THE EFFECT OF NITROGEN AND PHOSPHORUS ON THE GROWTH OF APPLE AND PEACH TREES IN SAND CULTURE

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OF APPLE AND PEACH TREES IN SAND CULTURE

by

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TABLE OF CONTENTS

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Introduction

Much investigational work has been done with fruit and vegetable plants of various kinds to determine the influence of nitrogen and phosphorus on growth and fruiting ability. Certain rather definite relationships have been found to exist between the available nitrogen supply and vegetative growth and likewise between vegetative growth and fruit production. In the same way, phosphorus has been shown to influence these conditions in certain respects and to have a rather marked influence on the root development of plants and on certain other characteristics that are associated with growth and fruit bearing.

During comparatively recent years many research workers have turned their attention to a study of plants grown in artificial media in which nutrient materials of various kinds could be supplied in the amounts desired and observations and determinations made to show the characteristic symptoms and conditions which develop in the absence or overabundance of certain elements. In short, the plants have been grown under controlled conditions where the worker has found it much easier to diagnose the cause of certain physiological disorders and then to use this information for the correction of similar troubles found under field conditions.

As stated in the work of Alexander, Morris and Young (1), the growth of plants in water culture and other media is an old practice. "In 1679 Edde Mariotte grew plants in water and found that they required earthly salts, nitre, and ammonia, and John Woodward in 1692 published the first definite account of growing plants without soil. Dunhamel, in 1758 was the first to grow plants to maturity in water culture. However, it was not until after the discovery of nitrogen, hydrogen and oxygen in 1785 that definite steps in the nutrition of plants were made."

Much information can be found in recent literature as to the effect of various nutrient elements on growth and composition of different plant parts and many reports have been written regarding the symptoms of malnutrition.

The purpose of this investigation was to determine the influence of nitrogen and phosphorus in varying amounts on the growth of apple and peach trees in sand culture and to study the characteristic symptoms which develop when these materials are omitted from the nutrient solutions or when they are used in quantities considered excessive. In a previous publication (88), the seasonal course of soluble nitrogen and phosphate phosphorus in apple and peach shoots of orchard trees under several cultural practices and different fertilizer treatments was reported. The investigation herein reported was done as supplementary to the previous work.

Review of Literature

Response to Nitrogen. The general effect of nitrogen is to promote vegetative vigor, increase leaf area, produce a development of deep green color in the foliage, cause leaves to be retained longer on the trees in a season and benefit the set of fruit. It is the nutrient element that is most likely to be found in insufficient quantities under average conditions and in many cases proves to be a limiting factor to successful production. Gardner, Bradford and Hooker (32), Chandler (12), Cooper (17), Armstrong (2), Hooker (42), Murneek (57), and others have pointed out that nitrogen fertilizer used with both apple and peach trees has resulted in increased vegetative activity, greater leaf area and an increase in the amount of bearing surface. Trees growing under conditions where the supply of available nitrogen is abundant develop darker colored foliage than under conditions where the available supply is limited. Proebsting (61), working in California, has found that nitrogen influences the amount of shoot growth, the abundance of foliage, the color of leaves, the time of leaf fall and the time of fruit maturity. Reports have also been given which show that trees which have made poor growth because of an insufficient supply of nitrogen are more subject to the attacks of some insect pests and are also less able to survive conditions of severe winter cold.

Heinicke (36) has shown that the nitrogen requirement of a large apple tree producing 25 bushels of fruit is 3.9 pounds per tree, and Magness (52) has calculated a necessary nitrogen intake of 1.5 to 1.75 pounds per tree per year. According to Magness, part of this intake may be returned to the soil in the form of blossoms, leaves, fruits, etc., but approximately one pound per tree per year is permanently removed from the soil. Magness emphasizes that these figures refer to nitrogen intake and not fertilizer applications and that the intake under certain soil conditions and with certain cultural practices may be much less than the amount applied in the form of fertilizer.

Howlett (43) found that the sodium-nitrate equivalent of the total nitrogen withdrawal up to full bloom by the total number of flowers on twenty- to thirty-year-old trees would range from .5 to 1.20 pounds and that this represents only a part of the nitrogen necessary for growth of the tree and development of the fruits to maturity. In his work he found but little withdrawal of nitrogen by flowers during the period of full bloom.

Lagasse (45) studied the nitrogen-carbohydrate ratios in apple trees and found in general that trees which received three pounds of nitrate of soda in the spring, alone or in combination with acid phosphate and muriate of potash, were much deeper green and made better terminal and spur growth than where no nitrate was used. He also found yields to be noticeably increased by the treatment.

VanSlyke (84) reported as early as 1905 on the total quantity of nitrogen required by some apple varieties and estimated that for heavy-bearing Baldwin trees 1.413 pounds per tree would be needed and for Rhode Island Greening 1.527 pounds per tree per year would be used.

Williams (92) made nitrogen determinations of apple trees which had been fertilized with nitrogen and found an increased amount of total nitrogen in shoots as a result of the fertilizer application. The amount of the increase was determined largely by the time of the fertilizer application. Three pounds applied in March definitely increased the percent of total nitrogen in the tree early in the season and when three pounds were applied after harvest it gave a high nitrogen concentration in the shoots which was maintained during the remainder of the season.

Sullivan and Cullinan (71), Sullivan and Baker (72), and Baker (4), have made extensive studies of the response of apple trees to nitrogen fertilizer and found terminal and trunk growth to be correlated with the nitrogen content of the trees. They found that cultivated trees with a cover crop, without organic fertilizer, made greater growth and contained more nitrogen than trees in bluegrass sod that received a nitrogen fertilizer. In their tests they found that trees in bluegrass made slower growth and came into bearing later but eventually surpassed the cultivated plot in growth, yield and nitrogen content. Sullivan (71) reported on the analysis of shoots from Grimes Golden trees and recorded the greatest total nitrogen content in trees that received tillage and a cover crop. He found these trees to have a greater total nitrogen content during the growing season than trees in sod or in alfalfa. The trees in sod showed the lowest amount of total nitrogen in spite of the fact that they were the only trees that received inorganic nitrogen fertilizer and the leaves on these trees were light green and terminal shoot growth was short. Sullivan found that the difference in total nitrogen between different plots was much greater during the active growing season than during the dormant season.

Under average conditions trees that are well supplied with nitrogen will make good growth and produce leaves that are synthetically active unless some adverse conditions such as poor drainage, shading, etc., prevents it. Thus Kraus and Kraybill (44) have pointed out in their outstanding study of the nitrogen-carbohydrate relationships in the tomato, that even tho an abundance of amino acids and other forms of soluble nitrogen is present, which may not necessarily include nitrate, yet without an available supply of carbohydrates there may be decomposition of protein. Vegetation is then weakened and the plants are not fruitful. Remy (63) has pointed out that if the nitrogen is below a certain level fruit bud differentiation is hindered.

In studies somewhat similar to those of Kraus and Kraybill, Laurent (46) and Godlewski (34) found that nitrate could be assimilated in darkness to amide compounds but not to protein and that protein synthesis could occur only in the presence of light.

Nightingale (58), working with several different kinds of plants, found that nitrate is not necessarily associated with the growth response of plants and that tomatoes with no nitrate in the nutrient culture or tissues of leaves, stems or roots grew rapidly when the carbohydrate supply was increased by subjecting the plants to short-day conditions or to total darkness. This investigator was of the opinion that nitrate in these plants may have been formed from the decomposition of protein or some other nitrogen compound.

With regard to the use of nitrogen fertilizer applied in the fall to fruit trees, most investigators are of the opinion that such applications do not tend to increase the percent of nitrogen found in the shoots during the dormant season. In fact, Roberts (66) points out that the absorption of large quantities of nitrogen late in the season might cause chemical changes in the tissues that would reduce resistance to winter cold. Roberts' findings seemed to indicate that as nitrogen was taken up there was a change in the carbohydrates even before these materials could be used in growth.

In some fall-fertilized Elberta peach trees at Lexington (89) only those fertilized with sulfate of ammonia showed an increase in soluble nitrogen during the dormant season, over the check trees. In fact, trees treated with cyanamid and sodium nitrate showed a decrease in their percentage of soluble nitrogen in comparison with the untreated checks. There was a downward trend during the winter in soluble nitrogen in peach twigs of all trees regardless of fertilizer treatment. The average for 24 weeks during fall and winter was lower than the percentages found in the same groups of trees before they were fertilized with nitrogen in the fall.

Several investigators have determined the nitrogen content of leaves, stems and roots of young trees during the latter part of the growing season and Combes (16) found that leaves undergoing senescence on the tree lost much of their nitrogen, while those yellowing off the tree lost very little even tho attached to a piece of the branch toward which nitrogen would normally move. He found that part of the nitrogen which passes back from the leaves accumulates in the branch near the point where the leaves were attached. He also concluded that nitrogen migrates in the fall from the leaves to the stems and then to the roots and he even ventured the suggestion that under certain conditions the roots may excrete nitrogenous substances into the soil. Both Combes (16) and Le Clerc (47) are of the opinion that the problem of what becomes of the nitrogen compounds at the time leaves are yellowing can only be solved by making an analysis of the branches and preferably the whole tree or plant. In the first part of this work, during which the seasonal course of soluble nitrogen was determined in shoot growth of Winesap apple and Elberta peach (88), it was found that soluble nitrogen averaged considerably lower during the winter, in both apple and peach, than during the active growing season. The nitrogen was considerably higher in peach shoots during the winter than in apple and the content of apple shoots was maintained at a relatively constant low level during the winter. At least, between the apple and the peach, there appears to be a close relationship between the soluble nitrogen content of winter shoots and the ability of the plants to resist winter cold.

Ripple (64) made studies of the transfer of nitrogen from the leaves and found that the nitrogen compounds which are translocated from the leaves are largely proteins, especially those forming the chloroplasts. He found the highest content of nitrogen in leaves in June and the lowest at the time of chlorophyll degeneration. Under conditions where nitrogen was deficient he found leaves beginning to yellow early in the season with the oldest leaves yellowing first. He indicated that the younger leaves may absorb nitrogen from the older, weaker ones.

Similar determinations were made by Murneek and Logan (56) and they concluded that nitrogen migrates from the leaves into the spurs and branches where it may be laid down temporarily in the form of reserve protein and that the removal of nitrogen from the leaves is due primarily to a decrease in the water-insoluble fraction. They found that eventually the nitrogen is translocated to the older wood and possibly to the root system. Murneek found that the amount of nitrogen translocated from the leaves to other parts of the tree may amount to as much as 22 to 40 percent. Weather conditions, according to their opinion, greatly influence the translocation of nitrogen, particularly its initiation and speed of movement. They found that cool weather appeared to hasten it but a killing frost destroyed the process.

Loomis (51) in his investigational work found large quantities of protein nitrogen stored in the bark and wood of trees whence it was digested and used in early spring growth. He considered the success of fall nitrogen applications and the cumulative effects of nitrogen fertilization with ammonia as probably related to this storage. He found that nitrogenous salts appeared to be synthesized to organic compounds in the roots of apple and other trees and as a result of this synthesis, to be readily translocated only in the phloem tissue. He found, that as a result of this, ringing stops the upward flow of nitrogen as well as the downward movement of carbohydrates. Studies of similar nature have been conducted by Curtis (19) (20) and Murneek and Logan (56).

Thomas (73) thinks that the nitrogen content of leaves of the apple begins to decline as soon as active growth ceases. He found the most rapid decrease to occur during yellowing and that it continued until defoliation was complete. His findings seem to indicate that storage is mainly in one- and two-year-old wood. In another study Thomas (75) found that nitrogen accumulated in one- and two-year twigs of the apple during the late dormant season and as growth started this nitrogen moved into the new shoots and leaves, depleting the tissues of the twigs. Similar results were found by Waltman (88) for apple and peach and by Piney (59) who studied the new growth of beech.

Results similar to those just mentioned were obtained by Traub (82) who found that the nitrogen maximum is reached in March or April just preceding rapid growth extension. After the marked decline in nitrogen with rapid growth extension the nitrogen content is relatively constant during the summer. It was also practically constant during the dormant season. He found that the dormant-season content of nitrogen is largely non-amino or protein nitrogen and decreases as the active growing season approaches and reaches a minimum usually in June.

Childers and Cowart (14) and several other investigators have shown that the photosynthetic activity of leaves is considerably influenced by their chlorophyll content and this in turn is affected by the available nitrogen supply. Iron also plays an important part in chlorophyll formation and altho it is not a part of the chlorophyll molecule an available supply is necessary because it serves as a catalyst. In a similar way, nitrogen is an essential element in the development of chlorophyll and also a component part of the chlorophyll molecule. Plants which are well supplied with nitrogen make more vigorous growth because of their greater ability to synthesize more food.

Response to Phosphorus. In general, the response made by plants to applications of phosphorus fertilizer is less pronounced than to nitrogen altho certain well-defined symptoms characterize plants growing under conditions where the phosphorus supply is deficient.

Russell (67) states that the most obvious effects of phosphorus are on the root system and the production of seed. Plants well supplied with this element have a much greater root development and produce seeds in a satisfactory way. Russell points out that phosphates are the most important phosphorus nutrients and that they tend to hasten the ripening process. Phosphorus appears to be essential to mitotic cell division, probably because it is a constituent of the nucleus and is necessary also for the normal transformation of starch. Apparently starch may form in the absence of phosphorus but does not change to sugar. Russell states further that phosphorus appears to increase the development of meristematic tissue and the efficiency of the chloroplast mechanism..

It is suggested by Gardner, Bradford and Hooker (32) that the elaboration and assimilation of phosphorus, like nitrogen, appears to take place in the leaves, for the most part. The amount of phosphorus assimilated is stated to be closely related to the amount of illumination the plant receives and appears to be connected with photosynthetic activity. They point out that the elaborated phosphate compounds occur in nucleic acids, nucleins and nucleo-proteins, substances always present in the cell nucleus and considered to be associated with various enzymes in all plant tissues. They state that most tissues contain approximately six times as much nitrogen as phosphorus. There is a suggestion that both nitrogen and phosphorus may be combined in the same molecule, altho phosphorus apparently does not play the same part as nitrogen in plant metabolism. These authors quote the work of Harris who says "It has been shown by several investigators that the content of phosphorus is generally low in acid soils and largely unavailable for use by plants." This condition is further explained by Stoddart who says that acid soils convert any calcium phosphate that may be present into soluble compounds which are either washed out or are fixed in an insoluble form by the formation of iron and aluminum phosphates.

Several investigators, including Blake, Nightingale and Davidson (10), have found that a deficient supply of phosphorus to young apple trees resulted in a high accumulation of carbohydrates in both tops and roots. These workers found, however, that the trees eventually became low in starch and proteins and high in sugars.

Lilleland (48) grew peaches in soils in California that were exceptionally low in phosphorus. He found that treated trees retained their leaves longer in the fall than the untreated check trees; however, the phosphorus fertilizer did not affect the time of bloom, time of ripening or the amount of shoot growth. He found a yellowing of the foliage which appeared to be due to a depression of nitrogen absorption caused by the addition of phosphorus. Proof was added to this assumption by the analysis of leaves, which showed a lower nitrogen content in phosphorus-treated trees. Results somewhat similar to these were obtained by Thomas (74) (75) who found lower P/N ratios in apple trees in tanks where nitrogen had been added. He also found a greater amount of phosphorus absorbed by these trees.

Further work by Lilleland (49) in California, on soils low in phosphorus, gave striking results in increased shoot and root growth from phosphoric applications on several species of fruit. Shoot growth of apples was increased by 79 percent, apricots 66, prunes 39, and peaches 105 percent. Apple root growth was increased 37 percent, apricots 44, prunes (apricot roots) 42, and peaches 80 percent. He found the top-to-root ratio to be increased on apples by the phosphorus application but obtained no significant difference on the other species.

Scott (69) found that in a sandy soil in South Carolina the omission of phosphorus to peaches did not show striking differences from the fertilized trees. However, the trees which received no phosphorus yielded significantly less, grew more slowly and showed poorer fruit-bud development. In this experiment an unsatisfactory growth of rye cover crop resulted on the plots where phosphorus was not used. Similar comments on cover crop growth under conditions where the phosphorus supply is limited are offered by Chandler (12) and others.

Nitrogen Deficiency. Deficiency in the nitrogen supply usually results in poor, weak growth, small, yellowed leaves and generally poor fruit development. Childers and Cowart (14) state that "Any nutrient which directly or indirectly influences leaf color, stomata or other characteristics of foliage would be expected to influence the leaf activity." Thus, they found that leaves deficient in nitrogen assimilated about one-third as much carbon dioxide and transpired about 70 percent as much water as did the full-nutrient leaves. Their trees were grown in washed sand in a greenhouse and the ones which received no nitrogen developed the most striking symptoms. The leaves were small and light green; none of the shoots grew more than twelve inches in length and all formed their terminal buds early. Similar results were obtained by Blake, Nightingale and Davidson (10) (11) with one-year-old Blaxtayman root-grafted apple trees grown in sand cultures in six different nutrient treatments. The lack of an external supply of nitrogen was associated with an early appearance of yellowish-green leaf blades and a reddening of veins of lower leaves. The upper leaves later exhibited this condition and all leaves assumed an upright position with the petioles, forming narrow angles with the stems. The angles formed by the leaf petioles with the main stem became more and more acute as growth continued. These investigators noted similar results in their study of growth of Delicious apple trees under field conditions (9) also the leaves became more brittle as they developed the yellowish-green color. The cambial activity of these trees was very limited and ceased early in the season, resulting in short shoots of small diameter. The carbohydrate accumulation was high and root growth extensive, woody and abnormally slender. In the second season new growth was very slow and weak and finally the trees produced a few small, spindly branches 2 to 6 inches long. The new growth developed from the original tree base rather than from the previous seasons growth. The new leaves were thin, narrow and definitely yellow from the time of their first appearance.

With peach trees grown in sand, Davidson and Blake (21) obtained results similar to those with apples. Shoot growth was restricted in length and diameter and the older leaves first yellowed and later the young leaves lost much of their green color. Typical purplish-red spots developed on the foliage and the cell walls were abnormally thick. Carbohydrates accumulated rapidly in the tops and roots were yellowish, slender but fairly extensive.

Davidson and Blake (22) point out in another publication that the development of a nutrient-deficiency symptom is dependent primarily on two factors: "(a) the rate of growth of the trees and (b) a failure of the root media to supply the limiting nutrients in amounts and proportions adequate for that rate of growth."

The results found by Blake and his co-workers were obtained also by Weinberger and Cullinan (91) Fisher (31) Wallace (85)and Hoagland and Chandler (39). Weinberger and Cullinan emphasized that there were no complete descriptions of the symptoms produced in peaches by lack of mineral elements, except phosphorus and potassium. With their trees which received no nitrogen a large number of fibrous roots were formed. They found relatively three times as much fibrous root growth by weight in proportion to top as for trees in complete nutrient solution.

Part of the work by Fisher (31) was with tomato plants which were given a culture containing excess nitrogen. This treatment stimulated vegetative growth at the expense of flowers and fruit. Terminal shoot growth of these plants was depressed but lateral branches were numerous and but few fruits were set. The leaves were spotted with dead areas, curled, roughly pimpled and yellowed interveinously. The time of maturity was greatly delayed and resistance to disease and insects reduced. Root growth was light brown with few branches.

