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THE EFFECT OF A VARYING SUPPLY OF NUTRIENTS UPON THE CHARACTER AND COMPOSITION OF THE MAIZE PLANT AT DIFFERENT PERIODS OF GROWTH.

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THE EFFECT OF A VARYING SUPPLY OF NUTRIENTS UPON THE CHARACTER AND COMPOSITION OF THE MAIZE PLANT AT DIFFERENT PERIODS OF GROWTH.

F. L. DULEY AND M. F. MILLER

The rate of absorption of mineral nutrients by plants has been the subject of much investigation. Most of this work has consisted of the analyses of plants at regular intervals during the growing period. In only a few instances has an attempt been made to vary the supply of nutrients during the various periods of growth in order to determine the effect upon the plant as well as upon the rate of absorption. The investigation here reported has to do with a study of the influence of such a variation in the supply of nutrients to the corn plant, not only upon the composition of the plant itself, but upon the character of growth. From a practical standpoint it is desirable to know something of the rate and character of nutrient absorption during various periods in the growth cycle, since this may have a direct bearing upon the time and rate of fertilizer application. The rate and time of nutrient absorption are also more or less important practical considerations in their relation to time of maturity and feeding value of the crops.

This investigation was carried on in the Department of Soils during the years 1913 to 1916[(a)] inclusive, but the report has been delayed because of the impracticability of completing all of the chemical work until after the period of the war. This analytical work was done entirely in the Department of Agricultural Chemistry under the direction of Drs. P. F. Trowbridge and C. R. Moulton to whom credit for this phase of the investigation is largely due.

HISTORICAL REVIEW

The literature having to do with investigations concerning plant composition and the effect of different nutrient solutions is voluminous. Consequently it has been necessary to limit this review to those articles which bear most directly upon the questions considered in this investigation.

Pierre[15*] did some of the earliest work on the composition of plants at different stages of growth. This work was con-

(a) During the years 1913 and 1914 J. C. Hackleman, then a member of the Department of Agronomy, assisted in the work.

*This and subsequent numerical references are to the Bibliography.

ducted in France from 1862-64. Chemical analyses of wheat plants grown in the fields were made at five different stages of growth. It was found that the plants contained practically as much of the mineral elements at the time the last bloom fell as they did when completely mature. It was concluded from these analyses that the wheat plant takes up most of its nitrogen, silicon, manganese, phosphoric acid, calcium, magnesium, potash, and sodium during the early stages of growth. During the last stage, including about thirty days, there was little or no gain in the total mineral constituents and in some cases an actual loss was recorded. There was, however, some increase in organic material during this last period. Similar results were obtained with the rape plant.

Pierre was not certain whether the plant ceased to absorb mineral elements during the last part of the growing period or whether there was a constant exchange of material between the plant and the soil.

Hornberger[6] studied the composition of the maize plant by making analyses of the different parts of the plant at seven day intervals. He found that the percent of all the mineral elements, as well as of nitrogen in the total plant, decreased as the plants grew older. The percent of ash in the roots was much more uniform than in the tops. In the tops, the percent of ash decreased more than half during the season. In the roots there was a slight decrease during the latter part of the season, but a subsequent rise at the end of the growing period. The percent P_2O_5 in the roots was less than half as much as in the tops. The percent K_2O was about half as much in the roots as in tops. The percent nitrogen in the roots was about half the percent in the tops early in the season, but increased to about two-thirds the percent in tops near the end of the period.

The author also showed that following a period of rapid absorption about the time of ear formation, there was a reduction in the rate of absorption of most of the elements. Following this there was a period of increased absorption of plant food and then again a period during the maturing of the plants in which there was an absolute loss in total weight of all the elements except phosphorus and the gain of the latter was greatly reduced during the last week.

Schweitzer[16] at the Missouri Station in 1888 studied the composition of different parts of the corn plant by analyzing field samples at several different periods of growth. The data given present a number of iregularities which can hardly be explained, but some of the general conclusions of the author are, "That the plant takes up nearly all the ash ingredients it needs during the first stages of growth, and subsequent additions are mechanically absorbed with the water imbibed by the roots." It was not certain that this would be true with phosphorus, magnesia, and potash. The nitrogen was absorbed very rapidly during the early stages of growth. He says further:

"The general tendency of the plants was to increase rapidly in all parts until August 6th. After this the stores are emptied into the ear and grain, and additional increase (which is readily discernable) comes from the activity of the husk rather than from that of the leaves. These, in so far as they are situated below the 8th or 9th node, the usual seat of the ear, seem to become productively inactive and dry up, whilst those above them yield their substances to the ear, and after drying represent a less valuable material than the lower ones."

Jones and Huston[8] at the Indiana Station studied the composition of the corn plant at different stages of growth. Analyses were made for K_2O, P_2O_5, and total nitrogen. In addition to these mineral elements, determinations were also made for albuminoid, amid, crude protein, crude fat, crude fiber, ash, and nitrogen free extract. The analyses showing the percent of mineral elements on the basis of dry matter are found in the following table.

Date	Stage of Development		Total N Percent	P_2O_5 Percent	K_2O Percent
June 16.	Forming 6th blade		4.050	0.422	5.034
July 14.	Forming 14th blade		3.270	0.585	5.377
Aug. 6.	Tassels showing		2.568	0.608	3.576
Aug. 28.	Silks drying	ears	2.155	0.793	1.309
		blades, stalks, etc.	1.403	0.392	1.929
Sept. 10.	Silks brown, pollen shed	ears	1.777	0.666	0.914
		stalks, blades	1.197	0.205	1.828
Sept. 24.	Glazing stage	ears	1.431	0.680	0.661
		stalks, blades	0.830	0.204	1.699
Oct. 1.	Ensilage stage	ears	1.557	0.649	0.576
		stalks, blades	0.780	0.133	1.841
Oct. 8.	Ready for shock	ears	1.519	0.685	0.481
		stalks, blades	0.753	0.149	1.584
Nov. 12.	Ready for husking	ears	1.652	0.656	0.489
		stalks, blades	0.744	0.143	1.547
Nov. 12.	Plants left in the field	ears	1.512	0.682	0.483
		stalks, blades	0.632	0.093	1.428

The total weight of ash increased regularly in both stalks and ears, but the percent decreased in many cases.

After the ears began to form, the total weight of nitrogen decreased in the stalk, altho the weight of the whole plant was rapidly increasing.

The nitrogen in the ear (even in its earliest stages) is practically all in the form of real albuminoids, the amount of amid nitrogen in the ears was never more than 1.5 lbs. per acre. Amid nitrogen was 10.7 lbs. per acre in stalks and leaves August 28 and but 4.5 lbs. on October 8. There was a sharp rise in the potash curve during the period of greatest starch formation, September 24 to October 1. The total weight of phosphorus and nitrogen decreased in stalks and increased in ears after August 28.

Ince[7] working at North Dakota found that the percent of nitrogen in the total crop based on the weight of dry matter slightly decreased as the season advanced. The total weight per acre of nitrogen in the crop increased as the crop approached maturity. The author therefore concluded that corn should not be harvested in North Dakota until it has at least reached the glazed stage.

Jordan[9] grew barley, peas, tobacco, tomatoes, buckwheat, rape, and turnips in boxes fifteen inches square and six inches deep. The plants were grown in a medium of sand with some organic matter in the form of moss. The experimental boxes included two general series, those in which graduated amounts of phosphoric acid were used, and those in which the same plan was followed with potash.

Under the conditions involved no fixed relation was maintained between the production of dry matter and the amounts of phosphorus and potassium utilized.

Up to a somewhat indefinite point the production of plant substance increased in most cases with the increase in the supply of the variable constituents, but beyond that point the utilization of both phosphorus and potassium compounds increased without any consistent and well defined corresponding increase of plant growth. There was in practically all cases a quite regular increase in the production of phosphorus and potassium compounds in the plants of the several species corresponding to the supply of these compounds in the soil.

Pember[14] found that 13 mgs. of P_2O_5 per week for the first ten weeks was sufficient for ten barley plants. When a large supply was available, however, they absorbed about 30 mgs. P_2O_5 per week from the third to sixth week. The percent of phosphorus was much increased by the larger application.

Plants receiving liberal amounts of phosphorus after being stunted by a period of limited supply developed normal plants before harvest.

Potassium recovered from the seed of plants varied but little regardless of the amount at their disposal, while the amount obtained from the seed-free plants was greatly influenced by the amount added.

Results of tests made for potassium and phosphorus in distilled water in which plants were allowed to remain for from one to two weeks after they had obtained their growth did not substantiate the belief that either element was freely given off by way of the roots at maturity.

Wilfarth, Römer and Wimmer[20] conducted experiments 1896-1904, in which they used barley, peas, spring wheat, potatoes, and mustard. Some of these plants were grown in the greenhouse, others in the field. Their results show a marked decrease in the percent of mineral elements as the plants grow older. This was usually accompanied by an increase in the total weight of the various elements, as well as dry matter.

It was noticeably true, however, in the case of barley and wheat grown in the field, that as the plants began to mature there was not only a decrease in the percent of mineral elements but also a very marked loss in the total weight of these elements in the plants. The roots usually lost a much higher percent of the mineral elements than did the tops. In the case of barley, the roots lost during the period of maturity 85.8 percent of the K_2O, 82.9 percent of the nitrogen and 84 percent of the P_2O_5. The tops of these same plants lost only 23.5 percent of the K_2O; 9.2 percent of the nitrogen, and 2.5 percent of the P_2O_5.

These authors assume that some of the food constituents which were necessary for the formation of the various plant substances, but which were not stored up as reserve material, were returned to the soil on approaching maturity. They seem to assume that this loss of plant food during the time of maturity is due to the cell sap carrying the dissolved constituents back to the soil.

Burd[2] grew barley plants in different soils in 1916 and 1917. Analyses of the plants were made at about two weeks intervals. It was found that, "Potassium and nitrogen, both in magnitude and rate of absorption by the plant at all stages, are more nearly proportional to the total growth and water content of the plant than to that of the dry matter, while the reverse is true of calcium, magnesium, and phosphorus."

At about eight or nine weeks there seemed to be a loss of total nitrogen and potassium, from which the author concludes that there was probably a movement of these elements back to the soil. This was succeeded by a period of renewed absorption.

The amounts of calcium, magnesium, and phosphorus increased in about the same proportion as the dry matter until the eighth or ninth week, after which these elements lagged behind the production of dry matter.

During the latter part of the growing period the dry matter more than doubled with only a small increase in nitrogen and with an actual loss of potassium.

No very definite relation could be established between the rate of absorption by the plant and the amount of soluble plant food in the soil.

Hoagland[5] carried out experiments in sand and water cultures with barley, where the concentration, composition, and reaction of the nutrient solutions were accurately controlled. In these experiments the amounts of mineral elements absorbed increased in all parts of the plant with the concentration of the nutrient solution.

In an experiment where strong solutions were used during the first part of the growing season and weaker ones during the latter part of the growing season it seemed that an optimum concentration and supply of nutrients must be furnished to the plant for perhaps eight or ten weeks.

Hoagland also states that potassium and nitrogen are stored principally in the tops while the principal accumulation of calcium and phosphorus is in the roots.

In water culture experiments it was shown that almost double the quantity of water per gram of dry weight is transpired by the plants in the solution of lowest concentration as compared with the quantity transpired by those of the highest concentration. This would seem to prove that transpiration is not necessarily an accurate criterion of growth. It seems quite clear that absorption may proceed independently of transpiration and that the plant may absorb and transpire at such rates as either to increase or decrease the concentration of the nutrient solution. The greater concentration or supply of one or more ions present during the later stages prolongs the period of vegetative growth and possibly interferes with the process of ripening without producing any large increase in yield. The percentage of absorption of the different elements from solutions of different concentrations was as follows:

Osmotic pressures atmospheres	NO_3	PO_4	K	Ca	Mg	SO_4
0.07	100.0	89.6	96.0	43.0	47.2	35.7
1.72	14.7	35.0	7.6	8.5	9.3	5.6

It is evident that a greater percent of the individual nutrients are removed from the weaker solutions. When, however, the total weight of each nutrient is considered it is found that the amount of each element absorbed increased with the strength of the solution. Hoagland believes from his work that the most important condition for a high yield in so far as the soil solution is concerned, is an adequate concentration and supply of nutrients during the first half of the growth cycle.

In the tops most of the Ca, Mg, PO_4 and K was present in a water soluble form. In the roots grown in the solutions of the higher concentrations large percentages of insoluble Ca and PO_4 were found.

From previous experiments it was concluded that there is not sufficient evidence to prove that the plant requires for optimum yield any very specific ratio of ions or elements within wide limits, provided the total supply and concentration of essential elements are adequate.

La Clerc and Breazeale[10] found in their work that dead tips of leaves are poorer in nitrogen and potash than the live portions of the same leaves. As the plant is in the process of dying the nitrogen tends to recede to the living portions of the plant. That this recession or translocation is upward and not downward toward the soil is shown from the fact that the nitrogen and potash content of the lower nodes, whether they be dead or alive, is considerably less than that of the upper nodes.

The dead leaves are lower in nitrogen than the dead stems, because their nitrogen has been transferred to the stem. The upper nodes contain more nitrogen than the lower ones. The results of this work failed to show any backward movement of the plant food from the plant to the soil.

The nitrogen showed a distinct upward movement from the leaves to the heads in wheat. Tests showed that mature plants may lose large amounts of plant food by the action of rains, which tend to leach it out. Four successive rains falling upon dead ripe wheat plants that had been grown in the greenhouse dissolved from the plants, nitrogen 27.62 per cent, phosphoric acid 20.22 percent, potash 63.66 percent, soda 46.65 percent, lime 51.59 percent, magnesia 54.62 percent and chlorine 90 percent.

(a) It is concluded from this work that on ripening, the salts held in the sap of the plants have a tendency to migrate from the dying to the living tissue.

(b) That this migration is upwards and not downwards, there being in fact little evidence to show excretion thru the roots into the soil.

(c) That plants exude salts upon their surfaces and the rain then washes these salts back to the soil.

(d) That the analyses of plants for ash ingredients may give misleading results when it is desired to determine the amount of plant food absorbed by or essential to plant growth, unless the leaching action of rain and dew as herein demonstrated be considered.

Shive, J. W. and Martin, W. H.[17] carried out work with a three-salt solution of $Ca(NO_3)_2$, KH_2PO_4, and $MgSO_4$. Thirty-six cultures were included in each series and the triangular method of comparison was used. The concentration of all solutions was approximately 1.75 atmospheres. Buckwheat was the plant used. The growing period of the plant was divided into two parts; (1) from germination to flowering stage (2) flowering stage to maturity (including ripening of seed).

The maximum yield was produced during the later stages of development in a medium having a lower osmotic proportion of potassium phosphate, a much higher proportion of calcium nitrate, and a much lower one of magnesium sulphate than had the medium which produced the highest yield during the early growth period.

The buckwheat plants respond just as readily to variations in the osmotic proportions of the salts in the different solutions during the later period of development as they do during the early stages of growth but this response is markedly different in the two stages of development.

The roots and tops, during each period produced their best growth in solutions of about the same composition and likewise the poorest development of roots and tops was produced by solutions of similar composition.

A. G. McCall and P. E. Richards[11] grew wheat plants in sand cultures with 36 different treatments. The nutrient solutions contained calcium nitrate, mono-potassium phosphate and magnesium sulfate.

