

THE ABSORPTION OF MINERAL NUTRIENTS  
AND THEIR EFFECT UPON THE METABOLISM OF THE PLANT  
WITH SPECIAL REFERENCE TO THE TOMATO.

by

Eileen DesBrisay.

A Thesis submitted for the Degree of

MASTER OF SCIENCE IN AGRICULTURE

in the Department

of

HORTICULTURE.

THE UNIVERSITY OF BRITISH COLUMBIA.

April 1934.

## CONTENTS.

	Page
Introduction .....	1
Purpose of the experiment .....	1 - 2
Review of Literature .....	2 -19
Calcium .....	3 - 5
Magnesium .....	5 - 6
Sulphate .....	6 - 7
Nitrate .....	7 -10
Potassium .....	11 -14
Phosphate .....	14 -17
General .....	18 -19
Preliminary Experiments .....	20 -26
Material and Methods .....	20 -24
Results tabulated .....	25 -26
Main Experiment .....	27 -51
Section I, Absorption Experiment .....	28 -32
Materials and Methods .....	28 -30
Results .....	30 -32
Section II, Nutrition Experiment .....	40 -51
Materials and Methods .....	40 -44
Results .....	44 -51
Subsidiary Experiments .....	52 -54
Discussion .....	55 -77
Calcium .....	56 -
Magnesium .....	57
Sulphate .....	58
Nitrate .....	59- 62
Potassium .....	63- 68
Phosphate .....	69- 72
Double Concentration .....	73- 75
Complete Starvation .....	76- 77
Recommendations .....	78
Summary .....	79 -82
Acknowledgements .....	83
Literature Cited .....	84 -89
Appendix	

THE ABSORPTION OF MINERAL NUTRIENTS AND THEIR EFFECT UPON  
THE METABOLISM OF THE PLANT WITH SPECIAL REFERENCE TO THE TOMATO

INTRODUCTION.

A backward glance over one hundred years shows that Sir Humphrey Davy (9) in early work in Agricultural Chemistry found mineral constituents to be essential for plant development. Liebig, in 1850, presented his classical Law of the Minimum, showing that certain particular minerals were necessary and that the absence of one of them retarded or prevented plant growth even though all others should be present in abundance. Lawes, at Rothamsted, followed Liebig, contradicting on some points and progressing to further findings on others. Wolff (53) in 1871, and again in 1880, showed that the quantitative composition of one and the same plant would vary according to the soil in which it was grown. Many later workers have denied, or substituted for, or elaborated upon the theories presented by these earlier ones. At the end of the century Loew (29) stated that plants absolutely require a certain minimum of each mineral nutrient; and in most cases they take up not only an excess of these various compounds but also substances which are perhaps useful, but not absolutely necessary to the plant. On these theories of Wolff and Loew the intention of the present investigation is based.

PURPOSE OF THE INVESTIGATION.

The tomato, *Lycopersicum esculentum* Mill., being a plant well adapted to nutrient cultures, has been chosen for the investigation. It is purposed to find when certain ions enter the tomato plant and to learn whether a withholding

of these ions at certain times will have an effect upon the growth and fructification of the plant. It was felt that fertilizers may often be applied when they are unnecessary; that is, as suggested by Loew, while the plant absorbed these nutrients, they might not be essential and normal development might be obtained without them. These elements might, therefore, be wastefully applied, or conversely, might not be supplied at the crucial time. These nutrient materials, as has been indicated, enter the plant in the ionic form: for instance when potassium nitrate is used as a fertilizer the K and  $\text{NO}_3$  ions are absorbed independently. The ions to be concentrated upon are  $\text{Ca}^{++}$ ,  $\text{Mg}^{++}$ ,  $\text{SO}_4^{--}$ ,  $\text{NO}_3^-$ ,  $\text{K}^+$ ,  $\text{PO}_4^{--}$

The absorption of these six ions has been followed throughout the life of the plant in the Absorption Experiment of Section I, and  $\text{NO}_3^-$ ,  $\text{K}^+$ , and  $\text{PO}_4^{--}$  have been especially studied in the Nutrition Experiment of Section II.

#### REVIEW OF LITERATURE.

Petrie (38) has recently presented a summary of the intake of ions by the plant and its relation to the respiration of the root, and lists as causes amongst others for ion absorption:

1. Chemical fixation.
2. Donnan equilibria in the cytoplasm
3. The accumulation of free ions in the vacuole at the expense of energy rendered available in respiration.
4. Adsorption

"These mechanisms operate in each living cell of the plant and the rate of supply of ions to the shoot will be determined within limits by the concentrations that are maintained in the cell-sap of the root cells lying in the path of the transpiration stream. This will, according to the hypothesis, depend on the rate of respiration of these cells, so that within limits the rate of respiration of the root cells will determine the rate of supply of ions to the roots. Some experiments with oat plants in which the roots were made to respire at different rates, and the rate of ion intake thereupon measured, were performed, and were found to conform with the above hypothesis." This is interesting in view of the present investigation.

A review of the theories and considerations of certain investigators on the particular ions is illuminating.

#### Calcium.

Calcium has long been regarded as an essential element. Its deficiency will cause a yellowing and dwarfing of all parts of the plant. It has been said to be necessary for the formation of cell walls and thus for normal leaf and root development. Some have considered it to be necessary for the synthesis of fats and probably of proteins, due to its formation of plant soaps. Nightingale (35) experimenting with ample calcium and calcium deficient tomato plants, found that in the calcium deficient plants, nitrates were not absorbed; there was therefore a definite interference with the formation of proteins essential to the protoplasts of living

cells. The yellowing and dwarfing of calcium starved plants was thus accounted for. Since the absorption of nitrates did not take place, there was an accumulation of carbohydrates. He suggests that calcium is present in the plant as "combined" and "uncombined" calcium, and that the latter type is directly responsible for the calcium activities in the plant. He re-establishes fairly conclusively the fact of the presence of a middle lamella of calcium pectate. Calcium deficient plants, he points out, are short-lived, the calcium present being confined to the lower parts of the plant. It is thus a non-migratory element and necessary at all times of growth. Colby (5) corroborates Nightingale, finding that low calcium plants absorbed very little nitrate, that calcium starvation prevented absorption of any considerable quantity of any ion, and that it prevented root growth entirely, the root tips invariably dying. The effect of calcium in antagonism and on cell permeability would seem to be apparent here. Dorothy Day (8) finds calcium deficient plants to be shorter, the lower leaves chlorotic, and the youngest tough and curled, but the difference is in a variation in the amount of elongation, rather than in the anatomical structure. She thinks that many solutions in use may have more than the "optimum amount of calcium", but undoubtedly certain plants are calciphiles and others calciphobes. Wallace (47) has reported on a "lime-induced chlorosis" of fruit trees growing in soils containing large amounts of calcium carbonate; since the trouble was corrected by applications of ferrous sulphate

sprays to the foliage, "it would seem that this chlorotic condition is due to the unavailability of iron", due in turn to an oversupply of calcium. Again, calcium has been found to be a co-enzyme, greatly facilitating pectase in its functions.

#### Magnesium.

Magnesium is the only mineral element in the chlorophyll molecule, but as such it holds the central position and is absolutely essential in its synthesis. Being a migratory element, that is, being capable of translocation, its lack may not show for some little time; but finally a spotted chlorosis will appear, beginning from the veins outwards. It is more abundant, according to Raber (40), in parts undergoing development, and is therefore thought to be necessary for the formation of nucleo-proteins. It seems also to be associated with plant oils and in some way to affect their synthesis. The cations, calcium and magnesium, perhaps because of their strongly antagonistic effects, are often linked together. Nightingale (35) found that there was no marked excess nor deficiency of magnesium in calcium deficient plants; that is, the absence of absorption of calcium did not affect that of magnesium. Tyson(46) states that it appears that "magnesium has an injurious effect on the plant when it is taken up in amounts equal to or greater than the amounts of calcium present, even though there are favorable concentrations and ratios of the other elements present;" though this will depend on the nature of the soil and the fertilizer treatments. But Pfeiffer and Rippel (39) have shown that in oat plants, the ratio

of magnesium to calcium may vary within rather wide limits, with no noticeable effect upon the plant. Tyson (46) has noted the percentage of calcium in leaves of large beets to be higher than the percentage of magnesium; whereas the percentage of magnesium in the leaves of small beets is higher than that of calcium. Raber (40) considers magnesium to be necessary for the transportation of phosphorus and suggests that it is only indirectly in this way associated with the synthesis of fats. In this connection Colby (5) has found phosphate absorption to be more badly affected by magnesium starvation than by potassium or sulphate starvation. Wallace (47) insists that a proper potassium : magnesium ratio is necessary in plant nutrition.

#### Sulphate.

The sulphate ion is the slowest moving of the ions according to Hoagland (19). The necessity of the element sulphur to plant nutrition, lies in the fact that it enters into the composition of proteins. Wallace (47) experimenting with ~~apples~~ and small fruits, found the omission of sulphate to produce in these plants a condition resembling in general that caused by partial nitrate starvation. There was a restricted shoot growth, a paling and yellowing of the leaves, followed by brilliant coloring and finally early defoliation. Colby (5) found that a sulphate omission had a depressing effect on the absorption of all the other elements, but that it was least depressing on nitrate absorption. The condition existing, however, might conform to Wallace's "partial nitrate

starvation" and therefore account for it. McMurtry (32) describes the veins as being a lighter green than the tissues between in sulphate chlorosis. Tomato seeds contain a considerable amount of sulphur, but insufficient to carry the new seedling to full development. Its deficiency, it is believed results in a retardation of cell division and a hindrance or suppression of fruiting. The slowly moving sulphate ion has an effect on the other ions in slowing down their absorption as Colby has shown.

#### Nitrates.

The essential nature of nitrate in the synthesis of proteins and therefore of protoplasm, is well recognized and the yellowing and stunting due to its lack is a familiar feature. Kraus and Kraybill (27) have demonstrated that a large yield of tomatoes is associated with an abundant supply of both nitrogen and carbohydrates, and that they must be in the correct ratio. Basing his work on theirs, Watts (51) finds that it is the amino-nitrate fraction within the plant which is of importance in fruiting. The percentage of nitrogen with special reference to the amino-acid fraction, decreases when temperature or intensity of light or duration of the photosynthetic period is increased, thereby increasing the carbohydrate content. A high carbohydrate content, especially starch, is usually accompanied by a low amino-nitrate content, while a low carbohydrate content is accompanied by a high to moderate amino-nitrate content. Fruitfulness is associated with a balanced carbohydrate ratio, giving a moderate succulence to

the plant. He therefore advises the grower: that to obtain the greatest fruitfulness, much nitrate may be used in an abundance of light conditions, such as in the field; whereas under less light conditions, such as in the greenhouse, less nitrate is needed. Nightingale (34) corroborates this work, emphasizing that it is the assimilated soluble compounds, that is the amino-acids, which are of importance not the nitrate nitrogen as such.

Murneek (33) believes that large quantities of nitrogenous material are necessary for the development of all parts of the tomato plant, including the fruit. He goes so far as to state that in the tomato "vegetative growth is controlled by the fruit". The plant "apparently does not store much nitrogen" and "a close and delicate balance between absorption and assimilation is probably established". The fruit in some way is able to monopolize practically all the incoming or elaborated nitrogen, thus causing an evident shortage in the strictly vegetative parts of the plant. He considers carbohydrates may also be similarly monopolized by the fruit, again causing a shortage. This shortage of carbohydrates and nitrogenous materials results in cessation of vegetative growth.

Emmert (10) shows there is a close correlation between the nitrate present in the soil and in the tomato plant and that this is, in turn, very closely correlated with yields. He also states that an alkaline reaction not only stimulates nitrification in the soil, but also stimulates both absorption and assimilation by the growing plants. He, too, finds tomatoes to be heavy nitrate feeders. In an alkaline medium, as

contrasted with an acid one, while there is more nitrate in the stems there is less in the growing points, since it is so rapidly utilized by the growing tips. In contrast to Emmert, Hoagland (18) claims that nitrate, usually one of the swifter moving ions, enters the plant more slowly in an alkaline medium.

Also working with tomatoes, MacGillivray (31) found a predominant storage of starch in plants from which nitrogen had been withheld. He also obtained higher sugars in the fruits.

McCool and Cook (30) obtained a rapid rate of transformation of nitrate nitrogen in small grains and Kentucky blue grass. This was indicated by a considerable decrease in nitrate content of the expressed sap three hours after the source of supply was removed.

Harrison (13) shows it to be possible to kill Kentucky blue grass plants, frequently fertilized with nitrates by repeated defoliations. The reason for this was that rapid growth exhausted the reserve carbohydrate supply and defoliation prevented a replenishing and therefore growth between defoliations became less and less.

In reference to light relationships, Tottingham and Stephens (45) found with young wheat plants that the nitrate radicle was absorbed more freely from  $KNO_3$  in nutrient solution than from nitrates of other common metals and this absorption was promoted by increases in blue to longer ultraviolet radiations. The form of radiation used, they point out, is

deficient as regards the shorter radiations as compared with sunlight. Totttingham and Lowsna (44) also found radiations of the highest frequency in the visible spectrum and the lowest in the ultraviolet to promote absorption of nitrates by young plants, but that yellow to violet rays increased the synthesis of protein, while long ultraviolet rays do not.

Brazeale (3) considers there is a direct relation between the absorption of potassium and nitrates: that potassium is probably necessary in the process of synthesis of protein-like compounds, although it does not enter into their chemical composition. If much nitrogen is available much potassium will be demanded; if little nitrogen is available little potassium will be demanded.