Under certain conditions it appears that the continued use of certain nitrogen fertilizers may produce physiological disorders. Rawl (62) reports on a case of this nature in a sandy soil in South Carolina where sulfate of ammonia alone had been used continuously over a period of years, and certain characteristic symptoms developed. The trees grew poorly, did not form fruit buds properly and produced low yields of small peaches. The leaves first changed to a yellowish light green, later to a very pale yellow, followed by burning or scorching of the tips and leaf margins. Tests of pH on the soils indicated that the continued use of sulfate of ammonia had resulted in high soil acidity. Complete fertilizers applied to these trees produced good growth and good yields of marketable fruit. The experiment was not arranged to show whether phosphorus or potassium gave the greatest benefit in affecting the recovery of the trees.

Phosphorus Deficiency. The general effect upon plants of an insufficient supply of phosphorus is less pronounced and probably in some respects less serious than for nitrogen. The fact that fruit trees frequently fail to show ready response to phosphorus applications under conditions where grain crops make noticeable gains, can probably be accounted for in one of three ways: (1) tree roots penetrate deep, if soil conditions permit, and in that way probably obtain part of their phosphorus supply from lower soil levels; (2) trees may actually use considerably less phosphorus than the shallow, fibrous-rooted grain crops;

(3) trees may be able to use their phosphorus in a different form from that required by plants of the grass family. In any event, there are conditions under which fruit trees develop symptoms of phosphorus starvation and considerable work has been done in recent years by means of artificial media which emphasize these characteristic symptoms so that they may be more readily recognized under field conditions.

The work of Blake, Nightingale and Davidson (10) (11) (21), Weinberger and Cullinan (91), Wallace (85), Hoagland and Chandler (39) and others, shows that phosphorus deficiency symptoms, in the early stages, are very similar to those of nitrogen starvation, except that decided yellowing of the foliage is not common. The upper leaves usually remained dark green with the mid-ribs, veins and petioles definitely tinged with purplish-red. Shoot growth was generally very slender and young leaves thin, small, dark green and tinged with purple. The green color of leaves where phosphorus was deficient was lacking in the luster characteristic of the foliage on plants making vigorous growth. Fibrous root growth was restricted by a deficiency of phosphorus and roots that formed were slender and contained an abundance of nitrate. Carbohydrate, largely sugar, accumulated in both tops and roots and was found in greatest amount near the tips of new growth.

Davidson (23) found that under some of the soil conditions of New Jersey, peach trees may develop deficiency symptoms of phosphorus and a base at the same time. In sand cultures, his studies indicated that phosphorus deficiency in peach trees develops independently of, or may coexist with, deficiencies of calcium, potassium or magnesium. Omission of phosphorus resulted in an increase in pigmentation and in the formation of narrow, dark ochre-green leaves, almost regardless of whether or not the treatment was also deficient in a base.

Leaves that are deficient in phosphorus are affected much less in their photosynthetic activity and transpiration rate than those deficient in nitrogen. This was shown by Childers and Cowart (14) who concluded that nitrogen plays a much more important role in photosynthesis and transpiration of apple leaves than phosphorus or potassium, alone or combined.

Procedure

Two varieties of apple and one of peach were used in this experiment. The apples were one-year-old grafted trees of the Staymared and Paducah varieties and the peaches were one-year-old Elberta trees. The trees were selected for uniformity from nursery stock of our own propagation and were taken directly from the nursery rows. They were treated uniformly as to top and root pruning and placed in the culture jars containing a high grade of washed, sharp sand. The trees were selected in March after having grown one season in the nursery and were washed free of all soil and the root system pruned so that all fibrous roots were removed and only moderate-sized roots left. The apple tops were cut back to a height of approximately fifteen inches and the lateral growth on the tops of the peach trees was reduced to stubs about an inch in length and these were thinned so that there was an opportunity for about five buds to start from each tree trunk.

The cultures consisted of seven different nutrient solutions with variations in the content of nitrogen and phosphorus and were applied in such a way that one tree of each of the apple varieties and two peach trees received the same nutrient treatment. The nutrient elements other than nitrogen and phosphorus were supplied to all trees in equal amounts. Three-gallon stone jars provided with a drainage hole in the bottom were used and 14,500 grams of sand were placed in each jar. A cork stopper containing a small glass tube was placed in the drainage hole so that a quantity of the solution from the sand could be collected for pH determination when fresh solution was added to the jars.

The jars were arranged out-of-doors, on a framework supported by small sawhorses. To provide a satisfactory cover for the jars, two pieces of board were used for each jar, cut in a semicircular form somewhat larger than the diameter of the jar. The straight edges were then beveled and small nails driven at the lower circular edge of each board to hold the halves in position. In this way the beveled edges were held together and the boards were held by the nails against the inside edge of the jar so that they provided a sloping cover for each container. A notch was made in each half of the cover, for the tree.

After the board covers were in position, a piece of heavy mulch paper was placed over each one and fastened to the boards by means of thumb tacks. To further prevent water entering the jar at the center of the cover where the tree trunk emerged, a pad of cotton was pushed into the hole between the tree and the board. Trouble was experienced in this connection by sparrows pulling the cotton from around the trees, so a one-hole rubber stopper split open on one side, was set around each tree on top of the cover and over the cotton. On several occasions during the course of the experiment, weighings were made before and following heavy rains and at no time did water enter the jars.

The sand used was a moderately fine grade of white glass sand obtained from West Virginia. It was thoroly washed with tap water and then with distilled water, and dried. It was found by chemical tests to contain no nitrogen or phosphorus. The analysis of the sand* showed it to run 99.58 percent silica with very small percentages of iron and aluminum oxides. In a previous experiment with strawberries (86) this medium was found to be entirely satisfactory for plant growth. For an experiment of this nature sand appears to be the most satisfactory medium and has been recommended and used successfully by many investigators (11) (13) (25) (54) (65) (70).

Composition of the Nutrient Solutions

Many different kinds of nutrient solutions have been suggested by investigators who have found them suited to their particular types of work. It appears probable that a solution containing all the necessary nutrient elements in proper proportions for general plant growth may not give equal results with different species of plants. For example, in the assimilation of nitrogen, it has been shown by Pirschle (60) and by Tiedjens and Robbins (77) that many crop plants can assimilate ammonium and nitrate provided the hydrogen-ion concentration of the nutrient solution is suitable to the form of nitrogen used. It appears further that the necessary pH value may be specific for each species. Tiedjens and Blake (79) state that it appears that pH values below 6 generally favor nitrate assimilation and values of 6 or above favor ammonium assimilation.

* Supplied by the firm in West Virginia from which the sand was obtained. A test here at this Station showed 99.85 percent insoluble in hydrochloric acid.

Studies which have indicated similar results regarding nitrate assimilation have been made by Baudisch (7) (8).

Tiedjens and Blake (79) found that apple trees absorbed and assimilated ammonium nitrogen without oxidation to nitrate and that the hydrogen-ion concentration of the culture medium limited, directly or indirectly, the assimilation of both ammonium and nitrate. Their studies indicated that in soils where the pH value was comparatively low ammonium was apparently oxidized to nitrate before assimilation of nitrogen occurred. Under conditions where the pH of the culture medium was favorable for ammonium and nitrate, respectively, ammonium produced a more rapid growth response than nitrate.

In a study of the effect of different nitrogen carriers on the performance of apple trees, Batjer and Sudds (6) found that trees made greater root growth where nitrate of soda was used in place of sulfate of ammonia. In their experiment, root growth on nitrated trees was often more than twice as much as on sulfated trees. They found also that the soil was much more acid where sulfate of ammonia had been used.

Studies similar to those of Batjer and Sudds were made by Clark and Shive (15) with tomato plants. Their findings showed that the concentration of ammonium nitrogen in the roots varied with the pH of the external medium. Higher concentrations of ammonium nitrogen were present in the roots of plants grown in solutions of high pH than in those grown in solutions of low pH. High concentrations of ammonium in the roots accompanied high rates of absorption of ammonium from the solutions.

The work of Tiedjens (78) indicated that the nitrate ion was assimilated most satisfactorily by tomato and apple when absorbed from an acid nutrient solution of approximately pH 4.00. The ammonium ion was assimilated most satisfactorily when absorbed from a nutrient solution having a constant pH value of 5.0 to 6.5, varying somewhat with the variety. He found that ammonium ions were immediately absorbed by plants without further change and were assimilated directly and more rapidly than the nitrate ion, and that the volume of growth obtained from nitrate and ammonium depended on the concentration of the nitrogenous salt in the nutrient solution and the available carbohydrates. Under conditions where a large amount of carbohydrate was available, ammonium was assimilated more rapidly than where the supply of available carbohydrate was small.

In an experiment with strawberries in sand culture (86) in which ammonium nitrate was used to furnish the nitrogen, the plants grew best at a reaction of pH 5.3 to 5.5. The nitrogen content of this solution was 242 ppm.

Work by Emmert (30) at the Kentucky Station, with tomatoes and lettuce grown in treated soil, gave variable results as to the best pH for plant growth and yield. With tomatoes, the heaviest yields were produced by the use of sodium carbonate added to the soil to maintain a pH of 8.3 to 8.4. The second heaviest yield resulted from the use of the same material where the pH was maintained at 7.3 to 8.0. The heaviest lettuce yields also were produced where sodium carbonate was applied to maintain a pH of about 7.5. It seems probable that some other effect than on pH value may have occurred from the use of sodium carbonate on this soil.

The results obtained by Hoagland (38) were similar to those of Tiedjens and Blake (79). He found that the reaction of a culture solution has an important bearing on the absorption of ions. He observed that the absorption of the NO_3 ion was favored by an acid reaction and that nitrate penetrated far more rapidly into the cell sap of some plants from an acid than from an alkaline solution. He further emphasized that the hydrogen-ion concentration may be one of the chief variables governing the colloidal behavior of the protoplasm of the cell. This view is further strengthened by Chandler (12) who points out that in winter-injured tissue there is an increase in hydrogen-ion concentration of the cell sap, accompanied by a disruption of the colloidal stability of the protoplasm.

The maintenance of a reaction that is most suitable to the growth of plants is difficult under soil conditions largely because of the buffer action of the soil. In artificial cultures of either sand or solutions a definite, stable pH is maintained more easily, altho several things have an influence on it. Trealease and Trealease (81) state that "the solution constituents that have the most pronounced influence upon reaction changes are the nitrates or ammonium salts employed as sources of nitrogen for the plants". Working with wheat plants in solution cultures, they obtained best growth at an approximately stable pH value of 5.1. Their cultures were arranged at pH values of 4.3, 5.1 and 6.0 and were maintained at these values by varying the ratio of NO_3/NH_4 in the solutions. The NO_3/NH_4 ionic ratios of 50/50, 80/20 and 90/10 were used to obtain the initial pH values indicated above. The salts employed were KNO_3 and $(NH_4)_2SO_4$. With the lower NO_3/NH_4 ratio the pH value of the solution decreased rapidly under influence of the plants and approached in extreme cases a pH value of 3.0. With the higher ratio, the pH value increased rapidly, tending to reach a limiting value of 6.5.

They state that "The anions of the nitrates, together with H ions derived from the solution, are absorbed by the plant more rapidly than the cations, thus tending to decrease the hydrogen-ion concentration. On the other hand, the ammonium salts have the opposite effect; their cations enter the plant more rapidly than their anions, and the hydrogen-ion concentration is thereby increased, regardless of whether the actual absorption of the cations occurs in company with OH ions derived from the solution or whether NH_3, resulting from a decomposition of NH_4OH, is absorbed by the plant." They found that young plants seem to remove NH_4 ions more rapidly than NO_3 ions.

Scofield (68) calls attention to the point that plants do not absorb water and dissolved substances from the soil solution in the same proportions that these constituents occur together in that solution. This evidently has a direct bearing on the absorption of different salts by plants growing in either sand or solution cultures.

Blake, Nightingale and Davidson (11) adjusted to pH 4.2 the nutrient solution to be used for apple trees in sand culture, and found that between the times when additional solution was added, the solution in the sand tended to become less acid, about pH 5.0 to 5.2. They found in previous work (79) with young apple trees, that the pH range indicated above was excellent for growth with the nutrient solution which they employed.

Suggestions for balancing nutrient solutions, their adjustment to a suitable reaction and the preparation of special equipment for use in growing plants in sand and solution cultures are offered by Turner and Henry (83), Davis and Hoagland (24), Hill and Grant (37), Hoagland and

Arnon (41), McCall (55), and Shive and Robbins (70).

In the preparation of the nutrient solutions used in this experiment it was desired to have variations only in the content of nitrogen and phosphorus. With this point in mind the solutions were arranged as follows:

1. Basal (complete).
2. No nitrogen.
3. Low nitrogen, 1/4 as much as No. 1.
4. Excess nitrogen, twice as much as No. 1.
5. No phosphorus.
6. Low phosphorus, 1/4 as much as No. 1.
7. Excess phosphorus, twice as much as No. 1.

A modification of the solution used by Blake, Nightingale and Davidson (11) was employed and iron was supplied to all solutions by the use of ferric citrate. One cc of a 0.5 percent solution of this material was used for each liter of solution at the time they were made up. This procedure has been found satisfactory by Marsh and Shive (53) and by Weinberger and Cullinan (91). At the beginning of this experiment and continuing for a period of ten days after the trees were set in the jars, only distilled water was added. This gave a chance for the reserve materials within the trees to be used before any nutrient solutions were supplied. After the trees had started to grow, the nutrient solutions were supplied at the rate of approximately 500 cc every other day during the first few weeks of the experiment. This amount of solution added to the jars resulted in the leaching of 50 to 100 cc which was collected each time for pH determination. As the season progressed and the trees grew, fresh solution was added to each jar each day and the amounts gradually increased. One tree of each of the apple varieties and two peach trees received the same nutrient treatment.

Table 1 gives the chemical compounds used, in grams per liter, and table 2 the concentration of the elements in each of the nutrient solutions used, in parts per million.

Table 1. Composition of the nutrient solutions, in grams per liter.

Compound	Basal	No nitrogen	1/4 nitrogen	2 nitrogen	No phosphorus	1/4 phosphorus	2 phosphorus
KH_2PO_4	0.2995	0.2995	0.2995	0.2995	---	0.0749	0.2995
$CaCl_2.2H_2O$	0.6456	0.6456	0.6456	0.6456	0.6456	0.6456	0.6456
$MgSO_4.7H_2O$	0.5878	0.5878	0.5878	0.5878	0.5878	0.5878	0.5878
NH_4NO_3	0.6400	---	0.1600	1.2800	0.4629	0.5143	0.4629
KNO_3	---	---	---	---	0.2224	0.1655	---
$(NH_4)\ H_2PO_4$	---	---	---	---	---	---	0.2523
$MnCl_2.4H_2O$	0.0180	0.0180	0.0180	0.0180	0.0180	0.0180	0.0180
H_3BO_3	0.0171	0.0171	0.0171	0.0171	0.0171	0.0171	0.0171
$FeC_6H_5O_7.3H_2O$	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050	0.0050

Table 2. Nutrient elements in the solutions, in parts per million.

Element	Basal	No nitrogen	1/4 nitrogen	2 nitrogen	No phosphorus	1/4 phosphorus	2 phosphorus
Potassium (K)	86	86	86	86	86	86	86
Calcium (Ca)	176	176	176	176	176	176	176
Magnesium (Mg)	58	58	58	58	58	58	58
Manganese (Mn)	5	5	5	5	5	5	5
Iron (Fe)	1	1	1	1	1	1	1
Phosphorus (P)	68	68	68	68	-	17	136
Nitrogen (N)	224	--	56	448	193	203	193
Chlorine (Cl)	318	318	318	318	318	318	318
Sulfur (S)	76	76	76	76	76	76	76
Boron (B)	3	3	3	3	3	3	3

The concentration of elements in these solutions varies somewhat from those employed by Blake, Nightingale and Davidson (11), particularly in the content of nitrogen and chlorine and in the absence of sodium. Under field conditions, where sodium nitrate is commonly used as a fertilizer, there is undoubtedly an accumulation of sodium in the soil which tends to cause an increase in the pH value. In the humid sections of the country the sodium is not likely to prove a detriment to plant growth. However, Hoagland and Snyder (40), working with strawberries, found that some varieties were highly susceptible to injury from sodium salts even tho the sodium was present only in moderate concentration in the solution. The symptom was a marginal burning which sometimes spread until the whole leaf was killed. Considerable diversity of opinion exists among investigators in regard to the most satisfactory concentration of elements for the best growth of plants. Cullinan and others (18), working with peach trees in sand cultures, found increases in growth of tops and roots when the nitrogen concentration of the nutrient solution was increased, up to 60 ppm. With phosphorus, however, they obtained no increased growth with concentrations above 4 ppm. It now appears from the work of Cullinan and others that the concentration of phosphorus used in the work herein reported was considerably greater than necessary. Nevertheless, the arrangement of cultures gave an opportunity for studying the effects of both deficiencies and excesses, in apples and peaches. Further evidence in this connection was obtained by Batjer and Degman (5) who found that growth in their phosphorus series was approximately uniform in all series which received 4 ppm or more of phosphorus. They found that phosphorus deficiency symptoms occurred only when the phosphorus was completely lacking. In their nitrogen studies with apple trees, they found somewhat less linear growth with the nitrogen concentration at 60 ppm than at 168 ppm. Reduction in the nitrogen supply below 60 ppm reduced the amount of growth almost quantitatively.

Growth Measurements. To determine the growth response of the trees for the different nutrient treatments, measurements of diameter and linear growth were made at weekly intervals thruout the summer. The diameter of the tree trunk was measured at the point where it came thru the cover of the jar and also one foot above the cover. The diameter of the new growth was calipered at a point approximately one inch from the older wood. The leaf and new-growth characteristics were observed frequently and measurements were made to determine the effect of the nutrient treatments on the angle formed between the leaf petioles and the shoots on which they were growing. At the end of the season the trees were removed from the jars, weighed and photographed and the effect of the treatments on root growth was studied. The results of these measurements together with several of the photographs are shown and described in the following pages.

Chemical Analyses. For the determinations of soluble nitrogen and phosphate phosphorus in this study, the first samples were taken from the top third of the twigs which were cut off each tree at the time of potting. Later, the top third of a shoot on each tree was analyzed. All determinations were made colorimetrically from samples taken in duplicate.

Methods of Analysis. In the previous work (88) chemical analyses of twigs were made at weekly intervals to determine the seasonal course of soluble nitrogen and phosphate phosphorus in Winesap apple and

Elberta peach trees in the orchard, under various treatments of culture and fertilization. The methods used for the analysis are briefly described in the bulletin just cited and in a journal article (87). They are modifications of the procedures developed by Emmert (26) (27) (28) (29) for his studies with vegetable plants. The determinations of both nitrogen and phosphorus were made upon duplicate samples. In 1926 it was suggested by Loomis (50) that colorimetric procedures for many types of determinations might eventually be found most suitable and he emphasized that any sample worth taking was worth duplicating. Loomis offered suggestions on methods of sampling, preservation of material and certain procedures for chemical determinations. He further stated that in the bulk of physiological analyses the statement of chemical results as percent of the green weight of the tissue appeared to be of the greatest significance. Various other methods have been developed for rapid chemical tests of plants and soil as a means for determining fertilizer needs, and suggestions on their use are offered by Gilbert and Hardin (33) and by Thornton, Connor and Frazer (76).