For the early growth period the solutions which gave the highest yield of tops are characterized by a high calcium nitrate content and a low proportion of magnesium sulphate, while the lowest yield of tops is associated with low calcium nitrate and a high proportion of magnesium sulphate. For this period the effect of the mono-potassium phosphate appears to have been almost entirely overshadowed by the other two component salts.

For the second 30-day period a striking similarity to the above is shown in the location of the areas of high and low yielding cultures from which it would appear that mineral food requirements of the wheat plant, during the second growth period were substantially the same as for the first 30-day period.

For the third and final growth period the solutions which gave the highest yielding plants are characterized by a relatively high concentration of calcium nitrate and a low proportion, not only of magnesium sulphate but also of mono-potassium phosphate, while the solutions producing low yields are characterized by a high proportion of mono-potassium phosphate without regard to the ratio of the other two salts. These results suggest a strong possibility that the acidity of the nutrient solution may be largely responsible for the low yielding cultures during the final growth period. The mean ratio of magnesium to potassium is practically the same for the nine best treatments for the first and second growth periods; and, as in the case of the magnesium calcium ratio, there is a slight increase for the final period, thus indicating an increase in physiological requirements for magnesium during the late stages in the development of the wheat plant.

A. G. McCall[12] found that young wheat plants grown in sand cultures showed optimal growth in solutions with osmotic concentrations lying between 1.0 and 2.0 atmospheres.

With the initial total concentration about 1.75 atmospheres the nutrient solution that produced the greatest dry weight of tops also produced the greatest dry weight of roots. This solution is characterized by having 2/10 of the total osmotic concentration derived from KH_2PO_4, 7/10 from $Ca(NO_3)_2$, and 1/10 from $MgSO_4$.

A comparison of the results of sand and solution cultures seems to show that selective absorption plays an important role in bringing about the observed physiological differences.

The sand culture solutions giving **low** yields of the tops are characterized by **wide** range in the Mg/Ca ratio, a very wide range in the Mg/K ratio and a narrow range in the Ca/K ratio **value.** The solutions giving **high** yields of tops show a **narrow** range in the Mg/Ca ratio and a comparatively wide range in both the Mg/K and Ca/K ratio values.

McCall[13] found that the proportions of nutrient salts which gave the best results for wheat also gave the best results for soybeans. The calcium nitrate in the nutrient solution seemed to play a very important part, since for both species of plants considered, good growth is associated with a **low** ratio of magnesium sulfate to calcium nitrate and a comparatively high ratio of calcium nitrate to mono-potassium phosphate while the ratio of magnesium sulfate to mono-potassium phosphate in these cultures appears to have had little influence in determining yields.

Davidson and LeClerc[3], divided the growing period of wheat into three periods and applied nitrate at the rate of 320 lbs. per acre at the beginning of each, (1) When the crop was about two inches high (2) Time of heading (3) Milk stage.

There was an increased protein content in both grain and straw as a result of nitrate applied at the second stage. An increase in the yield of straw as well as of grain was noted when nitrates were applied at the first stage. The presence of sodium nitrate in the soil at the milk stage of the grain had no effect on yield, quality or protein content of the grain.

Stiles[19] grew rye from February 10th to March 14th in water cultures and found no consistent difference due to variation in strength of nutrient solution. The solutions used were normal, N/5, N/10 and N/20. With barley in another series there was some decrease with the weaker solutions but the differences were not great.

Concentration of Solution:	Average dry weight in grams: (roots and tops)	Ratio of root to top.
N	628	1:4
N/5	622	1:3.7
N/10	555	1:3.4
N/20	471	1:3

These figures are compared by the author with those obtained by Hall, Brenchley and Underwood[4] with a slightly more concentrated solution in which they secured the following results:

Concentration	Dry weight
N	0.420
N/5	0.244
N/10	0.108
N/20	0.068

Brenchley[1] carried out water culture experiments with barley plants in nutrient solutions of various concentrations (Normal, N/5, N/10, N/20.) In none of these tests were the plants grown to maturity but they averaged about seven weeks old when harvested. The weight in grams of plants, including both tops and roots, grown in frequently changed solutions decreased quite regularly with a decrease in the strength of the nutrient solution.

The difference in growth of the plants Normal and N/5 solutions was relatively small. The author concludes from this that more frequent changes of the solution might be followed by as much growth in the N/5 as in the Normal concentration. With the weaker concentrations the amount of growth rapidly decreased. Some other investigations cited by the author have found less difference in growth due to changes in the concentration.

Smith[18] analyzed samples of corn at different times during the season. In all earlier stages of growth the greater share of the protein was found in the leaves; and even when the corn was ripe enough to cut, but little over half of it was found in the ears. It was found that the percent protein from the time the corn was in silk and tassel until ripe gradually decreased in the leaves but increased in the ears. It decreased in the stalks until the ear began to glaze, after this time the protein content of the stalks increased very materially.

PLAN OF THE EXPERIMENT

The corn plants in this experiment were grown in washed quartz sand to which the nutrient solutions of different concentrations were added. This sand was washed with tap water and then with distilled water until practically free of soluble material. It was found impractical, however, to wash out all the finely divided silica and tests showed the drainage water to contain an appreciable amount of this. The containers used were galvanized iron cylinders, 15 inches in diameter and 24 inches deep. They held approximately 235 pounds of sand. To prevent the zinc from exerting any action on the roots the cylinders were coated on the the inside with paraffin. They were filled with the sand to within about 1¼ inches of the top. The total pore space in the sand was about 40 percent. A coarse screen cover was made for each to protect the young plants. Each cylinder was provided with a drainage hole in the bottom which was left open during the course of the experiment. It was, however, provided with a screw cap which could be put on whenever it was desired to saturate the sand in washing out the nutrient solutions.

The variety of corn used was Reid's Yellow Dent and the length of the growing season was assumed to be 90 days. This was a little less than is usually required for maturing this variety, but preliminary tests showed that some of the plants would die and parts of the material be lost if held for more than 90 days. The growing season was then divided into three 30-day periods. The first period began at the time of planting but the seed had previously been kept moist for about one day which reduced somewhat the time for germination. The second period began about the time the larger plants were setting their ninth leaves. Twelve seeds were planted in each cylinder and the number of plants were gradually thinned down until each cylinder had three nearly uniform plants.

Preliminary experiments in 1913 had to do with the determination of a suitable nutrient solution. It was found that a dilution to 25 percent of the concentration of a modified Pfeffer's solution had slight influence upon the growth of maize plants. This has since been shown by Brenchley[1] to be true for barley plants. Since there was no consistent difference between the plants grown in solutions of normal and one-fourth normal concentrations, the results of the 1913 experiment have not been included in this report.

In 1914 it was decided to use a standard Pfeffer's nutrient solution for the stronger concentration and a solution of one-twentieth this strength for the weaker concentration. This weak solution was found to be only slightly more than enough to keep the corn plants alive and produced very little growth.

METHOD OF TREATMENT

In this experiment 14 different treatments were used and each was run in duplicate. With solutions of two different strengths and with the growing period divided into three parts all the possible combinations of strength of solution and period of growth were used. This may be illustrated by the following table in which O (optimum) will represent the standard solution and M (minimum) the one-twentieth normal nutrient solution.

No. of Cylinder	Treatment			
	1st 30-day period.	2nd 30-day period.	3rd 30-day period.	
A 1 & B 1	O	O	O	Harvested at end of 90 days.
A 2 & B 2	O	O	M	
A 3 & B 3	O	M	O	
A 4 & B 4	O	M	M	
A 5 & B 5	M	M	M	
A 6 & B 6	M	M	O	
A 7 & B 7	M	O	M	
A 8 & B 8	M	O	O	
A 9 & B 9	O	O	--	Harvested at end of 60 days.
A 10 & B 10	O	M	--	Harvested at end of 60 days.
A 11 & B 11	O	--	--	Harvested at end of 30 days.
A 12 & B 12	M	M	--	Harvested at end of 60 days.
A 13 & B 13	M	O	--	Harvested at end of 60 days.
A 14 & B 14	M	--	--	Harvested at end of 30 days.

The cylinders 9 to 14 were not run in duplicate the first year of the experiment.

METHOD OF PREPARING NUTRIENT SOLUTIONS

The nutrient solutions were made from the following stock solutions:

Calcium Nitrate ($Ca(NO_3)_2$	200 gms.	Made up to 2 liters.
Potassium Nitrate (KNO_3)	50 gms.	(same)
Potassium Chloride (KCl)	25 gms.	(same)
Mono-Potassium Phosphate (KH_2PO_4)	50 gms.	Made up to 2 liters.
Magnesium Sulphate ($MgSO_4$)	50 gms.	Made up to 2 liters.

When it was desired to apply nutrient solution 20 cc. of each stock solution was added for each four liters of distilled water. A few cc. of ferric chloride solution were added to supply some iron. The solution of minimum concentration was made in the same manner except that only one-twentieth the amounts of stock solutions were used.

The solution was usually applied until there was some drainage from the bottom of the cylinders, although the same amount was added to each. In some cases when transpiration had been high no solution would come through. During very hot weather when the plants used proportionally more water than was supplied in the nutrient solution distilled water was added to the cylinders to replace the water lost by transpiration.

In the middle and at the end of each 30-day period tap water was run through the cylinders for several hours followed by about 8 to 12 liters of distilled water to remove completely the nutrient solution so as to avoid the possible accumulation of any residual ions which might later change the character of the solution. This washing seemed to be complete as no noticeable effect of the strong solution could be seen when a change was made from an optimum to a minimum treatment.

During the first 30-day period, while the plants were small, solutions were added only about twice a week, but during the second and third periods when the temperature was higher and the plants larger, solutions were added every second day and in some cases every day. No effort was made to add a definite amount of solution during a given period, but an abundant supply was kept in the cylinders at all times.

RESULTS OF THE EXPERIMENT

In this experiment the weight of different parts of the plant was determined at the end of each thirty day period for the various combinations of treatments with optimum and minimum nutrient solutions. Later these different parts were dried, ground and analyzed for the various plant food elements.

The plant was divided into four parts, (1) roots, (2) stalks, tassels and shanks, (3) leaves, (4) ears. The average weights of the different parts of the plants for the 1914, 1915, 1916 crops are shown in Table 1.

PLANTS GROWN FOR THREE PERIODS

It will be noted from Table 1 and Figure 1 that treatment No. 1 (O-O-O) having optimum nutrients during the full 90 days pro-

TABLE I. AVERAGE DRY WEIGHTS OF THE DIFFERENT PARTS OF THE PLANTS FROM EACH CYLINDER.

No. Cylinder	Treatment	Roots	Stalks	Leaves	Ears	Top	Total
		grams.	*grams.*	*grams.*	*grams.*	*grams.*	*grams.*
A and B 1	O-O-O	96.43	160.00	222.7	305.24	687.94	784.37
A and B 2	O-O-M	98.705	177.70	187.2	205.81	570.71	669.42
A and B 3	O-M-O	56.012	64.90	112.0	83.30	260.20	316.30
A and B 4	O-M-M	57.725	84.70	84.8	9.78	179.28	237.01
A and B 5	M-M-M	22.654	31.30	39.9	0.36	71.56	94.21
A and B 6	M-M-O	21,256	37.50	70.7	19.75	127.95	149.21
A and B 7	M-O-M	95.971	182.60	166.1	62.11	410.81	506.78
A and B 8	M-O-O	93.183	161.40	199.9	97.77	459.07	552.25
A and B 9	O-O	72.224	122.20	197.0	----	319.20	391.42
A and B 10	O-M	46.244	39.50	97.1	----	136.60	182.84
A and B 11	O	8.320	----	16.9	----	16.9	25.22
A and B 12	M-M	13.180	2.30	17.8	----	20.1	33.28
A and B 13	M-O	36.310	40.30	95.7	----	136.0	172.31
A and B 14	M	2.545	----	1.61	----	1.61	4.16

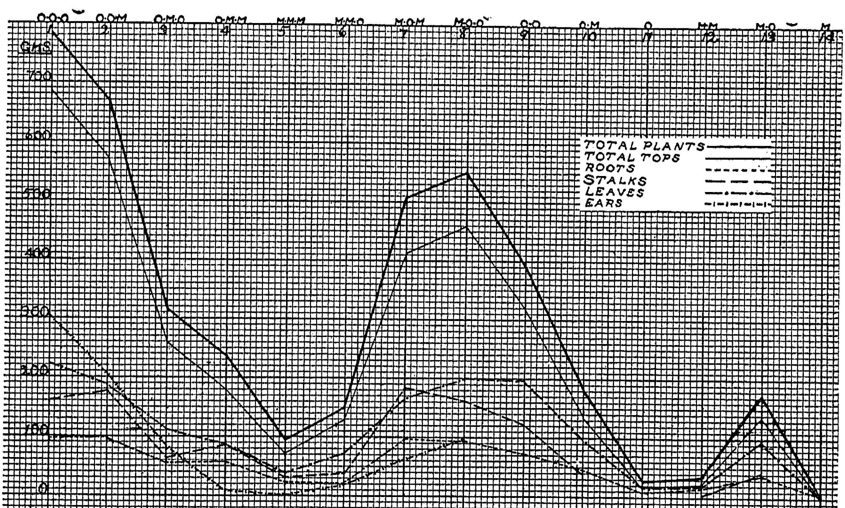

Fig. 1. Relative dry weight in grams of different parts of the plants at harvest. Nos. 1-8 were grown 90 days; Nos. 9, 10, 12 and 13, 60 days; Nos. 11 and 14, 30 days.

duced considerably greater total weight than any of the other treatments. The difference between the weights of plants in No. 1 and No. 2 (O-O-M) is not so great as the differences in other respects. In fact the principal difference in the weight of these two treatments is in the weight of ears produced. (See Plate VII). It is during the last 30-day period that the grain is produced and the small amount of nutrient supplied to treatment No. 2 during this period very materially decreased the production of grain. In fact these plants showed the effects of the weak solution by the dying of several of the lower leaves. The upper leaves took on a rather pale green color and showed little vitality.

In regard to the growth of the other parts of the plant there are some very strinking differences between Nos. 1 and 2. The weight of the ears and leaves was lowered in No. 2 in much the same proportion as was the total weight of the plants. The stalk and root development, however, was somewhat greater than in No. 1. When the plants were deprived of a liberal supply of plant food the roots increased in volume. This was particularly true during the third growth period. The roots in No. 2 were not only of greater weight but they were much more fibrous and less succulent than in No. 1. The increase in the stalk development of No. 2 over No. 1 cannot be explained, yet this fact seems to hold true as will be seen later, in all the treatments where the plants received minimum amounts of plant food during the last thirty-day period.

In No. 3 (O-M-O) where the plants received optimum, minimum, and optimum nutrients during the successive thirty-day periods, it will be seen from Table 1 and from Figure 1 that the total yield of dry matter was very materially reduced below that of No. 2(O-O-M) which had optimum amounts of plant food during the first 60 days and minimum amounts during the last 30 days. This serves to illustrate one of the very important points brought out in this investigation, that the second 30-day period of the growing season is by far the most important so far as the total amount of dry matter is concerned. (See plates III and VI). Some of the other cases to be described later will further bear out this statement. In No. 3 the weights of the various parts of the plant dropped very decidedly as compared with No. 2 although the weights of leaves and roots showed relatively less loss than did the other parts of the plant. In the case of the leaves this was evidently due to the fact that a copious supply of nutrient during the last period allowed the plant to maintain a fairly good leaf development.

