)	1.96
C (Excess Phosphate)	1.92
D (Excess Nitrate)	1.77
E (Excess All Three)	1.94

FIGURE 1

MOISTURE CONSUMPTION

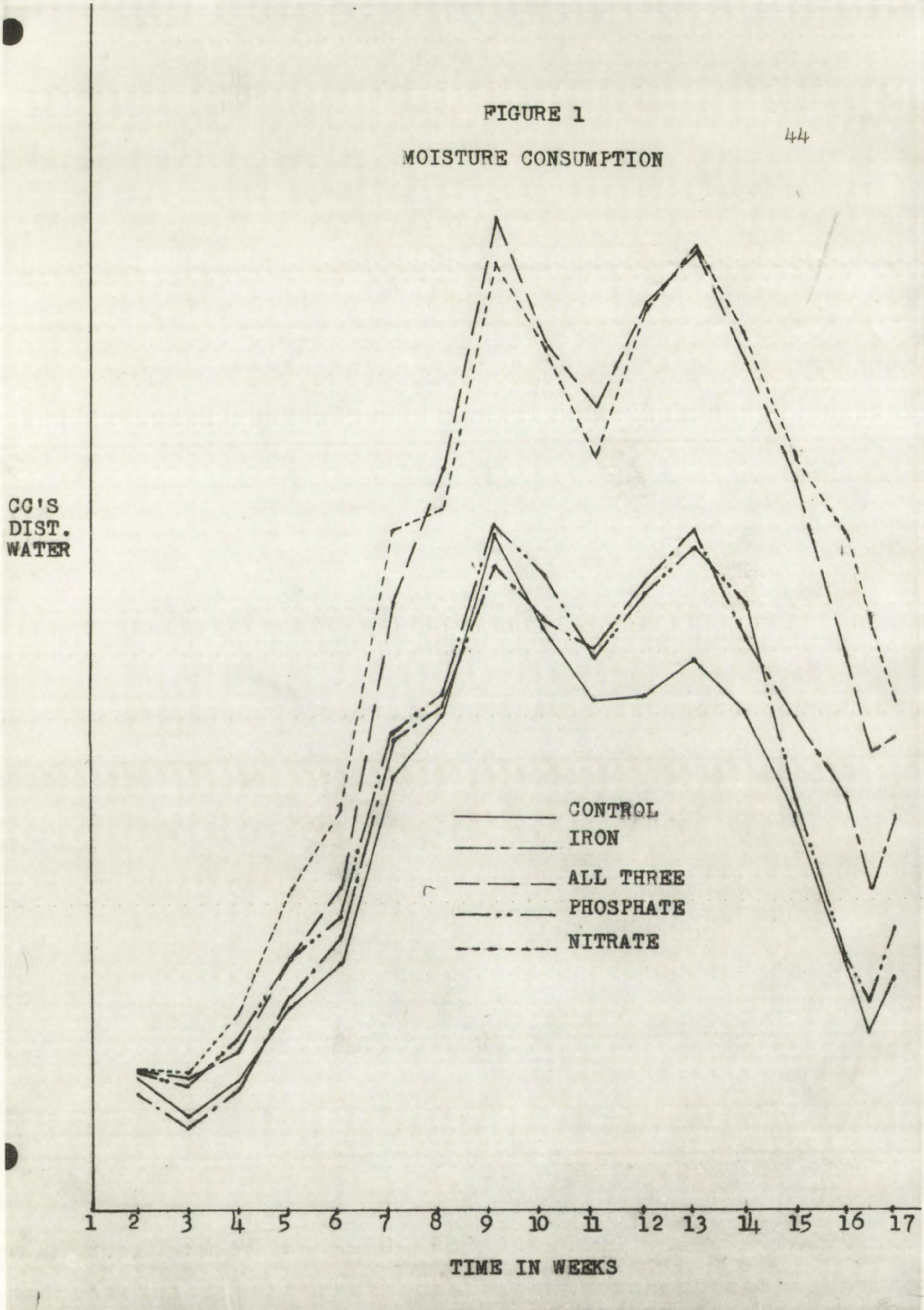

FIGURE 2

NUTRIENT SOLUTION pH'S