Further proof in regard to certain procedures that were followed in this work and the conclusions that were drawn has been given by Traub (82) who found that the greatest nitrogen content in twigs occurred in the spring just before growth began. Similar results were obtained in the previous study (88) in apple and peach trees in the orchard. Also in agreement with the work of Traub was the fact that nitrogen was relatively constant and at a low level during the dormant season. Similar results were obtained by Thomas (75) and Piney (59).

In this study and in the previous work, the outer third of twigs was used for analysis because preliminary tests (87) had shown that somewhat higher concentrations of soluble nitrogen occurred in this region than in the median and basal sections. From the results obtained it was thought that the portion of the twig showing the highest analysis of soluble nitrogen would present the most accurate picture of the amount available for metabolic processes. Harvey (35) has pointed out that substances which tend normally to decrease thruout the growing season, like nitrogen, are always most abundant in the tips of shoots and least abundant in the basal portions and are associated generally with good growth conditions.

It was found in the previous study (88) that, in tissues where no injury had resulted from freezing, an increase in the amount of phosphate phosphorus occurred slightly in advance of the time that new growth began but the amount in twig tissue was soon reduced when leaves had been formed in sufficient number to utilize the phosphorus. In twigs where severe winter injury had occurred (90) the amount of phosphate phosphorus continued to increase notwithstanding the fact that the injury was so severe that no new growth was formed. It has been pointed out by Gardner, Bradford and Hooker (32) that phosphorus is at a maximum in nearly all tissues when buds are swelling and that the chief difference between phosphorus and nitrogen in this respect is that phosphorus reaches a minimum in most tissues in April or May when trees are in bloom while the minimum for nitrogen is not reached until midsummer when active growth has been completed.

Fresh tissue was used for these analyses. A similar procedure has been suggested by Loomis (50). Tottingham (80) has pointed out that both freezing and desiccation modify the nitrogenous constituents in such a manner as to make impossible the true separation of the nitrogenous fractions. Other investigators have verified these results. It would appear from the conclusions reached by these different workers that a procedure of freezing or drying would change the amount of nitrogen from any one type of nitrogen determination and the amount would differ from that resulting from extraction of fresh tissue.

Results

Growth. After the trees had been set in the jars and new growth had started, the excess buds were removed so that only two shoots were allowed to grow. In practically all cases the most vigorous shoots developed near the distal end of the trunk. The two most vigorous shoots were permitted to grow in order that one of these might be used for chemical analysis after the trees had been growing for several weeks. Weekly records were kept from the beginning, on amount of new growth, trunk diameter increase and characteristics of leaf and petiole development. The results of these measurements are shown in the graphs and tables in the appendix.

Tables 3, 5 and 7 and figures 1, 2, 3, 4, 9, 10, 11 and 12 give the growth measurements for apples. Tables 4, 6 and 8 and figures 5, 6, 7, 8, 13, 14, 15 and 16 give the growth measurements for peaches. The measurements given for each date in the tables are averages of three weeks, while those shown in the figures are individual weekly measurements.

The results shown in tables 3, 5 and 7 for the growth of the apple trees indicate rather clearly that the response of the Paducah variety under the conditions of this experiment was better, in most cases, than that of Staymared. The exceptions to this statement were the Paducah tree growing in the no-phosphorus culture and the one which received the basal nutrient treatment. Measured by trunk diameter increase, either at the jar cover or one foot above, the no-phosphorus tree failed to respond satisfactorily, altho in percentage green weight gain it exceeded the Staymared. In the basal nutrient treatment, the Paducah tree made less linear growth and also showed a lower percentage green weight gain than the Staymared. In total linear shoot growth, the trees of the two varieties were nearly identical where phosphorus was omitted from the nutrient solution. In comparison with this, the Paducah tree showed a percentage gain in linear growth of 105 percent where the phosphorus was doubled over the amount used in the basal solution, while the Staymared tree showed a percentage gain of only 7.3 for the same treatment. This striking difference is at least suggestive of the phosphorus utilization of these two varieties and would indicate that Paducah trees should respond excellently in soil where the phosphorus content is high. In fact, such a response has occurred with Paducah trees in bluegrass soils where the phosphorus content is unusually high.

No explanation can be offered for some of the other differences in growth response of these two varieties in sand culture except to state that under field conditions trees of the Paducah variety grow more rapidly and come into bearing at a relatively earlier age than Staymared. Possibly some further explanation can be found in the natural growth response of these two kinds under field conditions. The Paducah is a variety of Kentucky origin and is considered to be a seedling of Rome Beauty. It possesses the habit of starting into growth relatively late in the spring and ceases growth fairly early in the summer. It grows vigorously, however, and bears heavily and regularly. The Paducah may be classed distinctly as a fall apple and the Staymared as a winter sort and this may account in some degree for the difference in growth of the two kinds in sand culture.

In every case except in the basal solution, the response in growth as measured by total linear increase was greater for Paducah than for Staymared. Likewise the percentage increase in weight of this variety was appreciably greater in all cases except the basal nutrient and no-phosphorus cultures.

The same relationship between the two varieties also held true for the gains in trunk diameter, whether the measurements were made at a point near the crown or one foot above that point. When the diameter measurements of the current growth were compared, however, the greatest gains were not always shown by the Paducah.

The stem diameter measurements for peaches showed quite consistent increases for all nutrient treatments except the ones where nitrogen was omitted. In this case, relatively small gains were made in either the old or current stem and likewise there were but small amounts of new linear growth.

In comparing the linear growth and percentage increases in weight of trees of apple and peach, the fact stands out rather clearly that the peach is more sensitive than the apple to a deficiency in the phosphorus supply. In the apple cultures where phosphorus was omitted the average gain in weight of the two trees was 94 percent while the peaches which received the same treatment gained only 15 percent. The symptoms of phosphorus deficiency, however, were more noticeable on the apple than on the peach trees with the possible exception of the change in the color of the foliage. In comparison with the peaches, which showed small percentage gains in weight in the absence of a phosphorus supply, the apples grew fairly well, while in the cultures where the phosphorus supply was doubled over the amount used in the basal solution, the apple trees gained considerably more than the peach.

Under field conditions in most soils of Kentucky, the content of water soluble phosphorus is low, averaging considerably less than one part per million. This is true in the areas where the principal commercial orchards of apples and peaches are grown. In the bluegrass section of Central Kentucky, the soils are outstandingly high in their phosphorus content but even under these conditions the water soluble fraction probably would not run more than one part per million. The bluegrass area is not a commercial fruit growing section and it appears doubtful if trees grown there thrive any better or even as well as in other parts of the state where the phosphorus content is known to be low.

In general, the cultures which contained no nitrogen appeared more detrimental to the peach trees than to the apples and the effect of this treatment on the peaches was most obvious in the lack of new growth, the yellowish green color of the leaves and the red discoloration of the bark.

In fertilization experiments with peaches under orchard conditions Ashley (3) found that the gains made by trees were in direct proportion to the amount of nitrogen which they received. The results obtained in the experiment herein reported do not agree with the findings of Ashley. For the quantities of nitrogen used in these cultures, there were only slight increases in green weight gain when the nitrogen was increased from 56 to 224 parts per million and even a slightly smaller gain when the nitrogen content of the solution culture was increased to 448 parts per million. It seems quite probable, however, that under field conditions and particularly on light soil with smaller quantities of nitrogen than were employed in these tests, gains made by trees would be in diract proportion to the quantities of nitrogen which they received. The relative quantities of nitrogen used in the first four cultures in this experiment were 0, 1, 4 and 8 while the respective green weight gains for these trees were 0, 1, 1.3 and 1.26. Nearly the same relationship was found for linear growth increases for the trees which received these four treatments with results of 0, 1, 1.1 and 1.1. It appears that nitrogen, when used in excess of 60 parts per million in solution cultures for peaches cannot be expected to give greatly increased results in linear growth increase or in green weight gains. In fact, Cullinan, Scott and Waugh (18) found that when nitrogen was used on peach trees at quantities of 120 and 168 parts per million the gains were not significantly greater than when it was used at 60 parts per million.

When the same comparison is made with the apple trees as is shown above for the peaches, it is found that the heavier nitrogen applications are even less effective in inducing vegetative growth. Comparing the green weight increases in the different nitrogen cultures, the respective gains were 0, 1, .19 and .68, for the relative quantities of nitrogen of 0, 1, 4 and 8, while the linear growth increases for the same trees were 0.1, .63 and .72. It appears that the heavier applications of nitrogen were detrimental to the growth of the apple trees in sand culture. A point of particular interest with respect to vegetative elongation and the diameter increase of current growth is the fact that shoot growth continued over a considerably longer period on the apples than on the peaches and that the diameter of the current growth continued to increase on the apple trees until late summer. On the peach trees, however, very little increase in shoot diameter occurred after August 3. The shoot growth on peach trees was rapid at first but was practically completed within a month or six weeks after the trees were potted. On the apple trees, shoot growth was moderately rapid but continuous until about the first of September. This comparative condition of growth, at least the elongation of shoots, is quite different from that of normal tree growth under field conditions. In general, with trees of moderate vigor, the apple completes its shoot growth in a season several weeks in advance of the time that shoot growth on peaches is terminated.

As stated previously, the roots of all trees were pruned uniformly at the time they were set in the jars. All the fibrous roots were removed and only roots of moderate size were left on the trees. At the end of the experiment the roots were examined and photographed. The results of the examination are recorded in tables 9 and 10.

Table 9. Growth of Staymared and Paducah apple tree roots in sand culture.

Nutrient treatment	Tree number *	Characteristics of the root growth
Basal	1.	Fairly good. Laterals slender and quite numerous. Fibrous growth dense.
	8.	Moderately good. Few slender laterals. Fairly good fibrous growth.
No nitrogen	2.	Very little growth. Tree died in the 7th week.
	9.	Extensive root system. Laterals numerous, slender and long. Fibrous growth heavy.
1/4 nitrogen	3.	Moderately heavy growth of laterals and fibrous roots.
	10.	Many long, slender roots but comparatively few new fibrous roots. In general fairly good.
2 nitrogen	4.	Good. Laterals long. Fibrous development good but not extensive.
	11.	Moderately good but neither lateral nor fibrous roots numerous.
No phosphorus	5.	Several long, slender laterals. Very little fibrous development.
	12.	Laterals long, slender and not numerous. Fibrous development poor.
1/4 phosphorus	6.	Rather poor. Not many laterals. Fibrous growth weak.
	13.	Fairly good. Laterals not numerous. Fibrous growth moderately dense.
2 phosphorus	7.	Very good. Laterals numerous. Fibrous growth heavy.
	14.	Good. Laterals fairly large and long. Fibrous growth moderately heavy.

* The first tree in each pair is Staymared; the second, Paducah.

Table 10. Growth of Elberta peach tree roots in sand culture.

Nutrient treatment	Tree number	Characteristics of the root growth
Basal	15.	Good. Good development of laterals. Many fibrous roots.
	16.	Rather poor. Not many laterals. Fibrous growth weak.
No nitrogen	17.	Moderately good but not heavy. Many slender laterals. Fibrous development quite dense.
	18.	Moderately good. Lateral growth fairly extensive. Fibrous growth only fair.
1/4 nitrogen	19.	Very extensive root system. Laterals long and numerous. Fibrous growth especially good.
	20.	Roots rather short but numerous. Lateral and fibrous growth good.
2 nitrogen	21.	Very poor. Both lateral and fibrous development small.
	22.	Poor. Laterals few and short. Fibrous growth very limited.
No phosphorus	23.	Rather poor. Laterals limited in size and number. Fibrous growth weak.
	24.	Weak and stunted. Not many laterals. Only a few weak fibrous roots.
1/4 phosphorus	25.	Good. Laterals long and numerous. Fibrous development good.
	26.	Fairly good. Laterals numerous but bunched together. Fibrous growth extensive.
2 phosphorus	27.	Good. Laterals long and numerous. Fibrous development moderately heavy.
	28.	Good. Laterals quite long. Fibrous growth moderately heavy.

The growth of roots in general, on both apples and peaches, was enhanced in the cultures in which the nitrogen supply was either lacking or limited. These results are in agreement with the findings of Blake, Nightingale and Davidson (11), Weinberger and Cullinan (91) and others. Weinberger and Cullinan found relatively three times as much root growth by weight in proportion to top on trees growing in a solution where no nitrogen was supplied as on trees growing in a complete nutrient solution. The response of trees under these conditions appears to be due to a cessation or marked retardation of cambial activity. In this work, lateral extension in growth of roots was apparently quite rapid but increase in diameter very limited when the nitrogen supply was low. Careful examination of the roots in the cultures where nitrogen was omitted disclosed that much of the cortex had died and sloughed off. In this respect, the roots of these plants differed considerably from those which had grown in the basal nutrient solution. In the latter, the diameter of the roots was larger and the cortical tissue was alive and white. Similar results were reported by Blake, Nightingale, and Davidson (11). With apple or peach trees which received no nitrogen, the effect of this treatment appeared to be much more serious upon top growth than upon root growth.

There was considerable evidence, particularly in the peach trees, that when the nitrogen supply was double the amount used in the basal solution, root growth was seriously retarded. This same condition has been noted on numerous occasions with plants under field conditions when the soil was extremely rich or when excess quantities of nitrogen-carrying fertilizers had been used. The effect of these conditions on root growth is generally exactly opposite to their effect on vegetative vigor of the parts above ground.

The trees growing in the cultures in which no phosphorus was supplied, formed only fairly good root systems and the treatment appeared more detrimental to the peach than to the apple. Particularly in the apple, the laterals were long and slender and in both kinds of trees the development of fibrous roots was poor. Russell (67) has pointed out that phosphorus is necessary for mitotic cell division and it appeared from the type of growth of roots in these cultures that cambial activity ceased relatively early where the external supply of phosphorus was lacking. Wallace (85) found that phosphorus starvation caused stunting of fruit tree roots and the cause for this appears to be lack of starch transformation. The starch forms satisfactorily in the absence of phosphorus but is not changed to sugars.

It was pointed out earlier in this discussion that the vegetative growth of peach trees was evidently seriously affected by the lack of an adequate phosphorus supply and now it appears from the studies of root growth in peach trees that this portion of the plant is likewise seriously checked when phosphorus becomes limited. The effect of this treatment on both top and root growth was more detrimental to the peach than to the apple.

When the phosphorus supply was doubled, the roots of all trees made good growth but it seems likely that the amount of phosphorus used in these solutions was more than was actually necessary for adequate and perhaps even for maximum growth.

Photographs of the root systems of all trees are shown in later pages.

The tissues of all trees were analyzed for soluble nitrogen and phosphate phosphorus at the time they were set in the jars and again in late summer. The first analyses were made from a portion cut from the top of each shoot which was growth of the previous year. Later in the summer, the upper third of one of the main shoots at the top of each tree was analyzed in the same way. The procedure used for the determinations is described in another publication (87). The results are given in table 11.

Table 11. Soluble nitrogen and phosphate phosphorus in the stems, April 18, and shoots, August 4, of apple and peach trees growing in sand culture. Parts per million of the fresh tissue.

Treatment	Basal		No nitrogen		1/4 nitrogen		2 nitrogen		No phosphorus		1/4 phosphorus		2 phosphorus	
Date of test	April 18	Aug. 4	April 18	Aug. 4	April 18	Aug. 4	April 18	Aug. 4	April 18	Aug. 4	April 18	Aug. 4	April 18	Aug. 4
Soluble nitrogen														
Staymared apple	477	1471	375	dead	401	1191	372	1667	393	1136	449	1408	472	1449
Paducah apple	338	1515	325	trace	317	1266	357	1449	310	901	273	1389	345	1316
Average	408	1493	350	--	359	1229	365	1558	352	1019	361	1399	409	1383
Elberta peach	275	287	146	trace	276	229	216	415	240	465	171	437	349	370
	204	296	130	trace	373	234	408	550	111	516	172	377	306	365
Average	240	292	138	trace	325	232	312	483	176	491	172	407	328	368
Phosphate phosphorus														
Staymared apple	290	387	250	dead	230	392	244	351	274	62	295	254	313	476
Paducah apple	233	370	209	142	247	404	236	410	167	59	160	249	191	437
Average	262	379	230	---	239	398	240	381	221	61	228	252	252	457
Elberta peach	213	526	182	323	208	444	274	426	196	trace	244	318	244	571
	208	500	210	253	274	476	172	488	248	trace	202	294	240	541
Average	211	513	196	288	241	460	223	457	222	trace	223	306	242	556

In both apples and peaches, the omission of an element from the nutrient solution resulted in only very small quantities of that element being found in the shoot growth of those trees in late summer. This was more particularly true of nitrogen than of phosphorus and was more pronounced in the peach than in the apple.

When the amount of either nitrogen or phosphorus was doubled, over the quantity in the basal solution, it resulted in additional quantities of these nutrients being found in the shoot tissues, but not in amounts proportional to the quantities added.

The findings for soluble nitrogen and phosphate phosphorus in this experiment differ considerably from the results obtained with apple and peach trees under field conditions (88). This was particularly true for nitrogen in the apple trees. In all the cultures except the one where no nitrogen was used, the soluble nitrogen of the apple shoots was much greater in late summer than when the trees were potted and much greater also than for trees in the orchard. A part of this difference may be accounted for by the fact that new shoot growth was analyzed in late summer, while the April 18 results were obtained from growth made the previous season. The nitrogen increase, however, was much greater than could be accounted for by the difference in age of the tissues analyzed. The increase appears to be due largely to the comparatively large quantities of nitrogen used in the nutrient solutions. The same condition, however, did not prevail in the shoots of the peach trees as they were found to contain considerably smaller quantities of soluble nitrogen than the apples and much smaller quantities than were previously found in peach trees under orchard conditions. The comparative characteristics of growth of the apple and peach trees in this experiment, particularly the length of time during which growth continued in the summer, appear to be important factors in explaining the difference in the soluble nitrogen content of the apple and peach shoots. The apple roots apparently remained active and continued to absorb nutrients over a longer time than did the roots of the peach trees. At the same time, shoot growth of the apple trees was steady and continuous over a much longer period than that of the peach. The condition of active growth over a long period and the high accumulation of soluble nitrogen in shoots of the apple, are practically the reverse of these conditions as they occur in orchard trees.

It appears reasonable to conclude that the nutrient treatment stimulated the apple trees to greater activity than is normal for this species but retarded the peach trees in their growth, particularly their season of growth, and in the absorption of nutrient elements by the roots. The other conclusion to which this statement obviously leads, is that a nutrient solution which is suitable to the growth of apple trees in sand culture may give quite different results with peach trees under the same conditions.