Davidson (6) found in certain field experiments that potassium was higher in plants from plots treated with  $\text{Na NO}_3$  than were those from the check plots. Here again is a linkage between the two.

Finally it is interesting to note that Kraus and Kraybell (27) think that nitrates "may aid in rapid growth and formation of new cells which have relatively thinner and less liquified walls and a greater percentage of amphoteric substances whose water holding capacity is relatively high." This would account for the fact that a high nitrate supply gives a high degree of succulence.

Potassium.

Considerable research upon the effect of potassium on tomato plants has been carried on by Jansen and Bartholomew and they have issued several bulletins and papers thereon. They find: there is evidence that potassium is necessary for cell division; that in a potassium deficiency, it is translocated and reutilized by the growing part of the plant; total and soluble nitrogen is much higher in potassium deficient plants; that there is an optimum potassium concentration which is conducive to the normal assimilation of carbohydrate compounds above and below which assimilation is reduced; and they suggest that in as much as high nitrogen and high sugars are correlated in the blooming stage of low potassium plants, the absence of good growth may have been due to a lack of condensation or polymerization of these compounds to more complex forms due to the potassium lack (23). Again (24) they further suggest "that rapid absorption of large amounts of potassium by plants during their early stages of growth with a subsequent translocation and reutilization during the later stages of development is, under some conditions, the process by which plants absorb potassium". There then followed a report on experiments with corn, cowpeas, soybeans, oats and Sudan Grass. It is noteworthy that in one of these experiments with one lot of plants, potassium was absorbed very slowly for a time and then rapidly whereas the next group absorbed it more steadily. This same irregularity was found in the present investigation. The nature

of the culture medium, whether water or soil culture, did not affect the general rate of absorption. This is again noteworthy suggesting the practicability of water and sand culture work to soil conditions. They maintain that plants take up potassium rapidly at all stages of growth if a good supply is available; and that when the concentration of the nutrient is reduced plants quickly readjust themselves to feed on the lower concentration. They point out that when fertilizing with potassium, there is no residual effect, since the plant will absorb potassium in such large concentrations if it is present in the soil solution; but if it is no longer supplied there will be translocation and reutilization. They found no definite relationships between the percentage of potassium in the plants and the simple carbohydrates and nitrogenous compounds (25).

Potassium is a rapidly moving ion. It is known to be radio-active: as such it is an energy producer and its uses therefore manifold. While sodium has been shown to replace potassium to some extent (14) it cannot do so in this field of radio-activity. Hoagland (19) finds the absorption of potassium to be depressed by sodium salts.

James and Penston (22) found potassium to be needed for greenhouse tomatoes in dull weather. Haas and Hill (15) in considering the work of Stoklasa, state the role of potassium to be partly indirect and only in darkness does it play an important part in protein development. Its radio-active quality is of interest in this connection and will be

discussed later. Jansen and Bartholomew, conversely, found potassium to be taken up by plants as readily by night as by day.

Wallace (49) and Tincker and Darbyshire (42) and numerous other workers have noticed an abnormal requirement for water in potassium starved plants. This is considered in the discussion and theories of such investigators as James (21) Weevers (52) and Warne (50) are presented there.

James and Penston (22) found potassium in all regions of the potato plant, and consider that it may be a high percentage of the dry matter. It is especially high in all actively growing tissues, i.e., in stem, root, sprout and reproductive parts. They can discover no evidence that potassium precedes and provokes growth but it is related to it. That plants may collect potassium they require for further growth they state, is allowable. This would be in accordance with Jansen and Bartholomew (24) who also qualify the statement using the expression "under some conditions." James and Penston think translocation of potassium in the form of salts of amino-acids or proteins is not unlikely. This is in contrast to Brazeale (3) who thinks nitrates and potassium are not chemically bound up but merely associated. The former workers base their opinion on the fact that potassium and proteins have a similar distribution in the meristematic tissues and appear to be abundant in sieve tubes. "The older leaves continually lose potassium while at the same time the younger ones gain it, and the work of Ruhland and

Wetzel quoted by Onslow (36) with begonia suggests a similar movement for amino-acids. Histochemical and analytical evidence considered together suggest a continuous circulating."

James (21) has found potassium to be plentiful at the surface of the plastids, in the cell vacuoles and cytoplasm and suggests that in view of the marked effect of potassium nutrition on carbohydrate metabolism, the presence of the metal at the chloroplast surface is interesting. Tincker and Darbyshire (43) agree that potassium is possibly a catalyst facilitating the condensation and hydrolysis of starch.

In working with corn stalks, Hoffer (20) reports that in the absence of potassium, there will be an accumulation of insoluble iron which kills the plant tissues. In addition to the necrotic effect upon the tissues, would be the suggestion that iron would not be present in as large quantities in its role of catalyst in photosynthesis, if it were in the insoluble form.

#### Phosphate.

A typical phosphorus deficiency will show a purpling and stunting of growth. Wallace (47) has lately found this to be true of such varied plants as strawberries, gooseberries, raspberries, apples and many workers have found it to be true of tomatoes and other crops. It has been considered to be necessary in the storage of carbohydrates, for the synthesis of nucleo-proteins and also it is of consequence in the assimilation of fats through the formation of phospholipids. MacGillivray (31) finds phosphorus to be essential

at all stages of growth. If there is a shortage, there will be a migration of phosphorus to the growing tip, and a re-utilization of it. But, MacGillivray states, "insomuch as blossoms require cell division for development" and fresh nuclear material, "it would seem the limited supply was not sufficient for all the organic and inorganic phosphorus necessary". He reports that in all plants, whether amply supplied with phosphorus or not there is a gradient of more and more phosphorus from the base of the stem upward until the fruit is reached, where there is as much as in the rest of the plant. He contrasts this function of phosphorus with that of nitrogen, where the highest concentration is found in the growing tips; and again, whereas nitrates move rapidly the movement of phosphates is slow. It has been contended that phosphorus is necessary for seed formation. MacGillivray protests that this seems to be true of the fruit as a whole and that it is just as essential to the formation of pulp as of the seeds. He points out, however, the difficulty of separating pulp from seed in the tomato. Statements that it is necessary to seed production are based on analysis of such plants as wheat and corn; but the outer coats of these is a portion of the carpel wall and therefore they are fruits. He points out that pulp is decreased in amount both in the carpel walls and in the central placenta region and that the differences are so great that one would expect a difference in variety. Fruits grown with a phosphorus deficiency had fewer and smaller seeds than the ample phosphorus plants,

but the seeds from both had almost the same percentage of phosphorus. They gave similar germination tests and produced similar plants. Phosphorus deficient plants showed an increase in the percentage of dry weight of starches and total nitrogen and a decrease of coaguable nitrogen, and of growth, pollination, size, weight and quantity of fruit. Gericke (11) working with wheat, felt that maturation was benefitted by a cessation of phosphorus but MacGillivray points out that the tomato differs from wheat in that there is vegetative growth and fruiting at the same time and that "it would seem essential to supply the plant with a continuous supply of phosphate. This is necessary during fruit formation if good sized fruits are desired" since such a large proportion is present in the fruit.

Andre (2 ) finds that a reutilization of phosphorus is greater than with the other elements and that this may be the reason why plants have such a small total amount of phosphorus. Emmert (10) reports the total phosphorus content of tomato leaves varied with the phosphate phosphorus content of the soil; it was high at a strongly acid concentration, low in a limed soil and medium in a sodium carbonate treated soil. The total phosphorus content of the fruit was not very consistent, lime applied to the soil decreased it somewhat, while phosphoric acid did not. Phosphate absorption was more badly depressed by magnesium starvation than by potassium or sulphate starvation, and a phosphate starvation seriously depressed nitrate absorption even causing a loss from the

roots late in the season. The Kentucky workers consider an analysis of the plant tissues for phosphorus, nitrogen and potassium to be of more value as an indicator of available soil nutrients than is an analysis of the soil itself. They have developed a speedy technique applicable to use in the field. Similar work has also been carried out in the field analysis of corn stalks at Purdue University.

Of particular interest in this investigation are Brazeale's findings that the absorption of both phosphorus and potassium increased up to a certain concentration after which there was a sharp decline.

General.

In conclusion are quoted a few additional investigations of interest. Wallace (47) whose experiments with apples and small fruits in sand cultures have already been referred to, shows that a deficiency of nitrate, potassium, phosphorus, calcium, magnesium and sulphur produces characteristic effects in the various plants, and the view is expressed that some of these may be of use for diagnostic purposes in the field. Davis (7), continuing Wallace's type of experiment with apples, found the omission of an element was reflected by a low percentage of that element in ash and dry matter, and demonstrates a high degree of correlation between symptoms exhibited and the amount of the related element in ash and dry matter. Gregory and Richardson (12) claim respiration to be subnormal when nitrogen is withheld, normal when phosphorus is withheld, and supernormal when potassium is withheld. They also show the rate of assimilation to be disturbed through the omission of these elements. A number of interesting observations are presented by Tyson (46) as a result of his experiments with sugar beets. He has found that in the early stages of growth the rate of absorption of elements is greater than that of assimilation. When the plant is making rapid growth there is a smaller percentage of the various nutrients in the dry matter, indicating that now assimilation is greater than absorption. The life processes are more influenced by the ratio and concentration than by a supply of any one element other

than nitrogen. He finds light intensity to be important in the utilization of mineral nutrients but not in their absorption: plants absorb just as much if they are shaded as unshaded. Nitrates increased the absorption of phosphorus and all plant foods increased the absorption of potassium. The intake of calcium was not increased by potassium, phosphates or nitrates. Hoagland (18) finds that with barley there will be absorption of nutrient materials at all stages, if a suitable concentration of ions be maintained. But intense absorption during later stages of growth lead to no important increases in crop yield, which seem rather to be conditioned in a large measure by a favorable supply and concentration in the early stages. Heydemann, however, (16) found with tomatoes that the assimilation of nitrogen, calcium, potassium, and phosphate proceeded at an equal rate for a time, after which potassium and nitrate were used more rapidly.

### PRELIMINARY EXPERIMENTS

The purpose of these experiments has already been pointed out: that is, an endeavor was made to learn the exact period of absorption of the ions  $\text{Ca}^{++}$ ,  $\text{Mg}^{++}$ ,  $\text{SO}_4^{--}$ ,  $\text{NO}_3^-$ ,  $\text{K}^+$  and  $\text{PO}_4^{--}$  in the development of the tomato, with the object of learning the most suitable time for fertilizer applications. Preliminary absorption experiments were carried out in the greenhouse during 1931-32.

#### Materials and Methods.

Three different sets of plantings were worked with in these experiments. The first ran from November 18, 1931 to January 7, 1932. On November 13 twelve tomato plants of an average height of 5.5 cm. were set up in 2 quart glass jars and grown in a nutrient solution. These were first thoroughly washed and rinsed with distilled water and covered with dark paper to prevent the growth of algae. The metal tops were cut and a cork with a 4 cm. bore fitted into the openings. The roots of the plants were rinsed free of any soil from the seed bed, the stems were wrapped with a small piece of absorbent cotton, and the plants were fitted through the corks into the jars. Hoagland's Nutrient solution of the normal concentration was made up and the jars almost filled with it. A few drops of iron citrate were added every few days and the solutions kept up to volume with distilled water. A sample of the nutrient solution was kept for the subsequent comparative analysis.

The plants were allowed to grow for one week, when the solutions were poured off, measured, and thoroughly mixed, and a sample taken. Upon removing the used solution from the jars, the plant roots were washed off and a fresh solution was given them. This procedure was carried on weekly.

The sample of solution in which the plant had grown and the sample of unused solution were taken to the laboratory and parallel analyses run on them for the ions:-  $\text{Ca}^{++}$ ,  $\text{Mg}^{++}$ ,  $\text{SO}_4^{--}$ ,  $\text{NO}_3^-$ ,  $\text{K}^+$ ,  $\text{PO}_4^{--}$ . Standard solutions containing known parts per million of these ions were also analyzed and compared with the check and used solutions. The parts per million of the various ions absorbed by the plant could thus be calculated. The ions were determined colorimetrically with a Klett Top Colorimeter:- The procedure for the nitrate ion was the phenol disulphonic method (1), for the potassium ion the method outlined by Cameron and Failyer (4), phosphates were determined by the ammonium molybdenum blue method of Parkes and Fudge (37), magnesium as outlined by Hubbard (17), and the calcium and sulphate ions according to the procedures of Richard and Wells (41).

Unfortunately this first planting could not be continued any length of time. A cold night caught the plants from which set-back they never greatly recovered. In addition it was not realized at this point that aeration was required in the solutions to provide sufficient oxygen for the roots. By January 7 so much disintegration of the roots was going on with the consequent release of the ions that it

was decided to abandon these plants. Table I, page 24, gives the parts per million of the ions absorbed during this period. By January 7 all ions were being diffused.