It seems that after the retarded growth caused by the small supply of nutrients during the second 30-day period, that the resumption of optimum conditions at the beginning of the last period showed its first effects upon the leaf development. The stalk growth seemed to have been stunted to such an extent that it could not revive. The length of nodes was materially reduced by the minimum nutrient from the thirtieth to sixtieth day and these were not able to overcome this condition by means of a supply of food during the last period. In the case of the leaves even though the lower ones had died and the others had turned a very sickly green during the second period, they seemed able to revive when plenty of plant food was supplied. Consequently they showed a marked development during the third period, which accounts for No. 3 losing relatively less in leaf growth than in stalk growth, when compared with No. 2. It will be noticed also that the development of ears in No. 3 was decidedly less than in No. 2. This is due to the fact that the plants in No. 3 were so severely set back during the second period that they seemed entirely unable to produce anything like normal ears during the third period of optimum treatment. (See Plate VII).

The root growth in No. 3 was less affected by the second period of minimum treatment than any other part of the plant. (See Plate VII). This is probably due to the fact that during the second period when the plants were receiving minimum treatment there was an increased development of the fibrous roots as was shown for No. 2 during the third period.

No. 4 (O-M-M) had optimum treatment during the first 30 days and minimum during the last 60 days. It will be noted that the treatment of No. 4 differs from No. 3 only in the final period. The total weight of plants in No. 4 dropped somewhat below that of No. 3 but the decrease was much less than was the case between Nos. 2 and 3.

This seems to be due to the fact that most of the vegetative growth is made during the second period and the continuation of the minimum treatment during the last period simply maintains the plants at about the condition they were in at the beginning of the period. This is shown by the weight of No. 4 at the end of the 3rd period which was 237.01 grams, while the total weight of plants in No. 10 which had the same treatment as No. 4 during the first 60 days, but was harvested at the end of that time, produced 182.84 grams of total dry matter. The weight of leaves in No. 4 was considerably less than in No. 3. The stalks, however, averaged 84.7 grams while the stalks in No. 3 averaged but 64.9 grams. This increase in the weight of stalks in cylinders receiving minimum treatment during the last period, as is shown in No. 2, No. 4 and No. 7 seems to be explainable only on the theory that there is some translocation of material from the leaves to the stalks.

In the case of the roots it will be seen that the weight in No. 4 (O-M-M) was slightly more than in No. 3 (O-M-O). This is similar to the result shown in case of No. 2 (O-O-M) where the plants receiving minimum nutrient during the third period produced more roots than those receiving optimum during the three periods. The weight of ears of No. 4 showed a very striking decrease, as compared with No. 3. In fact most of the ears produced on No. 4, as may be seen from the photographs (Plate VII) were really little more than small cobs since very few of these produced grain at all.

No. 5 (M-M-M) which received minimum treatment throughout the entire growing season produced a smaller total weight and smaller amount of leaves, stalks and ears than any of the other treatments. They were decidedly the poorest plants in the whole series. (See Plate VI). It is quite noticeable however, that the weight of roots is slightly heavier than in the case of No. 6 (M-M-O). This bears out still further the conclusions drawn from Nos. 2 and 4, that a minimum amount of plant food in the solution seems to be conductive to root development during the latter part of the growing period.

In No. 6 (M-M-O) the plants received minimum nutrient during the first 60 days and optimum nutrient during the last 30-day period. The supplying of this larger amount of plant food during the last period seemed to stimulate these plants a great deal. They took on new vigor and the leaves became darker green in color and the internodes increased very materially in length. The increase over No. 5 (M-M-M) which had the same treatment during the first two periods was mainly in leaves and ears. The increase in weight of stalks was comparatively small and the roots as shown above actually weighed less than did the roots of No. 5. The ears, however, showed quite a material increase over those of No. 5 even though there was only a small amount of grain produced and the cobs were small and short as may be seen from the photographs. (Plate VII).

No. 7 (M-O-M) received minimum nutrient during the first and third periods with optimum during the second period. The results from this treatment are very remarkable, especially when we compare the total weight or the weights of the different parts with No. 4 (O-M-M) or No. 6 (M-M-O) which also had minimum nutrient during two periods and optimum nutrient during only a single period. It will be noted, however, that No. 4 had the optimum nutrient during the first period, No. 6 during the third period while No. 7 had the optimum nutrient during the second 30-day period. This treatment illustrates very clearly that the second period is by far the most important, so far as the production of the vegetative parts of the plant is concerned. It may be noted from the curves (Figure 1) that the increase in weight of the different parts of No. 7 over No. 6 was greater for the roots, leaves, and stalks than was the case with the ears. The weights of stalks, in the case of No. 7 is relatively higher than are the leaves, when compared with No. 6, and here again as is the case with No. 2 and No. 4, the minimum nutrient during the final period has tended to produce a high yield of stalk as compared with the leaves or as compared with No. 1, No. 3 and No. 8 which had optimum nutrient during the last 30 days. The minimum nutrient during the third period is less conducive to ear production as is shown by the fact that the increase in yield of ears over No. 6 is less than that of the other parts of the plant.

No. 8 (M-O-O), which had minimum nutrient during the first period and optimum nutrient during the last two, shows a decrease in weight as compared with No. 2 which had optimum nutrient during the first two periods and minimum during the last period. The total weight of plants in No. 8 was 552.25 grams, as compared with 316.3 grams for No. 3 which had optimum nutrient during the first and third periods and minimum during the second period. The plants in No. 8 were stocky, and showed a heavy leaf development. It may be seen from Table 1 that the weight of leaves in No. 8 was 199.9 grams as compared with 187.2 grams in case of No. 2 and 112.0 grams in the case of No. 3. It also gave a very decided increase over No. 7 (M-O-M) which had the same treatment during the first two periods. The stalks and roots, however, show a lower weight than those of No. 7. This relative difference in the weight of stalks and roots has already been pointed out in the discussion of the other results. The weight of ears in No. 8 is somewhat greater than in case of No. 7 (M-O-M) or No. 3 (O-M-O), but is much less than in case of No. 2 (O-O-M). This low weight of ear in No. 8 is due partly to the fact that these plants were very succulent and growing rapidly when harvested. Due to their late start the ears were not as mature as they would have been if the plants had continued their growth 10 to 20 days longer. This puts No. 8 at a decided disadvantage since the plants in No. 1 and No. 2 had practically completed their growth at the end of 90 days and would have made little increase in weight, while No. 8 was really just getting well started at ear production and seemed capable of further development that would have brought its weight up almost to that of No. 2 or No. 1. (See Plate VIII).

PLANTS GROWN ONE AND TWO PERIODS

(See Plates I, IV, and V).

No. 9 (O-O) had optimum nutrients for 60 days and was harvested at the end of that time. It produced a total weight in two periods that was greater than the weights in the case of Nos. 3, 4, 5 or 6. The weight of leaves was greater than any except No. 1 and No. 8. This shows that practically all of the leaf development is made by the end of the second period where there is a plentiful supply of plant food. (See Plate IV). Where the supply is limited during the first part of the growing period there may be considerable leaf development during the third period. This fact is brought out by the results of No. 6 and No. 8. The weight of stalks in No. 9 averaged 122.2 grams which was also greater than that produced by Nos. 3, 4, 5 or 6 all of which had minimum during the the second period. No. 9 had the same treatment as No. 1 or No. 2 for the first two periods but the root development was much lower showing that there was considerable root development during the third period under either optimum or minimum conditions.

The total weight of plants in No. 10 (O-M) which had optimum nutrients during the first thirty days and minimum during the second thirty days was 182.84 grams as compared with 237.01 grams in the case of No. 4 and 316.3 grams in No. 3 which had the same treatment during the first 60 days. It will be seen from this that No. 4 gained only 54.17 grams during the third period while No. 3 gained 133.46 grams. It is furthermore quite noticeable that part of these increases may be accounted for in the weight of ears, thus showing that there was really very little increase in the vegetative growth during the last period. The weight of leaves in No. 10 was 97.1 grams while in No. 4 the weight of leaves was only 84.8 grams. This would indicate that the leaves of plants in No.

4 which had one more period of minimum nutrient, lost their weight either by translocation or by the washing out of some of the mineral matter during rains. The weight of roots with this treatment was considerably lower than in the case of No. 9. This seems not to bear out the statement regarding the results where the plants were grown for three periods because most of these showed an increase in root development where the plant food was cut down near the end of the experiment. This smaller root growth in No. 10 may be due to the fact that during the first period such growth was necessarily small, and when the concentration of the nutrient solution was reduced at the beginning of the second period, the plants were so stunted that the development of roots was not able to equal that of No. 9 which was receiving an optimum nutrient solution, and making its most rapid development of plant tissue during this period. In other words the ratio of the weight of roots in No. 10 to No. 9 was narrower than the ratio between the aerial parts of the plants.

No. 11 (O) had optimum treatment for 30 days at the end of which time the plants were harvested. The total weight of plants produced during this period was 25.22 grams, or about one-fifteenth of the weight produced by No. 9 (O-O) in 60 days. The weight of roots was 8.32 grams and the weight of tops 16.9 grams. In other words the root development was about one-third the total weight of the plant. (See Table 1 and Plates I and II). While in the case of No. 9 which grew for 60 days the weight of roots was about one-fifth the total weight of plant. The ratio of roots to tops was less during the later stage as shown by Table 17. This shows that the production of tops during the second period is relatively much greater than the production of roots where the supply of plant food is optimum.

No. 12 (M-M) had a weak solution for 60 days the plant being harvested at the end of this time. The total weight of plants averaged 33.28 grams and it may be seen that No. 5 produced an average of 94.21 grams during three periods of minimum nutrient. This again shows that with minimum nutrient the development of plants, although small, is gradual during the entire growing season and the time of maturity is delayed. The weight of roots was 13.18 grams in No. 12 as compared with 22.65 grams for the root development in No. 5. This would seem to indicate that the root development during the third period where the plants were receiving minimum nutrient, was also gradual. The stalk growth in No. 12 however was very small. In fact most of the plants produced no stalks, but were simply divided into two parts, leaves and roots.

In No. 13 (M-O) the plants grew for 60 days, receiving minimum nutrient during the first 30 days and optimum during the second 30 days. The total weight of dry matter was slightly greater than in case of No. 6 which has two periods of minimum nutrients preceding one of optimum. The total increase during the second period can only be seen by a comparison with No. 14 (M) which had but one period of minimum treatment before the plants were harvested. The weight of plants in No. 14 averaged 4.16 grams while the weight of plants in No. 13 averaged 172.31 grams, or an increase during the second period of 40 times the growth produced during the first period. The root development in No. 13 was greater than in the case of No. 12. The root growth in No. 14 which had but one period of minimum treatment is approximately one and one-half times the leaf growth. (See Plate II.) This is the only case where the weight of roots exceeded the weight of tops.

CHEMICAL COMPOSITION OF PLANTS

Chemical analyses were made to determine the amount of ash, nitrogen, phosphorus, potassium, calcium and magnesium. The plants were divided into four parts, roots; stalks, tassels and shanks; leaves; and ears. These analyses were made on the plants from each of the fourteen different treatments.

UTILIZATION OF NITROGEN

The percent of nitrogen in the plants was noticeably higher when they were receiving optimum amounts of this element just previous to harvest. (See Figures 2, 4, 6, 8, and 10.) It seems that when a liberal supply of this element is available, the plants take it up in large quantities. This fact is shown in Nos. 1, 3, 6, and 8 which were receiving optimum amounts of nitrogen at the end of the growth period. (See Tables 2, 7, and 15.) It is also noticeable in Nos. 9, 11, and 13, which received optimum nutrient during the first or second period, previous to harvesting.

The percent of nitrogen in the stalks exceeded that in the roots in Nos. 3, 6, and 8 all of which had at least one period of minimum but received optimum nutrient during the final period. Nos. 2, 4, and 7 which were receiving minimum amounts of nitrogen during the final period, have a higher percent in the roots than in the

TABLE 2. WEIGHT OF NITROGEN IN VARIOUS PARTS OF THE PLANTS FROM EACH CYLINDER. (IN GRAMS).

No. Cylinder	Treatment	Roots	Stalks	Leaves	Ears	Top	Total
A and B 1	O-O-O	1.064	1.302	3.144	5.915	10.361	11.425
A and B 2	O-O-M	.673	.780	1.780	2.976	5.536	6.209
A and B 3	O-M-O	.552	.795	1.634	1.682	4.111	4.663
A and B 4	O-M-M	.337	.360	.531	.140	1.031	1.368
A and B 5	M-M-M	.148	.199	.387	----	.586	.734
A and B 6	M-M-O	.296	.623	1.371	.539	2.533	2.829
A and B 7	M-O-M	.561	.908	1.535	1.020	3.463	4.024
A and B 8	M-O-O	1.196	2.213	3.206	2.177	7.596	8.792
A and B 9	O-O	.854	1.866	3.601	----	5.467	6.321
A and B 10	O-M	.323	.427	.637	----	1.064	1.387
A and B 11	O	.143	----	.525	----	.525	.668
A and B 12	M-M	.111	----	.250	----	.250	.361
A and B 13	M-O	.475	.933	2.438	----	3.371	3.846
A and B 14	M	.016	----	.025	----	.025	0.041

stalks. No. 1 which had optimum nutrient throughout the entire period also showed more nitrogen in the roots than in the stalks. It seems that in this treatment much of the nitrogen has been translocated to the ear during the third period, since the percent of nitrogen in the roots, leaves and stalks was lower than at the end of the second period, as shown by No. 9. In No. 5 which received minimum nutrient throughout the entire period, the percentage of nitrogen in roots and stalks was practically the same. Nos. 9, 10, and 13 which grew only two periods showed a higher percent of nitrogen in these stalks than in the roots. The percent nitrogen in the leaves, was higher than that in the stalks or roots, in all cases, except in No. 10 which had optimum treatment during the first period and minimum during the second period. In this case, the percentage of nitrogen in the stalks was considerably higher than in the roots, and the low percent of this element in the leaves was doubtless due to the fact that the plants were receiving very small amounts during the 30 days previous to harvest and some of the nitrogen originally present in the leaves seems to have concentrated in the stems during the second period.

The ears contained a much higher percent of nitrogen than any other part of the plant averaging about 0.5 percent higher than the nitrogen in the leaves, and almost double the percent found in the stalks or roots. The nitrogen in the ears from No. 6 (M-M-O) was higher than in the ears from any of the other plants. This may have been due to the fact that the plant had received minimum nutrient during the first 60 days, and then when a large amount was added the plant seemed to absorb it at a more rapid rate because it had been stunted during the first part of its development. No. 8 (M-O-O) shows this same effect but to a less degree. It will be noted also from Table Nos. 7 to 13 that the nitrogen in the roots, stalks, leaves, and ears was higher in the case of No. 6 (M-M-O) than in any of the others that were grown for the full three periods.

In case of the roots, stalks and leaves the percent of nitrogen under all of the treatments was higher than that of any of the other elements except potassium and in the case of the roots except calcium which was slightly higher in Nos. 1 and 2. In the case of ears the percent nitrogen was higher than the percent potassium. The percent phosphorus, in the ears, however, was relatively higher than in the other parts of the plant. The results coincide with the results obtained by Jones and Huston[8]. The percent nitrogen in the leaves, roots and stalks gradually decreased from the first to the third period, wherever optimum nutrient was given throughout as in the case of Nos. 11, 9, and 1. This decrease in the percent nitrogen during the successive stages of growth has been will shown by Wilfarth, Römer and Wimmer[20], in the case of wheat, barley and potatoes.