The content of phosphate phosphorus in the shoots of both apple and peach trees in the sand cultures was more nearly like that of trees in the orchard and varied much less than nitrogen between the first and last determinations in the season. In general, accumulation of phosphate phosphorus in the peach shoots was greater than in those of the apple, apparently because of early cessation of growth and failure to utilize the nitrogen and, consequently, the phosphorus which were available.

The conditions to which all these trees were subjected, especially in nutrient supply, were quite different from those which would occur in normal orchard soil. Fresh supplies of certain nutrients were given the trees at frequent intervals and the amounts present were in excess of the probable quantities found in good orchard soil. This was probably more particularly true of nitrogen than of phosphorus. Under average conditions of rainfall the supply of available nitrogen in soil during late summer is moderately high but twig tissues of apple trees at that time usually average only two to four hundred parts per million of soluble nitrogen, on the basis of green weight of tissue (88). Thus, in comparing the content of soluble nitrogen of orchard trees with the findings in this experiment, it is obvious that the nutrient treatments led to some unusual developments in the nutrient content of the shoot growth.

Reaction of the Nutrient Solution. In the preparation of nutrient solutions for use on apple trees in sand culture, Blake, Nightingale and Davidson (11) found that if the pH of the solutions was adjusted to 4.2 it gave excellent results. They also found that between the periods of nutrient applications the cultures tended to become less acid, about pH 5.0 to 5.2.

Since the cultures used in this experiment were designed after those of Blake, except for some modifications, it was deemed advisable to adjust the pH to approximately the same degree as that found most suitable by him. After the solutions were prepared and the iron had been added, the pH of each was determined by means of a quinhydrone apparatus which was frequently checked for accuracy against a standard buffer solution of known pH.

Some differences in pH were found in the solutions when they were first prepared and adjustment was made by adding 0.1 N H_2SO_4 where needed. The original pH value of each solution, the amount of acid used per liter and the pH value after adjustment are given in the following table.

Solution No.	pH before treatment	Amount of acid per liter (c. c.)	pH after treatment
1.	4.92	2.03	4.24
2.	5.09	1.20	4.28
3.	4.96	1.30	4.23
4.	5.01	1.25	4.26
5.	5.33	1.35	4.23
6.	5.35	1.13	4.23
7.	4.85	1.12	4.26

Beginning on May 17 and continuing at weekly intervals thruout the summer, pH determinations were made of the nutrient solutions that had been in the sand and in contact with the tree roots. That is, once in each week, when fresh solutions were added to the jars, some of the solution which ran from the drainage tube at the bottom was used for the pH determination. Fifty to 100 cc of solution drained from each jar at the time fresh solution was added. No pH record was made during the first ten days of the test when all trees were treated uniformly with distilled water. Thus, the data for pH determinations on the cultures start on the date when the first nutrient solutions were added to the jars. The results are shown in figures 17, 18, 19 and 20.

The reaction of the nutrient solution was quickly changed in all cultures, from pH 4.2 to nearly 7.0, when it was first added to the sand. Nearly the same reaction change occurred when the sand alone was treated with distilled water, as is shown in figure 21. As the season progressed and the treatments continued, the nutrient solutions which had been in the sand and in contact with the tree roots became more acid. After about seven weeks the solution from all cultures except two was more acid than when it was first added. The exceptions were the basal solution and the one without nitrogen, for the apple trees, and the solution without nitrogen and the one with 1/4 N for the peach trees. Other investigators have observed the tendency of plants to render the nutrient solution more acid. In general, the solutions averaged somewhat more acid for the apple than for the peach cultures. The solution which contained no nitrogen changed less than the others and was more pronounced in this respect in the jars where peaches were growing than in the apple cultures. In fact, in the peach cultures without nitrogen, the average reaction of the solution after passing thru the sand was less acid than at the time of its addition to the jars, during the experiment. The no-nitrogen solution from the apple cultures was less acid than originally, for the first nine weeks. In the experiment with sand in which no trees were growing, after the sudden initial reduction in acidity, the reaction of the solutions gradually became more acid but there were no sudden and rapid reductions in pH later in the test as was observed in both the apple and peach cultures. In the sand alone, the solution which contained no nitrogen was very slightly less acid than the basal solution. In the tree cultures, the reduction in pH must have resulted partly from the action of the sand but probably was caused mainly by the action of the tree roots such as selective absorption by the roots and excretion of acid substances into the solution.

The greater acidity of the solutions which contained nitrogen appears to be due to a combination of at least two factors. Tree roots have a tendency to increase the acidity of a nutrient solution probably by the excretion of certain materials from the roots and by the carbon dioxide which they give off. Also, absorption of the ammonium ion from ammonium nitrate to a greater extent than the NO_3 ion could cause the formation of nitric acid and a consequent increase in acidity. When the nitrogen was omitted from the solution the reaction was less acid than the others, after being in the sand, even tho adjusted to the same hydrogen-ion concentration as the others when it was prepared. These facts are shown by the No. 2 line in figures 17, 19 and 21.

Following the experiment with the trees in sand culture, a test was arranged to show the effect of the sand alone on the reaction of the nutrient solution. This was done because the results shown in figures 17 and 19 indicate that contact with the sand changed the reaction of the nutrient solutions from about pH 4.2 to 6.5 - 7.0, when they were first added. In this test four jars of the same lot of unwashed sand were treated with distilled water for a little over two weeks. Water was added every other day in sufficient quantity so that approximately 100 cc drained from each jar. pH determinations were made each time that water was added. After treatment with distilled water for two weeks, the jars of sand were treated with nutrient solutions which had been adjusted to pH 4.2. Two jars were treated with the basal nutrient solution and two with the solution which contained no nitrogen. Fresh solution was added and pH determined every other day. For the graphic representation, the two jars which received the same treatment were averaged. The results are shown in figure 21. The wavy line indicates the date on which the nutrient solutions were added. The reaction of both nutrient solutions was changed from pH 4.2 to about pH 6.5, after addition to the sand. A similar change in reaction occurred, from pH 5.7 to pH 8.6, in the distilled water, as shown in the figure.

Deficiency Symptoms. The arrangement of cultures in this experiment permitted the study of deficiency symptoms of both nitrogen and phosphorus with apple and peach trees. It likewise gave an opportunity to study any typical characteristics which developed under conditions where these two elements were used in excess.

Nitrogen Deficiency Symptoms. Characteristics of nitrogen deficiency were evident on the trees in the no-nitrogen jars within a comparatively short time after the nutrient treatments were started. These symptoms were noticeable earlier on the peach than on the apple and gradually became more pronounced. Most noticeable was the failure of these trees, particularly the peach, to develop a deep green color. The leaves gradually became yellowish green and brittle, as the season progressed, and were smaller and more slender than those on the trees in any of the other treatments. One of the apples failed to make any appreciable new growth and died about the middle of June. The other apple developed fairly well in the stem diameter but poorly in linear growth. Both peach trees which received no nitrogen grew poorly from the beginning and failed to develop satisfactory new growth. The average percentage gain in green weight of these two trees was only about one-tenth that of the two which received the basal nutrient solution. As the season progressed and growth continued, the angle between the leaf petioles and the stem, on the trees which received no nitrogen, became continuously more acute. Similar results were noted by Blake, Nightingale and Davidson (11).

The no-nitrogen trees developed a distinctly red color on the base of the leaf petioles and on the bark of the trunk. This characteristic is not infrequently noted on orchard trees growing under conditions where the nitrogen supply is limited.

Along with the failure of these trees to develop a suitable leaf size and color it was noted that the abscission of the leaves started earlier in the season and that the length of time during which leaves were retained on branches was considerably shorter than for those given other nutrient treatments.

Cullinan, Scott and Waugh (18) have shown that when nitrogen was supplied to peach trees in amounts of 60 parts per million, growth was good and continued until September. In quantities lower than this, growth was reduced and certain deficiency symptoms were noticeable. Altho their trees were somewhat larger when nitrogen was used at 120 and 168 parts per million, the increases were not significantly greater. Similar results were obtained in the test herein reported. The growth and weight increases of the trees were approximately as good when nitrogen was used at 56 as when used at 224 parts per million, and no additional benefit resulted when the nitrogen concentration was 448 parts per million.

The root growth of the trees which received no nitrogen averaged better than that of the trees which received an optimum or a maximum supply. In general, fibrous growth was especially good where nitrogen was omitted from the solution. Other investigators have reported similar results.

Phosphorus Deficiency Symptoms. As previously stated, the omission of phosphorus from the nutrient solution was apparently more detrimental to the peach than to the apple trees. This is shown particularly in table 6, by relative percentage weight increases of the trees in the no-phosphorus series. The percentage gains in weight of the peach trees, when phosphorus was omitted, were nearly as small as for the no-nitrogen treatment.

Both apples and peaches in the no-phosphorus series maintained a dark color thruout the summer and became almost a bronze shade late in the season. The color began early in the season as a purplish-red which increased in intensity as the season progressed and the treatment continued. Abscission of foliage from the trees in this treatment occurred later than in those where nitrogen was omitted and was more or less scattered over the branches, whereas on the no-nitrogen trees the leaves from lower branches dropped first and dropping proceeded gradually upward.

In this series the leaves of both apple and peach trees were characteristically long and narrow. A similar type of leaf growth on no-phosphorus trees was noted by Cullinan, Scott and Waugh (18). This type of leaf growth was noted more particularly and was observed earlier in the season on the peach than on the apple trees.

It appears from the work of other investigators that the amount of phosphorus used in these tests, even in the solution containing the

minimum amount, was greater than necessary for optimum growth of peach trees. Cullinan, Scott and Waugh (18) found no appreciable gains in peach trees when phosphorus was used in excess of 4 parts per million. Results of this experiment point to the same conclusion, but the apple trees apparently responded in gains where the greatest quantity of phosphorus was added. In general, the root growth on the no-phosphorus trees was poor; laterals were long and slender but not numerous and fibrous development was markedly limited. On the other hand, the apple and peach trees which received the heaviest addition of phosphorus developed good roots with numerour laterals and moderately heavy to heavy fibrous growth.

Summary

(1) This experiment was supplementary to a previous study of nitrogen and phosphorus relationships in orchard trees of Winesap apple and Elberta peach, analyzed at weekly intervals throughout an entire year. It was undertaken primarily for the purpose of observing the symptoms which developed when nitrogen and phosphorus was lacking in the nutrient solution or were supplied in excess. Results were recorded by means of caliper measurements of old and current growth, green weight increases, observations and photographs of root growth, chemical analysis of shoots and pH determinations of nutrient solutions that has been in the sand and in contact with the tree roots.

(2) All nutrient solutions were adjusted to approximately pH 4.2 and when they were first added to the culture jars were changed to a decidedly less acid reaction, about pH 7.0. Further tests in which nutrient solutions were used on jars of sand in which no trees were growing gave nearly the same results. The first solutions which drained

from the sand were much less acid than when they were first added, regardless of whether the liquid used was distilled water or nutrient solution. As the leaching continued, on either the tree cultures or sand alone, the solutions gradually became more acid.

(3) Tests of distilled water leaching from the sand and of the sand itself did not disclose the presence of any alkaline material in quantities large enough to account for the decided reduction in hydrogen-ion concentration of the solutions that had drained from the sand. In view of this fact, it seems reasonable to assume that the change in hydrogen ion concentration from pH 4.2 to about pH 7.0 must have been due largely to adsorption by the sand.

(4) In the case of both the tree cultures and the sand alone, all solutions which leached from the jars were more acid after the initial treatment. The most acid reaction developed in the solution which contained the greatest quantity of phosphorus in addition to the usual amount of nitrogen. The least acid reaction was found in the solution which contained no nitrogen. During the last seven weeks of the test, all solutions except the no-nitrogen cultures of the peach trees were more acid than when added to the jars.

(5) The no-nitrogen solution changed much less in pH than the others during the course of the experiment and their concentration of hydrogen ions was considerably less. The reaction of this solution, even at the conclusion of the test, was less acid in the peach cultures than when added to the jars.

(6) The decidedly acid reaction found during the last few weeks of the experiment in all solutions which contained nitrogen, appears to

have been due to a combination of factors. First, probably the continued excretion of certain materials and CO_2 from the roots. Second, the probable hydrolysis of the ammonium nitrate salt and the assimilation of the NH_3 radicle to a greater extent by the roots than that of the NO_3 with the consequent formation of nitric acid. And finally, a continued lowering of the absorptive ability of the sand as the nutrient treatments continued.

(7) Although there is the possibility that the reaction of the solutions may have had some effect upon tree growth, particularly during the first few weeks of the experiment, it seems reasonable to assume that it did not play a part for any appreciable length of time because the reaction of the solutions changed rather rapidly to a point at which other investigators have found trees to grow best.

(8) When nitrogen was omitted from the nutrient solution growth of the trees was seriously affected. The treatment was more noticeably detrimental to the peach than to the apple and was characterized by yellowish, stunted foliage, early cessation of growth, and premature defoliation.

(9) Leaves on trees where nitrogen was omitted assumed an upright position and the leaf petioles formed sharp angles with the branch on which they grew.

(10) Omission of nitrogen from the nutrient solution apparently enhanced the growth of roots. Fibrous root development particularly was good on trees which received this treatment.

(11) Current linear growth was small and slender on trees of the no-nitrogen series and the percentage gains in weight were considerably less than in any other treatment.

(12) When the amount of nitrogen used was double that in the basal solution, the trees increased in weight but not in proportion to the amount of nitrogen added. In fact, with the apples, the best results were obtained when the nitrogen content of the nutrient solution was only one-fourth the amount used in the basal treatment. With the peaches, the basal nutrient application resulted in the greatest average percentage gain in green weight.

(13) When the nitrogen or phosphorus supply was doubled, additional quantities of these elements accumulated in the tissues but not in proportion to the amounts added in the nutrient solution.

(14) In general, the response made to any nutrient treatment was somewhat different in the two apple varieties used.

(15) In all treatments except the basal solution, the response in total linear increase was greater for Paducah than for Staymared apple. The same relationship between varieties also held true for the gains in trunk diameter.

(16) With the peach trees, there were consistent trunk diameter increases for all nutrient treatments except the one where nitrogen was omitted. The latter increased only slightly in old stem or current growth diameter, and linear growth was very weak.

(17) Percentage gains in weight of the trees indicated quite clearly that the peach is more sensitive to a deficiency of phosphorus than is the apple. On the other hand, the peach trees did not respond as satisfactorily to heavy phosphorus application as did the apples.

(18) In its effect on gain in green weight, omission of phosphorus from the nutrient solution used on peaches was nearly as serious

as omission of nitrogen. Defoliation did not occur as early, however, and the leaves did not develop the chlorotic appearance characteristic of leaves on nitrogen-deficient trees.

(19) Phosphorus-deficiency symptoms were similar in both apple and peach altho somewhat more pronounced in the apple. The leaves were dark green changing to a dark yellowish green or bronze color late in the season, and were characteristically long and narrow. Leaf abscission occurred later and was more scattered over the branches than in the no-nitrogen trees.

(20) Omission of phosphorus from the nutrient solution seriously affected root growth, particularly the development of fibrous roots. Laterals on these trees were long and slender but few, and fibrous growth was noticeably limited. Doubling the quantity of phosphorus resulted in extensive root development in both apple and peach trees.

(21) Analysis of the new growth, in late summer, for soluble nitrogen and phosphate phosphorus, showed that the omission of either element from the nutrient solution resulted in a marked reduction of that particular element in the twig tissues. In this respect, the omission of nitrogen gave more pronounced results than the omission of phosphorus and smaller quantities were found in the peach than in the apple.

LITERATURE CITED

1. Alexander, L. J., Morris, V. H., and Young, H. C. 1939. Growing Plants in Nutrient Solution. Ohio Agr. Exp. Sta. Sp. Circ. 56.

2. Armstrong, W. D., Stuckey, H. P., and Cochran, H. L. 1935. Nitrogen Fertilizer Studies with the Elberta Peach. Proc. Amer. Soc. Hort. Sci. 33: 268. Abs.

3. Ashley, T. E. 1931. Some Vegetative Responses of the Peach to Applications of Nitrate of Soda. Proc. Amer. Soc. Hort. Sci. 28: 28-33.

4. Baker, Clarence E. 1936. The Relation of Nitrogen and Soil Moisture to Growth and Fruitfulness of Apple Trees under Different Systems of Soil Management. Purdue Agr. Exp. Sta. Bul. 414.

5. Batjer, L. P., and Degman, E. S. 1937. The Effect of Varying Amounts of Nitrogen, Potassium and Phosphorus on the Growth and Assimilation of Young Apple Trees. Proc. Amer. Soc. Hort. Sci. 35: 255.

6. Batjer, L. P., and Sudds, R. H. 1937. The Effect of Nitrate of Soda and Sulfate of Ammonia on Soil Reaction and Root Growth of Apple Trees. Proc. Amer. Soc. Hort. Sci. 35: 279-282.

7. Baudisch, Oskar 1911. Uber Nitrat- und Nitrit-Assimilation. Ber. 44: 1009.

8. Baudisch, Oskar, and Maeyer, Erwin 1913. Uber Nitrat- und Nitrit-Assimilation. V. Ber. 46: 115-125.

9. Blake, M. A., and Davidson, O. W. 1934. The New Jersey Standard for Judging the Growth Status of the Delicious Apple. N. J. Agr. Exp. Sta. Bul. 559.

10. Blake, M. A., Nightingale, G. T., and Davidson, O. W. 1936. Responses of Young Apple Trees to Nutrient Deficiencies. Proc. Amer. Soc. Hort. Sci. 34: 137-138.

11. Blake, M. A., Nightingale, G. T., and Davidson, O. W. 1937. Nutrition of Apple Trees. N. J. Agr. Exp. Sta. Bul. 626.

12. Chandler, W. H. 1925. Fruit Growing. Houghton Mifflin Co., Cambridge, Mass.

13. Chapman, H. D., and Liebig, G. F. Jr. 1938. Adaptation and Use of Automatically Operated Sand-Culture Equipment. Jour. Agr. Res. 56: No. 1.

14. Childers, N. F., and Cowart, F. F. 1935. The Photosynthesis, Transpiration, and Stomata of Apple Leaves as Affected by Certain Nutrient Deficiencies. Proc. Amer. Soc. Hort. Sci. 33: 160-163.

15. Clark, H. E., and Shive, J. W. 1934. The Influence of the pH of a Culture Solution on the Assimilation of Ammonium and Nitrate Nitrogen by the Tomato Plant. Soil Sci. 37: 459-476.

16. Combes, R. 1926. Etude de la Migration Automnal des Substances Azotées chez le chêne par l'analyse de Plantes Entières. Compt. Rend.Acad. Sci. (Paris) 182: 16: 984-987.

17. Cooper, J. R., and Wiggans, C. B. 1929. A Study of the Effect of Commercial Fertilizers on the Performance of Peach Trees. Ark. Agr. Exp. Sta. Bul. 239.

18. Cullinan, F. P., Scott, D. H., and Waugh, J. G. 1938. The Effect of Varying Amounts of Nitrogen, Potassium and Phosphorus on the Growth of Young Peach Trees. Proc. Amer. Soc. Hort. Sci. 36: 61-68.