Second plantings were set up in the same manner as the first ones on January 22nd. The plants chosen were 8 cm. high. Hoagland's solution was used for the first two weeks. Shive's solution for the following three weeks and Hoagland's for the final week. At the time Shive's solution was substituted the question of aeration was becoming urgent and it was felt that a change of medium might alleviate the necessity of arranging for the aeration. The plants were given a fresh solution weekly as with the previous planting, and analyses were made. Again, unluckily, the plants were chilled and little growth was being made. On February 20, it was decided to use aeration on half the plants. A system was set up as follows:- A pump was installed and connected with the jars by a system of glass and rubber tubings. The amount of air entering each jar was controlled and kept uniform by clamping the rubber tubing. A distinct improvement in the appearance of the plants was apparent but it was found to be too late to stimulate them to normal growth, with the hope of reaching maturity in the few weeks still left. Consequently two weeks later, this planting was also discarded. Whereas considerable disintegration had been going on before aeration, as was indicated by the analysis, the tests run following its application showed a lower concentration of ions being diffused out by the plant. The final week the solutions from the non -

aerated and the aerated plants were both compared with the original. Analysis showed those plants which had been aerated to be, upon the whole, healthier than the non-aerated. A further difficulty with all plantings was root injury, due to the weekly disturbance and the washing of the roots with cold water. Table II, page 24, gives the analysis results for this planting. It is noted that in the period March 4 - 11, the final week, aerated and non-aerated results are given.

A third planting was made on March 18. Six large plants about to blossom were set up in glass jars in the manner previously employed. Hoagland's solution was used and aeration was installed. Again difficulties were experienced in maintaining the continuous functioning of the pump, and in preventing injury and breaking of the roots when changing the solutions in handling plants of this size. These plants were grown for five weeks, and as before weekly analyses were made. Very little growth took place, but some fruit was obtained. Table III, page 24, gives the absorption during this period.

TABLE I.

Nutrients absorbed in p.p.m. by the first planting.

Period	Nov.13-20	Nov.20-27	Nov.27-Dec.4	Dec.4-11	Dec.11-18
NO <sub>3</sub>	0.0	25.	62.	6.0	30.0
K <sub>3</sub>	16.	21.	0.00	11.0	8.0
PO <sub>4</sub>	0.0	30.	1.0	73.0	1.0
Ca	0.0	+	49.0	9.0	7.0
Mg	0.0	0.0	17.0	9.5	0.0
SO <sub>4</sub>	+	0.0	0.0	0.0	-25.8

TABLE II.

Nutrients absorbed in p.p.m. by the second planting.

Period	Jan.22-Feb.5	Feb.5-19	Feb.19-26	Feb.26-Mar.4	March 4-11	Aer.	Non-Aer
NO <sub>3</sub>	67	2.2	30.05	9.3		100	228
K	25.8	84.5	-45.	27.		-12.2	0
PO <sub>4</sub>	0	-13.9	38.	-33.		-53.6	-76.6
Ca	3	-10.8	-15.7	-7.5		-9.2	-32.4
Mg	7.2	-.6	-.1	3.		10.	-6.6
SO <sub>4</sub>	26.3	-11.5	-50.	-		-10.8	-27.2

TABLE III.

Nutrients absorbed in p.p.m. by the third planting.

Period	1st two weeks Average weekly	3rd week	4th week	5th week
NO	97.5	0.0	0.0	100.
K <sub>3</sub>	46.3	-16.8	42.5	-23.
PO	0.	11.3	33.3	9.1
Ca <sup>4</sup>	81.	-33.2	-33.	0.0
Mg	8.5	-3.2	0.0	9.0
SO <sub>4</sub>	2.75	14.3	0.0	11.5

### RESULTS.

The results of the first two experiments were largely negative, showing the action of an unhealthy plant rather than a normal healthy one.

Ca, Mg, and  $\text{SO}_4$  were consistently diffused out of the plant under the adverse conditions.  $\text{NO}_3$  continued to be absorbed in some degree at all times, except on one occasion when the plants were disintegrating rapidly. K and  $\text{PO}_4$  did not act with any consistency, but there was less diffusing out of the K ion than of the  $\text{PO}_4$  from the unhealthy plants.

With aeration analysis showed a distinct lessening of disintegration.

The third planting, showing the period between blossoming and fruiting, gave the following general absorption results:

$\text{NO}_3$  was absorbed at first, but then ceased. It was noted that the plants made little vegetative growth at this time, which would correlate the lack of  $\text{NO}_3$  absorption. The final week, absorption again occurred. The K ion was absorbed in large quantities alternately with none at all or even a diffusion out. This diffusion was explained on the grounds that the roots were inadvertently broken in changing the solutions from week to week. The  $\text{PO}_4$  ion was absorbed in same quantity the third and four week but very little the fifth week. There was Ca absorption the first two weeks and thereafter a diffusion out which was again accounted for by the breaking

of the roots, and consequent diffusing out of the ions. There was diffusion out of Mg when large amounts of Ca were diffused out, but this diffusion was followed by renewed absorption.

SO<sub>4</sub> showed a fairly consistent absorption.

### MAIN EXPERIMENT.

The Preliminary Experiments were followed by further absorption and nutrition investigations in 1932-1933.

The Absorption Experiment concerned the ions dealt with in the preliminary work which has been presented, that is,  $Ca^{++}$ ,  $Mg^{++}$ ,  $SO_4^{--}$ ,  $NO_3^-$ ,  $K^+$ ,  $PO_4^{--}$ . The materials and methods used and the results obtained are presented in Section I.

The Nutrition Experiment concerned the effect of a deficiency of nitrate, potassium and phosphate, a change in concentration, and complete starvation. The materials and methods used are given in Section II. The results upon plant growth and fructification, and a chemical analysis are presented.

Since interesting correlations were found to occur, discussion of the results of the two experiments appears under one heading.

### VARIETY USED.

Riverside Favorite tomato seeds were planted in well-washed non-nutrient sand, and watered with distilled water only. These seedlings were used in both the Absorption and Nutrition Experiments.

## SECTION I. ABSORPTION EXPERIMENT.

### Materials and Methods.

A new method was devised for the absorption experiment. A pump was no longer available, and since it had been shown in the preliminary experiments that aeration was essential, water cultures could not be used. Accordingly a series of sand cultures was set up. On December 20, four of the seedling tomato plants were planted in five inch clay pots of well washed quartz sand. Means were taken to prevent the sand from leaching out of the drainage hole, by covering it with an aluminum thimble an inch in diameter. The plants were watered with Hoagland's nutrient solution of the regular concentration. A check pot of sand with no planting was also set up. The pots were placed upon pint sealers, that any drippings might be caught. Brown paper was wrapped around the sealers to prevent algae growth in the drippings and dark paper was fitted over the tops of the pots around the plants to prevent algae growth on the nutrient salts in the sand. The amount of solution fed to each plant was tabulated and the check pot watered with an equal amount. Plate I, Fig. (a) (Appendix) shows the arrangement of the pots of the mature plants upon the sealers.

After seventeen days the solutions were withdrawn for analysis. Procedure was as follows: Distilled water was flushed through each pot to wash out the salts which were present there. The washings were collected in crocks and

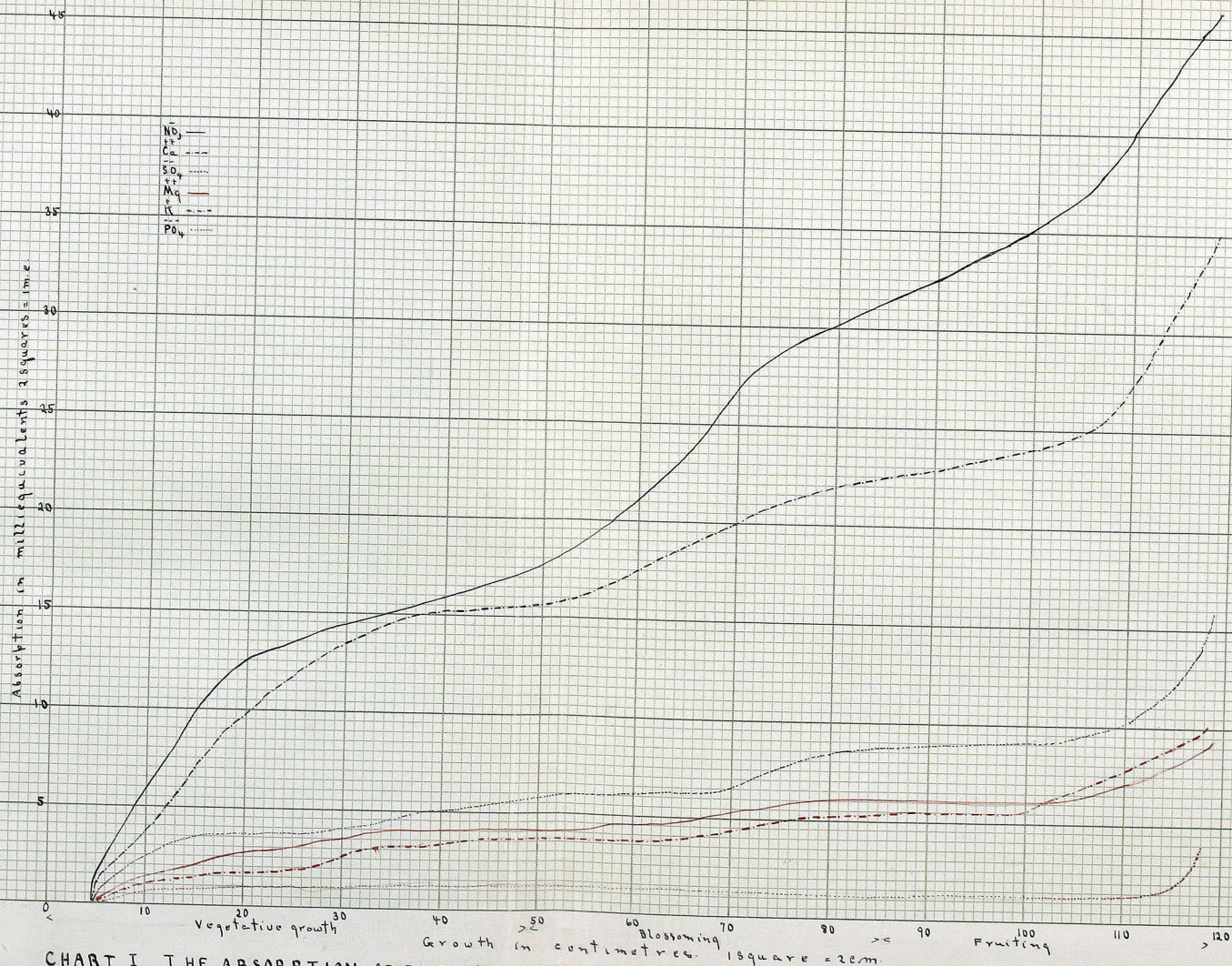


CHART I THE ABSORPTION OF THE IONS IN MILLIEQUIVALENTS CHARTED AGAINST GROWTH IN CENTIMETRES.

measurement was made of the solution which passed through each pot; sufficient water was used to bring this measurement up to twice the volume of the nutrient solution fed to the plant. The washings of the four pots were well mixed and a sample was taken. The check pot was similarly treated and a sample taken of the washings from it. It was felt that the use of the check pot would provide an adequate comparison as the unused solution, since it was realized that the pots might absorb nutrients which must not be attributed to the plant. The scheme for washing out the salts is shown in Plate I, Fig. (b) (Appendix). After washing the plants through in this fashion it was found necessary to allow them to dry out for a day or more before feeding the new solution: otherwise it would drip through the pots at all parts and control of the quantities of the solution would be lost. The fresh solution was supplied in such a quantity as the pot would take without leakage. During the first period, which was seventeen days, each plant received 500 c.c. The amount fed was gradually increased until 2050 c.c. was being given in June, the final month. The pots were washed through and a fresh solution given, as has been described. After two three-week periods, and thereafter every two weeks, analyses of the used and unused solutions and comparison with a known standard were made in the manner of the preliminary experiments. Measurement of growth was taken at each change of the solution. All suckers were removed and the plants kept to one stem and staked. At the fourth changing of the solution on March 7th,

the plants were transplanted to 6 inch pots, the average height at this time being 49.6 cm. They remained in these until the close of the experiment on June 29th, when it was considered vital activity was ceasing.

### Results.

Tables are presented to show the absorption of the various ions:

Table IV.- Page 33: The absorption of the nutrients in parts per million (p.p.m.) and in milli-equivalents (m.e.) for the periods between analysis.

Table V. - Page 34: The absorption of the nutrients in p.p.m. and m.e. during vegetative growth, blossoming and fruiting.

Chart I. - Page 29: The absorption of the ions in milli-equivalents charted against growth in centimeters.

It is notable that all the ions are absorbed throughout the life of the plant, Mg only, definitely ceasing to enter two weeks before the others stopped.

At blossoming time there was a slight falling off in nitrate absorption, but during an unusually fine period it went up again to almost as high a point as it had reached during the period of purely vegetative growth. Potassium showed a continuous fluctuation in absorption until the final month or more when it dropped very low. Phosphate absorption increased gradually until blossoming time, when it suddenly ceased for one period, was low through blossoming time and increased again during fruiting. Absorption of calcium increased gradually as early growth was being made, after which

it fluctuated. A reference to Chart I, Page 29a, however, shows that both calcium and nitrate absorption fairly well follow the growth curve. No calcium was absorbed early in June and then like the phosphate there was suddenly a large amount absorbed the latter part of the month; the fruit had been, and still was, ripening in large quantities. Magnesium absorption also fluctuated though there was little correlation with calcium absorption. Sulphate was absorbed in the largest amount early in the vegetative growth but was used in a fairly uniform degree until harvesting of the plants.

The relative amounts of the six ions absorbed in milli equivalents is also indicated in Chart I, Page 29a. It is shown that nitrates are absorbed in the largest amounts, with calcium next in quantity. The phosphates ions enter in the smallest amounts.

