

THE EFFECT OF DEFICIENT NUTRIENT SOLUTIONS AND LONG AND SHORT LIGHT PERIODS UPON THE CARBOHYDRATES OF PEAS THESIS FOR THE DIGREE OF M. S. B. H. Grigsby 1932

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> Thesis for Decree of L. S. B. L. <u>Grigsby</u> 1932.

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DN R.D. Hubbard

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INTRODUCTION

A study of the literature shows that considerable attention has been given to an inquiry into the influence of certain chemical elements on the rate of photosynthesis, and into the influence of the length of exposure to light on the amount of organic matter produced. The interaction of these two factors seems not to have received much serious attention.

The work reported in this paper is an attempt to show some effects upon photosynthesis and translocation in the garden pea arising from the deficiency of potassium and calcium in the nutrient solution and from three different light exposures.

HISTORICAL REVIEW

A study of photosynthesis can be grouped under two headings: the first including all work on the relation of mineral elements to photosynthesis and the second including all work on the effect of length of light period on the synthesis of food by plants.

A large part of the work with mineral elements has had to do with the effect of increasing amounts of the elements on photosynthesis, but with such work this paper is not concerned.

Nobbe (18), one of the earliest workers to study the effect of a so-called nutrient solution lacking an element, found that plants manufactured less starch when potassium was absent. Stoklasa (30) supported this view and reported a direct connection between the presence of

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potassium and photosynthetic activity. Reed (21), working with algae, mosses, and ferns, also found that potassium was essential for carbohydrate synthesis and showed that potassium accumulated in those parts of the plant concerned with carbohydrate transport. The theory that potassium functions in carbohydrate condensation is supported by Duggar (5,272), Hartwell (11), Killer (15,347), Russel (24,68), and Yasuda (32). Hartwell (11) also reported an accumulation of starch in vegetative parts of the plants growing in potassium deficient solutions and considered it due to retarded growth of the plants, due to lack of potassium. Janssen and Bartholomew (13) found that tomato plants deprived of potassium show an increase in percentage of dry matter.

Smith and Butler (28) found that wheat plants are able to translocate carbohydrates as readily in the absence of potassium as in its presence. Nightingale, Schemerhorn, and Robbins (16) found that tomato plants grown in a solution lacking potassium are able to translocate carbohydrates as well as plants high in potassium. They also reported that an accumulation of carbohydrates may occur because of the retarded nitrogen assimilation by plants in the deficient solution.

Much work has been done in regard to the effect of calcium deficiency in nutrient solutions. Most workers (5, 9, 12, 15, 19, 24, and 29) seem to agree that this element is used to neutralize certain acids produced in the growth processes of the plant. They also agree that calcium forms an intergal part of the cell walls, being laid down as calcium pectate in the middle lamella. Boehm (2) reported an indirect effect caused by lack of calcium. He found that it stops starch transfer because of an inactivation of the enzyme diastase. Groom (9)

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also reported an accumulation of starch in calcium deficient plants. In addition, he found that those carbohydrates that had been converted into starch could not be reconverted into soluble forms. Duggar (5, 180) and Killer (15, 257) report that calcium plays an important role in carbohydrate translocation.

Hobart (12) affirms that calcium has nothing to do with photosynthesis. Schimper (26) found that plants could translocate carbohydrates equally well in the absence of calcium as in its presence. Nichtingale, Addoms, Robbins, and Schermerhorn (17) supported this view and considered that any accumulation of carbohydrates in calcium deficient plants was due to a lack of nitrate absorption and subsequent protein synthesis.

Cruzit and Hibbard (10) reported that the absence of an element retarded translocation and impaired photosynthesis.

Tincker (31) found that plants in short light exposures were able to maintain a high rate of synthesis due to removal of the endproducts of the photosynthetic process. Redington (22) reported that light exposures up to eighteen hours gave better growth that most plants and that the poor growth of briefly exposed plants was due to impaired photosynthesis. Pfeiffer (20) found that with longer light exposures, tomato plants showed an increase in carbohydrate reserves and total growth over plants in short light exposures. Aso and Lurai (1) reported that barley and peas exposed to electric light at night made much faster growth than control plants. Deats (4) found that tomatoes and peppers exposed to light for varying periods had growth rates proportional to the length of light exposure. Starch formation was also found to be proportional to the length of day.

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Garner and Allard (8) reported that the growth of plants was proportional to the length of exposure to light and not to the intensity of the light.

Clements (3), working with water cultures, found that short exposures to light markedly affected the position of the best cultures on a twenty-one culture triangle.

EXPERIMENTAL PROCEDURE

The plants used in this experiment were grown in the Botany greenhouse at Michigan State College, East Lansing, Michigan. The water culture method was used in preference to sand cultures. One set of plants was grown in the spring of 1931 and another in the early winter of 1931. These particular seasons were chosen in order to secure conditions as favorable as possible for the growth of the plants, since in this locality plants do not grow well in the greenhouse during summer and early fall. The garden pea variety, Alaska, was used in both sets, because preliminary work showed that it grew exceedingly well in water cultures. It was also easy to secure a large number of seedlings similar as to age, length of leaf, and general vigor. The seed for both sets came from the same source and was from the 1930 crop.