19. Curtis, O. F. 1935. The Translocation of Solutes in Plants. McGraw-Hill Co.

20. ______________ 1936. The Translocation of Mineral Elements in Plants. Proc. Amer. Soc. Hort. Sci. 34: 222-223.

21. Davidson, O. W., and Blake, M. A. 1936 (Abstract). Responses of Young Peach Trees to Nutrient Deficiencies. Proc. Amer. Soc. Hort. Sci. 34: 247-248.

22. ______________________________ 1937. Nutrient Deficiency and Nutrient Balance with the Peach. Proc. Amer. Soc. Hort. Sci. 35: 339-346.

23. Davidson, O. W. 1938 (Abstract). Symptoms of Malnutrition in the Peach Resulting from Various Combinations of Nutrient Deficiencies. Proc. Amer. Soc. Hort. Sci. 36: 87-88.

24. Davis, A. R., and Hoagland, D. R. 1928. An Apparatus for the Growth of Plants in a Controlled Environment. Plant Physiology 3: 277-292.

25. Eaton, F. M. 1935. Automatically Operated Sand-Culture Equipment. Jour. Agr. Res. 53: No. 6.

26. Emmert, E. M. 1930. A Method for the Rapid Determination of Phosphorus in Fresh Plant Tissue. Plant Physiology 3: 413-417.

27. ___________ 1934. Tests for Phosphate, Nitrate, and Soluble Nitrogen in Conducting Tissue of Tomato and Lettuce Plants, as Indicators of Availability and Yield. Ky. Agr. Exp. Sta. Circ. 43.

28. Emmert, E. M. 1935. Method for Quickly Determining Nitrogen in Plants and Soluble Nitrogen as a Measure of the Nitrogen Available for Anabolic Processes. Plant Phys. 10: 355-364.

29. ____________ 1935. New Methods for the Determinations of the Availability of Nitrogen and Phosphorus to Plants. Jour. Amer. Soc. Agron. 27: No. 1.

30. ____________ 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. Ky, Agr. Exp. Sta. Res. Bul. 314.

31. Fisher, P. L. 1935. Responses of the Tomato in Solution Cultures with Deficiencies and Excesses of Certain Essential Elements. Md. Agr. Exp. Sta. Bul. 375: 283-298.

32. Gardner, V. R., Bradford, F. C., and Hooker, H. D. 1939. The Fundamentals of Fruit Production. McGraw Hill Co.

33. Gilbert, B. E., and Hardin, L. J. 1927. The Current Mineral Nutrient Content of the Plant Solution as a Possible Means of Chemical Control of Optimum Fertilization. Jour. Agr. Res. 35, No. 2.

34. Godlewski, E. 1911. Sur le Role des Nitrates dans l'alimentation des Plantes. Rev. Sci. (Paris) 49, II 6: 178.

35. Harvey, E. M. 1923. A Study of Growth in Summer Shoots of the Apple with Special Consideration of the Role of Carbohydrates and Nitrogen. Ore. Agr. Exp. Sta. Bul. 200.

36. Heinicke, A. J. 1937. Cultural Conditions Influencing the Manufacture of Carbohydrates by Apple Leaves. Proc.N. Y. State Hort. Soc. 149-160.

37. Hill, H., and Grant, E. P. 1935. The Growth of Turnips in Artificial Cultures. Cent. Exp. Fm. Ottawa,Can. Sci. Agr. 15 : 9.

38. Hoagland, D. R. 1923. The Effect of the Plant on the Reaction of the Culture Solution. Cal. Agr. Exp. Sta. Tech. Paper No. 12.

39. Hoagland, D. R., and Chandler, W. H. 1932. Some Effects of Deficiencies of Phosphate and Potassium on the Growth and Composition of Fruit Trees under Controlled Conditions. Proc. Amer. Soc. Hort. Sci.29:267-271.

40. Hoagland, D.R., and Snyder, W. C. 1933. Nutrition of Strawberry Plants under Controlled Conditions. (a) Effect of Deficiencies of Boron and Certain other Elements: (b) Susceptibility to Injury from Sodium Salts. Proc. Amer. Soc. Hort. Sci. 30: 288-294.

41. Hoagland, D. R., and Arnon, D. I. 1938. The Water-Culture Method for Growing Plants Without Soil. Cal. Agr. Exp. Sta. Circ. 347.

42. Hooker, H. D. Jr. 1922. Certain Responses of Apple Trees to Nitrogen Applications of Different Kinds and at Different Seasons. Mo. Agr. Exp. Sta. Res. Bul. 50.

43. Howlett, F. S. 1926. The Nitrogen and Carbohydrate Composition of the Developing Flowers and Young Fruits of the Apple. Cornell Agr. Exp. Sta. Memoir 99.

44. Kraus, E. J., and Kraybill, H. R. 1922. Vegetation and Reproduction with Special Reference to the Tomato. Ore. Agr. Exp. Sta. Bul. 149.

45. Lagasse, F. S. 1926. The Effect of Fertilizers on the Chemical Constituents of Fruit Spurs. Proc. Amer. Soc. Hort. Sci. Rept.

46. Laurent, J. 1904. Recherches sur la Nutrition Carbone des Plantes vertes á l'aid de Matieres Organiques. Rev. Gén. Bot. 16: 231-241.

47. Leclerc, Du Sablon 1904. Rechersches Physiologiques sur les Matieres du Reserve des Arbres. Rev. Gén. Bot. 16: 386-401.

48. Lilleland, O. 1932. Experiments in K and P Deficiencies with Fruit Trees in the Field. Proc. Amer. Soc. Hort. Sci. 29: 272-276.

49. ____________ 1935. Phosphate Response with Closely Planted One-year-old Fruit Trees. Proc. Amer. Soc. Hort. Sci. 33: 114-119.

50. Loomis, W. E. 1926. Methods for the Analysis of Horticultural Plants. Proc. Amer. Soc. Hort. Sci. 23: 285-293.

51. ____________ 1934. The Translocation of Nitrogen in Woody Plants. Proc. Amer. Soc. Hort. Sci. 32: 61-64.

52. Magness, J. R., and Regeimbal, L. O. 1938. The Nitrogen Requirement of the Apple. Proc. Amer. Soc. Hort. Sci. 36: 51-55.

53. Marsh, R. P., and Shive, J. W. 1925. Adjustment of Iron Supply to Requirements of Soy Beans in Solution Culture. Bot. Gaz. 79, 1.

54. Martin, J. P., and Carpenter, C. W.. 1939. The Growth of Plants in Water and Sand Cultures. The Hawaiian Planters Record. Vol. XLIII, No. 2. Sec. Quart.

55. McCall, A. G. 1916. A Method for the Renewal of Plant Nutrients in Sand Culture. Ohio Jour. of Sci. 15: 3, 101-103.

56. Murneek, A. E., and Logan, J. C. 1932. Autumnal Migration of Nitrogen and Carbohydrates in the Apple Tree. Mo. Agr. Exp. Sta. Res, Bul. 171.

57. Murneek, A. E. 1936. Fertilizing Fruit Trees with Nitrogen. Mo. Agr. Exp. Sta. Bul. 363.

58. Nightingale, G. T. 1927. The Chemical Composition of Plants in Relation to Photoperiodic Changes. Wis. Agr. Exp. Sta. Res. Bul. 74.

59. Piney, M. 1929. Variations Qualitatives et Quantatives des Substances Azotees chez une Plante Ligneuse au début de la Periode de Vegetation. Rev. Gen. Bot. 41: 67-93.

60. Pirschle, Karl. 1931. Nitrate und Ammonsalze als Stickstoffquellen für Höhere Pflanzen bei Konstanter Wasserstoffionenkonzentration. Ztschr. Wiss. Biol. Abt. E. Planta. 14: 583-676.

61. Proebsting, E. L., and Kinman, C. F. 1933. Orchard Trials of Nitrogen and Phosphorus. Proc. Amer. Soc. Hort. Sci. 30: 426-430.

62. Rawl, E. H. 1935. Peach Tree Abnormalities Developing from Applications of Nitrogen Fertilizer Alone. Proc. Amer. Soc. Hort. Sci. 33: 293-298.

63. Remy, Th. 1913. Stickstoffversorgung und Blütenansatz der Obstbäume. Deut. Landw. Gesell. Mitteil. 29 : 416-427.

64. Ripple, A. 1921. Die Frage der Eiweisswanderung beim Herbstlichen Vergelben der Laubblätter. Biol. Zentralbl. 41: 508-523.

65. Robbins, W. R. 1928. The possibilities of Sand Culture for Research and Commercial Work in Horticulture. Proc. Amer. Soc. Hort. Sci. 25: 368-370.

66. Roberts, R. H. 1921. Nitrogen Reserves in Apple Trees. Proc. Amer. Soc. Hort. Sci. 18: 143-145.

67. Russell, E. J. 1927. Soil Conditions and Plant Growth. Longmans, Green and Co. Ltd. N. Y.

68. Scofield, C. S. 1927. The Effect of Absorption by Plants on the Concentration of the Soil Solution. Jour. Agr. Res. 35, No. 8.

69. Scott, L. E. 1938. Response of Peach Trees to Potassium and Phosphorus Fertilizers in the Sandhill Area of the Southeast. Proc. Amer. Soc. Hort. Sci. 36: 56-60.

70. Shive, J. W., and Robbins, W. R. 1939. Methods of Growing Plants in Solution and Sand Cultures. N. J. Agr. Exp. Sta. Bul. 636.

71. Sullivan, J. T., and Cullinan, F. P. 1931. Carbohydrate and Nitrogen Relationships in Apple Shoots as Influenced by Soil Management. Proc. Amer. Soc. Hort. Sci. 28: 519-525.

72. Sullivan, J. T., and Baker, C. E. 1936. Effect of Cultural Treatments on the Growth and Nitrogen Content of Apple Shoots and Spurs. Proc. Amer. Soc. Hort. Sci. 34: 149-154.

73. Thomas, W. 1927. Nitrogen Metabolism in Pyrus malus. III The Partition of Nitrogen in the Leaves, One and Two Year Branch Growth and Non-bearing Spurs Throughout a Year's Cycle. Plant Phys. 2:2: 109-137.

74. ________ 1932. Utilization of Nitrogen, Phosphorus and Potassium by Pyrus malus Subjected to Differential Treatment with Nutrient Salts. Proc. Amer. Soc. Hort. Sci. 29: 239 Abs.

75. Thomas, W. 1933. Absorption, Utilization and Recovery of Nitrogen, Phosphorus and Potassium by Apple Trees Grown in Cylinders and Subjected to Differential Treatment with Nutrient Salts. Jour. Agr. Res. 47: 565-582.

76. Thornton, S. F., Connor, S. D., and Fraser, R. R. 1936. The Use of Rapid Chemical Tests on Soils and Plants as Aids in Determining Fertilizer Needs. Purdue Agr. Exp. Sta. Circ. No. 204.

77. Tiedjens, V. A., and Robbins, W. R. 1931. The Use of Ammonia and Nitrate Nitrogen by Certain Crop Plants. N. J. Agr. Exp. Sta. Bul. 526.

78. Tiedjens, V. A. 1932. Some Observations on the Assimilation of Ammonium and Nitrate Nitrogen in Some Horticultural Plants. Proc. Amer. Soc. Hort. Sci. 29: 253-254.

79. Tiedjens, V. A., and Blake, M. A. 1932. Factors Affecting the Use of Nitrate and Ammonium Nitrogen by Apple Trees. N. J. Agr. Exp. Sta. Bul. 547.

80. Tottingham, W. E., Schultz, E. R., and Lepkovsky, S. 1924. The Extraction of Nitrogenous Constituents from Plant Cells. Jour. Amer. Chem. Soc. XLVI; 203-209.

81. Trealease, S. F., and Trealease, H. M. 1935. Changes in Hydrogen-ion Concentration of Culture Solution Containing Nitrate and Ammonium Nitrogen. Amer. Jour. Bot. 22: 520-542.

82. Traub, H. P. 1927. Regional and Seasonal Distribution of Moisture, Carbohydrates, Nitrogen and Ash in 2-3 Year Portions of Apple Twigs. Minn. Agr. Exp. Sta. Tech. Bul. 53.

83. Turner, W. I., and Henry, V. M. 1939. Growing Plants in Nutrient Solutions. J. Wiley and Sons. N. Y.

84. VanSlyke, L. L., Taylor, O. M., and Andrews, W. H. 1905. Plant Food Constituents Used by Bearing Fruit Trees. N. Y. (Geneva) Agr. Exp. Sta. Bul. 265.

85. Wallace, T. 1930. Some Effects of Deficiencies of Essential Elements on Fruit Trees. Ann. Appl. Biol. 17: 649-657.

86. Waltman, C. S. 1931. Effect of Hydrogen-ion Concentration on the Growth of Strawberries in Sand and in Soil. Ky. Agr. Exp. Sta. Res. Bul. 321.

87. Waltman C. S. 1936. A rapid Method for Determining Soluble Nitrogen and Phosphate Phosphorus in Woody Tissue. Proc. Amer. Soc. Hort. Sci. 34: 130-132.

88. ____________ 1936. The Seasonal Course of Soluble Nitrogen and Phosphate Phosphorus in the Shoot Growth of Winesap Apple and Elberta Peach. Ky. Agr. Exp. Sta. Bul. 367.

89. ____________ 1937. The effect of Fall Nitrogen Fertilization on the Soluble Nitrogen and Phosphate Phosphorus Content of Dormant Peach Twigs. Proc. Amer. Soc. Hort. Sci. 35: 273-278.

90. ____________ 1938. Phosphate Phosphorus and Soluble Nitrogen Changes in Living and Winter Killed Peach Twigs. Proc. Amer. Soc. Hort. Sci. 36: 181-184.

91. Weinberger, J. H. and Cullinan, F. P. 1936. Symptoms of Some Mineral Deficiencies in One-year Elberta Peach Trees. Proc. Amer. Soc. Hort. Sci. 34: 249-254.

92. Williams, C. F. 1931. Season Variations in Nitrogen Concentration in Twigs of Peach Trees under Sandhill Conditions. Proc. Amer. Soc. Hort. Sci. 28: 39-44.

Table 3. Stem diameters of the apple trees growing in different solutions. Millimeters.

Solution	Basal		No nitrogen		1/4 nitrogen		2 nitrogen		No phosphorus		1/4 phosphorus		2 phosphorus	
Variety	S *	P *	S	P	S	P	S	P	S	P	S	P	S	P
	Measured at jar cover													
May 11	9.5	10.5	10.0	10.0	11.0	9.5	12.0	8.5	9.8	9.8	12.0	8.0	10.0	9.5
" 25	9.5	11.0	10.2	10.0	11.2	9.8	12.0	8.9	9.8	10.0	12.0	8.2	10.4	9.5
June 15	9.6	11.4	10.5	10.1	11.6	10.2	12.8	9.2	9.8	10.0	12.7	8.4	11.2	9.8
July 6	10.0	11.7	dead	10.4	11.8	10.3	13.1	9.8	10.2	10.0	12.9	8.8	11.5	10.3
" 27	10.0	11.8	-	10.9	12.0	10.4	13.9	10.4	10.4	10.4	13.0	9.4	11.9	10.9
Aug. 17	10.2	11.8	-	11.0	12.1	11.0	14.1	10.9	10.4	10.5	13.0	10.0	12.0	11.2
Sept. 7	10.4	12.0	-	11.1	12.3	12.2	14.4	11.3	10.9	10.8	13.0	10.6	12.0	11.5
Dec. 21	10.8	12.3	-	11.3	12.3	13.0	14.8	11.3	11.0	10.8	13.0	10.8	12.3	11.8
Gain	1.3	1.8	-	1.3	1.3	3.5	2.8	2.8	1.2	1.0	1.0	2.8	2.3	2.3
Percent	13.7	17.1	-	13.0	11.8	36.8	23.3	32.9	12.2	10.2	10.8	35.0	23.0	24.2
	Measured 1 foot above the jar cover													
May 11	9.0	7.5	7.5	7.5	9.0	7.5	9.0	7.0	8.0	8.0	8.8	6.0	8.5	7.0
" 25	9.0	7.8	7.8	8.0	9.4	8.0	9.1	7.0	8.0	8.0	9.0	6.0	8.8	7.2
June 15	9.0	7.9	8.0	8.0	9.5	8.0	9.4	7.3	8.1	8.0	9.3	6.1	9.0	7.4
July 6	9.2	8.1	dead	8.4	9.8	8.2	9.7	8.0	8.7	8.1	9.3	6.5	9.4	8.3
" 27	9.3	8.7	-	8.7	9.9	8.8	10.3	9.6	8.8	8.3	9.3	7.3	10.2	8.9
Aug. 17	9.4	9.4	-	8.9	10.2	9.4	10.7	9.4	9.0	8.4	9.4	7.7	10.4	9.6
Sept. 7	9.8	9.5	-	9.0	10.4	9.9	11.0	9.5	9.0	8.5	9.5	7.8	11.0	9.8
Dec. 21	9.8	9.8	-	9.0	10.5	10.0	11.3	10.0	9.0	8.5	10.0	8.0	11.3	10.0
Gain	0.8	2.3	-	1.5	1.5	2.5	2.3	3.0	1.0	0.5	1.2	2.0	2.8	3.0
Percent	8.9	30.7	-	20.0	16.7	33.3	25.0	42.8	12.5	6.3	14.3	33.3	32.9	42.9

* **S = Staymared, P = Paducah.**

Table 4. Stem diameters of peach trees growing in different solutions. Millimeters.

Solution	Basal		No nitrogen		1/4 nitrogen		2 nitrogen		No phosphorus		1/4 phosphorus		2 phosphorus	
Number	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Measured at jar cover														
May 11	12.0	10.5	9.0	10.0	9.5	10.3	10.0	9.8	10.8	10.3	11.0	10.0	9.3	9.0
" 25	12.3	10.8	9.3	10.0	9.8	10.9	10.1	10.0	11.2	10.5	11.0	10.0	9.7	9.4
June 15	13.1	10.8	9.5	10.0	10.0	11.1	10.3	10.0	11.3	10.6	11.5	10.1	9.8	9.5
July 6	13.8	10.9	9.8	10.3	10.2	11.4	10.8	10.0	11.3	10.8	12.0	10.8	10.0	9.9
" 27	14.0	11.4	9.8	10.3	10.4	11.5	11.1	10.0	11.5	10.8	12.0	11.0	10.0	10.0
Aug. 17	14.1	11.7	9.8	10.3	10.5	11.6	11.4	10.5	11.6	10.8	12.0	11.0	10.0	10.1
Sept. 7	14.4	11.8	9.8	10.3	10.9	11.9	11.5	10.5	11.9	10.8	12.3	11.0	10.2	10.3
Dec. 21	14.5	11.8	9.8	10.3	11.0	12.0	11.5	10.5	12.0	11.0	12.8	11.3	10.3	10.3
Gain	2.5	1.3	0.8	0.3	1.5	1.7	1.5	0.7	1.2	0.7	1.8	1.3	1.0	1.3
Percent	20.8	9.8	8.9	3.0	15.8	16.5	15.0	7.1	11.1	6.8	16.4	13.0	10.8	14.4
Measured 1 foot above the jar cover														
May 11	8.8	8.0	7.5	8.0	8.0	8.8	8.5	9.0	8.8	8.8	10.0	8.8	8.0	7.8
" 25	8.9	8.3	7.5	8.1	8.1	8.8	8.6	9.0	8.8	8.8	10.0	8.9	8.1	8.3
June 15	9.4	8.7	7.8	8.5	8.4	9.0	8.8	9.1	8.9	9.0	10.1	9.0	8.6	8.7
July 6	9.7	9.1	7.8	8.8	8.7	9.4	9.6	9.7	9.4	9.4	10.9	9.0	8.8	9.0
July 27	10.0	9.5	7.8	8.8	9.2	10.0	9.9	9.9	9.5	9.5	11.0	9.4	9.0	9.3
Aug. 17	10.1	9.8	7.8	8.9	9.8	10.4	10.3	10.0	9.5	9.5	11.0	9.8	9.3	9.3
Sept. 7	10.3	9.9	7.9	9.0	10.4	10.5	10.5	10.2	9.8	9.5	11.0	10.2	9.3	9.4
Dec. 21	10.3	10.0	8.0	9.0	10.8	11.0	10.8	10.3	10.0	9.8	11.5	10.5	9.5	9.5
Gain	1.5	2.0	0.5	1.0	2.8	2.2	2.3	1.3	1.2	1.0	1.5	1.7	1.5	1.7
Percent	17.0	25.0	6.7	12.5	35.0	25.0	27.1	14.4	13.6	11.4	15.0	19.3	18.8	21.8

Table 5. Length of shoot and diameter at the base of the shoot, of apple trees growing in different solutions. Millimeters.