Table VI, Page 35, presents data on the relation of the absorption of nitrate and potassium to the ratio of sunshine to possible sunshine and to the solar radiation as measured by a black bulb thermometer. Data was obtained from the Dominion Meteorological Service and is therefore reliable, but it is pointed out that complete statistics were not available for the early months of the year. The averages, however, are felt to be representative. There seems to be very little correlation between the elementary absorption and solar radiation, but with the ratio of sunshine to possible sunshine there is a notable correlation. During periods of greater sunshine there is generally greater nitrate

absorption, and in periods of lesser sunshine there is lesser potassium absorption.

TABLE IV

The absorption of the nutrients in parts per million and milli- equivalents for the periods between analyses.

PERIODS	Déc. 30 Jan. 17 17 Days	Jan. 17 Feb. 7 21 Days	Feb. 7 Feb. 21 14 Days	Feb. 21 Mar. 7 14 Days	Mar. 7 Mar. 20 13 Days	Mar. 20 Apr. 3 14 Days	Apr. 3 Apr. 20 17 Days	Apr. 20 May 4 14 Days	May 4 May 18 14 Days	May 18 June 1 16 Days	June 1 June 15 14 Days	June 15 June 29 14 Days
ions	p.p.m. m.e.	p.p.m. m.e.	p.p.m. m.e.	p.p.m. m.e.	p.p.m. m.e.	p.p.m. m.e.	p.p.m. m.e.	p.p.m. m.e.	p.p.m. m.e.	p.p.m. m.e.	p.p.m. m.e.	p.p.m. m.e.
NO <sub>3</sub>	225.2 3.63	436.8 7.00	225.00 3.63	208.00 3.35	440. 7.09	297.10 4.700	419.50 6.77	277.00 4.46	234.20 3.77	97.00 1.56	0.00 0.00	0.00 0.00
K	32.5 0.83	27.00 0.69	45.65 1.14	30.0 0.89	28.6 0.73	28.60 0.73	53.00 1.35	60.4 1.54	30.10 .77	3.80 .097	0.00 0.00	0.00 0.00
PO <sub>4</sub>	4.9 0.13	10.65 0.337	26.11 0.825	0.0 0.00	8.1 0.025	1.90 0.06	3.30 0.13	12.3 0.39	15.30 0.48	19.16 0.60	0.00 0.00	24.70 0.78
Ca	43.6 2.18	113.6 5.68	123.3 6.16	22.10 1.10	90.3 4.50	37.80 1.89	65.05 3.25	69.0 3.45	72.25 3.61	31.10 1.55	0.00 0.00	27.80 1.39
Mg	19.4 1.59	7.15 .58	19.9 1.64	4.50 0.35	16.7 1.40	8.30 0.68	2.10 0.17	13.5 1.11	17.30 1.42	0.00 0.00	0.00 0.00	0.00 0.00
SO <sub>4</sub>	67.16 1.40	95.7 1.99	44.25 .92	69.6 1.45	32.5 .68	62.00 1.30	79.30 1.69	60.5 1.26	39.95 .83	55.60 1.16	79.00 1.64	71.00 1.49

TABLE V.

The absorption of the six nutrients in parts per million and milli-equivalents during vegetative growth, blossoming and fruiting. Attention is drawn to the fact that with the tomato, vegetative growth continues with blossoming and fruiting, up to the approximate time at which prolific blossoming ceases. Blossoming in turn continues practically throughout the life of the plant.

Period	Dec. 30 - Mar. 7 Vegetative Growth		Mar. 7 - April 3 Blossoming		April 3 - June 29. Fruiting		Total
Ion	p.p.m.	m.e.	p.p.m.	m.e.	p.p.m.	m.e.	p.p.m. m.e.
NO <sub>3</sub>	1095.00	17.61	737.00	11.79	1027.50	16.56	2859.00 45.96
K	135.15	3.55	57.10	1.46	147.30	4.63	339.55 9.64
PO <sub>4</sub>	41.51	1.29	10.00	0.08	50.06	2.38	101.57 3.67
Ca	302.60	15.12	128.10	6.39	265.20	13.25	695.90 34.76
Mg	50.95	4.16	25.00	2.08	32.90	2.70	108.85 8.94
SO <sub>4</sub>	276.71	5.76	94.50	1.98	385.35	8.07	756.56 15.81

TABLE VI

Relation of the absorption of nitrate and potassium to the ratio of sunshine to possible sunshine and to solar radiation.

Period	Vegetative Growth			Blossoming.		Blossoming and Fruiting.			
	Dec. 30 Jan. 17	Jan. 17 Feb. 7	Feb. 7 Feb. 21	Feb. 21 Mar. 7	Mar. 7 Mar. 20	Mar. 20 Apr. 3	Apr. 3 Apr. 20	Apr. 20 May 4	May 4 May 18 June 1 June 15
Ratio of sunshine to possible sunshine	.268	.302	.39	.42	.532	.34	.61	.50	.42 .39 .45
Absorption of NO <sub>3</sub> in p.p.m.	225.20	436.80	225.0	208.00	440.00	297.00	419.50	277.00	234.20 97.00 00.0
Absorption of K in p.p.m.	32.50	27.00	45.6	35.00	28.60	28.50	53.00	60.40	30.10 3.80 0.00
Solar Radiation	79.65°	78.00°	80.4°	104.05°	102.3°	93.7°	107.8°	109.5°	108.9° 112.2° -

TABLE VII  
RESULTS OF NUTRITION EXPERIMENT,  
showing size and weight.

Series	Av.Ht.of Plant at Change of Treatment Mar. 4.	Effect on the plant first visible	First Fruit	Average height at harvesting in feet.	Average length of roots in inches	Average green weight of tops.	Average green weight of roots.	Total green weight in grs.	Average dry weight of tops	Average dry weight of roots	Percentage moisture in tops.	Average weight of fruit per plant in grs.	Average No. of fruit per plant	# Average weight of fruit
I. Full Nutrient	34.375	-	May 14	7.20	16.75	485.20	88.80	574.0	110.00	22.00	77.33	2354.8	58.0	40.6
II. Nitrate Deficiency	32.75	Mar. 23 Yellowing	May 9	4.80	12.60	149.00	33.00	182.5	24.50	4.10	83.56	460.8	20.75	23.9
III. Potassium Deficiency	X 27.1	Bronzing	May 16	6.75	20.50	333.75	54.50	388.2	77.7	8.00	76.66	1550.4	27.0	57.4
IV. Phosphate Deficiency	33.1	May 19th Purple Mottling	May 2	7.10	21.00	477.38	69.25	546.6	83.20	16.25	82.58	1402.3	34.75	40.2
V. 2 x Concen- tration	33.75	-	May 9	7.25	22.25	429.25	92.5	522.0	102.50	14.25	76.12	2269.8	36.3	54.2
VI. Complete Starvation	32.00	Mar. 23	May 4	4.55	13.00	137.25	35.25	172.5	26.75	4.50	80.55	407.8	15.0	27.2

X - The treatment was changed in these plants at an earlier date.

# - There was considerable variation in the size of the fruits. While those of the Potassium deficiency show a larger average sized fruit, there was considerable variation in size and the total amount by weight was low.

TABLE VIII.  
CHEMICAL ANALYSIS OF VEGETATIVE PARTS.

Series	Percentage of carbohydrates in oven-dry weight.												Percentage Proteins in oven-dry weights		
	LEAVES				STEMS				ROOTS				Leaves	Stems	Roots
	Free reduc- ing sugars	Total Sugars	Starch	#Total Car- bohydrates	Free reduc- ing sugars	Total Sugars	Starch	#Total Car- bohydrates	Free reduc- ing sugars	Total Sugars	Starch	#Total Car- bohydrates			
I. Full Nutrient	2.70	6.40	5.10	11.50	1.80	10.24	9.36	19.60	1.48	1.49	5.75	7.24	12.66	7.35	12.125
II. Nitrate Deficiency	2.70	2.70	5.00	7.70	3.04	8.99	16.72	25.71	1.33	2.20	14.00	15.20	8.200	2.895	4.375
III. Potassium Deficiency	6.60	6.85	6.80	13.65	1.35	8.56	8.22	16.78	0.90	0.96	17.70	18.66	14.00	9.25	15.25
IV. Phosphorus Deficiency	3.05	3.05	6.42	9.47	1.81	9.42	12.00	21.42	0.73	1.12	10.00	11.12	16.25	8.62	14.75
V. 2 x Concen- tration	3.50	4.00	6.75	10.75	1.45	12.72	10.95	25.67	2.14	2.36	4.14	6.60	11.62	8.25	19.81
VI. Complete Starvation	2.50	2.50	4.25	6.75	2.22	11.20	14.72	25.92	1.40	1.47	14.40	15.87	8.375	3.45	19.45

# - Total carbohydrates: Any additional carbohydrates not analyzed for are considered to be included in small amounts in Total Sugars or Starch.

TABLE IX  
CHEMICAL ANALYSIS OF THE FRUIT.

Series	p.H.	Total Acidity in Terms of Citric Acid.	Specific Gravity	Free Reducing Sugars in Percentage			Total Sugars in Percentage			Total Proteins in Percentage			Percent Percent	
				Extracted Juice	Green Weight.	Dry Weight	Extracted Juice	Green Weight	Dry Weight	Extracted Juice	Green Weight	Dry Weight	Dry Wt. of Fruit	Moisture in Fruit
I. Full Nutrient	4.86	.512	1.0747	2.00	1.81	16.36	2.19	1.98	17.08	.3725	.323	2.92	11.06	88.94
II. Nitrate Deficiency	4.75	1.64	1.033	1.80	1.58	18.12	1.92	1.68	19.26	.454	.399	4.70	8.72	91.28
III. Potassium Deficiency	4.85	.512	1.0378	1.63	1.44	16.21	1.83	1.63	18.35	.818	.722	8.02	8.88	91.12
IV. Phosphorus Deficiency	4.85	.5376	1.0271	1.7	1.5	17.52	2.08	1.82	21.26	.716	.628	7.33	8.56	91.44
V. 2 x Concentration	4.96	.512	1.059	2.20	1.85	18.60	2.31	1.97	19.60	.5691	.486	4.83	10.05	89.95
VI. Complete Starvation	5.3	.704	1.057	1.76	1.50	15.18	1.80	1.53	15.48	.402	.343	3.46	9.88	90.12

## SECTION II. NUTRITION EXPERIMENT.

### Materials and Methods.

Nutrition experiments were commenced on November 8. Twenty-four young tomato plants of a height of 4.5 cm. were planted in five inch pots of well-washed quartz sand. They were to be divided into six series which were to be treated as follows:

- I. Full nutrient throughout growth and fruiting.
- II. Full nutrient until blossoming time and then a nitrogen omission.
- III. Potassium deficiency treatment.
- IV. Full nutrient until blossoming time and then a phosphate omission.
- V. Full nutrient throughout, but fed twice the concentration once a week instead of the regular concentration twice a week.
- VI. Full nutrient until blossoming time and then an omission of all nutrients.

All plants were watered with Hoagland's solution, four times the regular concentration being used for the first two waterings. For the potassium deficiency series (Series III) sodium was substituted for some of the potassium. Series I, II, III, IV and VI were fed the solutions twice a week and Series V once a week with the double concentration. Further waterings were given with distilled water as seemed necessary. For several weeks the normal concentration of the salts was given until, on January 3, it was doubled and was kept so for the remainder of the experiment. The amount of solution given each plant was gradually increased from 50 c.c. to 150 c.c.

The plants were kept to a single stem and all suckers were removed.

On January 20, the pots with the potassium deficiency treatment (Series III) were well washed through with distilled water and all potassium was omitted from that time on. Substitution was made with sodium according to Hoagland's deficiency solutions. At this time the plants averaged 16 cm. in height.

By January 31, the five series of nutrient plants had reached an average height of 23.3 cm. and the potassium deficiency plants a height of 17 cm. They were thereupon transplanted to 10 inch pots, 14 of the pots being glazed and 10 clay. The plants were staked and 250 c.c. of the nutrient solutions given. This quantity of solution was fed for several waterings and was then gradually brought up to 400 c.c. at which it was maintained for the duration of the experiment. Waterings with distilled water were given as required, the clay pots evaporating considerably more than the glazed.

The first week in March it was felt blossoming time had arrived, at which point the treatment was to be changed. March 7 the pots were well washed through with hose water and finally with distilled water, so that all traces of salts might be removed. Measurement of the plants was taken. On March 10 waterings were given according to the series outlined above. Hoagland's deficiency solutions being used for the omission treatments. 400 c.c. of solution, of twice the normal concentration was given twice a week as before the

change of treatment; series V received four times the concentration once a week.

Pollination was secured, partly by hand and partly by tapping the stakes; all plants, however, were given identical treatment.

Observations were made as to the subsequent behavior of the six series as regards amount of growth, discoloration of foliage, time of fruit ripening. The fruits were picked as they ripened and records of size and weight were kept.

Plates II, Fig. (a) and (b), (Appendix), show the stand of plants in the greenhouse at maturity.

On June 20 the plants were harvested. Top and root measurements and weights were taken and the plants were spread out to dry on the greenhouse benches. Throughout the summer they were continually turned in order to become thoroughly air-dried. When quite dry they were weighed and stored. Total weights of the fruit produced were recorded and representative samples were preserved, some in alcohol and others by sterilization in quart jars.

#### Chemical Analysis.

Chemical analyses were made in the laboratory upon oven-dried samples of leaves, stems and roots for reducing sugars, total sugars, starches and proteins. The p.H. and total acidity of the fruits were taken and they also were analyzed for reducing sugars, total sugars, starches and proteins.