Seeds were carefully selected for size, color, and healthy appearance. They were treated with 1 - 100 bichloride of mercury for five minutes and soaked in water for six hours. After soaking, the seeds were planted on moist paper toweling in a large galvanized iron germinating tray which had been cleaned and thoroughly disinfected. The seeds were kept covered and moist for five days, after which time it was possible to

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select seedlings that were healthy, with two-inch stems, and in sufficient quantity to fill all culture jars.

The culture solutions were made up in twelve-liter glazed stoneware jars. These jars before they were used were thoroughly cleaned, disinfected with a 1 - 100 solution of forty per cent formaldehyde and washed well with distilled water, to remove any formaldehyde that might have been left in the jars.

In this experiment Shives (27) three-salt nutrient medium R_5C_2 was used as the full or complete solution. The potassium deficient solutions were made by substituting sodium for the potassium ion in potassium phosphate. The calcium deficient solutions were made by replacing the calcium ion with sodium in equal proportions. All stock salt solutions were made up to 1 - molar concentrations in quantities sufficient for the entire experimental period. Culture solutions were then made up from these stock solutions to have a calculated osmotic concentration of one atmosphere. Table I shows the volume of stock salt solutions used in each type of culture solution.

Table I. Number of cubic centimeters of single salt stock solutions to make twelve liters of each type of culture solution and having (1) a total concentration of one atmosphere.

Culture	MgS0	$Ca(NO_3)$	KH_PO	NaNO_	NaH, PO
Complete	180	63	216	-	
linus Potassium	180	63	-	-	216
linus Calcium	180	•	216	63	•

(1) In addition, each culture received 20 c.c. of 5% ferric tartrate, 3 c.c. M MnSO₄ and 3 c.c. <u>M</u> H₃BO₃ solutions. 14

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The plants were grown on galvanized wire screening having four meshes to the inch. These screens were cut to fit the top of the jars, washed, heated, and coated with paraffin before being used. As the plants grew they were held upright by the aid of short wooden dowel pins 1/4" in diameter and sufficiently long to serve the purpose.

Fifty seedlings were placed on each of eighteen screens in such a manner that all seedlings received as nearly as possible the same amount of space. All seedlings were started on complete nutrient solution and given artificial illumination at night. Aëration was provided by forcing air to the bottom of the jars for a period of one hour and thirty minutes each day. These conditions were maintained for a period of two weeks during which time all solutions were renewed once. The cotyledons were then cut off and the stems supported by a small wad of non-absorbent cotton placed around the stem and the plants allowed to grow for another week.

When the plants were three weeks old and well established a certain number of them were transferred to solutions deficient in potassium or calcium and placed under varied light conditions. The cultures were divided into three groups. Six sets of fifty plants each were placed in solutions as follows:

- (1) two jars of solution R_5C_2 complete
- (2) two jars of solution R_5C_2 minus potassium
- (3) two jars of solution R_5C_2 minus calcium.

One group was left in the same place in the greenhouse it occupied in the beginning, but was not given any artificial illumination. Hereafter plants in this group will be referred to as "intermediate light" plants. A second group was placed in a large specially constructed,

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well as rated box so that all light could be kept out when that was necessary. This box was kept open for ten hours each day and the plants in this group will hereafter be referred to as "short light" plants. A third group was placed on a bench at one end of the greenhouse in the light given off by two 1000 watt Mazda lamps, provided with large Benjamin reflectors and suspended three and one-half feet above the top of the culture jars. These lights were turned on for the period of the experiment and the plants grown beneath will hereafter be referred to as "long light" plants. The temperature of the air above these plants was kept about equal to that of the air in other parts of the greenhouse by means of a twelve-inch electric fan kept running constantly. At night the light from the lamps was kept from the other plants in the greenhouse by means of a black cambric curtain.

Plants under all light exposures continued to receive the daily period of a fration and all solutions were renewed twice each week until the end of the experiment.

The experiment was considered completed when those plants, in all light exposures, which were in calcium deficient solutions showed definite injury and wilting had begun. At this stage observations on all plants were made and the plants harvested. Stems and leaves were separated, dried, weighed, ground, and later chemical (1) analyses were made of all samples.

(1) In the second series roots were also taken for analysis.

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CHEIICAL METHODS

All samples for analysis were dried according to the recommendations of the Committee on Methods for Chemical Analysis for the American Society of Plant Physiologists (23). Two-gram samples of the dried material were used for carbohydrate analysis. These were extracted with eighty per cent ethyl alcohol and filtered. The alcohol was removed from the filtrate by heating on an electric hot-plate and supplying a steady blast of air during the heating process. This method, adapted from the work of Gardner (7), saved several hours of time, but was wasteful of alcohol. Results obtained in this way were identical with those of duplicate samples evaporated by the method outlined by the Committee.