Table 2 shows the total weights of nitrogen in the different parts of the plant as well as the total for the tops and whole plant. It may be seen from these data that the total weight of nitrogen increased at each successive cutting, even though the percent nitrogen decreased. (See also Figures 3, 4, 7, 8, and 11.) This agrees with the results obtained by Hornberger[6], Schweitzer[16], Jones and Huston[8], and Ince[7], who worked with maize. It does not agree, however, with the results of Wilfarth, Römer and Wimmer[20], who worked with barley, spring wheat, and potatoes, for they found a decrease as the plant approached maturity of both the percent and total amount of nitrogen. Neither do these results support the theory of LeClerc and Breazeale[10] that a great amount of plant food is removed by rains, because these corn plants were grown in the open and were subject to some heavy rains during each season. These authors state, however, that there is a translocation of nitrogen from the leaves to the stems or other parts of the plant. This may account for the fact that the leaves as well as stems contained less nitrogen at the end of the third period than at the end of the second. It seems that this nitrogen was used up in ear formation. This fact was also shown by Smith.[17] This is well illustrated by the fact that the leaves of Nos. 1, 2, 4, and 7 decreased in weight of total nitrogen during the last 30 days, while none of these plants except No. 7 decreased in the total amount of nitrogen in the tops. The total weight of nitrogen in the stalks decreased during the third period in Nos. 1, 2, 4, 7, and 8. Most of this nitrogen too was doubtless stored in the ear since none of the plants except Nos. 2 and 7 decreased in total nitrogen when the whole plant is considered, and in the case of No. 2 the loss from the roots was greater than the loss from the total plant.

UTILIZATION OF PHOSPHORUS

The percent phosphorus was noticeably low in the roots of Nos. 6 (M-M-O) and 8 (M-O-O) as compared with the amounts in other parts of the plants. In most of the other treatments this condition did not obtain. (See Tables 7, 9, 11, and 13.) No. 10 showed a markedly low content as compared with Nos. 9 and 11. (See Table 15.) No. 11 (O) showed that there was a very rapid absorption of phosphorus during the early stage when there was a plentiful supply of the nutrients available. No. 13 also showed a very rapid absorption of phosphorus during the second period when optimum nutrient was provided following minimum nutrient during the first 30 days. Pember[13] showed that after a period of starvation plants revived when a good supply of phosphorus was given. The percents phosphorus in the roots and leaves of No. 13 were only slightly lower than in No. 11. No. 13 also produced a fairly good growth of stalks and the percent of phosphorus in these plants was high. The total amount of phosphorus in No. 13 was more than six times as great as in No. 11. In No. 9 where optimum nutrient was supplied for 60 days the percentage of phosphorus in both the roots and tops was much less than in No. 11 which had optimum the first 30 days. This lower percentage in No. 9 was probably due to a very great increase in the total dry weight of the plants due to the building up of large amounts of carbonaceous material. The total weight of phosphorus in No. 11 at the end of the first period was 0.143, while the total weight of phosphorus in No. 9 at the end of the second period was 1.496 grams while the total weight of dry matter in No. 11 was 25.2 grams and the total

TABLE 3. WEIGHT OF PHOSPHORUS IN VARIOUS PARTS OF THE PLANTS FROM EACH CYLINDER. (IN GRAMS).

No. Cylinder	Treatment	Roots	Stalks	Leaves	Ears	Top	Total
A and B 1	O-O-O	.405	.564	.735	1.135	2.434	2.839
A and B 2	O-O-M	.254	.396	.393	.689	1.478	1.732
A and B 3	O-M-O	.264	.337	.517	.366	1.220	1.484
A and B 4	O-M-M	.146	.181	.157	.035	.373	.519
A and B 5	M-M-M	.049	.062	.091	----	.153	.202
A and B 6	M-M-O	.107	.245	.398	.133	.776	.883
A and B 7	M-O-M	.255	.464	.417	.233	1.114	1.369
A and B 8	M-O-O	.356	.679	.800	.458	1.955	2.311
A and B 9	O-O	.333	.462	.701	----	1.163	1.496
A and B 10	O-M	.122	.132	.218	----	.350	.472
A and B 11	O	.043	----	.100	----	.100	.143
A and B 12	M-M	.028	----	.062	----	.062	.090
A and B 13	M-O	.179	.248	.516	----	.764	.943
A and B 14	M	.005	----	.003	----	.003	.008

weight of dry matter in No. 9 was 391.4 grams. This shows a ratio of 1 to 10.4 in the phosphorus content and of 1 to 15.5 in the dry weights.

The percent of phosphorus in the leaves was lower than that in the stalks in all but No. 5 (M-M-M) and here the difference was not great. The percent of phosphorus in the ears was noticeably higher than in other parts of the plant, in all cases except No. 3 (O-M-O). In this case the phosphorus was very high in all parts excepting the ears in which it was relatively low. It may be noted, however, that the percent of phosphorus in the ears of No. 3 was higher than any except in Nos. 6 and 8. In both these cases optimum amounts of phosphorus were being supplied when the plants were harvested and they had also received at least one period of minimum during the course of the experiment.

As compared with the other elements, phosphorus was higher than calcium and magnesium in the ears. In the roots, stalks and leaves the percent of phosphorus was very similar to that of magnesium and in most cases lower than the percent of calcium. It varied more in the different treatments than did either magnesium or calcium.

Table 3 shows that in all cases there was a gain in the total amount of phosphorus during each successive period. Nos. 3, 6, and 8 which received optimum nutrient during the last period, and yet did not have sufficient time to mature the ears because of the late start, had a high percent of phosphorus in the vegetative parts of the plant. That is, it was present in the plant ready for translocation to the ear if sufficient time had been given for maturity and as was said in the case of nitrogen Nos. 6 and 8 were at a great disadvantage in this respect because they were still making rapid growth and absorbing large quantities of food at the time of harvest.

UTILIZATION OF POTASSIUM

The percent of potassium in these plants corresponds very closely with the percentages found by several investigators. (See Tables 7, 9, 11, 13, and 15.) This element is more abundant in the stalks, leaves and roots, than any of the other elements. In the ears, however, the percentage of nitrogen is greater than that of potassium. No. 14, which had minimum nutrient and was harvested at the end of the first period showed a slightly higher percent of nitrogen than potassium in the leaves. (See Figure 6.) In No. 11 (O) which has optimum nutrient for one period and which was harvested at the end of that time, the percent of potassium in the leaves was 5.593. This was much higher than that found in any of the other plants. Jordan[8] showed that a high percentage like this was not responsible for much increase in growth. No 13 (M-O) which had minimum nutrient during the first and optimum nutrient during the second period, also showed a high potassium content. This rise in the potassium content may also be noted in the case of Nos. 6 (M-M-O) and 8 (M-O-O) which had previously had one or more periods in which they received a minimum supply of plant food. That there was some potassium lost from the leaves during the third period of growth is shown by the fact that No. 9 (O-O) which had two periods of optimum showed 5.366 grams of potassium in the leaves while No. 1 (O-O-O) which had three optimum periods showed only 4.806 grams. It may be a question just what became of this potassium in the leaves, for the stalks and roots of plant No. 1 showed both a higher percent and a greater total weight of this element than did the stalks and roots in No. 9. It may be, as suggested by Burd[2] that the potassium has moved back to the soil. It seems far more likely, however, that if this potassium had been translocated at all it had been used in the stalks, roots and ears since the weight of potassium in the whole plant increased during the third period, except in Nos. 2 (O-O-M)

TABLE 4. WEIGHT OF POTASSIUM IN VARIOUS PARTS OF THE PLANTS FROM EACH CYLINDER. (IN GRAMS).

No. Cylinder	Treatment	Roots	Stalks	Leaves	Ears	Top	Total
A and B 1	O-O-O	1.621	5.426	4.806	2.188	12.420	14.041
A and B 2	O-O-M	1.302	3.337	2.911	1.537	7.785	9.087
A and B 3	O-M-O	.769	1.314	1.771	.840	3.925	4.694
A and B 4	O-M-M	.666	.748	.880	.089	1.717	2.383
A and B 5	M-M-M	.297	.413	.595	----	1.008	1.305
A and B 6	M-M-O	.334	1.059	1.574	.329	2.962	3.296
A and B 7	M-O-M	1.247	2.485	2.535	.668	5.688	6.935
A and B 8	M-O-O	1.812	4.979	4.686	1.343	11.008	12.820
A and B 9	O-O	1.049	3.517	5.366	----	8.883	9.932
A and B 10	O-M	.369	.631	1.604	----	2.235	2.604
A and B 11	O	.286	----	.945	----	.945	1.231
A and B 12	M-M	.134	----	.426	----	.426	.560
A and B 13	M-O	.748	2.407	3.368	----	6.075	6.823
A and B 14	M	.047	----	.021	----	.021	.068

and 4 (O-M-M). On the other hand, certain small amounts of potassium might have been lost during the later stages of growth due to the effects of rain and dew as suggested by LeClerc and Breazeale[10], since these plants were grown in the open and exposed to the weather at all times. It will be noted in Figures 2 to 5 that the potassium and nitrogen curves run fairly well together in most cases, but that the potassium is considerably higher in all parts of the plant except in the ears. The percent of potassium in the ears was lowest in No. 1 which had optimum treatment throughout the entire period and produced the greatest weight of ear. It was highest in Nos. 6 and 8 which were receiving optimum treatment during the last period, but had previously had one or more periods of minimum. The weight of ears produced in No. 5 was so small that a sample could not be obtained for analyses. (See Plate VII).

Figure 11 shows that the total weights of potassium for the different treatments were in about the same order as those of nitrogen and phosphorus. The total weight of potassium was greater than any of the other elements except in the ears where the nitrogen averaged about two and one-fourth times as much as the potassium. The weight of potassium was only about twice as great as phosphorus in the ears while it was almost seven times as much in the leaves and stalks. No. 5 (M-M-M) having minimum nutrient for the three periods absorbed relatively high amounts of potassium, calcium and magnesium and low amounts of nitrogen and phosphorus. The reverse was true of No. 6 which had optimum during the third period.

In general this experiment showed a tendency toward a decrease in the weight of potassium in the leaves and a gain in weight of this element in the stalks and roots during the third period. This would indicate that some potassium has been translocated from the leaves to other parts of the plant. Or it may be as suggested by Le Clerc and Breazeale[10] that the leaves have lost some of their potassium due to rain and dew. In this case the gain in potassium by the roots and stalks could only be explained by there being an additional absorption of this element during the last period.

UTILIZATION OF CALCIUM

The percent calcium in the roots was lower than that in the leaves in cases where the plants were receiving minimum nutrient at the last period, but was higher in other parts of the plant. (See Tables 7-15). The percent of calcium ran higher in the leaves and roots than in the other parts of the plant, and was higher in the leaves, in all cases than phosphorus or magnesium. In the roots it was also higher than nitrogen in cases of Nos. 1 and 2. (See Figure 2.) The variation between the different treatments was much less marked than was the case with the nitrogen, phosphorus or potassium except in the roots where the various treatments showed marked differences in calcium content. This seems to correspond to Hoagland's[5] results that with high concentrations of the nutrient solution there is very high storage of insoluble calcium and phosphorus in the roots. In the case of the stalks the percent calcium was above that of phosphorus in all cases except Nos. 3, 6, 8, and 13. It will be noted again that all of these plants had previously had one or more periods of minimum nutrient. In case of the young plants Nos. 9 and 10 the percent calcium was also above that of phosphorus, and as in case of the leaves and ears the variation between the different treatments was very slight. It would seem that the amount of calcium stored depends much less upon the amount available than is the case with the other elements.

In the case of ears, it will be noted that, the percent of calcium was lower than that of any other of the elements given. This is the only part of the plant where the percent of calcium is lower

TABLE 5. WEIGHT OF CALCIUM IN VARIOUS PARTS OF PLANTS. (IN GRAMS).

No. Cylinder	Treatment	Roots	Stalks	Leaves	Ears	Top	Total
A and B 1	O-O-O	1.089	.783	2.122	.177	3.082	4.171
A and B 2	O-O-M	.703	.697	1.513	.125	2.335	3.038
A and B 3	O-M-O	.403	.275	.778	.065	1.118	1.521
A and B 4	O-M-M	.264	.266	.464	.009	.739	1.003
A and B 5	M-M-M	.109	.091	.226	----	.317	.426
A and B 6	M-M-O	.164	.143	.471	.025	.639	.803
A and B 7	M-O-M	.549	.601	1.093	.053	1.747	2.296
A and B 8	M-O-O	.843	.612	1.601	.104	2.317	3.160
A and B 9	O-O	.840	.530	1.633	----	2.163	3.003
A and B 10	O-M	.220	.154	.498	----	.652	.872
A and B 11	O	.069	----	.126	----	.126	.195
A and B 12	M-M	.069	----	.110	----	.110	.179
A and B 13	M-O	.367	.243	.681	----	.924	1.291
A and B 14	M	----	----	----	----	----	----

than magnesium. This fact was also shown in Burd's[2] analysis of the heads and grain of barley.

Both the percent and total weight of calcium in the leaves of the plants having optimum treatment, increased as the plants grew older. The roots showed an increase in the total weight of calcium during the last period but not in the percentage composition. Hornberger[6] showed that the percent of calcium in the roots and ears decreased with the age of plants, but the total weight increased.

UTILIZATION OF MAGNESIUM

Magnesium is absorbed in more uniform amounts by the various treatments than any of the other elements. (See Figure 10). It will be noticed that the graph representing magnesium forms almost a straight line. It would seem from this that the weak nutrient solution used contained enough magnesium for the normal growth of the plants and even though a much larger amount was added in the optimum nutrient solution than the plant could utilize the amount of absorption was only slightly affected. (See Figures 2-10). It is a striking fact that the total weight of magnesium is lower than calcium in all the vegetative parts of the plant, but is higher than this element in the ear even though the percent of magnesium is lower in the ear than in any other part of the plant. This fact has been noted by many investigators.

The percent of magnesium in the roots is higher than in the other parts of the plant. In most cases it is higher in the leaves than in the stalks.

Figure 10 shows that the curves representing the percent of magnesium and calcium in the total plant are similar for the various treatments but the calcium is noticeably higher. The magnesium is absorbed in much smaller amounts than calcium in the leaves. In the ears, however, magnesium is absorbed in more than twice as large amounts as is calcium.

TABLE 6. WEIGHT OF MAGNESIUM IN VARIOUS PARTS OF PLANTS. (IN GRAMS).

No. Cylinder	Treatment	Roots	Stalks	Leaves	Ears	Top	Total
A and B 1	O-O-O	.265	.301	.701	.470	1.472	1.737
A and B 2	O-O-M	.260	.338	.434	.315	1.087	1.347
A and B 3	O-M-O	.155	.144	.269	.133	.546	.701
A and B 4	O-M-M	.168	.138	.181	.018	.337	.505
A and B 5	M-M-M	.071	.069	.085	----	.154	.225
A and B 6	M-M-O	.067	.087	.166	.038	.291	.358
A and B 7	M-O-M	.226	.290	.337	.100	.727	.953
A and B 8	M-O-O	.263	.365	.626	.187	1.178	1.441
A and B 9	O-O	.228	.330	.546	----	.876	1.104
A and B 10	O-M	.122	.103	.186	----	.289	.411
A and B 11	O	.043	----	.050	----	.050	.093
A and B 12	M-M-	.044	----	.048	----	.048	.092
A and B 13	M-O	.104	.139	.258	----	.397	.501
A and B 14	M	----	----	----	----	----	----

The percents and also the amouns of magnesium, calcium, and phosphorus, were on the whole much less variable than the potassium and nitrogen when the solution was changed from optimum to minimum or vice versa. This seems to indicate that it was mainly a shortage of potassium and nitrogen that limited the growth under the conditions of minimum treatment.