The extraction of the sugars from leaves, stems, and roots was accomplished in the following manner: Samples which ranged from 10 to 25 grams were placed in Erlenmeyer flasks, and 100 c.c. of alcohol plus 1.5 gram of  $\text{Ca CO}_3$  were added. These were boiled for 15 minutes when the clear liquid was decanted off. This was repeated twice by adding further 50 c.c. portions of alcohol and again decanting the liquid. After the third extraction the residue was transferred to a Saxhleit extractor; 200 c.c. of alcohol with 1 gram of  $\text{Ca CO}_3$  was used for the extraction which continued for several hours until the liquid siphoned over colorless. This was added to the liquid previously decanted and distilled down to about 75 c.c. 200 c.c. of distilled water were added, the mixtures were placed on a hot plate and again brought down to about 100 c.c., care being taken both at this point and during distillation not to let the temperature go beyond  $90^\circ \text{C}$ . The alcohols now having been driven off the mixture of sugars and water was strained through cheese-cloth, and the filtrate was cleared with neutral lead acetate and delead with sodium oxalate. Actual determination of sugars was made by the Lane and Eynon Method (28) by the use of Fehling's Solution and methylene blue as an indicator. This was found to give excellent results.

Total sugars were found by inverting 50 c.c. of the sugar solution with 5 grs. of picric acid. The mixture was boiled exactly 10 minutes, was cooled, and neutralized

with 20% Na OH, and then the sugars determined.

Starches were determined by boiling the pulp remaining from the sugar extractions in 20 c.c. of conc. H Cl diluted to 250 c.c. for  $2\frac{1}{2}$  hours. The mixture was allowed to stand, was nearly neutralized with Na OH and filtered. Determination of the resulting sugars was again made by the Lane and Eynon Method.

Determination of the sugars of the sterilized fruit was made by straining out the pulp through a cotton sack and squeezing it very dry, then clearing the juice with lead acetate and deleading with sodium oxalate. Determination was made as with the vegetative parts.

The Kjeldahl Method of protein analysis was used for leaves, stems, roots and fruit.

The p.H. of the fruit was taken by the quinhydrone method; and total acidity was determined by titration against Na OH using phenolphthalein as an indicator.

### Results.

Complete records of the morphological changes in the plants as a result of the six different treatments were kept. A report at the end of three and a half weeks is quoted:

"The Full Nutrient plants show good healthy growth with an abundance of fruit forming. The Nitrate omission plants are now showing the effects. Yellowing of the lower leaves commenced within ten days of the change of the treatment. The vegetative part of the plant is losing its succulence, though there is growth from the upper part.

Blossoms are still appearing and fruit is being set, but hardly more than is the case with plants deprived of all nutrients. Potassium deficient plants have made almost as good growth as the full nutrient, but they look slightly less virile and slightly less fruit is being borne. Blossoms appeared quite as early as with the other series. So far the omission of phosphorus is not noticeable in any way. The plants are healthy, growing and fruiting well. Those plants with which the concentration of the solution was varied (Series V) from the beginning showed slightly the best growth. There are many fruits which are somewhat further advanced than those of the Full Nutrient Series in which the same amount was fed, but in two periods instead of one. Within a week the Complete Starvation plants were showing some yellowing. There has been little if any further growth. Blossoming and fruiting is continuing though the fruits are not maturing as rapidly as in the Full Nutrient Series. The whole vegetative part of the plant is lifeless in appearance."

Table VII, Page 36, gives the final morphological effect of the various treatments.

Plate III, fig. (a), (b), (c), (d), (e), and (f) (Appendix), portray the typical mature plant of each series contrasted with a typical plant of the Full Nutrient Series. In all photographs the Full Nutrient plants are designated "C" - Complete.

A comparison of the leaves of all series is given in Plate IV (Appendix). Unfortunately they are not in color

but, in that they were photographed from the same spot, the comparison in size is a true one. The fragile nature of the Nitrate deficiency and the Complete Starvation (-ALL) plants is visible. All leaves were cut from the same position on the plant and were representative ones.

Plate V (Appendix) shows typical roots of the plants of the six series.

Table VIII, Page 37, presents the data obtained by chemical analysis of leaf, stem, and root; and Table IX, Page 39, presents the data obtained by chemical analysis of the fruits.

The leaves of the Nitrogen deficiency plants continued to yellow throughout the treatment and finally whitened until by June 20, the date of harvesting, they had become very fragile, with the veins prominent and a purplish cast. Reference to Table VII, Page 36, and Plate III, fig. (a), (Appendix), shows growth, green and dry weights, the amount and size of the fruits to have been much less than that of the Full Nutrient plants. The leaves are smaller and there was poor root growth. None of the fruits were larger than 6 cm. in diameter but they were usually well shaped. The percentage of moisture in the tops was relatively high. Chemical analysis showed the vegetative parts to be high in carbohydrates; especially so were the stems and roots where large quantities of starch were present; reducing sugars were high in the stems. In the fruits, the p.H. was 4.75 more acid than any of the other series. Total acidity was 1.64 (in terms of Citric Acid) which was three times as great as that of any of the other

series except the Starvation plants, in which case it was twice as great. Specific Gravity was lower than that of the Full Nutrient fruits indicating a lesser amount of mineral and volatile matter. The dry weight is also lower. Total sugars were slightly higher than in the check plants. Proteins were rather higher in the fruits but low in leaves, stems and roots.

In the Potassium deficiency series a bronzing gradually made its appearance on the leaves. By June 6 a yellowing had appeared around this bronzing and by harvest time many of the leaves so affected had shrivelled. The effect of the potassium omission was therefore gradual. The plants were scarcely less tall than those of the Full Nutrient Series but the green and dry weight was less and there was less fruit produced. Plate IV, (Appendix), shows the leaves to be somewhat less vigorous than those of Series I. The roots show an interesting condition in being long and spindling, and leathery with few root hairs; they were dark brown in color. The average size and weight of the fruits was considerably greater than those of any other series, there being more fruits measuring 6.5 - 7 cm. in diameter; but, as has been noted the total fruit production was lower. Chemical analysis showed a high reducing sugar content in the leaves. The roots have a low proportion of both reducing and total sugars, but starches are particularly high, giving a high carbohydrate figure. The p.H. and total acidity of the fruit juices was much as in the control plants, the p.H. being 4.85 and the acidity .512.

The Specific Gravity again was somewhat low. The percentage of dry weight of the fruit was less than that of the Full Nutrient fruits, so that while total sugars were somewhat higher in the Potassium deficiency series when calculated to dry weight, they were slightly lower in the extracted juice. Protein content was found to be high in leaf, stem, root and fruit.

No effect of Phosphorus starvation was apparent in the Series IV plants until May 9 when a purple mottling or blotching appeared on the leaves of the lower half of one of the plants. A week later it had made its appearance on two of the others. Only just before harvesting did it appear on the fourth. This mottling crept upwards to some degree and then halted. A strong correlation was obtained here with the Absorption Experiment. At no time was there a severe effect; the plants were otherwise perfectly healthy and fruiting went on in an apparently normal manner. A study of Table and Plates, however, shows the average dry weight of the tops to be low and the moisture content to be high. Fruit production is considerably lower, the average size is the same but the number of fruits produced per plant is much less. Like the Potassium deficiency plants there was much irregularity in size which ranged from 4 to 7 cm. This same irregularity, however, was found in plants given the Full Nutrient treatment. Plate IV, fig. (d), (Appendix), shows the leaf; it is difficult to discover any blotching and it is apparently stronger than the "K" leaf. The roots were usually less

extensive than those of the complete feeding, as Plate V, fig. (d), (Appendix) indicates, and there were relatively fewer root hairs. These roots, too, were brown in color. Analysis showed no significant difference between these phosphorus deficient plants and the check plants in total and reducing sugars. Reducing sugars were slightly higher in the leaves and lower in the roots of plants with the phosphorus lack. The stems showed the same relative increase of total over reducing sugars in both series. Starches were high in both stems and roots. The fruit juices showed no variation in p.H. but the total acidity was slightly higher. The Specific Gravity of the juices was lower than for any of the other series and the percentage of the dry weight of the fruit was also lower. This will be discussed later. Both reducing and total sugars were found to be a little higher than the check plants when calculated to dry weight but lower on the green weight basis. Proteins were notably high in root, leaf and fruit, but were not found so in the stem.

The plants of Series V, double the concentration fed half as often, have been reported as making slightly better growth than the Series I check plants. Both continued strong healthy plants. At harvesting some of the leaves had become a paler green or the normal dark green had become somewhat blotched and recently formed blossoms on both were shrivelling. The tables and plates show little difference in any respect except in fruit production. The amount produced was almost the same, but the average number of fruits on the Series I

plants was greater than on the Series V plants, but those of the latter series were larger than those of the former. Both reducing and total sugars taken for the plant as a whole, that is leaf plus stem plus root, were in approximately the same percentage in both series. The Full Nutrient plants showed a slightly higher total sugar content in the leaf, and the double concentration plants in stem and root. Both showed high total sugars in the stem. The p.H. of Series I was 4.86, while of Series V it was 4.96. Total acidity, nevertheless was the same. Protein content was higher in the roots and fruits of the double-concentration plants; it was slightly higher in the stems of this series but higher in the leaves of Series I. The Specific Gravity of the juices and the dry weight of the fruits of the two series approximated each other.

The Complete Starvation plants exhibited a continuous yellowing, with cessation of growth. Some of the fruits developed brown lesions and spots. Later the foliage became bronzed and purpled and finally colorless, with a blue cast about the veins, much as the foliage of the Nitrate deficiency plants. A comparison of these two series is shown in Plate III, fig. (b), (Appendix). The Tables and Plates show that plants which have been starved of all nutrients reflect the treatment in a much restricted growth of root, stem and leaf, and a small fruit production. On the other hand, the chemical analysis evidenced reducing and total sugar content to be equal to that of the fully fed plants in root, stem and leaf, and almost so in the fruit, with the exception only of a low

invert sugar content in the leaf of the starved plant. Since the leaves of the starvation plants had begun to wither, it is possible the invert sugars had passed from the leaves to the stem. The percentage of moisture in the tops of these plants, nevertheless, was greater than that in the Full Nutrient ones. Proteins were higher in roots and fruits of the starved plants, and higher in the stem and leaves of the well-nourished ones. The p.H. of the juices was higher for the starvation plants, but total acidity was greater. The Specific Gravity of the juices and the percentage of dry weight of the fruit were a little less for the starvation series, indicating a lower mineral and volatile matter content.

### SUBSIDIARY EXPERIMENTS.

#### (a) Complete Potassium Omission -

Seeds of plants which had been grown in 1932 with no potassium whatever were planted. Plant (a) of Plate VI, (Appendix), received no potassium throughout its lifetime, whereas plant (b) was fed potassium in the usual amounts from blossoming time. The difference in height is notable, though neither attained any great size. Both, however, bore fruit as is evidenced in the photograph. The green weight of the top of plant (a) was 14.2 grams, and that of plant (b) 31.5 grams.

#### (b) Seed Experiment -

Seeds from all series of the Nutrition Experiment, from the Absorption Experiment, from the 1932 Potassium omission seeds, and seeds from plant (a) of the Subsidiary Experiment (a) were planted in 1933. Germination tests were run by planting the seeds in flats of well washed quartz sand and watering with distilled water only. A description of the seeds and the percentage of germination obtained is given in Table X, page 53.

A second series of flats was planted similarly, but was fed a complete nutrient solution. These plants were cared for in the manner of the Nutrition Experiment and are now in ten inch glazed and clay pots. Plants whose parents and grand-parents had no potassium are slighter stemmed and

TABLE X.

Description and Percentage Germination of  
Seeds in Subsidiary Experiment (b)

Series	Description and Size	Percentage Germination
Full Nutrient	taken as normal	58
2 x Concentration	as Full Nutrient but more wringled	81
Potassium deficiency	as Full Nutrient but depressed	54
Potassium omission 1932 seeds	slightly smaller but uniform in size	68
Potassium omission 1933 seeds	smaller than 1932 parents and more variable	65
Phosphate deficiency	slightly smaller and less uniform	49
Nitrate deficiency	smaller and less uniform in size and shape	66
Complete starvation	smaller and less uniform in size and shape	77
Absorption Plants	smaller than Full Nutrient but uniform	74

rather less vigorous than those whose parents only were deprived, and these latter in turn, are only slightly less so than the plants from the seeds of the Potassium deficiency plants of the Nutrition Experiment. The plants from the seeds of the other five series of the Nutrition Experiment show a more or less uniform growth. Seedlings from the Absorption Experiment had a much better root system than any others, and it is noticeable that the plants are making better growth. The effect of starvation in one generation has little permanent effect.

(c) Phosphate and Potassium Omission -

Seedling tomatoes from seeds of plants completely starved of phosphates and from seeds of potassium deficient plants are being grown. They are being entirely starved of the nutrient in question. Histological examinations of these and the potassium range in Experiment (b) are being carried on.

(d) Iron Detection in Potassium Starved Plants -

A test for iron deposits in the tissues of plants treated with a potassium omission according to the method described by Hoffer (20) were performed. Plants from seeds of the Potassium deficiency series of the Nutrition Experiment which were fed no potassium were used. In the absence of potassium, iron is believed to accumulate in that it becomes insoluble. A very distinct browning of the tissues resulted indicating this accumulation. When seeds of the various potassium deficient treatments being grown in Subsidiary Experiment (b), now being fed a complete nutrient were tested, no brown discoloration appeared.