Solution	Basal		No nitrogen		1/4 nitrogen		2 nitrogen		No phosphorus		1/4 phosphorus		2 phosphorus	
Variety	S*	P*	S	P	S	P	S	P	S	P	S	P	S	P
Length of shoot														
June 8	2	3	2	3	2	2	3	3	2	2	2	3	3	3
" 22	35	35	10	40	20	65	115	130	70	55	70	230	195	235
July 13	90	165	dead	73	95	270	250	270	190	125	166	300	310	293
Aug. 3	177	255	--	85	230	459	355	363	270	250	179	375	400	455
" 24	325	301	--	102	345	615	415	454	330	335	181	470	495	535
Sept. 14	438	345	--	109	515	695	445	508	377	382	185	493	550	595
Dec. 21	519	353	--	113	540	715	455	513	382	387	189	498	557	722
Average gain	436		--	113	628		484		385		344		640	
Diameter of shoot at base														
June 8	1.5	1.0	1.5	2.0	1.0	1.5	2.0	2.0	1.3	1.3	1.0	2.0	1.8	2.3
" 22	3.0	3.3	2.8	3.3	2.5	3.3	3.5	3.8	3.0	2.8	2.8	4.0	3.8	4.8
July 13	3.5	5.0	dead	3.8	3.5	4.5	5.0	4.8	4.3	4.0	3.8	4.8	5.0	5.8
Aug. 3	4.3	3.5	--	4.0	4.8	6.5	5.8	6.0	5.0	5.0	4.0	5.5	5.5	6.0
" 24	4.8	6.0	--	4.3	6.0	7.8	6.5	6.5	5.5	6.0	4.5	6.3	6.3	6.3
Sept. 14	7.8	6.5	--	4.3	7.3	9.0	7.0	7.0	6.0	6.3	4.8	6.8	7.0	6.5
Dec. 21	7.0	6.5	--	4.3	8.5	9.5	8.0	7.8	7.0	6.5	5.5	7.3	7.5	6.8
Average gain	7.4		--	4.3	9.0		7.9		6.8		6.4		7.2	

* S = Staymared, P = Paducah.

Table 6. Length of shoot and diameter at the base of the shoot, of peach trees growing in different solutions. Millimeters.

Solution	Basal		No nitrogen		1/4 nitrogen		2 nitrogen		No phosphorus		1/4 phosphorus		2 phosphorus	
Number	15	16	17	18	19	20	21	22	23	24	25	26	27	28
	Length of shoot													
June 8	3	3	3	3	3	3	3	3	4	3	4	3	3	4
" 22	195	225	115	125	320	290	365	455	530	230	410	305	590	515
July 13	790	825	118	125	670	725	960	720	580	345	1285	505	770	660
Aug. 3	848	865	118	125	695	805	980	740	580	355	1340	550	810	680
" 24	865	890	118	125	705	895	990	745	580	355	1384	592	825	680
Sept.14	870	890	118	125	705	905	990	745	580	355	1400	610	825	680
Dec. 21	879	910	118	125	705	934	1022	769	580	355	1400	615	825	682
Average gain	895		122		820		896		468		1008		754	
	Diameter of shoot at base													
June 8	1.5	1.8	1.3	1.0	1.8	2.0	1.8	1.8	2.3	1.8	2.3	1.8	1.5	1.8
" 22	4.8	4.0	3.3	3.3	4.0	4.5	4.5	3.8	4.8	4.0	5.0	4.5	4.5	4.5
July 13	5.0	5.3	3.3	3.3	5.3	4.8	5.3	4.5	5.3	4.5	5.5	4.5	5.0	5.0
Aug. 3	5.3	5.5	3.3	3.3	6.3	5.8	5.3	4.8	5.3	5.3	6.3	5.5	5.3	5.0
" 24	5.3	5.5	3.3	3.3	6.5	6.0	5.3	4.8	5.3	5.3	6.5	5.5	5.3	5.0
Sept.14	5.3	5.5	3.3	3.3	6.5	6.0	5.3	4.8	5.3	5.3	6.5	5.5	5.3	5.0
Dec. 21	6.0	6.0	3.3	3.5	6.8	6.0	5.5	4.8	6.0	6.3	7.0	5.8	5.3	5.0
Average gain	6.0		3.4		6.4		5.2		5.7		6.4		5.2	

Table 7. Green weight of the apple trees at the beginning and end of the experiment. Grams.

Solution	Basal		No nitrogen		1/4 nitrogen		2 nitrogen		No phosphorus		1/4 phosphorus		2 phosphorus	
Variety	S*	P*	S	P	S	P	S	P	S	P	S	P	S	P
April 20	64.0	42.0	51.0	53.0	69.0	42.0	70.0	40.0	52.0	44.0	69.0	30.0	66.0	50.0
Dec. 21	98.3	61.0	dead	66.7	156.9	122.5	139.6	94.1	98.2	87.5	97.0	70.2	123.5	126.2
Gain, grams	34.3	19.0	--	13.7	87.9	80.5	69.6	54.1	46.2	43.5	28.0	40.2	57.5	76.2
Percent	56.3	45.2	--	25.9	127.4	191.7	99.4	135.0	88.9	98.9	40.6	134.0	87.1	152.4

* **S = Staymared, P = Paducah.**

Table 8. Green weight of the peach trees at the beginning and end of the experiment. Grams.

Solution	Basal		No nitrogen		1/4 nitrogen		2 nitrogen		No phosphorus		1/4 phosphorus		2 phosphorus	
Tree	15	16	17	18	19	20	21	22	23	24	25	26	27	28
April 21	64.0	66.0	54.0	55.0	64.0	66.0	66.0	59.0	65.0	62.0	68.0	65.0	52.0	55.0
Dec. 21	101.0	110.5	56.8	59.0	90.5	104.0	112.5	89.0	76.5	69.5	115.5	87.0	78.0	74.5
Gain, grams	37.0	44.5	2.8	4.0	26.5	38.0	46.5	30.0	11.5	7.5	47.5	22.0	26.0	19.5
Percent	57.8	67.4	5.2	7.3	41.4	57.6	70.5	50.9	17.7	12.1	69.9	33.9	50.0	35.5

Legends for the Graphs

No. 1. Diameter of Staymared apple trees at the jar cover.

No. 2. Diameter of Staymared apple trees 1 foot above the jar cover.

No. 3. Diameter of Paducah apple trees at the jar cover.

No. 4. Diameter of Paducah apple trees 1 foot above the jar cover.

No. 5. Diameter of Elberta peach trees Nos. 15, 17, 19, 21, 23, 25, and 27, at the jar cover.

No. 6. Diameter of Elberta peach trees Nos. 15, 17, 19, 21, 23, 25, and 27, 1 foot above the jar cover.

No. 7. Diameter of Elberta peach trees Nos. 16, 18, 20, 22, 24, 26, and 28, at the jar cover.

No. 8. Diameter of Elberta peach trees Nos. 16, 18, 20, 22, 24, 26, and 28, 1 foot above the jar cover.

No. 9. Diameter of the current growth of Staymared apple trees, 1 inch from the main stem.

No.10. Linear current growth of Staymared apple trees.

No.11. Diameter of the current growth of Paducah apple trees, 1 inch from the main stem.

No.12. Linear current growth of Paducah apple trees.

No.13. Diameter of the current growth of Elberta peach trees Nos. 15, 17, 19, 21, 23, 25 and 27.

No.14. Linear current growth of Elberta peach trees Nos. 15, 17, 19, 21, 23, 25 and 27.

No.15. Diameter of the current growth of Elberta peach trees Nos. 16, 18, 20, 22, 24, 26 and 28.

No.16. Linear current growth of Elberta peach trees Nos. 16, 18, 20, 22, 24, 26 and 28.

(Legends for graphs, continued)

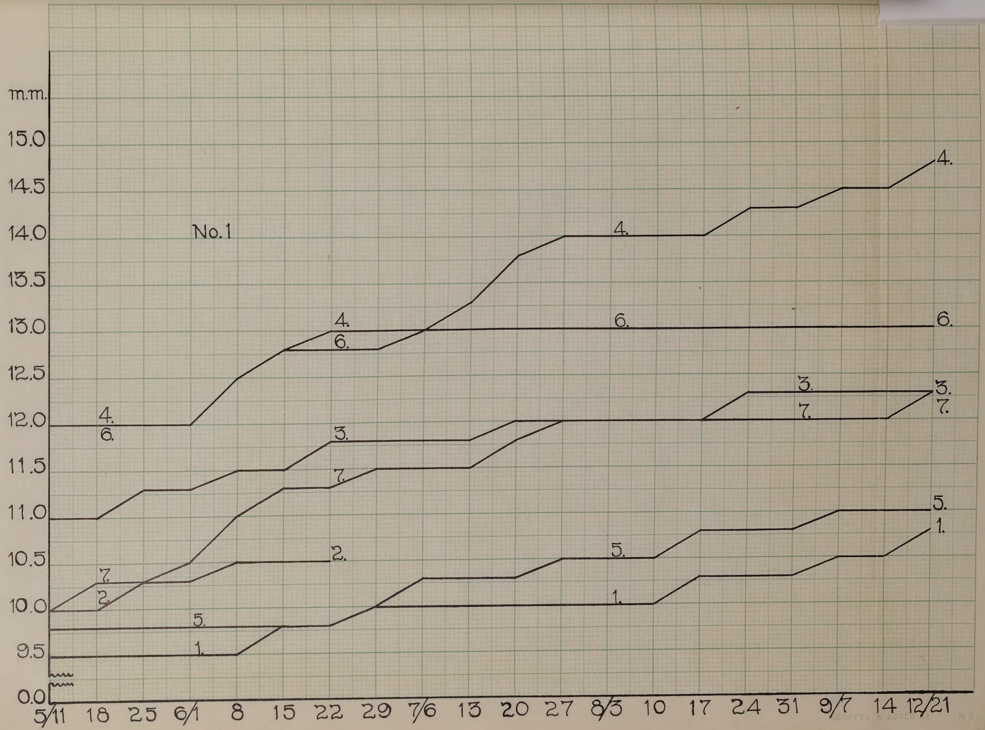
No. 17. Acidity of the culture solutions in which apple trees were growing, as determined weekly in liquid drained from each jar.

No. 18. Average weekly acidity of all the solutions in which apple trees were growing.

No. 19. Acidity of the culture solutions in which peach trees were growing, as determined weekly in liquid drained from each jar.

No. 20. Average weekly acidity of all the solutions in which peach trees were growing.

No. 21. Acidity of distilled water and nutrient solutions as affected by sand alone.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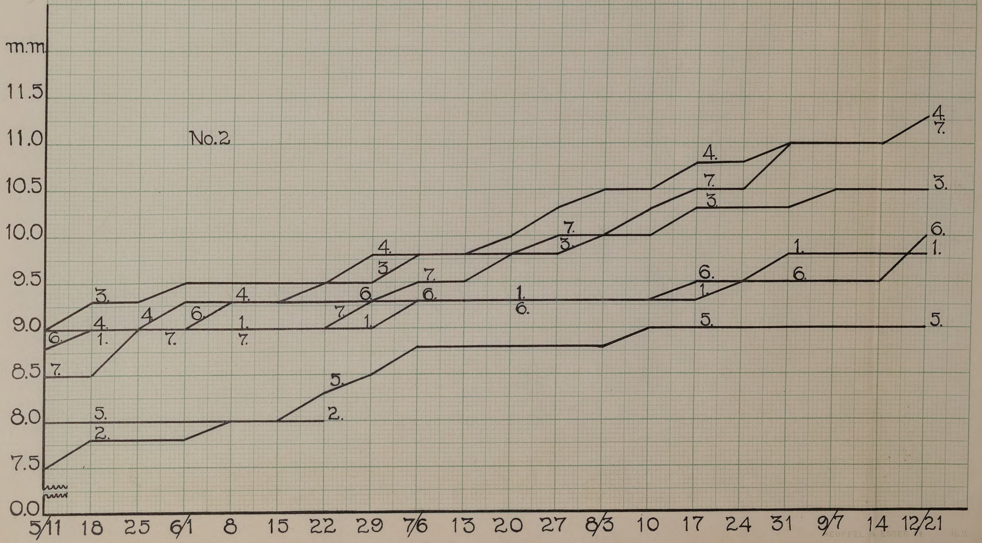
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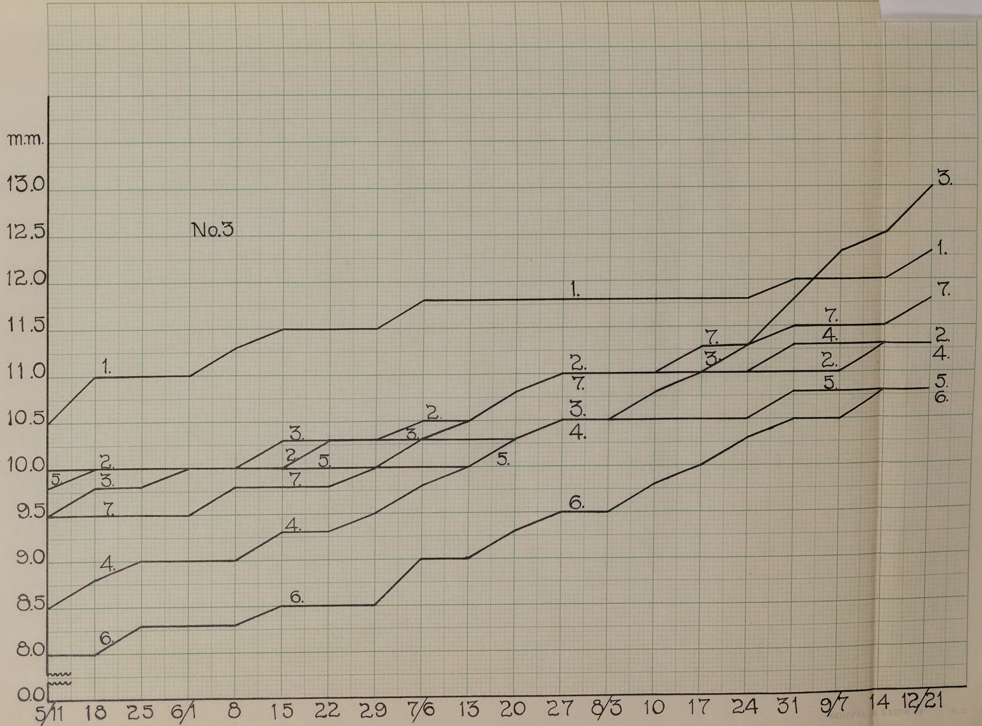
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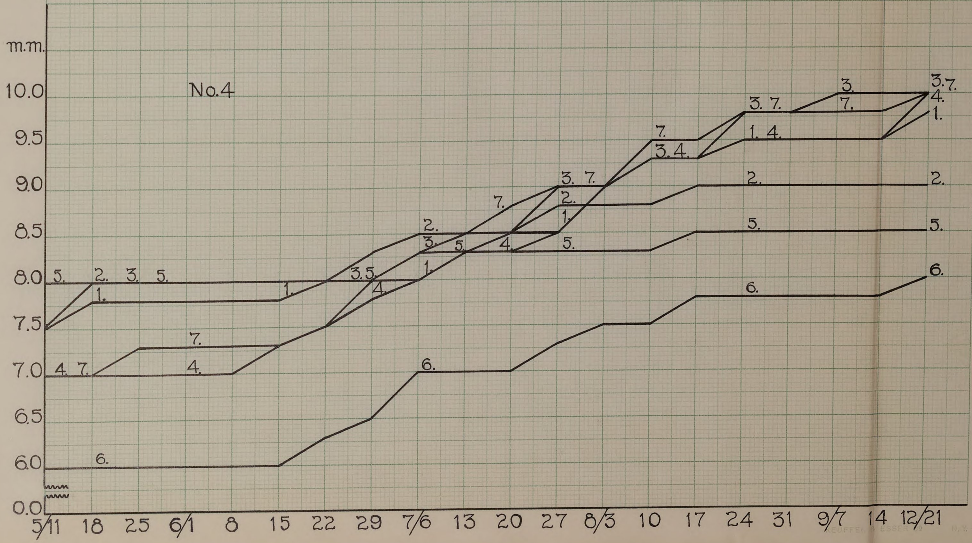
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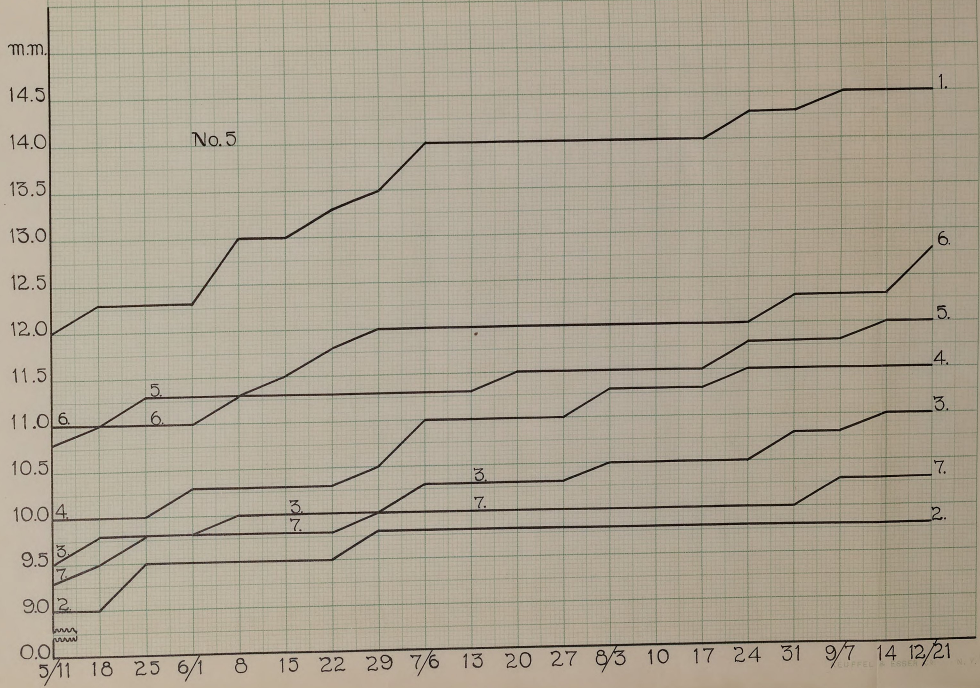