TABLE 7. AVERAGE PERCENTAGE COMPOSITION OF ROOTS.

No. Cylinder	Treatment	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
A and B 1	O-O-O	1.103	.420	1.681	1.129	.275
A and B 2	O-O-M	.682	.258	1.319	.712	.263
A and B 3	O-M-O	.985	.471	1.372	.720	.277
A and B 4	O-M-M	.584	.253	1.153	.458	.291
A and B 5	M-M-M	.654	.217	1.309	.480	.311
A and B 6	M-M-O	1.391	.507	1.571	.771	.315
A and B 7	M-O-M	.584	.266	1.299	.572	.235
A and B 8	M-O-O	1.284	.383	1.944	.905	.282
A and B 9	O-O	1.183	.461	1.452	1.163	.315
A and B 10	O-M	.698	.264	.799	.476	.263
A and B 11	O	1.715	.512	3.440	.834	.520
A and B 12	M-M	.842	.213	1.013	.522	.332
A and B 13	M-O	1.310	.492	2.062	1.012	.286
A and B 14	M	.633	.196	1.845	----	----

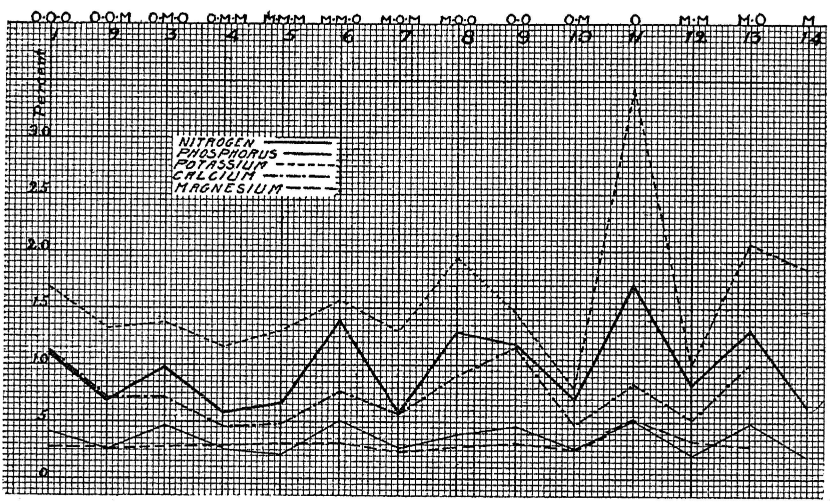

Fig. 2. Percent of the various elements contained in the roots under the different treatments.

TABLE 8. TOTAL WEIGHT OF ELEMENTS IN ROOTS (IN GRAMS).

No. Cylinder	Treatment	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
A and B 1	O-O-O	1.064	.405	1.621	1.089	.265
A and B 2	O-O-M	.673	.254	1.302	.703	.260
A and B 3	O-M-O	.552	.264	.769	.403	.155
A and B 4	O-M-M	.337	.146	.666	.264	.168
A and B 5	M-M-M	.148	.049	.297	.109	.071
A and B 6	M-M-O	.296	.107	.334	.164	.067
A and B 7	M-O-M	.561	.255	1.247	.549	.226
A and B 8	M-O-O	1.196	.356	1.812	.843	.263
A and B 9	O-O	.854	.333	1.049	.840	.228
A and B 10	O-M	.323	.122	.369	.220	.122
A and B 11	O	.143	.043	.268	.069	.043
A and B 12	M-M	.111	.028	.134	.069	.044
A and B 13	M-O	.475	.179	.748	.367	.104
A and B 14	M	.016	.005	.047	----	----

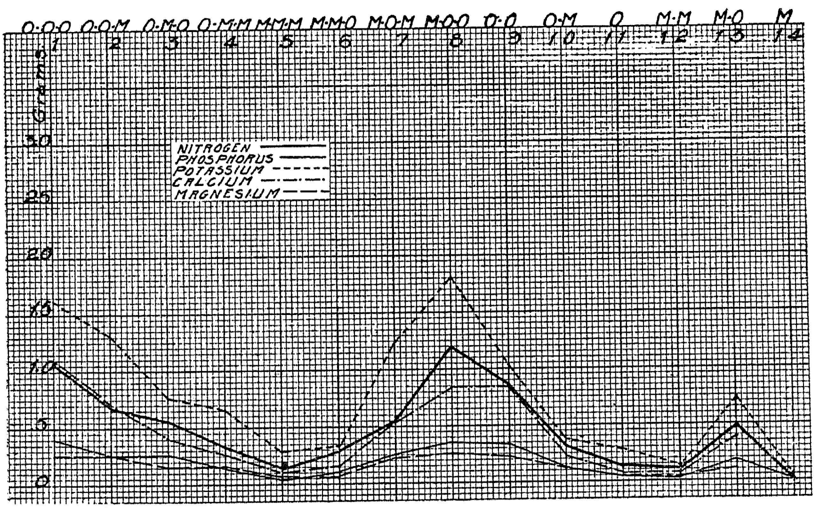

Fig. 3. Total weight of elements in roots (weights in grams).

TABLE 9. AVERAGE PERCENTAGE COMPOSITION OF STALKS, TASSELS, AND SHANKS.

No. Cylinder	Treatment	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
A and B 1	O-O-O	.814	.353	3.391	.461	.188
A and B 2	O-O-M	.439	.223	1.878	.392	.190
A and B 3	O-M-O	1.225	.519	2.025	.423	.223
A and B 4	O-M-M	.425	.214	.883	.314	.163
A and B 5	M-M-M	.635	.197	1.320	.290	.219
A and B 6	M-M-O	1.660	.653	2.825	.380	.233
A and B 7	M-O-M	.497	.254	1.361	.329	.159
A and B 8	M-O-O	1.371	.421	3.085	.379	.226
A and B 9	O-O	1.527	.378	2.878	.434	.270
A and B 10	O-M	1.080	.333	1.598	.390	.260
A and B 11	O	----	----	----	----	----
A and B 12	M-M	----	----	----	----	----
A and B 13	M-O	2.316	.616	5.972	.603	.346
A and B 14	M	----	----	----	----	----

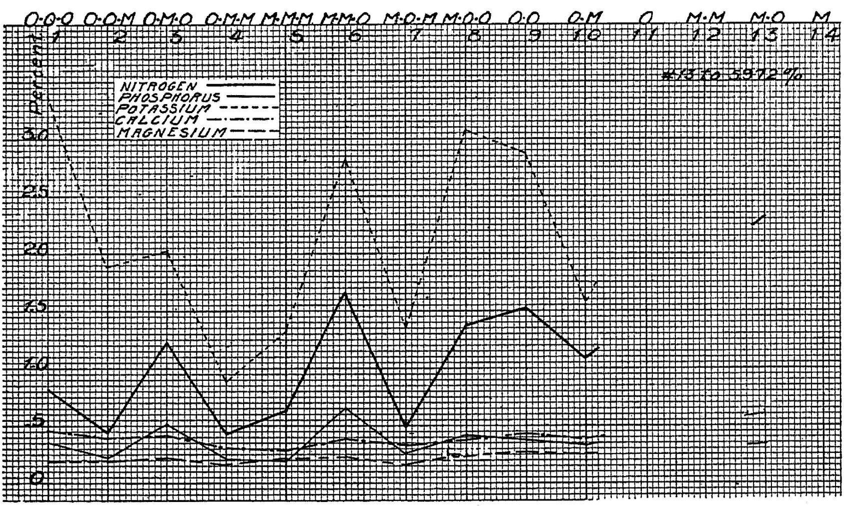

Fig. 4. Percent of the various elements contained in the stalks under different treatments.

TABLE 10. TOTAL WEIGHT OF ELEMENTS IN STALKS, TASSELS, AND SHANKS (IN GRAMS).

No. Cylinder	Treatment	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
A and B 1	O-O-O	1.302	.564	5.426	.783	.301
A and B 2	O-O-M	.780	.396	3.337	.697	.338
A and B 3	O-M-O	.795	.337	1.314	.275	.144
A and B 4	O-M-M	.360	.181	.748	.266	.138
A and B 5	M-M-M	.199	.062	.413	.091	.069
A and B 6	M-M-O	.623	.245	1.059	.143	.087
A and B 7	M-O-M	.908	.464	2.485	.601	.290
A and B 8	M-O-O	2.213	.679	4.979	.612	.365
A and B 9	O-O	1.866	.462	3.517	.530	.330
A and B 10	O-M	.427	.132	.631	.154	.103
A and B 11	O	----	----	----	----	----
A and B 12	M-M	----	----	----	----	----
A and B 13	M-O	.933	.248	2.407	.243	.139
A and B 14	M	----	----	----	----	----

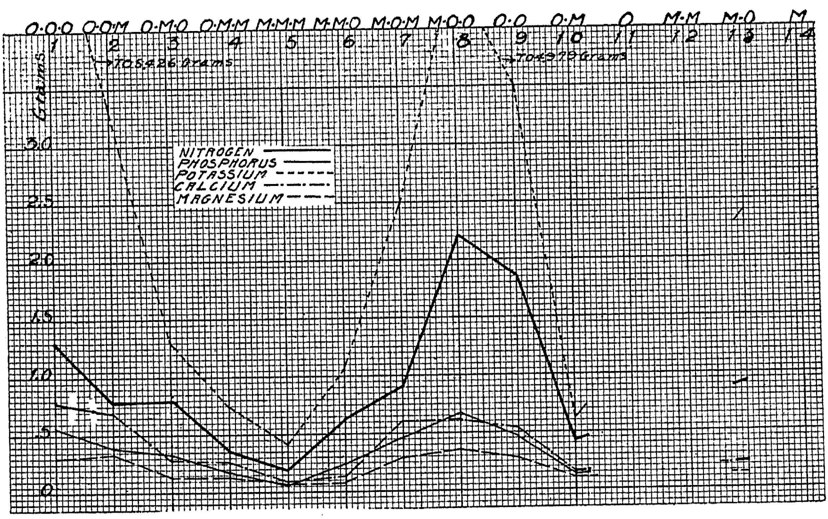

Fig. 5. Total weight of elements in stalks.

TABLE 11. AVERAGE PERCENTAGE COMPOSITION OF LEAVES.

No. Cylinder	Treatment	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
A and B 1	O-O-O	1.412	.330	2.158	.953	.315
A and B 2	O-O-M	.951	.210	1.555	.808	.232
A and B 3	O-M-O	1.459	.462	1.581	.695	.240
A and B 4	O-M-M	.626	.185	1.038	.547	.214
A and B 5	M-M-M	.971	.229	1.492	.566	.213
A and B 6	M-M-O	1.939	.563	2.226	.667	.235
A and B 7	M-O-M	.924	.251	1.526	.658	.203
A and B 8	M-O-O	1.604	.400	2.344	.801	.313
A and B 9	O-O	1.828	.356	2.724	.829	.277
A and B 10	O-M	.656	.225	1.652	.513	.192
A and B 11	O	3.108	.593	5.593	.748	.296
A and B 12	M-M	1.406	.347	2.395	.616	.262
A and B 13	M-O	2.548	.539	3.833	.712	.270
A and B 14	M	1.555	.202	1.289	----	----

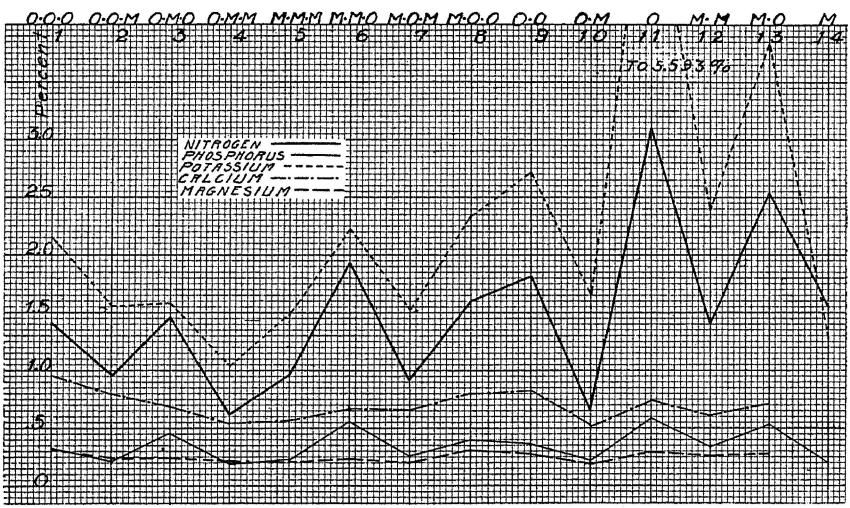

Fig. 6. Percent of the various elements contained in the leaves.

TABLE 12. TOTAL WEIGHT OF ELEMENTS IN LEAVES (IN GRAMS).

No. Cylinder	Treatment	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
A and B 1	O-O-O	3.144	.735	4.806	2.122	.701
A and B 2	O-O-M	1.780	.393	2.911	1.513	.434
A and B 3	O-M-O	1.634	.517	1.771	.778	.269
A and B 4	O-M-M	.531	.157	.880	.464	.181
A and B 5	M-M-M	.387	.091	.595	.226	.085
A and B 6	M-M-O	1.371	.398	1.574	.471	.166
A and B 7	M-O-M	1.535	.417	2.535	1.093	.337
A and B 8	M-O-O	3.206	.800	4.686	1.601	.626
A and B 9	O-O	3.601	.701	5.366	1.633	.546
A and B 10	O-M	.637	.218	1.604	.498	.186
A and B 11	O	.525	.100	.945	.126	.050
A and B 12	M-M-	.250	.062	.426	.110	.048
A and B 13	M-O	2.438	.516	3.668	.681	.258
A and B 14	M	.025	.003	.021	----	----

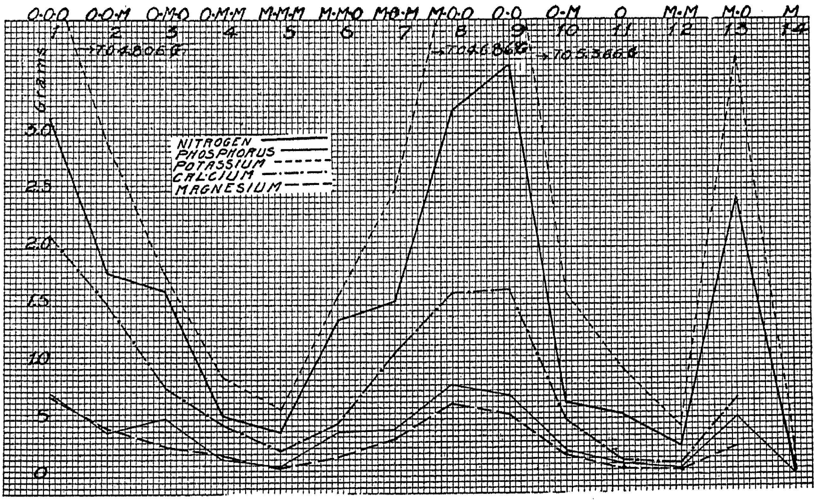

Fig. 7. Total weight of elements in leaves.

TABLE 13. AVERAGE PERCENTAGE COMPOSITION OF EARS.