### DISCUSSION.

The findings of the investigation would seem to indicate that Petrie (38) is correct in his theory that the rate of respiration of the root cells of the plant will determine the rate of absorption of the ions. Evidence points clearly to the fact that the plant absorbs the nutrients which its metabolism requires. It is impossible to agree with Loew (29) that in most cases they take up not only an excess, but also substances which are "perhaps useful, but not absolutely necessary to the plant".

Absorption of the ions studied was found to take place throughout the life of the plant, and a strong correlation was obtained between the Absorption and Nutrition Experiments. A discussion of the individual ions is presented, when these correlations will be pointed out. Calcium, magnesium and sulphate were worked with only in the absorption experiment so that statements cannot be made regarding their essential nature. There were no plants in the Nutrition Experiment which were withheld these ions. But such a strong correlation was obtained between the two experiments in regard to the other ions that it would seem permissible to suppose that these too were probably being absorbed in only the required amounts.

Calcium.

In the Preliminary Experiments 1 and 2, the diffusion of calcium into the solution is accounted for by the disintegration of the plants, when the cells in separating would release the calcium of the middle lamella. In the third Preliminary Experiment, the early absorption during growth would be expected since calcium is required in the building up process and is of importance in the absorption of the other essential elements (Colby). When these plants began to disintegrate there was again a diffusion out.

In the Main Absorption Experiment there was a gradual increase of absorption during earlier growth. The calcium was required for the division of the cell in the formation of the middle lamella, and for normal root and leaf growth. The effect of calcium on nitrate absorption is an interesting point. It is noted that Dorothy Day (8) thinks there to be too much calcium in some nutrient solutions. However the importance of calcium in cell permeability, through its effect on other ions, and as a corrector of poor soil conditions, cannot be overestimated. No calcium was absorbed early in June when growth had reached its maximum, but the renewed absorption in large quantities when fruiting was at the maximum opens up an interesting field. One wonders if calcium is present in large amounts in the fruits, and it is suggested that a mineral analysis of the fruit for calcium would be of value in explaining this renewed activity in the absorption of calcium. Such is later shown to be the case in regard to phosphates also.

Magnesium.

During the adverse conditions of the first two Preliminary Experiments there was a diffusing out which would be accountable to breaking down of the cells and disintegration of chlorophyll. When absorption did occur, as it did in several periods, magnesium entered in fairly large amounts to be utilized in the building up process. In the third Preliminary Experiment, magnesium absorption fluctuated; it was diffused out when calcium was diffused out in large quantities. Whether there is a linkage here is uncertain.

In the Main Absorption Experiment, there was again a fluctuation in magnesium absorption. One might hope to explain it on the grounds of chlorophyll development in the photosynthetic reactions, but there appears to be no correlation with sunlight, as one would expect, if such were the cause. The correlation of growth and magnesium absorption, however, is fairly well defined, as a reference to Chart I (Page 29a), will show. In the early stages of growth more proportionately was required than at any other time. Recalling the migratory quality of magnesium this would seem reasonable.

Sulphate.

Like calcium and magnesium, the sulphate ion, on the whole, was consistently diffused out of the plant under the conditions of Preliminary Experiments 1 and 2. Indeed it was even more continuously diffused out. In the third Preliminary Experiment it was, in all but one period, consistently absorbed.

In the Main Absorption Experiment sulphate was absorbed fairly uniformly throughout the whole period of growth and fructification. The largest amount of absorption occurred during vegetative growth, however, and again during the heavy ripening of fruits. Since it enters into the composition of proteins, it would be constantly required as long as growth was going on. The literature has shown it to be present in the seed, and it would seem that the fruit must contain a considerable quantity. Again a chemical analysis of the fruit would be valuable; the persistent absorption of sulphate through all phases of development and in fruiting, would suggest that it must be present in some quantity in the fruit.

### Nitrates.

Nitrates, it would seem from the data of both the Nutrition and Absorption Experiments, are being constantly utilized by the plant as long as growth and fruiting is progressing. If the life processes of the tomato are similar to those of the small grains, and the rate of transformation of nitrate nitrogen in the plant is very rapid as shown by McCool and Cook (30), it would logically follow that a constant supply of nitrate must be maintained that protoplasm might be built up. The consequences of the withholding of nitrate from the Series II plants, therefore, were the expected ones in lack of growth and discoloration of the foliage. The leaves have lost the power of chlorophyll formation. In contrast to the fragile pale lavender of the leaf of the tomato in the final stages, MacMurtrey (32) with the tobacco plant obtained a yellowing followed by a "firing" of the lower leaves to a bright brown color. Nightingale (34) in contrast to McCool and Cook and to Murneek, thinks nitrates may be stored within the plant until the proper conditions arise for synthesis to other forms of nitrogen. If this is so the cessation of nitrate absorption in the third planting of the Preliminary Experiment could be accounted for. There was little growth during two periods, possibly due to adverse conditions, and little nitrate was needed. As fruiting commenced more nitrates would be required, according to Murneek (33), and there was a further absorption of them.

The literature cited in the introduction by Tottingham and Stephens (45) and Tottingham and Lowsna (44) on the influence of shorter light rays is of intense interest in reference to the increased absorption of nitrates on bright days, Table VI, page 35. It has been mentioned that utilization of nitrogen is very rapid; we know photosynthesis to be continually going on; and have often observed the rapidity and suddenness of growth almost and in truth overnight, following sunny weather, when there would be much carbohydrate manufactured and much nitrate enter the plant. It would seem, therefore, that there is an immediate response in metabolism to an adequate nitrate and carbohydrate supply. The potassium and nitrate relationship is interesting in this connection, in that less potassium is absorbed on bright days. This will be more fully discussed under potassium, but it is suggested here that potassium possesses some kinetic or electrical energy akin to light rays, which make its absorption in large amounts unnecessary during bright weather. Brazeale's (3) claim that the supply of nitrogen is the limiting factor in the absorption of potassium would still be a valid one under this hypothesis, though lesser amounts would be required during sunshine. That nitrates should be more readily available from a  $\text{KNO}_3$  solution than from other nitrate solutions is an interesting point. Both  $\text{K}^+$  and  $\text{NO}_3^-$  however are rapidly moving ions and would have some effect one upon the other. We obtained little correlation between temperature and nitrate and potassium absorption as evidenced by Solar Radiation,

Table VI, page 35, while Tottingham did.

As is consistent with Kraus and Kraybill's work, fruit production was very low, but the percentage of moisture was relatively high. The high starch content of stems and roots would also be in accord with Kraus and Kraybill's theory. The accumulation of these carbohydrates would be due to the non-utilization of the manufactured sugars of the leaves, now stored as starch in stem and root. Proteins naturally were low. Here there is a low protein content, which would indicate a low-amino nitrate content, balanced against a high carbohydrate supply, which has resulted in a low fruit production. Of interest at this point is Harrison's work (13) already referred to where, by frequently cutting off the carbohydrate supply and still maintaining a high nitrate supply, Kentucky Blue Grass plants were actually killed. By lowering the nitrate supply and thereby keeping a better balance the plants continued to send up rhizomes which tillered.

Murneek's claim that the fruit of the tomato draws on the nitrate and carbohydrate supply is probably a valid one. Though fruit production was low, they continued to develop after nitrates were withheld, and were quite as high in proteins and sugars as were the Full Nutrient plants.

The high acidity in the fruits might be considered to be due to a possible calcium-nitrate relationship. It has been shown by Nightingale and his co-workers (35) that nitrates are not absorbed in the absence of "free" calcium. Possibly the opposite condition may also be true. The "free calcium" might have a neutralizing effect on the organic acids. An

analysis of the fruits for calcium would be of interest, in order to learn if a nitrogen deficient plant also contains less calcium.

Potassium.

The relationship of nitrate and potassium absorption has already been discussed and reference made to Table VI, page 35, showing the effect of sunlight on their absorption; it has been pointed out that lesser amounts of potassium are absorbed on bright days. This corroborates James and Penston's findings, though refuting those of Jansen and Bartholomew (24). It is suggested that the reason for this irregular absorption may be found in the fact that potassium is radio-active, and that an important part of its function in the plant is such. When the sun supplies this energy, lesser amounts of potassium are required. The plant has adjusted itself to this situation. In fact, it would seem that plants are not merely the creatures of casual circumstance, absorbing materials whether they are useful or not as is sometimes thought, but that they have developed during their long existence a working relationship toward outward conditions. This, and other phases of the Absorption Experiment which will be pointed out later most clearly point to the plant absorbing only the nutrients which it requires. It was shown in the Absorption Experiment that growth and nitrate absorption were strongly correlated and the Nutrition Experiment bore this out. Now a consideration of potassium and its radio-active quality evidences that the thrifty plant absorbs less potassium in fine weather. Temperature, as recorded by the black bulb thermometer, was without effect. The literature shows, however, that James and Penston (22) and Jansen and Bartholomew (24) think that plants may collect and

store potassium. They both qualify their statements, however. Undoubtedly the absorbed potassium must be reutilized as will be shown later.

This peculiar radio-active quality of potassium is also outstanding in consideration of the water-holding qualities of plants. Many workers have noted that potassium deficient plants require much more water than do those with a normal supply. The water is quickly transpired and the leaves soon wilt. A digression at this point to a consideration of a recent paper by Shull (42) is illuminating: He points out that the relation between root and soil and soil water is a dynamic one, and that it is in the water itself that this dynamic force principally resides. A water deficit which reduces vapor pressure of the cell colloids by 7% below that of pure water is believed to develop forces close to 100 atmospheres. "The cell may not, for some reason develop sufficiently high forces to attract the water, which passes on up the transpiration stream." A water deficit may exist in the root when the tensional pull of the water column in the tracheae draws the water more rapidly from the living cells in the xylem than it can be supplied by transfer of the water from the epidermis across the intervening cells to the pericycle. This pull may exceed the force of osmotic diffusion and the hindrances of the cell wall and protoplasm. The forces which are important in determining the osmotic pressure of the cell are physical, chemical, colloidal, or electrical. Imbibition also plays an important role in supplying the plant with water and in the transfer of

water in the plant. "It is suggested that in the absence of potassium, the electrical properties of the cell are lessened, and that the osmotic forces are therefore reduced, resulting in a decreased ability on the part of potassium deficient cells to draw water from the stream. A certain osmotic force would still exist due to colloidal matter, sugars and such like, and imbibition would play its part. An abundance of water would, therefore, be required by potassium starved plants. James (21) corroborates this theory in pointing out that the potassium present is in many cases capable of exerting a considerable portion of the osmotic pressure recorded by Dixon, and that a higher concentration of potassium will result in a greater ability on the part of the cell to maintain its turgidity. Especially will this be the case, if as recorded by Kotyschew and Eliasberg (26), all of the potassium in the cell exists in an ionic form. In many plants potassium salts seem to be the predominant soluble salts, and this may be the case with tomatoes. Warne (50) has shown, with potatoes, there is a withdrawal of potassium from the assimilating areas remote from the main veins, and suggests there may be as a consequence less photosynthesis in those areas; the carbohydrate concentration will be reduced in those spots, wilting will follow due to a reduced osmotic pressure and discoloration and scorch will result. It is suggested that the bronzing of the leaves of potassium deficient tomato plants may be also in part due to this. The linkage of the bronzing with an iron accumulation also forms an interesting speculation. MacMurtrey

(32) has also found a localization of potassium starvation effect.

A study of Table VII, page 36, shows the Series III plants to have produced less growth and fruit than did those of Series I which were fed the normal amount of solution. Jansen and Bartholomew (23) and James (21) have both shown that less carbohydrates are manufactured and James (21) has shown fewer proteins are synthesized. An absence of growth, therefore, would be expected. Chemical analysis shows a high percentage of starch to be stored in the roots, and that proteins are high in all parts. Evidently a high percentage of the carbohydrates which were manufactured were not utilized and there was in turn available nitrogenous matter. The leaves, too, were high in reducing sugars which have neither been assimilated nor translocated. This is in accordance with Jansen and Bartholomew's findings that in the absence of potassium there will not be an assimilation of carbohydrates and of soluble nitrates; and recalls his statement that high proteins and high sugars found in the absence of good growth and fruiting in potassium deficient plants are likely due to a lack of polymerization of these to higher compounds.

Attention is drawn to the brown leathery roots of the potassium deficient plants, with a suggestion of a storage organ. This is interesting in view of the large amount of starch present in them. It is recalled that there are few root hairs, but these roots are, nevertheless, very efficient as absorbing agents, for large quantities of water were transpired.

While fruit production was low in quantity, there were many large fruits. These though were apt to be irregular in shape. Both sugar and protein content was high in these fruits. Probably the available potassium was utilized by the earlier formed fruits of a cluster and from them there would be no re-translocation. Then the abundance of unutilized nitrogenous matter and sugars would be readily available to swell the size of the fruits. Irregularity in shape might be due to an improper balance. The later fruits formed in the cluster would necessarily be smaller. The average weight of the fruits, nevertheless, was high.

The dry weights of the tops and fruits were less and the Specific Gravity of the juices was less in these potassium deficiency plants than those receiving Full Nutrient, thus indicating that there is less mineral and volatile matter. Sugars and proteins being higher, the percentage of other dry matter would be still less. It is recalled that James and Penston (22) consider potassium to make up a large part of the dry weight of plants, and therefore in the absence of potassium from the plant food there is a noticeable difference in dry weight.

The preliminary experiments in Section I showed less diffusion out of potassium in the first two experiments and then the same irregularity of absorption in the third experiment which was obtained in the main experiment.