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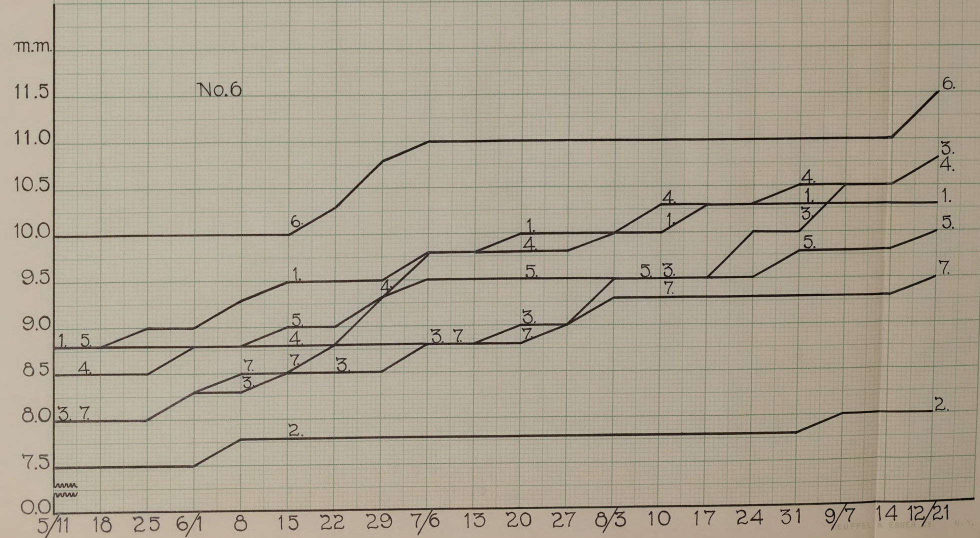
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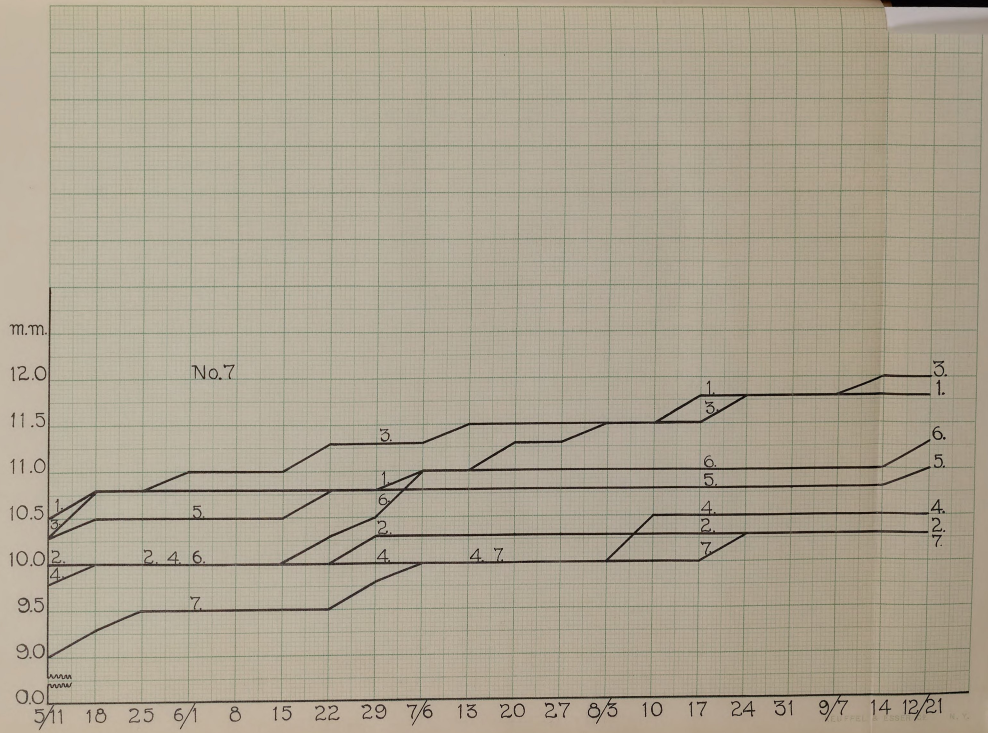
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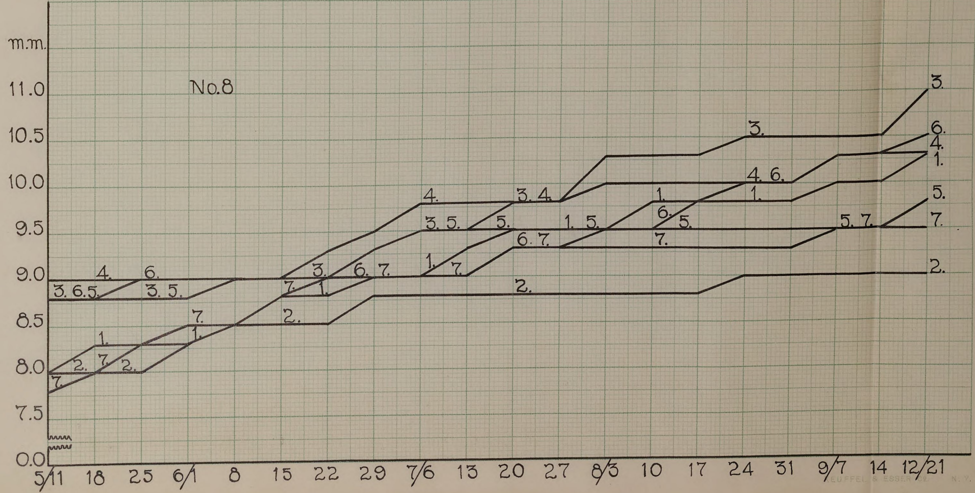
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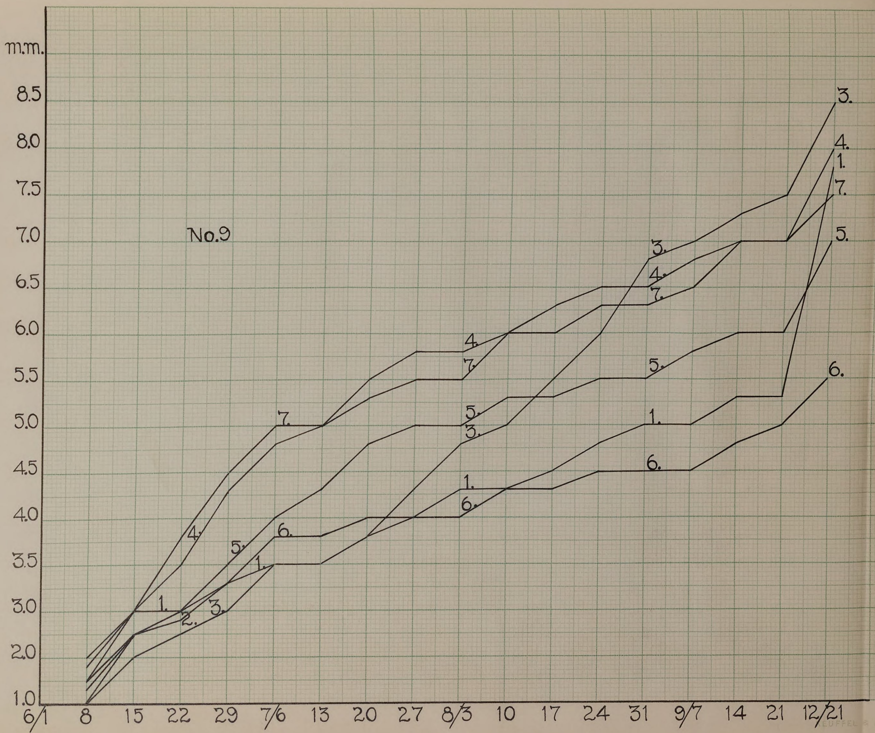
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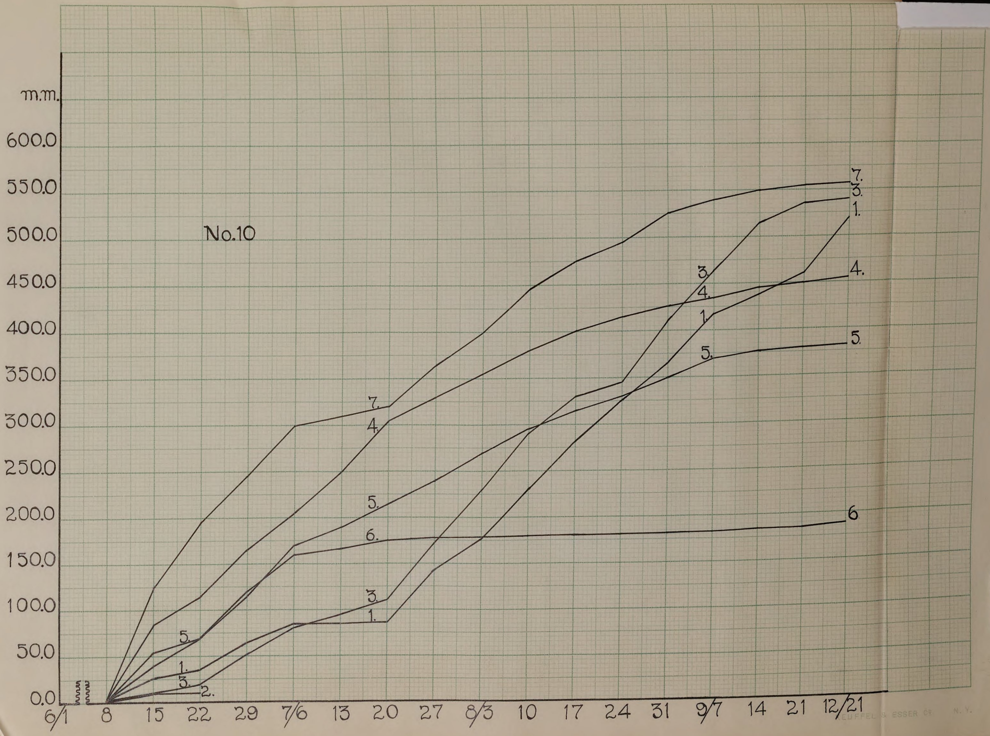
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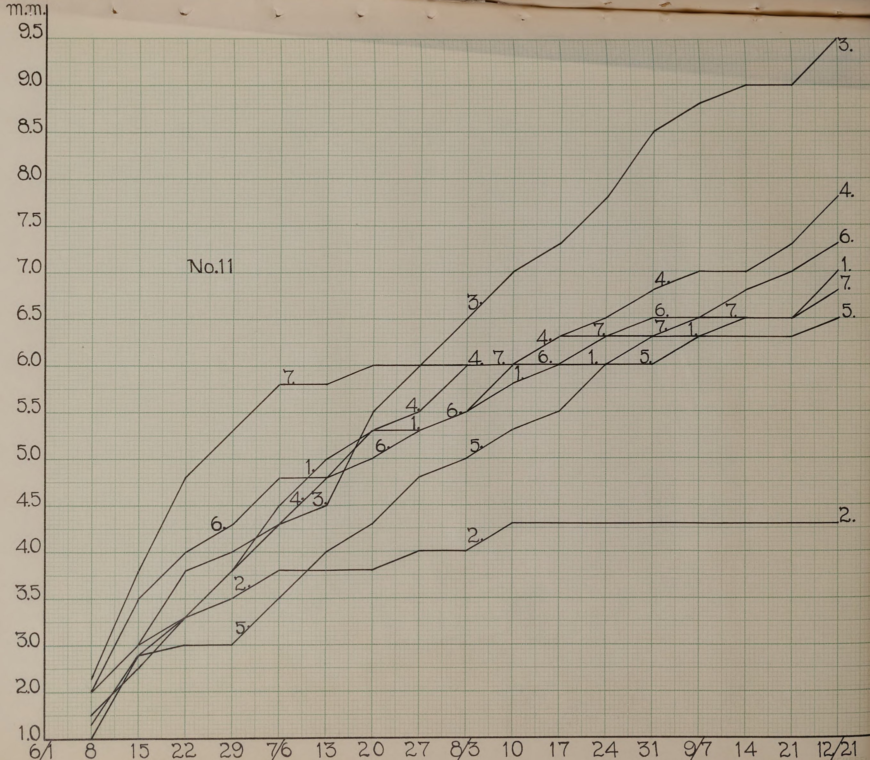
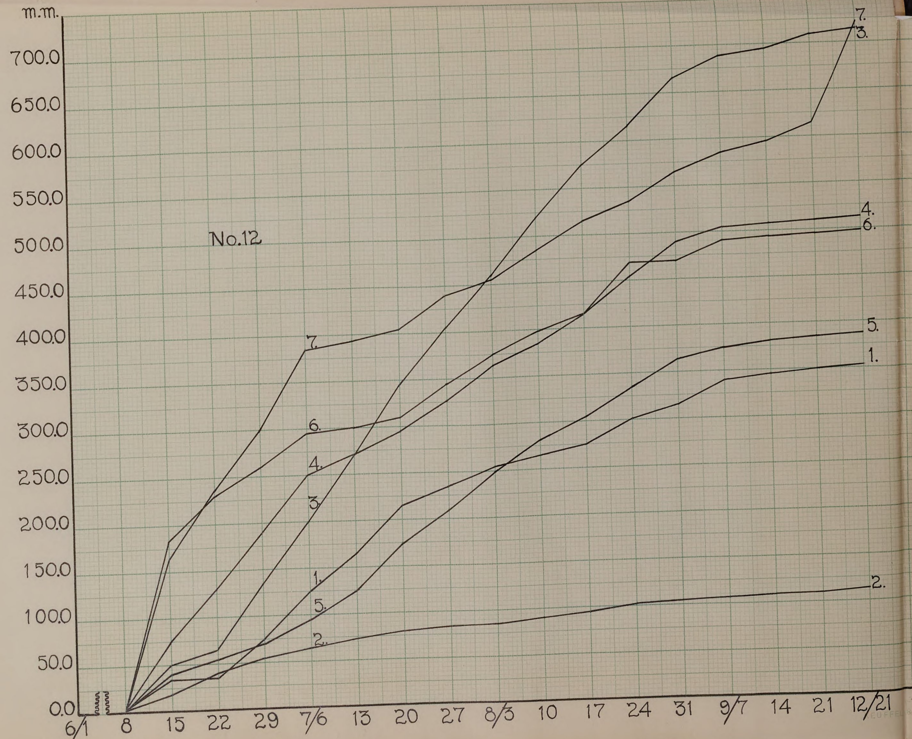
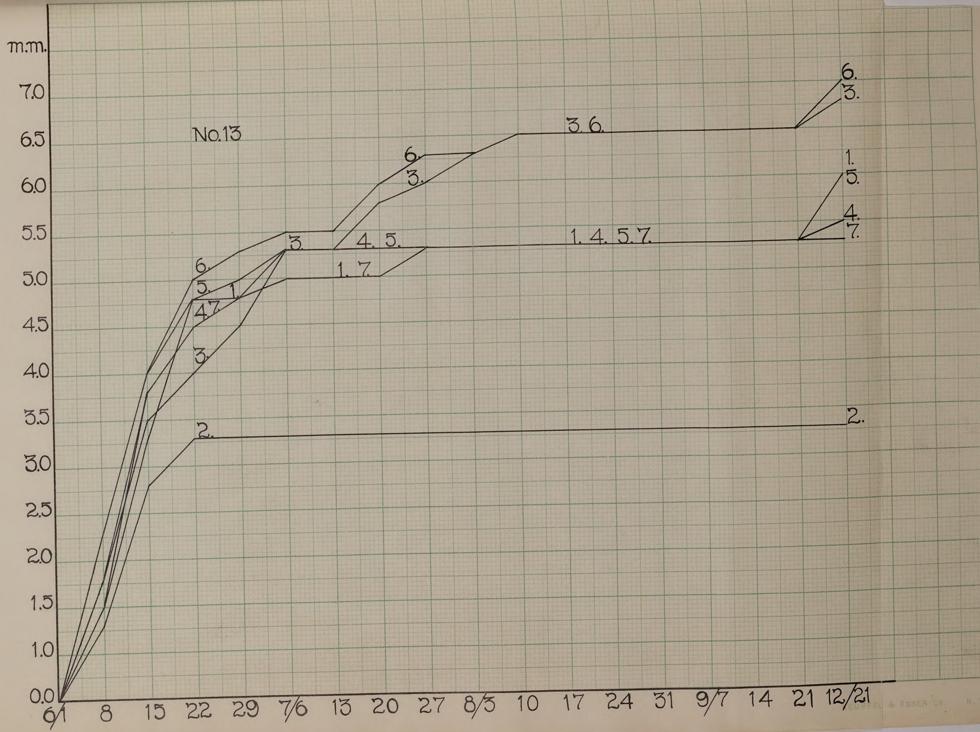
17
24
31
9/7
14
21
12/21
7.
3.
1.
4.
5.
6
2.