No. Cylinder	Treatment	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
A and B 1	O-O-O	1.938	.372	.717	.058	.154
A and B 2	O-O-M	1.446	.335	.747	.061	.153
A and B 3	O-M-O	2.019	.440	1.008	.078	.160
A and B 4	O-M-M	1.435	.356	.911	.094	.183
A and B 5	M-M-M	----	----	----	----	----
A and B 6	M-M-O	2.730	.673	1.667	.126	.192
A and B 7	M-O-M	1.642	.375	1.075	.086	.161
A and B 8	M-O-O	2.227	.469	1.374	.106	.191

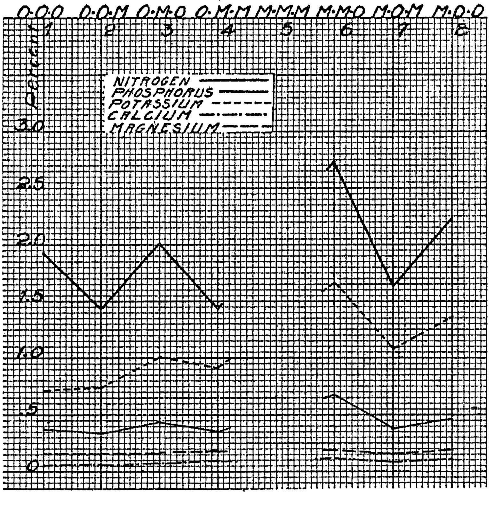

Fig. 8. Percent of the various elements contained in the ears.

TABLE 14. TOTAL WEIGHT OF ELEMENTS IN EARS (IN GRAMS).

No. Cylinder	Treatment	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
A and B 1	O-O-O	5.915	1.135	2.188	.177	.470
A and B 2	O-O-M	2.976	.689	1.537	.125	.315
A and B 3	O-M-O	1.682	.366	.840	.065	.133
A and B 4	O-M-M	.140	.035	.089	.009	.018
A and B 5	M-M-M	----	----	----	----	----
A and B 6	M-M-O	.539	.133	.329	.025	.038
A and B 7	M-O-M	1.020	.233	.668	.053	.100
A and B 8	M-O-O	2.177	.458	1.343	.104	.187

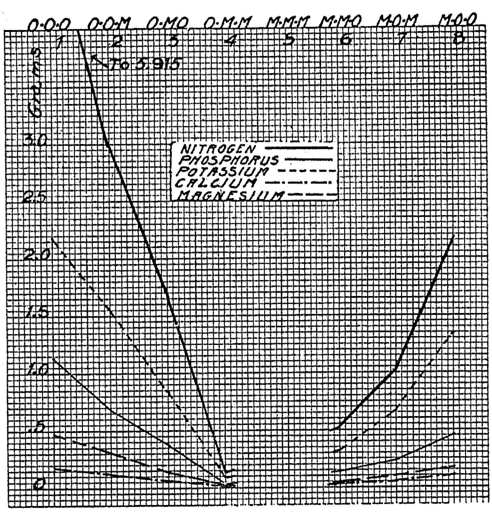

Fig. 9. Total weight of elements in ears.

TABLE 15. PERCENT OF VARIOUS ELEMENTS IN TOTAL PLANTS.

No. Cylinder	Treatment	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
A and B 1	O-O-O	1.456	.362	1.790	.532	.221
A and B 2	O-O-M	.928	.259	1.357	.454	.201
A and B 3	O-M-O	1.474	.469	1.484	.481	.221
A and B 4	O-M-M	.577	.219	1.005	.423	.213
A and B 5	M-M-M	.779	.214	1.385	.452	.239
A and B 6	M-M-O	1.895	.592	2.209	.538	.239
A and B 7	M-O-M	.794	.270	1.368	.453	.188
A and B 8	M-O-O	1.592	.418	2.321	.572	.261
A and B 9	O-O	1.615	.382	2.537	.767	.282
A and B 10	O-M	.758	.258	1.424	.477	.225
A and B 11	O	2.648	.507	4.881	.773	.369
A and B 12	M-M	1.084	.270	1.683	.538	.276
A and B 13	M-O	2.232	.547	3.959	.749	.291
A and B 14	M	.985	.192	1.635	----	----

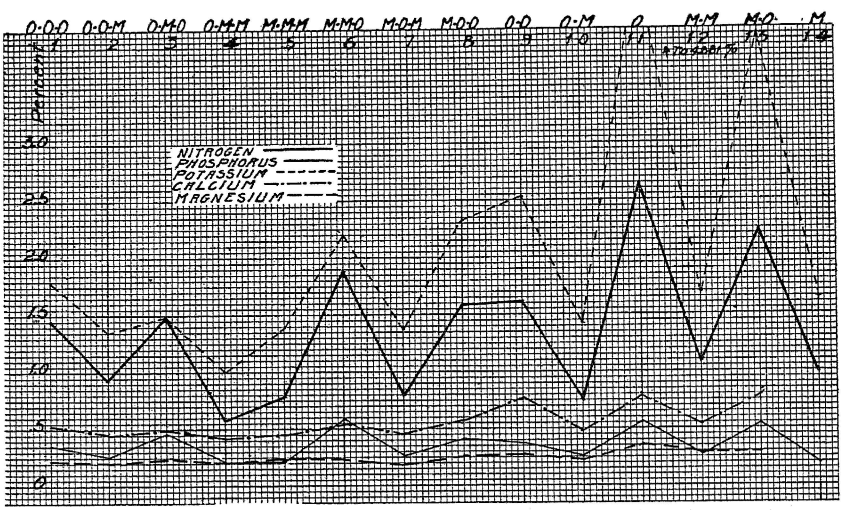

Fig 10. Percent of the various elements contained in the total plants.

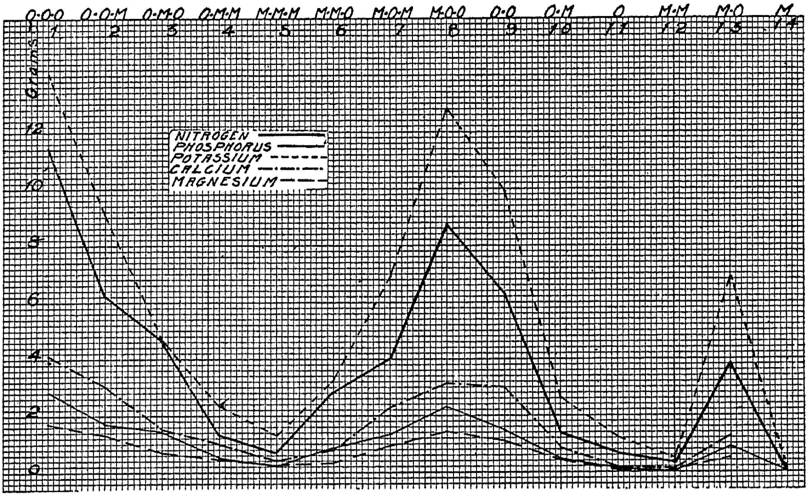

Fig. 11. Total weight of all elements in total plants.

TABLE 16. WEIGHT OF ASH IN VARIOUS PARTS OF THE PLANT AND TOTAL IN WHOLE PLANTS FROM EACH CYLINDER. (IN GRAMS).

No. Cylinder	Treatment	Roots	Stalks	Leaves	Ears	Top	Total
A and B 1	O O O	14.539	11.802	15.794	6.379	33.975	48.514
A and B 2	O-O-M	9.455	7.991	9.944	4.275	22.210	31.665
A and B 3	O-M-O	5.665	3.465	6.701	2.400	12.566	18.231
A and B 4	O-M-M	4.376	2.167	3.946	.197	6.310	10.686
A and B 5	M-M-M	1.530	1.038	2.180	----	3.218	4.748
A and B 6	M-M-O	1.901	2.498	4.991	.958	8.447	10.348
A and B 7	M-O-M	7.007	6.345	8.174	1.692	16.211	23.218
A and B 8	M-O-O	10.059	11.025	13.091	3.485	27.601	37.660
A and B 9	O-O	7.869	8.290	14.946	----	23.236	31.105
A and B 10	O-M	3.225	1.827	5.170	----	6.997	10.222
A and B 11	O	.893	----	2.355	----	2.355	3.248
A and B 12	M-M	1.540	----	1.314	----	1.314	2.854
A and B 13	M-O	4.623	5.346	9.123	----	14.469	10.092
A and B 14	M	.268	----	.171	----	.171	.439

SPECIAL OBSERVATIONS

Root Development—The character and amount of root development was very materially affected by the strength of the nutrient solution during different periods of growth. With minimum nutrient the root growth was proportionately greater than where the optimum was used. Table 17 shows the ratio between the root

TABLE 17. RATIO OF ROOTS TO TOPS. (ROOTS=1) (a)

	1st period.	2nd period.	3rd period.
A and B 1	2.03	4.41	7.13
A and B 2	2.03	4.41	5.78
A and B 3	2.03	2.95	4.64
A and B 4	2.03	2.95	3.11
A and B 5	0.63	1.52	3.15
A and B 6	0.63	1.52	6.02
A and B 7	0.63	3.74	4.28
A and B 8	0.63	3.74	4.92

(a) It should be noted in Tables 17-21 that the figures given for the first period are derived from Nos. 11 and 14 which were harvested at the end of the first period. Also the figures given for second period are derived from Nos. 9, 10, 12, and 13 which were harvested at the end of the second period.

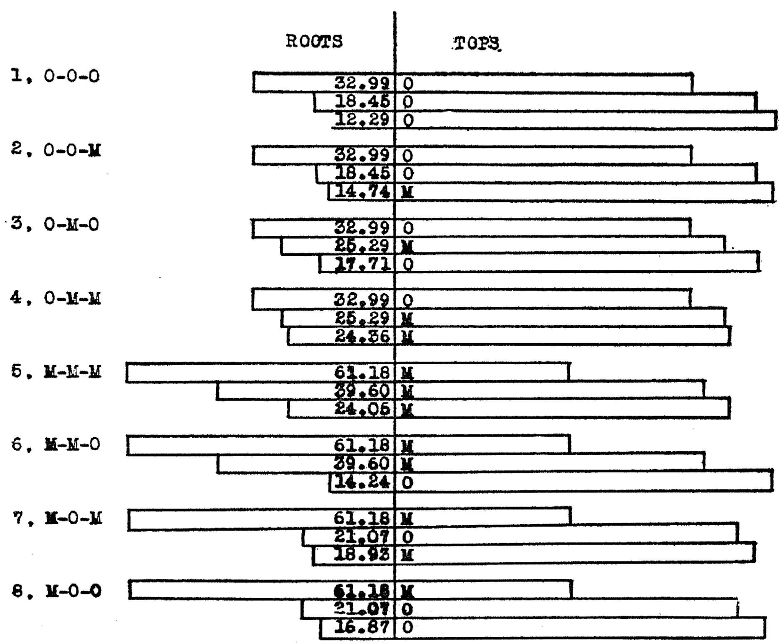

Fig. 12. Relative weights of roots and tops for different treatments at the three stages of growth. (The lines represent 1st, 2nd, and 3rd periods beginning at top. Figures represent percent.)

and top growth for the different treatments at each of the three growth periods.

It will be noticed from Table 17 that the greatest proportion of roots to tops is found during the early stages of growth. As the plants grow older the tops increase in weight more rapidly than do the roots. This increase is gradual where the strength of the solution remains unchanged. Where the solution is changed from minimum to optimum during the second period the ratio of roots to tops becomes noticeably wider. The most striking case, however, was in No. 6 where the solution was minimum for two periods and then changed to optimum. The ratio of roots to tops in this case changed from 1:0.63 in the first period to 1:6.02 in the third period. Where the solution was changed from optimum to minimum the ratio of roots to tops changed very slowly as is shown by Nos. 3 and 4.

During the second period the greatest increase in root weight was in plants having optimum nutrient. In the third period it was in plants having minimum nutrient. Whenever minimum nutrient was supplied the plants had a tendency to produce more fibrous roots. This may be seen by noticing Plates V and VII, root Nos. 12, 2, 4, 5, and 7. Optimum treatment caused the plants to produce more succulent main roots, but a smaller number of fine roots.

TABLE 18. THE PERCENT OF TOTAL WEIGHT OF PLANT OCCURRING IN THE ROOTS AT THE END OF EACH PERIOD.

	Percent roots 1st period.	2nd period.	3rd period.
A and B 1	32.99	18.45	12.29
A and B 2	32.99	18.45	14.74
A and B 3	32.99	25.29	17.71
A and B 4	32.99	25.29	24.35
A and B 5	61.18	39.60	24.05
A and B 6	61.18	39.60	14.24
A and B 7	61.18	21.07	18.93
A and B 8	61.18	21.07	16.87

The chemical composition of the roots varied from period to period. The percents of the various elements tended to decrease as the plants grew older, but the total weight of the elements increased. There are a few cases where the plants receiving minimum nutrient during the last period showed a lower total weight of elements than at the end of the second period.

TABLE 19. PERCENT OF TOTAL WEIGHT OF NITROGEN OF THE PLANTS, OCCURRING IN THE ROOTS AT THE END OF EACH PERIOD.

	1st period.	2nd period.	3rd period.
A and B 1	21.40	13.51	9.31
A and B 2	21.40	13.51	10.83
A and B 3	21.40	23.28	11.83
A and B 4	21.40	23.28	24.63
A and B 5	39.02	30.75	20.16
A and B 6	39.02	30.75	10.46
A and B 7	39.02	9.08	13.94
A and B 8	39.02	9.08	13.60

The proportion of the total nitrogen of the whole plant that was found in the roots tended to decrease as the plants grew older except in No. 4 (O-M-M), which showed a steady increase and in No. 7 and in No. 8 which increased slightly during the third period. These results are shown in Table 19. The proportion of potassium and phosphorus of the whole plant found in the roots is shown in Tables 20 and 21.

In all treatments and in each of the three periods, minimum nutrient stored a greater proportion of nitrogen, phosphorus, and potassium in the roots than did the optimum nutrient.

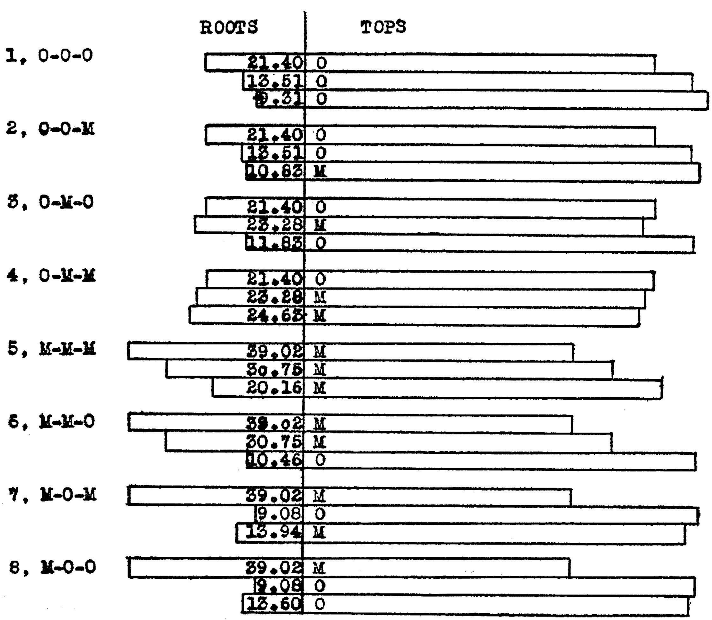

Fig. 13. Relative proportion of the total nitrogen of the plant contained in the roots and tops. (Figures represent percent).

TABLE 20. PERCENT OF TOTAL WEIGHT OF PHOSPHORUS OF THE PLANTS OCCURRING IN THE ROOTS AT THE END OF EACH PERIOD.