The success in growing plants from seeds whose parents had no potassium for two generations would lend strong

support to the theory of the translocation of potassium in potassium deficient plants. It must undoubtedly be stored in the seed and then be reutilized repeatedly in the new plant. These seeds, as Table X, page 53, shows are smaller in size than normal seeds and become more so each year of continued potassium starvation. The seeds from the potassium deficiency plants of 1933 showed little difference from the Full Nutrient seeds; those from the complete potassium omission grown in 1932 were considerably smaller; while the 1933 complete potassium omission seeds whose forebears had received no potassium for two generations were further declined in size and showed greater variation. They did, however, carry enough potassium to ensure a reasonable development to the new seedling in the germination test. All plants from seeds of even the second generation of omission when fed a complete nutrient are making good growth and fruiting, though, as was pointed out under "Results", they are less vigorous.

Phosphate.

That a small total amount of phosphates is required for plant growth (Andre) would be in accordance with the findings in the Absorption Experiment where less phosphate was absorbed in milli-equivalents than any other ion. The gradual absorption during the growing period and then the sudden cessation about blossoming time, followed by an absorption of small quantities, and the later increase during fruiting is intensely interesting in view of the correlation in the Nutrition Experiment. It is notable that no effect of phosphate starvation appeared in Section II Phosphate deficiency plants until nearly two months after the omission from the feedings. The plants of the two sections were about two weeks apart in growth processes. At the time corresponding to the development of the Nutrition plant at which phosphates were withheld, it ceased to be absorbed by the plant of the Absorption Experiment. Apparently the plant had all that it required for its present needs or was reutilizing what it did have. There was none being absorbed and the plant of the Nutrition Experiment showed no effect of its omission. Later, in blossoming, small amounts were absorbed and, finally, as fruiting became more prolific, larger amounts were used. It was only at this point that the Nutrition Experiment plant developed the purpling which is accepted as an indication of a phosphate lack. Brazeale (3), it has already been mentioned, found also, that phosphate absorption by wheat plants increased up to a certain concentration after which there was a sharp decline

According to MacGillivray (31), phosphate is necessary for cell division and therefore for all stages of growth; but if there is a shortage there will be translocation and reutilization. This was probably the case with our plants. He also points out that large quantities of phosphorus are used in the fruit: "half the phosphorus of the plant is in the fruit". It is at this stage that the Section I plants again absorbed large quantities of phosphates, and that the Section II plants showed its lack. Table VII, page 36, and Plate III, (appendix) show the growth of the phosphorus deficiency plants to be very similar to that of the Full Nutrient plants. A further study of the table, nevertheless, indicates a lower dry weight of tops and a distinctly lower fruit production. This would support the theory of MacGillivray again, that phosphates are necessary in the synthesis of nucleo-proteins, and that phosphorus is high in the fruits. The activity maintained would be due to the translocation and reutilization. The McGillivray plants were treated with an entire phosphate omission from the seedling stage and where his plants showed a very decided effect in decreased growth and fructification ours showed a relatively slight one. It would seem that the plant can manage with a relatively small amount of phosphorus.

The purpling of the leaves would be due to a discontinuance of chlorophyll production, accompanied by other changes as yet unaccounted for; possibly accumulations of end products due to a disorganization of the cell, on account of a derangement in functioning, decomposition of chlorophyll,

or some obscured reason. MacGillivray suggests that an accumulation of sugars would stop a further synthesis of sugars, and it is unlikely chlorophyll would be formed if it were not going to be used.

The roots of the MacGillivray plants were a dark brown. Ours also were darker than those of the Full Nutrient feeding. Whether this is an indication of high starch storage is a logical question, for a similar but more pronounced effect was found in the roots of the potassium deficient plants where starches were in an even higher percentage. The phosphorus deficient plants did not lack root hairs to any great extent as did the potassium deficient series. The high starch content of the roots would be due to the fact that nucleo-proteins are not formed in the absence of phosphorus and the carbohydrates are not utilized.

It seemed early, that there would be fruit production equal to the Full Nutrition plants, for there were an equal number of floral buds. MacGillivray too, found this, but suggests that there is later a falling off. The earlier buds pollinated would draw on the phosphorus and continue to grow at the loss of the later ones. As was pointed out in the case of the potassium deficiency plants, this would account for the irregularity of size. While we did not obtain the pronounced difference in amount of pulp and difference in seed size, our results ran fairly parallel with his. The lower dry weight and the lower Specific Gravity of the fruit is accounted for by the fact that phosphate is considered to make up such a large part of the tomato fruit. Protein and

sugar content of the fruits were high. Since nucleo-proteins and phospholipoids are not formed in the absence of phosphorus and the carbohydrates are not utilized, larger amounts of nitrogenous matter and sugars would be available. With an increased depletion of phosphorus, MacGillivray obtained a higher percentage of carbohydrates and total nitrogen in leaf and stem also. His records throughout are extreme in the light of ours. Evidently a small amount of phosphorus will have very effective results.

Seeds grown in the Subsidiary Seed Experiment (b) are shown by Table X, page 53, to be only slightly smaller than the Full Nutrient seeds and give a similar germination test. Again, it is pointed out that the plants of this investigation were not so greatly starved for phosphorus as were MacGillivray's. Seeds of the Subsidiary Experiment (c), on the other hand, which were from parents which had no phosphate fed, and are now being fed none, have produced a seedling, at present 12 inches high, which differs in leaf shape from the parent, so that here one would indeed "expect a difference in variety". This same effect of a phosphorus omission has been found by other workers in the University. A genetical study and chromosome count show no difference in such cases. It seems to be a cytological mutation.

Double Concentration.

Hoagland (18) has said that yields seem to be determined by a favorable supply and concentration in the early stages of growth, rather than by intense absorption in the later stages. Tyson, (46) has stated that the life processes are more influenced by the ratio and concentration of the nutrients than by a supply of any one element. Both are probably referring to a well-balanced solution and to concentration in that sense. The two statements are only applicable to this investigation in a general way. Nevertheless, the changing of the concentration in Series V, giving double the concentration, but only half the feedings, undoubtedly gave interesting results. The plants were normal in every way, fruiting well. They did, however, seem to make slightly more succulent growth than the Series I, Full Nutrient plants; the fruits were somewhat larger in average size, but since practically the same total weight of fruit was produced, they were necessarily fewer in numbers. Total sugars were slightly higher in the leaf of the Full Nutrition plant, but in the double concentration they were higher in stem and root. Since the total sugars were practically the same for the two types of plants taken as an entity, i.e., root plus stem plus leaf, it is probable that the Double Concentration plants may have been a little more advanced than the checks and the sugars were passing out of the leaf to the stem and root. Total starches were identical in the two series. Proteins were much higher in the roots and somewhat so in the fruits. These

differences in protein content are unaccounted for, but it would seem the difference in concentration may have produced a slightly more succulent vegetative growth, perhaps with more nitrogenous matter which has resulted also in larger fruits.

In considering the question of concentration, attention is drawn to the Subsidiary Experiment (b), where seeds from the Absorption Experiment plants were grown. In the Germination Experiment, the roots were consistently larger and more vigorous. Those plants from the Absorption Plant seeds which are being fed a complete nutrient now, are making noticeably better growth than those from the Full Nutrient seeds. It is possible the question of a balance of salts may enter in this connection. In the Absorption Experiment, the plants were washed through with distilled water fortnightly, thus keeping the roots washed clean. The fresh nutrients absorbed would be unaffected by any deposit of unused materials. If the plant was thus able the more readily to keep the balance it desired, the advantage might be reflected in the seed. These plants are being kept under observation, and they will be followed to maturity and compared with the plants from Series I seeds.

It is suggested that the more frequent waterings with distilled water which the Double Concentration plants would receive over the other Series might perform the function of keeping the roots washed off. It is noted that the roots of Series V plants were not superior to those of Series I. Indeed it cannot be said that the plants as a whole were superior.

But seemingly a change in concentration does have an effect. It is pointed out elsewhere that this investigation seems to show that plants absorb only those nutrients which they require and will use. There may, however, be an alteration in these requirements in response to a change of environment.

### Complete Starvation Plants.

The change of color in the leaves is an intriguing point in the Complete Starvation plants. Nitrate omission resulted in a yellowing and finally a whitening with a purple cast; potassium omission produced a bronzing; and phosphate deficiency gave a purpling. It would seem that the symptoms of all three types of starvation were present here in some degree, though that of the nitrate starvation was most apparent. In the Complete Starvation plants a yellowing first appeared, and later a bronzing and purpling, until finally they became completely colorless and fragile.

That growth and fruiting should be less would be expected in that the plant had only the materials within itself to draw upon. That fruiting should occur would be in conformity with the law that reproduction will tend to occur when an organism is deprived of its accustomed growth environment. In this case, however, the nutrients were not cut off until the blossoms had formed. Since growth was so greatly decreased, the percentage of sugars to weight did not vary greatly from the Full Nutrient plants; though the percentage of dry weight of stems and fruits and the Specific Gravity of the fruits was slightly less, it is probable the mineral content would not vary to any great extent either. Starches were high in the roots. Before the leaves began to yellow, photosynthesis would be continuing and if the carbohydrates were not being utilized in growth there would be an accumulation. Apparently these

were stored in the roots. The proteins in the plant as an entity, were equal to those of the check plants, but by far the largest amount was in the root.

Acidity was slightly higher in the fruits of the fully starved plants. Organic acid content must have been greater: this is not accounted for.

Note Regarding Pots:-

Two types of large pots were used in the Nutrition Experiment, glazed and clay. The clay pots required more watering, but no apparent difference in growth was obtained. The pots were mixed throughout the series.

### RECOMMENDATIONS.

It is recommended that in growing tomatoes, soils must be kept supplied with mineral nutrients at all stages of growth. Some qualifications as to the supply may be made, however. While nitrates are needed throughout growth, a larger amount may be supplied in the field where light conditions are at the maximum, than in the greenhouse under poorer light conditions. The value of calcium is too well known to require stressing here. Magnesium and sulphates seem to be required throughout the life of the plant, but small amounts are actually used. Potassium and phosphate fertilizers need not be applied in large quantities to an annual crop since there is a reutilization of both these nutrients.

Field tests upon the plants themselves are an excellent indication of the available nutrients in the soil.

It is suggested that an investigation in regard to the mineral content of the plant, and particularly of the fruit, under omission treatments such as were carried out in this investigation, with additional treatments of a calcium, and a sulphate omission or deficiency, would be of considerable interest and value.

SUMMARY.

1. Investigations were carried out with the tomato plant, *Lycopersicum esculentum* Mill., as to: - (a) the period of development at which the nutrient ions  $\text{Ca}^{++}$ ,  $\text{Mg}^{++}$ ,  $\text{SO}_4^{--}$ ,  $\text{NO}_3^-$ ,  $\text{K}^+$ , and  $\text{PO}_4^{--}$  were absorbed; and (b) the effect the partial withholding of nitrate, potassium, and phosphorus, a change in concentration of the ions, and a complete starvation might have on the growth, fructification, and sugar and protein content of the vegetative parts of the plant and the fruit.
2. The methods employed and the results obtained for each of the two parts of the investigation are given separately as Section I and Section II, but since interesting correlations developed between the two experiments, discussion is reserved until the findings of both are presented, and is therefore general.
3. In Section I, which is nominated, Absorption Experiment, the plants were grown in nutrient cultures and analysis of the culture was made fortnightly to find the absorption for the designated ions during that period.
4. In Section II, designated as Nutrition Experiment, the plants were grown in nutrient sand cultures and six series of treatments were given as follows:- I Full Nutrient, II Nitrate omission from blossoming time, III Potassium deficiency throughout, IV Phosphorus deficiency from blossoming time, V Double the concentration of Series I, but

fed once a week instead of twice, VI Complete Starvation from blossoming time.

5. Tables, plates and descriptions are given to show that the elements, calcium, magnesium, sulphur, nitrogen, potassium and phosphorus are essential to normal plant growth, and that their omission causes a typical starvation effect.
6. Calcium, magnesium and sulphates are absorbed at all stages of growth and fruiting, but the effect of their omission was not studied.
7. Nitrates are necessary at all stages of growth, blossoming and fruiting; more are utilized during bright weather.
8. Potassium is absorbed throughout the life of the plant. It seems to have a radio-active or electrical quality and is not required in as large quantities in sunlight as in dull weather. In its absence there will be a reutilization of the potassium already present. The ability of plants completely starved of potassium to continue into the third generation, without being supplied any, gives strong support to the theory of reutilization.
9. Phosphorus is needed for both growth and fruiting. But, as evidenced by a cessation of absorption at blossoming time, correlated with an indifference to its omission at that time, it would seem not to be essential, at least in added quantities at that point. Since it is more abundant in the growing parts of the plant, it is possible there is

a reutilization at that time. Storing would be a possibility, but the evidence of this investigation does not point to a storage of mineral nutrients by plants.

10. A change in concentration gave slightly more succulent growth and a larger average size of fruit. There were fewer fruits, but the total weight was almost equal to that produced by the Full Nutrient check plants. The total amount of ions fed in the two series was identical.
11. A complete starvation of all nutrients and of nitrates only produced similar results.
12. The amount of fruit produced in all omission series was considerably less than in the check plants: in the Potassium deficiency it was 60% of the check, in the Phosphate omission from blossoming it was 65%, in the Nitrate omission from blossoming it was 20%, and in the Complete Starvation 18%.
13. Analyses were made of the leaf, stem, root and fruit of all series in Section II, for carbohydrates and proteins and tables are given presenting the findings.
14. A high storage of starch was found in the roots of the plants of all omission treatments, and of proteins in the roots of the Potassium deficiency, Phosphate omission and Complete Starvation plants.
15. The variations in sugar, starch and protein content are discussed in detail.