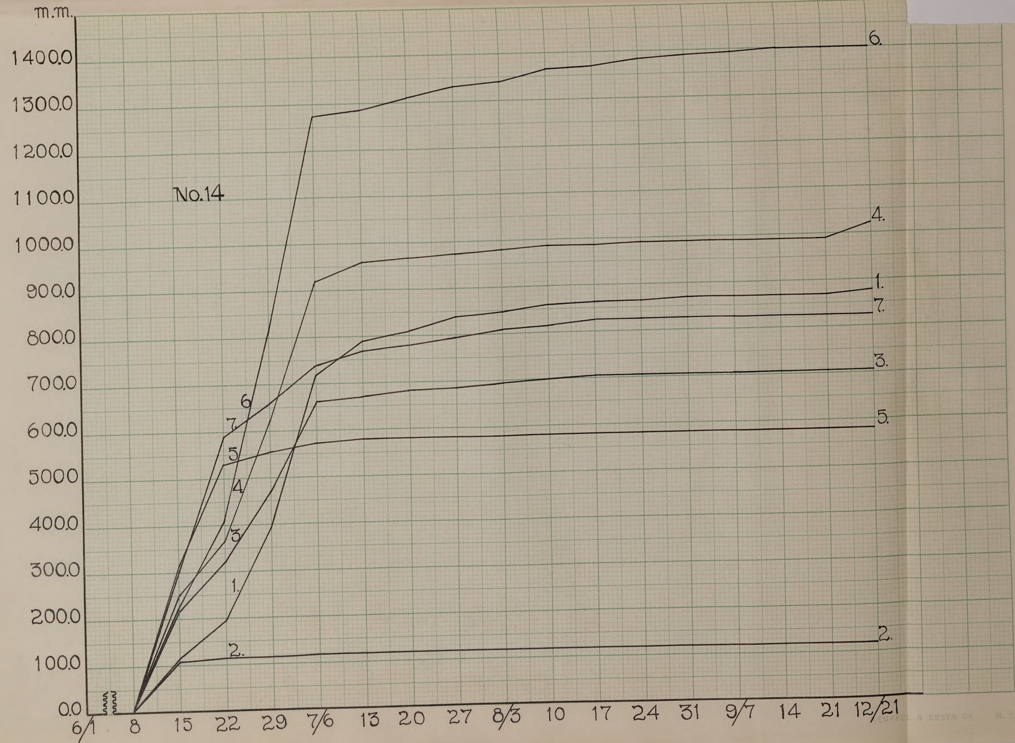


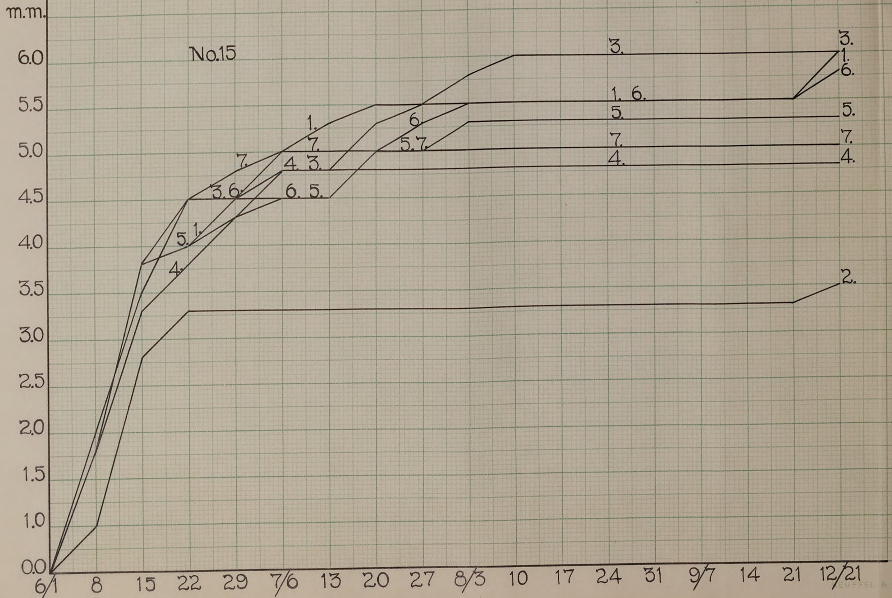
m.m.
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.0
1.0
6/1
8
15
22
29
7/6
13
20
27
8/3
10
17
24
31
9/7
14
21
12/21
No.11
3.
4.
6.
1.
7.
5.
2.



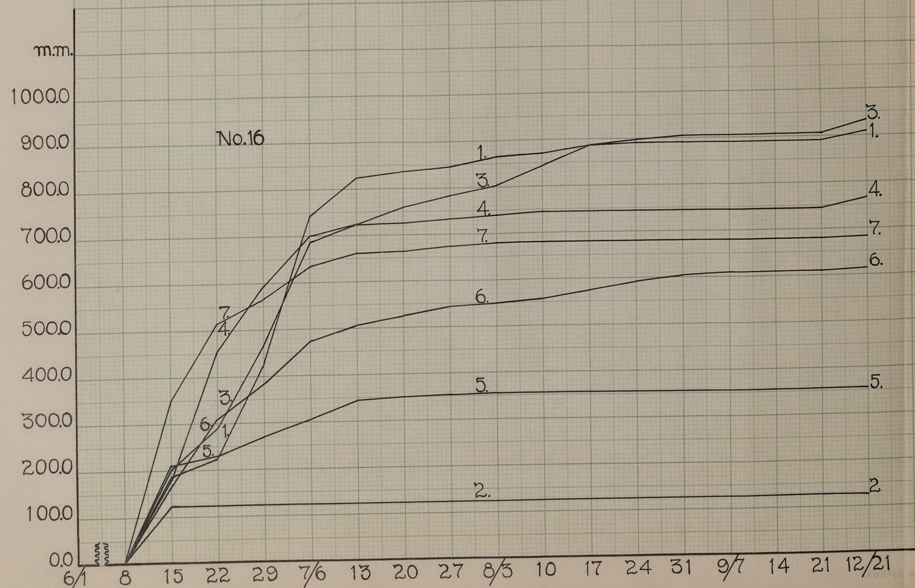
m.m.
700.0
650.0
600.0
550.0
500.0
450.0
400.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
No.12
6/1
8
15
22
29
7/6
13
20
27
8/3
10
17
24
31
9/7
14
21
12/21
1.
2.
3.
4.
5.
6.
7.


m.m.
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.0
No.13
6.
5.
1.
4.7.
3.
2.
3.
4. 5.
1. 7.
6.
3.
3. 6.
1. 4. 5. 7.
6.
3.
1.
5.
4.
7.
2.
6/1
8
15
22
29
7/6
13
20
27
8/3
10
17
24
31
9/7
14
21
12/21


m.m.
No.14
1400.0
1300.0
1200.0
1100.0
1000.0
900.0
800.0
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
6/1
8
15
22
29
7/6
13
20
27
8/3
10
17
24
31
9/7
14
21
12/21
1.
2.
3.
4.
5.
6.
7.

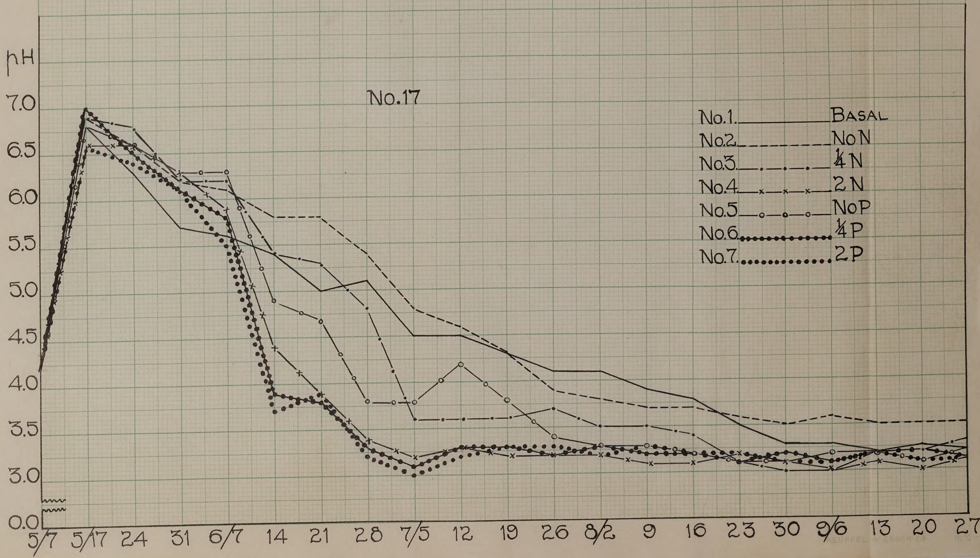


No.15
m.m.
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.0
6/1 8 15 22 29 7/6 13 20 27 8/3 10 17 24 31 9/7 14 21 12/21
1.
2.
3.
4.
5.
6.
7.
1. 6.
3.6
4. 3.
6. 5.
5.7.
5.



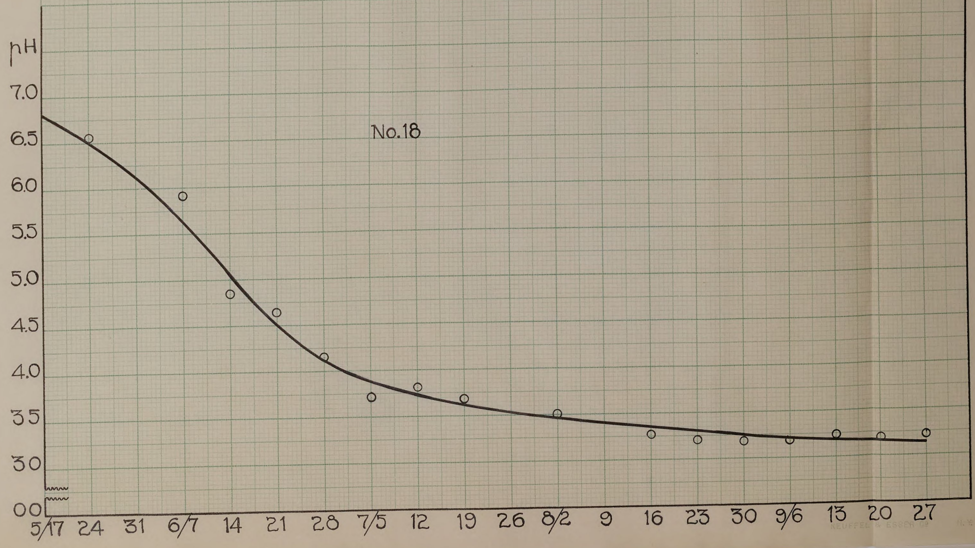
No.16
m.m.
1000.0
900.0
800.0
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
6/1
8
15
22
29
7/6
13
20
27
8/3
10
17
24
31
9/7
14
21
12/21
1.
2.
3.
4.
5.
6.
7.

P-50



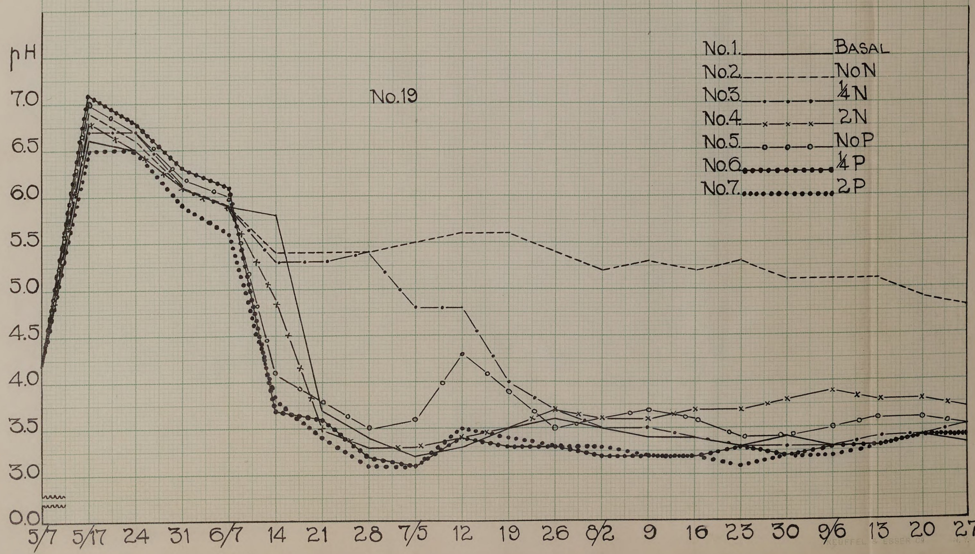
pH
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
0.0
No.17
No.1 BASAL
No.2 No N
No.3 ¼ N
No.4 2 N
No.5 No P
No.6 ¼ P
No.7 2 P
5/7 5/17 24 31 6/7 14 21 28 7/5 12 19 26 8/2 9 16 23 30 9/6 13 20 27

P.51.



pH
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
0.0
No.18
5/17 24 31 6/7 14 21 28 7/5 12 19 26 8/2 9 16 23 30 9/6 13 20 27

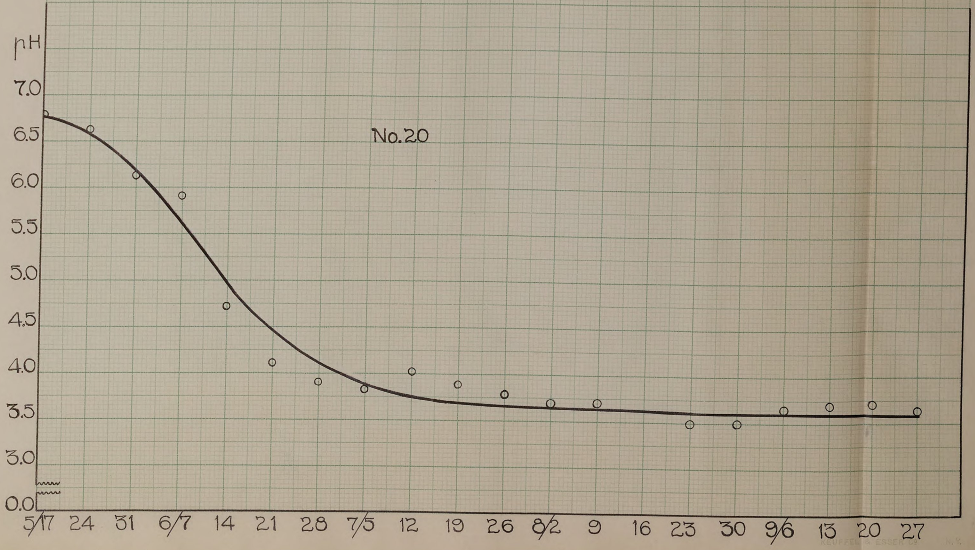
P.52



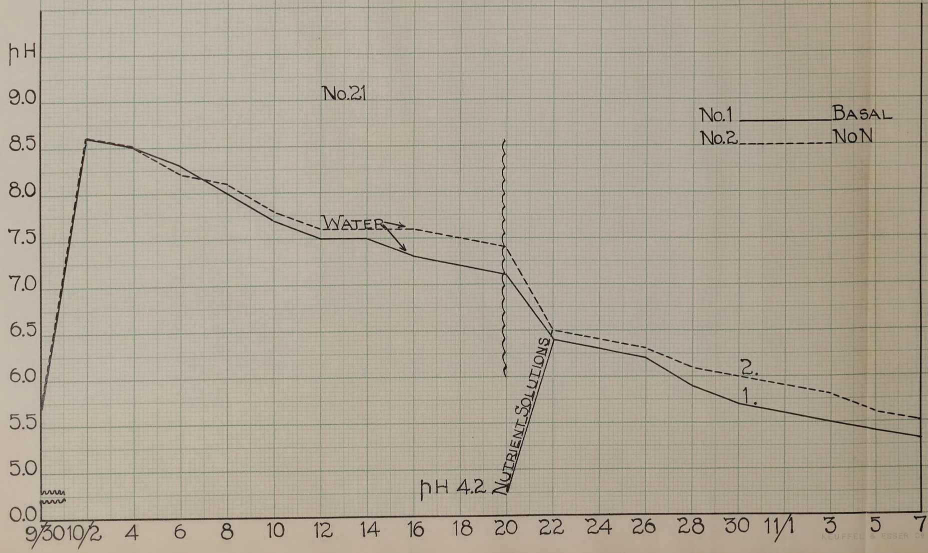
ENGRAVING 384—2. 10 X 10 TO THE HALF INCH. WHEN ORDERING STATE COLOR, DRAWING OR TRACING PAPER OR CLOTH. PRINTED IN U.S.A.

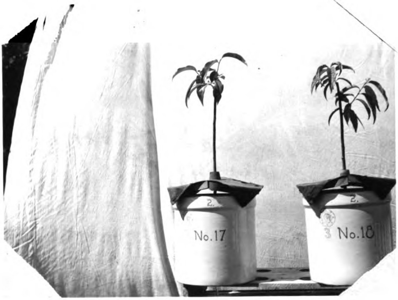
KEUFFEL & ESSER CO. N.Y.

P 53



pH
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
0.0
No. 20
5/17
24
31
6/7
14
21
28
7/5
12
19
26
8/2
9
16
23
30
9/6
13
20
27


pH
No.21
No.1 Basal
No.2 No N
Water
2.
1.
Nutrient Solutions
pH 4.2
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
0.0
9/30 10/2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 11/1 3 5 7



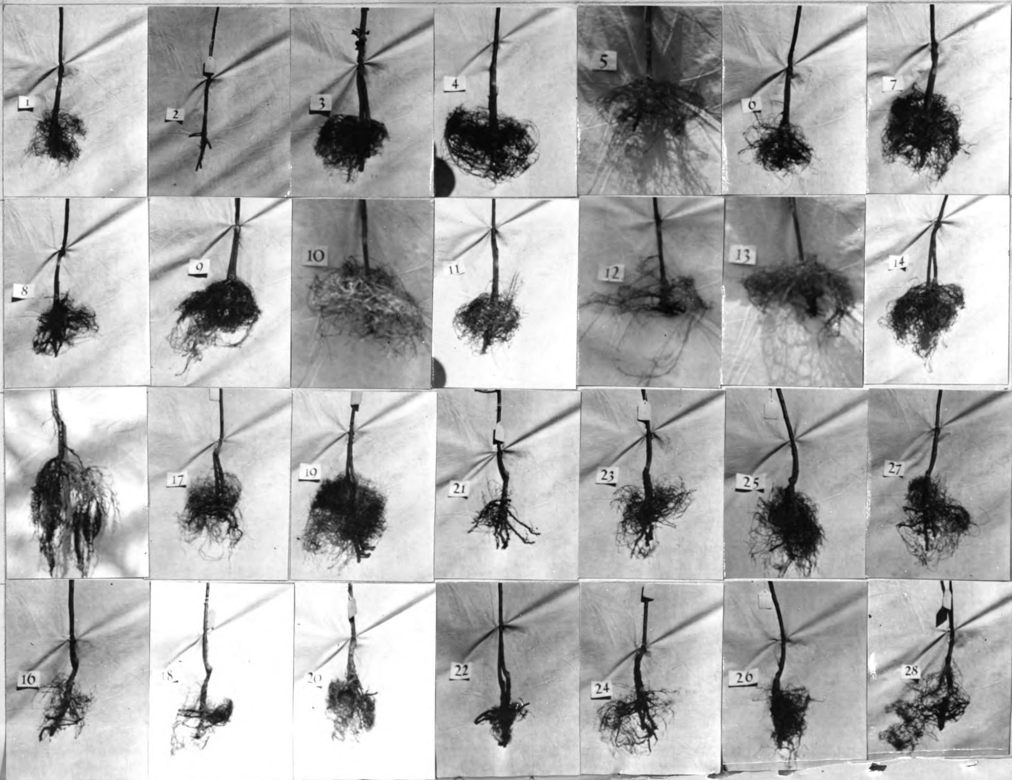
Some of the peach trees during the experiment. Nos. 15 and 16, basal culture; Nos. 17 and 18, no nitrogen.

1

1

Some of the peach trees during the experiment. Nos. 23 and 24, 1/4-phosphorus; Nos. 27 and 28, 2-phosphorus.

Roots of apple and peach trees at the close of the experiment.



1
2
3
4
5
6
7
8
9
10
11
12
13
14
17
19
21
23
25
27
16
18
20
22
24
26
28