	1st period.	2nd period.	3rd period.
A and B 1	30.07	22.25	14.26
A and B 2	30.07	22.25	14.66
A and B 3	30.07	25.84	17.78
A and B 4	30.07	25.84	28.13
A and B 5	62.50	31.11	24.25
A and B 6	62.50	31.11	12.11
A and B 7	62.50	18.98	18.61
A and B 8	62.50	18.98	15.44

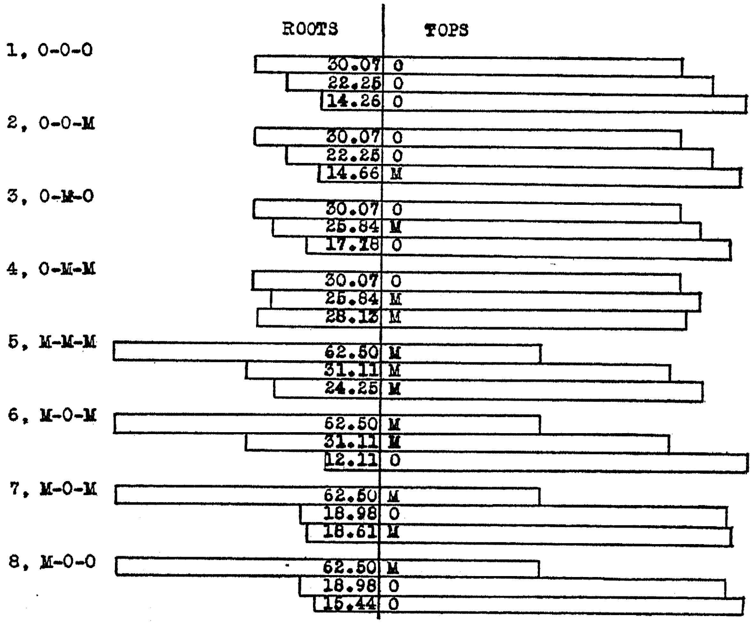

Fig. 14. Relative proportion of the total phosphorus of the plants contained in the roots and tops.

TABLE 21. PERCENT OF TOTAL WEIGHT OF POTASSIUM IN THE PLANTS OCCURRING IN THE ROOTS AT THE END OF EACH PERIOD.

	1st period.	2nd period.	3rd period.
A and B 1	23.23	10.55	11.54
A and B 2	23.23	10.55	14.32
A and B 3	23.23	14.17	16.38
A and B 4	23.23	14.17	27.94
A and B 5	69.11	23.92	22.75
A and B 6	69.11	23.92	10.13
A and B 7	69.11	10.96	17.98
A and B 8	69.11	10.96	14.13

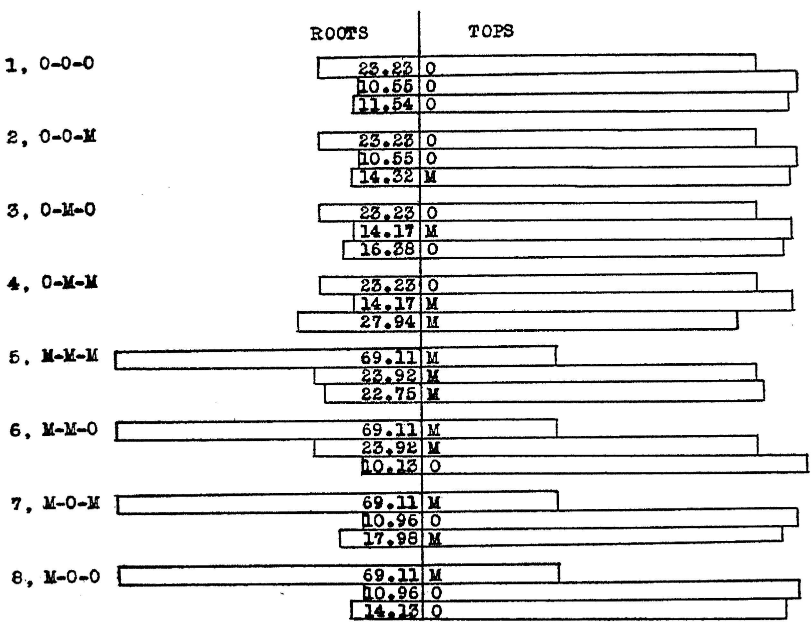

Fig. 15. Relative proportion of the total potassium of the plants contained in the roots and tops.

The Relation of Dry Weight to Green Weight of Plants—The widest ratio between the dry matter produced and the green weight of the plants is to be found in the plants when young. Plants receiving optimum nutrient at time of harvesting showed the greatest range. A comparison of the ratios of dry matter to green weight at the three different periods may be seen from Table 22. No. 11 showed a ratio of 1: 10.11; No. 9, 1: 7.45 and No. 1 a ratio of 1: 3.83.

That optimum nutrient, during the later stages of growth delayed maturity is shown by the results of Nos. 1, 3, 6, and 8, which had optimum during the last period, as compared with Nos. 2, 4, 5, and 7, which had minimum during the last period. It has already been pointed out that the late maturity of Nos. 6 and 8 will account very largely for the low production of ears on these plants. This is still further brought out by the fact that No. 1 contained 4.446 grams of nitrogen in the tops exclusive of ears while No. 8 contained 5.419 grams. This shows that there was actually a supply of nitrogen in No. 8 that could have been utilized in ear production if time had allowed.

TABLE 22. RATIO OF DRY WEIGHT TO GREEN WEIGHT OF TOPS AND THE PERCENT OF DRY MATTER IN THE PLANTS WHEN HARVESTED.

	Percent Dry Matter.	Dry Weight.	Green Weight.
A and B 1	26.04	1	3.83
A and B 2	27.55	1	3.62
A and B 3	22.04	1	4.53
A and B 4	26.89	1	3.71
A and B 5	23.79	1	4.20
A and B 6	18.20	1	5.49
A and B 7	21.36	1	4.68
A and B 8	19.12	1	5 22
A and B 9	13.40	1	7.45
A and B 10	15.33	1	6.52
A and B 11	9.89	1	10.11
A and B 12	14.68	1	6.81
A and B 13	8.25	1	12.10
A and B 14	19.59	1	5.10

Relation of Leaf Surface to Weight of Leaves—As the plants grew older there was a decided increase in thickness of leaf and weight of dry matter per unit area. This is well shown in the optimum and minimum nutrient treatments at different periods. The abbreviated table below, taken from Table 23 shows the square inches of leaf surface necessary to produce one gram of dry matter under extreme conditions.

	1st period	2nd period	3rd period
Continuous Optimum (a) No. 1.	57.9	26.1	23.3
Continuous Minimum (a) No. 5.	77.0	46.7	25.5

(a) the area of both sides of the leaves is considered.

TABLE 23. RELATION OF LEAF SURFACE TO WEIGHT OF LEAVES.

	Wt. Leaves	Leaf Area sq. in.	Sq. in. Area of Leaf= 1 gm. dry Mat.
A and B 1	222.7	5192	23.3
A and B 2	187.2	3722	19.8
A and B 3	112.0	2695	24.0
A and B 4	84.8	1895	22.3
A and B 5	39.9	1019	25.5
A and B 6	70.7	1223	17.3
A and B 7	166.1	3536	21.2
A and B 8	199.9	4476	22.3
A and B 9	197.0	5155	26.1
A and B 10	97.1	2939	30.2
A and B 11	16.9	980	57.9
A and B 12	17.8	833	46.7
A and B 13	95.7	4275	44.6
A and B 14	1.61	124	77.0

The foregoing figures show that with minimum nutrient the area per unit weight is greater than with optimum treatment. This is partly due to the fact that under the minimum nutrient the plants take up less mineral matter. The mineral matter does not account for all the weight however, and it seems certain that increasing the strength of solution greatly accelerates carbohydrate production in the leaves.

Figure 16 shows that none of the plants except No. 5 (M-M-M) and No. 6 (M-M-O) produced an increase in the amount of leaf surface during the third period. The leaf surface in the other treatments seemed to be at its maximum at, or shortly after the end of the second period. Usually about the time of ear formation some of the lower leaves began to dry up. This reduced the leaf area in several cases. This was not so noticeable in No. 6 and No. 8, which received optimum following minimum nutrients. The greatest total amount of leaf surface was in plants having optimum during the first and second periods regardless of the final period.

TABLE 24. AVERAGE LEAF AREAS (IN SQUARE INCHES).

Pot Nos.	Treatment	1st Period.	2nd Period.	3rd Period.
A and B 1	O-O-O	1074	5834	5192
A and B 2	O-O-M	912	5757	3722
A and B 3	O-M-O	962	2740	2695
A and B 4	O-M-M	975	2807	1895
A and B 5	M-M-M	99	763	1019
A and B 6	M-M-O	105	775	1223
A and B 7	M-O-M	107	4554	3536
A and B 8	M-O-O	104	4625	4476
A and B 9	O-O	1016	5155	----
A and B 10	O-M	1120	2939	----
A and B 11	O	980	----	----
A and B 12	M-M	115	833	----
A and B 13	M-O	110	4275	----
A and B 14	M	124	----	----

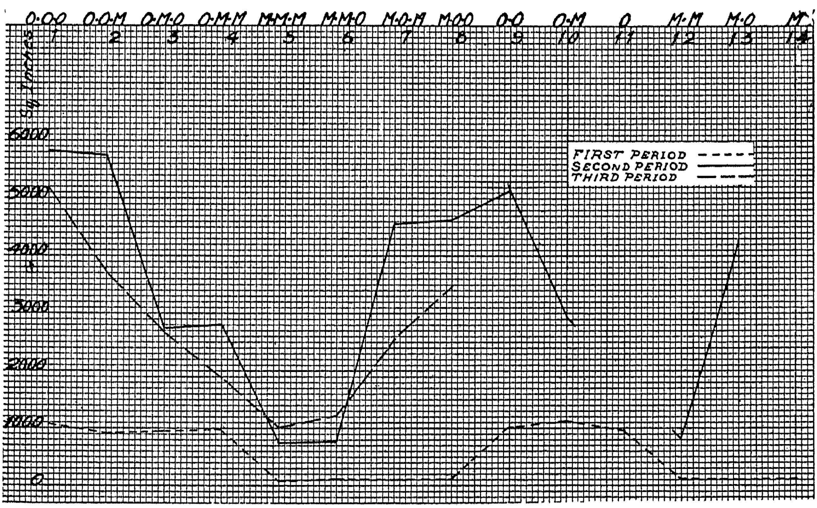

Fig. 16. Average leaf area for each treatment at different stages of growth.

Physiological Condition of Leaves—Where minimum nutrient was supplied the leaves took on a pale green color and showed a smaller supply of chlorophyll than in case of optimum nutrient. Often this was a yellowish green with light reddish striations. As the plants grew older the leaves began to die along the edges and sometimes the whole leaf died. This was most pronounced on plants that had minimum nutrient following optimum. Where minimum followed minimum the plants seemed to accustom themselves to the minimum nutrient and survived longer than plants such as No. 2 which received optimum nutrient at first and was later reduced to minimum.

TABLE 25. AVERAGE LENGTH OF INTERNODES UNDER DIFFERENT TREATMENTS.

	Av. Height* Plants 1914-16	Av. Number* leaves on 3 plants 1914-16	Av. Length Internodes 1915-16	Av. Length Internodes 1914-16
	Inches		*Inches*	*Inches*
A and B 1	100	46	6.82	6.54
A and B 2	101	45	6.75	6.74
A and B 3	75	42	4.99	5.49
A and B 4	74	43	4.57	5.26
A and B 5	57	31	4.83	5.74
A and B 6	62	29	6.62	6.57
A and B 7	90	40	7.09	6.65
A and B 8	89	40	7.14	6.70

*To nearest whole number for three plants in each cylinder.

The length of internodes was very noticeably affected by the different treatments. With minimum nutrient the length was materially reduced. This is most noticeable in No. 4 which had optimum nutrient the first period followed by two periods of minimum. The average length of internodes for the years 1915-1916 on plants from No. 4 (O-M-M) was 4.57 inches. On plants from No. 2 (O-O-M) it was 6.75 inches. It must be remembered, however, that the measurement included the entire stalk and tassel. The internodes below the ears were very much shorter than those above. The internodes on plants from No. 7 (M-O-M) and No. 8 (M-O-O) were also very materially lengthened by optimum during the second period and measured 7.09 inches and 7.14 inches respectively. The total number of leaves was reduced where the plants received minimum nutrient, particularly during the first period.

Plants Nos. 7 and 8 which had minimum treatment during the first period followed by optimum in the second period had fewer leaves than Nos. 1 and 2. The plants, however, were approximately the same height. The internodes were therefore longer than in the plants having optimum treatment during the first period. The length of internodes is not very well correlated with weight of stalks for in most cases plants having minimum nutrient during the last period showed a somewhat shorter internode and an increase in dry weight of stalk as compared with plants having similar treatment during the first two periods but optimum during the last period.

TABLE 26. PERCENT NITROGEN OF WHOLE PLANT CONTAINED IN LEAVES.

	1st period.	2nd period.	3rd period.
A and B 1	78.59	56.96	27.51
A and B 2	78.59	56.96	28.66
A and B 3	78.59	45.91	35.04
A and B 4	78.49	45.91	38.08
A and B 5	60.98	69.25	52.72
A and B 6	60.98	69.25	48.45
A and B 7	60.98	46.62	38.14
A and B 8	60.98	46.62	36.46

Loss of Elements During Growth—Some of the plants showed a loss in the total amount of the different elements during the last period. This was particularly true of the nitrogen and potassium where the plants were receiving minimum nutrient during the last period. A glance at Table 27 shows that the losses are few when the whole plant is considered. The number of losses greatly increase in certain parts of the plant as for example in the leaves as is shown in Table 28.

TABLE 27. TOTAL PLANTS GAIN OR LOSS OF TOTAL WEIGHT OF ELEMENTS DURING THIRD PERIOD.

	N	P	K	Ca.	Mg.
1	+	+	+	+	+
2	—	+	—	+	+
3	+	+	+	+	+
4	—	+	—	+	+
5	+	+	+	+	+
6	+	+	+	+	+
7	—	+	+	+	+
8	+	+	+	+	+

TABLE 28. LEAVES' GAIN OR LOSS OF ELEMENTS DURING THIRD PERIOD.

	N	P	K	Ca.	Mg.
1	—	+	—	+	+
2	—	—	—	—	—
3	+	+	+	+	+
4	—	—	—	—	—
5	+	+	+	+	+
6	+	+	+	+	+
7	—	—	—	+	+
8	+	+	+	+	+

Whether this greater loss from the leaves is due to leaching caused by rains as suggested by LeClerc and Breazeale[8] or to a translocation of the material cannot be definitely stated from the results of this experiment. As shown, previously, however, by a comparison of the nitrogen in the leaves and ears of plants No. 7 (M-O-M) and No. 8 (M-O-O) it seems that there must have been considerable translocation. From No. 2 (O-O-M) we might also be reasonably safe in assuming that there was some loss due to leaching. The percent nitrogen of the whole plant found in the leaves may be seen from Table 26.