16. Sugars were found not to vary to any great extent in the fruits; proteins varied rather more.
17. Acidity was found not to vary to any extent except in the Nitrate omission series.
18. Seedlings grown from seeds of the Absorption Experiment plants had a more extensive root system than had any of the others, and this is reflected in a somewhat better growth they are making over the Full Nutrient seedling plants. It is suggested that a better balance of salts was maintained in washing the roots of the Absorption plants fortnightly.
19. The results of the investigation strongly suggest that plants absorb only those nutrients which they require and will utilize.
20. It is recommended that a mineral analysis of the fruits of similarly grown plants, with a Calcium deficient and a Sulphate deficient series added, would be of value.
21. It is further recommended that all mineral nutrients must be kept continually supplied to the growing plant, but that other than calcium and nitrate they need not be supplied in large amounts.

ACKNOWLEDGMENTS

Sincere thanks are rendered to Dean F. M. Clement for a very kind consideration and interest.

To Dr. A. F. Barss for his kindly and sympathetic attitude towards the work, the writer is indebted.

Grateful acknowledgment and appreciation is expressed to Dr. G. H. Harris, who suggested the investigation and whose advice and assistance were at all times most graciously and generously given.

Thanks are also extended to Mr. Frank Garnish for many courtesies at the greenhouse.

LITERATURE CITED.

- (1) American Association of Agricultural Chemists (A.O.A.C.)  
Washington, D.C.
- (2) Andre G.  
1918 Repartition des elements minereaux et l'azote  
chez le vegetat etoile. Comp. Rend. Acad. Sci.  
(Paus) 167.1004 - 1006.
- (3) Brazeale, J.F.  
1928. Effects of one element of plant food upon the  
absorption by plants of another element.  
Univ. Ariz. Agr. Exp. Sta. Tech. Bul. 19
- (4) Cameron and Failyer.  
Jour. Amer. Chem. Soc. 25: 1068.
- (5) Colby, Harold L.  
1933. Seasonal absorption of nutrient salts by the  
French prune grown in solution cultures.  
Plant Physiol. 8 (1): 1-34
- (6) Davidson, Jehiel.  
1933. The possible effect of H ion concentration on  
the absorption of potassium and phosphorus  
under field conditions. Jour. Agric.  
Res. 46 (5): 449-506.
- (7) Davis, M.B.  
1930. Some effects of the deficiencies of nitrogen,  
potassium, calcium and magnesium with  
special reference to the behavior of cer-  
tain varieties of apple trees. Jour. Pomol.  
and Hort. Sci. - Vol. 8 No.4.
- (8) Day, Dorothy.  
1929. Some effects of calcium deficiency on *Fisum*  
*sativum*. Plant Physiol. 4 (4): 493-506.
- (9) Davy, Sir Humphrey.  
1814. Elements of Agricultural Chemistry.

(10) Emmert, E.M.

1931. The effect of soil reaction on the growth of tomatoes, and lettuce, and on the nitrogen, phosphorus and manganese content of the soil and plant. Univ. Kent., Agric.Exp. Sta. Res. Bul. 314.

(11) Gericke, W.F.

1924. The beneficial effect to wheat growth due to depletion of available phosphorus in the culture media. Science (N.S.) 60: 297-8.

(12) Gregory, F.Q. and Richardson, F.J.

1929. Physiological Studies in Plant Nutrition. Ann. Bot. XLIII: 119.

(13) Harrison, Carter M.

1934. Responses of Kentucky Blue Grass to variations in temperature, light, cuttings, and fertilizing. Plant Physiol. 9: 83-105.

(14) Hartwell, L and Damon, S.C.

1919. The value of sodium when potassium is insufficient. Rhode Is. State College. Agr.Exp.Sta.Bul.177.

(15) Haas and Hill.

1922. An Introduction to Plant Products.

(16) Heydemann, F.

1929. The nutrition of the tomato. Gartenbaum-weissenshaft E.S.R. - J.J.

(17) Hibbard, P.L.

1923. Methods of Chemical Analysis, Univ. Calif.

(18) Hoagland, D.R.

1919. The relation of the concentration and reaction of the nutrient medium to growth and absorption of the plant. Jour. Agr. Res. 18: 73-117.

(19) Hoagland and Martin, J.C.

1923. Effects of salts on the intake of inorganic elements on the buffer system of the plant. Univ. Cal. Tec. Paper No.8.

- (20) Hoffer, G.N.

1930. Testing corn-stalks chemically to aid in determining their plant needs. Purdue Univ. Agr. Exp. Sta. Bul. 298.

- (21) James, W.D.

1930. Studies of the physiological importance of the mineral nutrients in plants I. Relation of potassium to the properties and function of the leaf. Ann. Bot. XLIV: 173-98.

- (22) James, W.D. and Penston, N.L.

1933. Studies of the physiological importance of the mineral elements in plants IV. The quantitative distribution of potassium in the potato plant. Ann. Bot. XLVII: 279-93.

- (23) Jansen, G. and Bartholomew, R.P.

1929. Translocation of potassium in tomato plants and its relation to their carbohydrate and nitrate distribution. Jour. Agr. Res. 38: 447 - 65.

- (24) Jansen, G. and Bartholomew, R.P.

1929. Luxury consumption of potassium by plants and its significance. Jour. Amer. Soc. Agron. 21: 751-765.

- (25) Jansen, G. and Bartholomew, R.P.

1931. The rate of absorption of potassium by plants, and its possible effect on the potassium remaining in soil from applications of potassium fertilizers. Univ. Ark. Coll. Agric. A.E.S. Bul. 265.

- (26) Kostyschew, S. and Eliasberg, P.

1920. Ueber die Form die Kalium - verbindungen in lebenden Pflanzen gewebe. Zeitsch. Physiol. Chem. 110 (228).

- (27) Kraus, E.J. and Kraybill, R.H.

1918. Vegetation and reproduction with special reference to the tomato. Ore. Agr. Exp. Sta. Bul. 149.

- (28) Lane, J. Henry and Eynon, Lewis.  
1923. The determination of reducing sugars by means of Fehling's solution with methylene blue as an internal indicator. Jour. Soc. Chem. Ind. 42: 32.
- (29) Loew, Oscar.  
1899. Physiological role of nutrients. U.S. Depart. Agric. Division of Vegetables. Physiology and Plant Bulletin 18.
- (30) McCool, M.M. and Cook, R.L.  
1930. Rate of intake, accumulation and transformation of nitrate nitrogen by small grains and Kentucky blue grass. Jour. Amer. Soc. Agron. 22.(9):757-64.
- (31) MacGillivray, J.H.  
1927. Effect of phosphate on the composition of the tomato plant. Jour. Agr. Res. 34: 97.
- (32) McMurtrey, J.E., Jr.  
1932. Distinctive effects of the deficiency of certain essential elements on the growth of tobacco plants in solution cultures. U.S.A. Dept. Agric. Tech.Bul. 340: 1-42.
- (33) Murneek, A.E.  
1926. Effects of Correlation between vegetative and reproductive functions in a tomato. Plant Phys. 1: 3-56.
- (34) Nightingale, G.T.  
1927. The chemical composition of plants in relation to photoperiodic changes. Univ. Wis. Agr. Exp. Sta. Res. Bul. 74.
- (35) Nightingale, G.T., Addoms, R.M., Robbins Scharmerhum, W.R.  
1931. Effects of calcium deficiency on nitrate absorption and on metabolism in the tomato. Plant Physiol. 6: 605-30.
- (36) Onslaw, M.W.  
1931. The Principles of Plant Biochemistry.

- (37) Parkes and Fudge.  
Ammonium molybdenum blue method for determining phosphate.
- (38) Petrie, Arthur H.K.  
1933. The intake of ions by the plant and its relation to respiration of the root. Australian Jour. Exp. Biol. and Med. Sci. 11:25 - 34.
- (39) Pfeiffer, T. and Rippel, A.  
1920. Der einfluss von kalk und magnesia auf das wachstum der pflanzen. Jour. Bandw. 68: 5 - 39.
- (40) Raber.  
1928. Principles of Plant Physiology.
- (41) Richard and Wells.  
American Jour. Chemistry 27: 459.
- (42) Shull, Charles A.  
1930. Absorption of water by plants and the forces involved. Jour. Amer. Soc. Agron. 22: 459-71.
- (43) Tincker, M.A.H. and Darbyshire, F.V.  
1933. Studies on the formation of tubers and other storage organs. The influence upon translocation of the period of light and the supply of potassium. Ann. Bot XLVII: 27-51
- (44) Tottingham, W.E. and Lowsna, Henry.  
1928: Effects of light upon nitrate assimilation in wheat. Jour. Amer. Chem. Soc. 50: 436.
- (45) Tottingham, W.E., Stephens, H.S. and Lease, E.J.  
1934. Influence of shorter light rays upon absorption of nitrate by the young wheat plant. Plant Physiol. 9: 127-42.
- (46) Tyson, James.  
1930. The influence of soil conditions, fertilizer treatments, and light intensity on growth, chemical composition and enzymic activity

of sugar beets. Mich. State Coll.  
Agr. Exp. Sta. Tech. Bul. 108.

(47) Wallace, T.

1925. Experiments on the manuring of fruit trees.  
II. Jour. Pomol. and Hort. Sci. V. No. 1.

(48) Wallace, T. and Mann, C.E.T.

1926. Investigations on the chlorosis of fruit trees.  
Jour. Pomol. and Hort. Sci. V. No.2

(49) Wallace, T.

1928. Experiments on the manuring of fruit trees.  
Jour. Pomol. and Hort. Sci. VII. No.1

(50) Warne, L.G.G.

1934. The distribution of potassium in normal and  
scorched foliage. Ann. Bot. XLVIII:57 - 67.

(51) Watts, W.M.

1931. Some factors which influence growth and fruiting  
of the tomato. Univ. Ark. Agr. Exp. Sta.  
Bul. 267.

(52) Weevers, T.

1911. Untersuchungen über die Localisation und  
Funktion des Kalium in der Pflanze.  
Rec. Trav. Bot. Neerland. VIII.

(53) Woolf, E.

1870. Ashen Analysis.

APPENDIX.



PLATE I, fig. (a). Absorption Plants  
set up.



PLATE II, fig. (b). Absorption Plants  
being washed through.



Fig. (a)



Fig. (b)

PLATE II. Nutrition Experiment at Maturity.



Fig. (a)



Fig. (b)



Fig. (c)



Fig. (d)

PLATE III. Typical Full Nutrient and Starved Plants.



Fig. (e)



Fig. (f)



Fig. (g)



Fig. (h)

PLATE III. Typical Full Nutrient and Starved Plants.

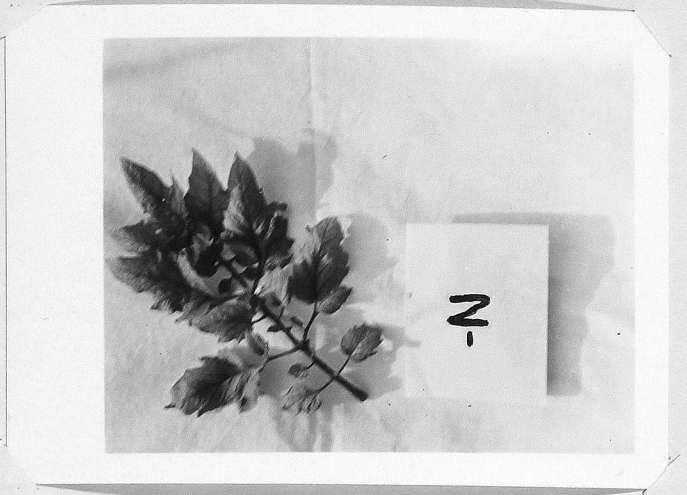


PLATE IV. Showing Variation in leaves.

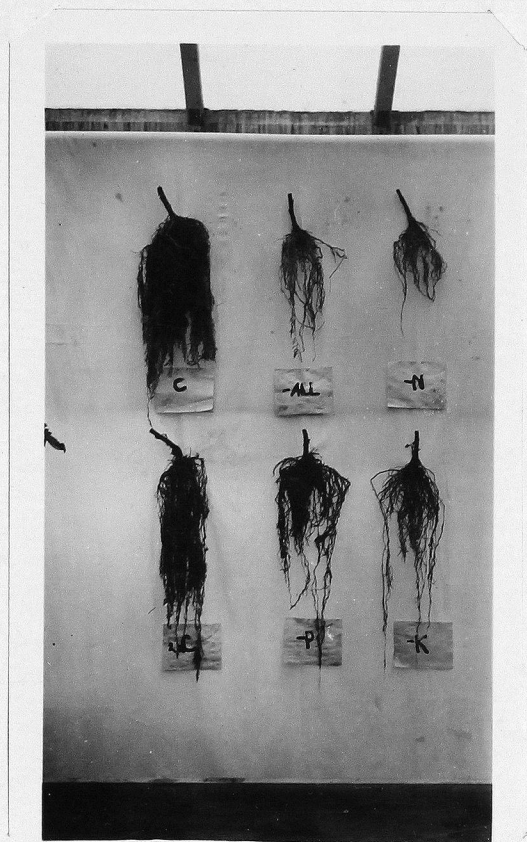


PLATE V. Showing variation in roots.



PLATE VI. The Potassium Omission Plants of Subsidiary Experiment (a), showing on the left the plant which has had no potassium for two generations. The one on the right was from the same seeds but was fed potassium at blossoming.