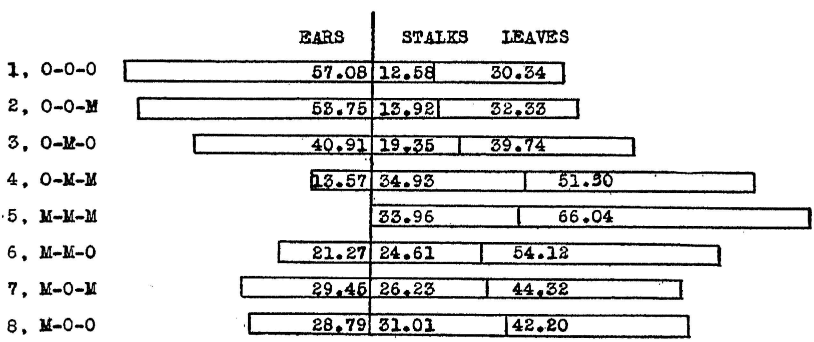

Fig. 17. Distribution of the nitrogen in the tops of the plants at the end of the third period. (The figures represent the percent of the total nitrogen contained in each part).

SUMMARY

1. In this experiment maize plants were grown in sand cultures with Pfeffers nutrient solution of normal and N/20 concentrations, these being used in all possible combinations, in the three 30-day periods of growth.

2. It was found that the second 30-day period was by far the most important in the production of the vegetative parts of the plants.

3. Ear production was confined entirely to the third 30-day period.

4. The growth of tops was increased by the optimum supply of solution, regardless of the period in which it was applied.

5. A low supply of nutrient solution was conductive to increased root weight and to fibrous root development. This was particuarly true during the last period.

6. The ratio of roots to tops became wider as the plants grew older, or as the concentration of the nutrient solution was increased. With minimum nutrient at the end of the first period the weight of roots was 61.18 percent of the total weight of plants, but at the end of the third period where optimum nutrient had been supplied throughout the three periods the weight of roots was only 12.29 percent of the total weight of plants.

7. Optimum nutrient during the third period largely determined ear production, but where there was a copious supply of mineral elements present at the end of the second period the leaves and stalks contained enough material to produce fair ears even where the third period had minimum nutrient.

8. The percent of nitrogen and potassium in the plants was approximately proportional to the supply of nutrients during the period just previous to harvest. The percent of phosphorus was much less influenced by a variation in the nutrient supply.

9. The percents of calcium and magnesium in the plants were more constant with the different treatments than those of the other elements. The calcium, however, showed considerable variation in the roots and leaves. The corn plants, seemed to be incapable of taking up these elements in excessive amounts even though there was a plentiful supply in the nutrient solution.

10. The percent of magnesium was higher than the percent of calcium in the ears, but was lower in all other parts of the plant.

11. The proportion of the total nitrogen of the plant that was contained in the roots increased whenever minimum nutrient was applied.

12. In plants where the growth was most nearly normal more than half the nitrogen in the tops was contained in the ears.

13. In the most fully developed plants the proportion of potassium in the roots was increased during the third period. This would seem to indicate a loss of this element from the tops or possibly a return of some of it to the roots by a downward movement from the aerial parts of the plant.

14. In all treatments and in each period, minimum nutrient supply allowed a greater proportional storage of nitrogen, phosphorus, and potassium in the roots than did optimum nutrients.

15. Minimum nutrient supply reduced the length of internodes, but this was most striking where the plants had received optimum nutrient during the first period.

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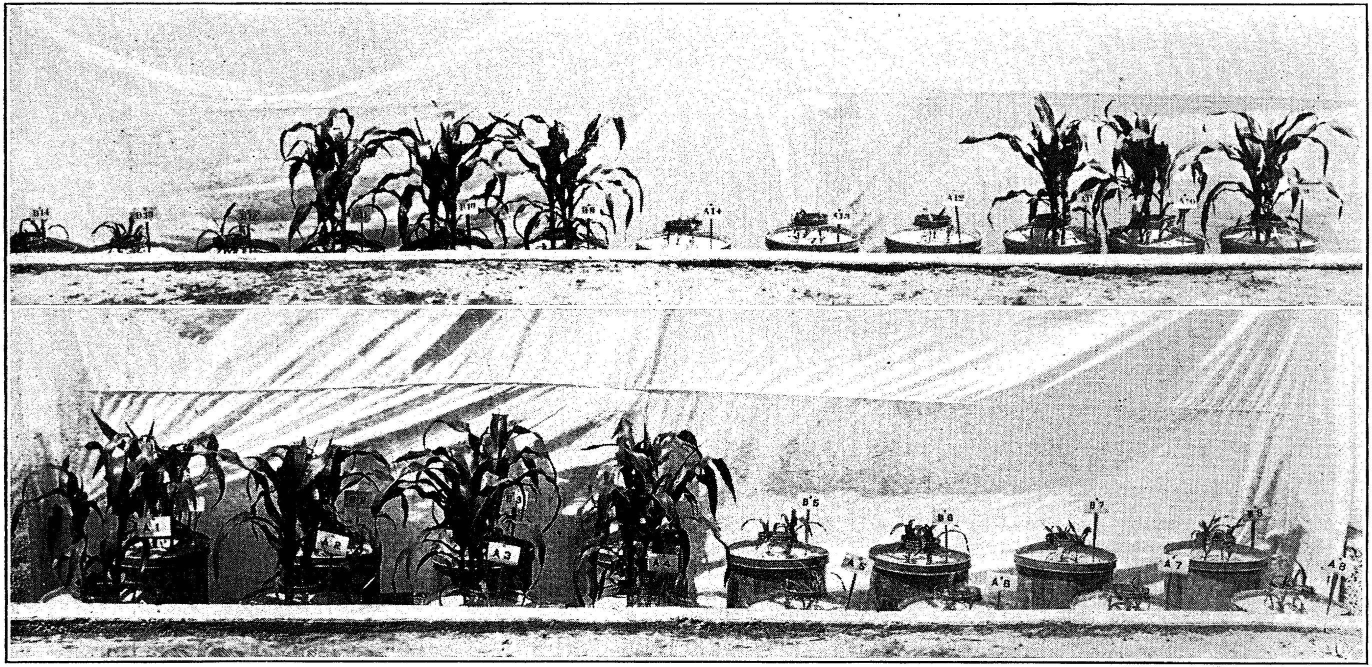

Plate I. Corn growing in sand culture. Series A and B, 1-14, July 5, 1916 End of first thirty-day period of growth. Pots 1 to 4 and 9 to 11 received normal (optimum) solution and pots 5 to 8 and 12 to 14 received 1/20 normal (minimum) nutrient solution.

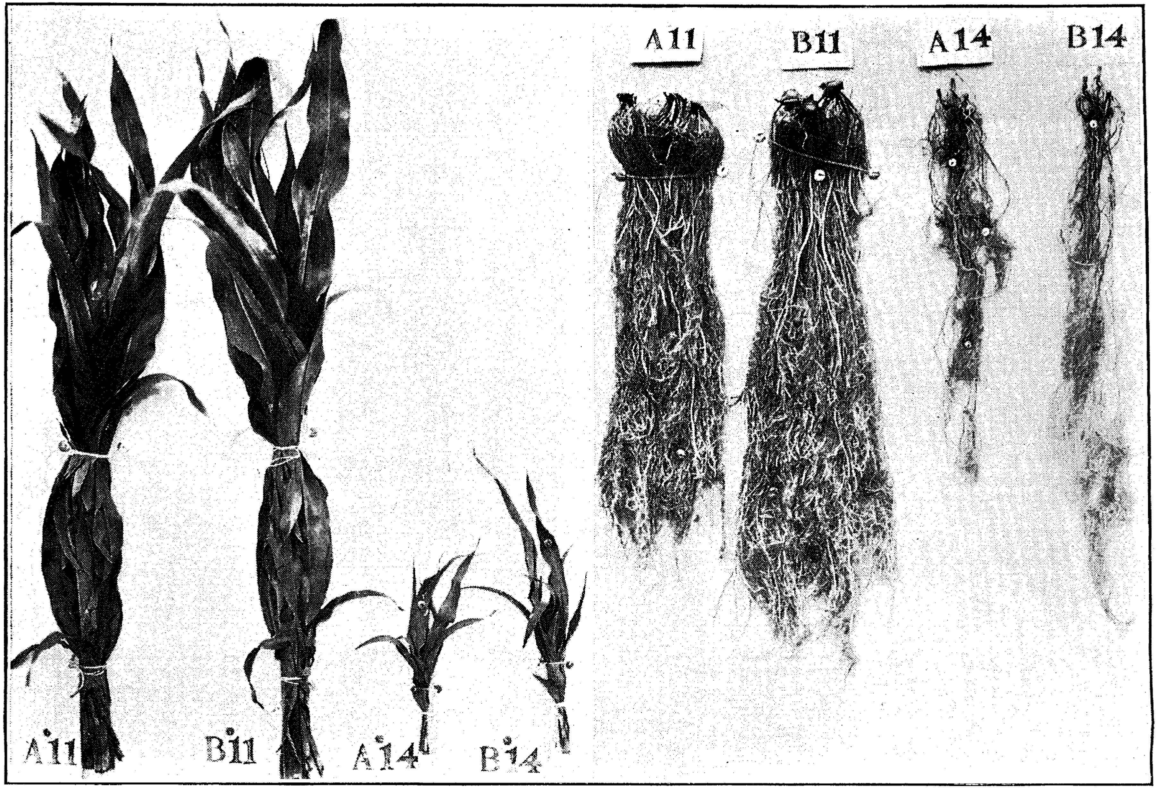

Plate II. Corn tops and roots harvested at end of first thirty-day period. A 11 and B 11 had optimum and A 14 and B 14 minimum nutrients.

Plate III. Corn at end of second thirty-day growing period. SeriesA and B 1 8.

	Treatment 1st period	Treatment 2nd period
A 1, B 1 A 2, B 2	Optimum	Optimum
A 3, B 3 A 4, B 4	Optimum	Minimum
A 5, B 5 A 6, B 6	Minimum	Minimum
A 7, B 7 A 8, B 8	Minimum	Optimum

B13 B12 B10 B9 A13 A12 A10 A9

Plate IV. Corn at end of second thirty-day growing period. Series A 9 - 10 - 12 - 13 and B 9 - 10 - 12 - 13.

	Treatment 1st period	Treatment 2nd period		Treatment 1st period	Treatment 2nd period
A 9, B 9	Optimum	Optimum	A 12, B 12	Minimum	Minimum
A 10, B 10	Optimum	Minimum	A 13, B 13	Minimum	Optimum

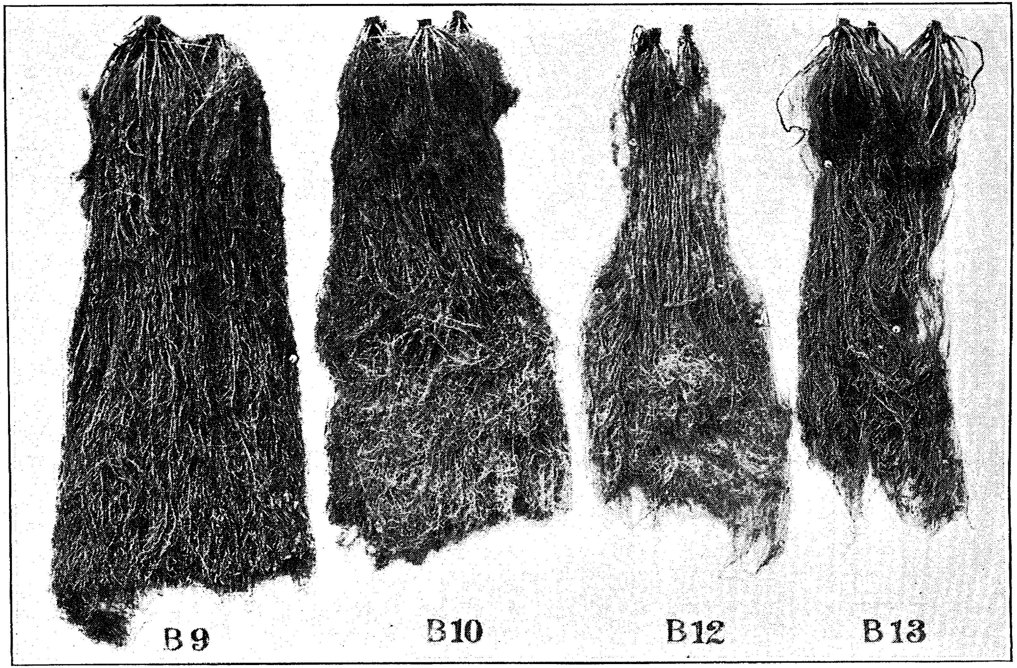

Plate V. Roots from plants harvested at end of second thirty-day period. These are from plants B 9 - 10 - 12 - 13 shown in Plate IV.

	Treatment 1st period	Treatment 2nd period		Treatment 1st period	Treatment 2nd period
B 9	Optimum	Optimum	B 12	Minimum	Minimum
B 10	Optimum	Minimum	B 13	Minimum	Optimum

Plate VI. Series A and B 1 - 8, end of third thirty-day growing period, showing condition of corn when harvested. The treatments were as follows:

	Treat. 1st period	Treat. 2nd period	Treat. 3rd per.		Treat. 1st period	Treat. 2nd period	Treat. 3rd period
A 1, B 1,	Optimum	Optimum	Optimum	A 5, B 5,	Minimum	Minimum	Minimum
A 2, B 2,	Optimum	Optimum	Minimum	A 6, B 6,	Minimum	Minimum	Optimum
A 3, B 3,	Optimum	Minimum	Optimum	A 7, B 7,	Minimum	Optimum	Minimum
A 4, B 4,	Optimum	Minimum	Minimum	A 8, B 8,	Minimum	Optimum	Optimum

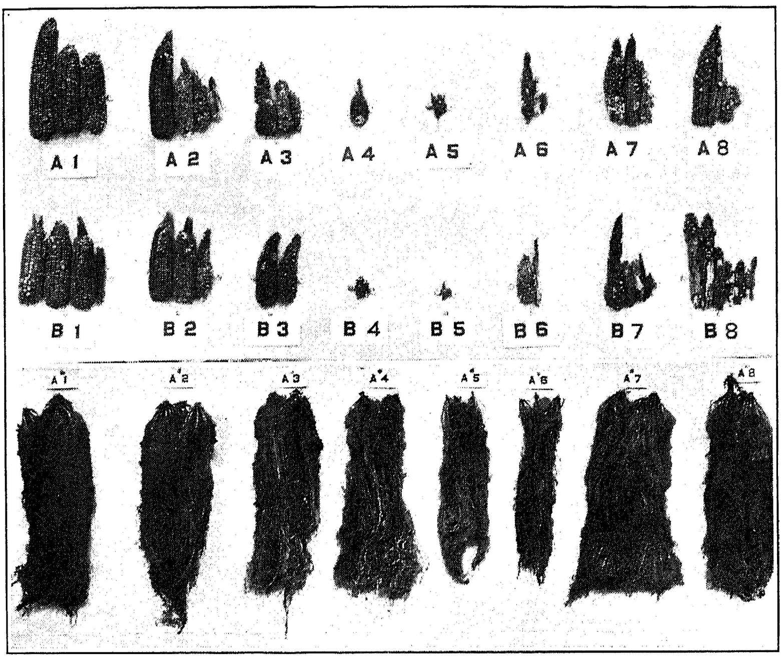

Plate VII. Ears and roots from plants receiving treatments as shown in Plate VI. Ears from 1915 crops; roots from 1916 crop.

ABOVE—A1 and A5
BELOW—A3 and A8

ABOVE—A3 and A2
BELOW—A6 and A7

Plate VIII. Direct comparison of some of the corn plants at the end of the third period, showing the effects of supply of nutrients at various stages of the plants' development.