The residue, after evaporation, was taken up in water, clarified with Horme's dry lead, deleaded with disodium phosphate, following the recommendations of Englis and Tsang (6). It was then made up to volume aliquots taken for sucrose determinations.

Soluble dextrins, insoluble starches, and hemicelluloses were extracted by the method outlined by the Committee and the reducing power of all fractions determined by the Shaffer-Hartman (26) procedure. The results were calculated to grams of cuprous oxide and the corresponding amounts of glucose obtained from the Munson and Walker tables and expressed as per cent of dry weight. Tables III and IV show the results of the carbohydrate analyses.

For purposes of comparison the percentage of simple sugars and sucrose were combined and hereafter will be referred to as "sugars". The percentage of dextrin, insoluble starch and hemicellulose were

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combined likewise and will be referred to as "non-sugars". The values for sugars and non-sugars in plants in long light were taken as unity and ratios calculated for all other values for both Series I and II. These values are shown in Tables IV and VII.

DESCRIPTION OF PLANTS IN SERIES I AT HARVEST TIME

The plants in all cultures and under all light exposures appeared to grow normally for one week after being changed to the deficient solutions. After that time the minus calcium plants seemed to grow none at all and characteristic red patches began to appear on the leaves in all light exposures, the degree of injury being proportional to the length of exposure. These patches first appeared near the midrib and at the ends of small veins, but as the injury increased its spread outward toward the leaf margins until finally the entire leaf became dried and brown. Before the leaves became dry all tendrils on the plants had wilted and become dry. The potassium deficient plants also showed indications of leaf injury but of a different kind and to a lesser extent. In these plants grayish white patches appeared on the margins of the older leaves and gradually spread to the inner portions of the leaf. These patches seemed to be dry immediately after appearing, spread very slowly, and never appeared on young leaves. Plants in complete solutions showed no injury in any case. A detailed description of the plants under each light exposure follows.

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Series I

Long Light.

1. Complete:

plants healthy, 36 inches tall and growing vigorously, light green in color, many blossoms and pods.

2. Minus Potassium:

plants of same height as those in complete solution, color similar, but many leaves showing the type of inury just described, fewer blossoms and pods than in the complete solution.

3. Minus Calcium:

plants 24 inches tall, many of the leaves dying but still light green in color and showing the dark red patches already described, no blossoms or pods present.

Intermediate Light.

1. Complete:

plants 32 inches tall, dark green leaves, none of which were dead, several blossoms and pods present.

2. Minus Potassium:

plants 30 inches tall, leaves green but showing grayish patches described above, some blossoms and half grown pods present. 3. Minus Calcium:

plants 22 inches tall, leaves similar to those described under long light minus calcium, but more of them still green, no blossoms or pods present.

Short Light.

1. Complete:

plants 36 inches tall, as healthy as the "complete" plants in long and intermediate light, fewer blossoms and pods present than in other plants in complete solution.

2. Minus Potassium:

plants 34 inches tall, leaves green, but showing some grayish patches, few blossoms and pods present.

3. Minus Calcium:

plants 22 inches tall, leaves wilted but not dry, red patches present, few blossoms and no pods present.

EXPERIMENTAL RESULTS

The dry weights of stems and leaves of plants in Series I were taken and ratios calculated as percentages of dry weight of long light complete plants. These values are shown in Table II.

In Series I, plants in complete solution show a decrease in weight as the light exposure is shortened. Leaves in short light show an increase of six per cent in weight over the intermediate light plants and stems show an increase of one per cent, but these differences are not significant.

Leaves of minus potassium plants show a slight increase in weight in long light, but in all other light exposures there is a noticeable decrease. Minus potassium stems are lighter in dry weight than the complete stems. Short light minus potassium stems, however, show a five per cent increase over minus potassium plants in intermediate light, both show less increase than minus potassium long light plants.

Leaves of minus calcium plants show a decrease as the light period is shortened and the decrease is greater than in minus potassium or complete plants. The stems show practically the same weight in both short and intermediate light, but long light causes a nine per cent increase. All values for minus calcium stems are lower than the corresponding parts in other solutions.

These results are in accord with the generally observed fact that the length of light exposure directly influences the growth of plants and that growth generally decreases as the light is reduced. It is also observed, with one exception, that when an element is lacking a decrease in weight occurrs. Long light minus potassium leaves are the only exception. Minus calcium plants show the greatest decrease of all plants.

Thus, for plants growing in deficient solutions for the length of time they were in this experiment, and, for seedling plants of the garden pea, a deficient solution usually results in a low dry weight while a short light exposure produces the same effect but to a greater degree.

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		Le	aves	Ste	ms
Culture	Light	Dry wt.	Ratio	Dry wt.	Ratio
solution	treatment	grams		grams	
	Long	18.0876	100.0	24.9693	100.0
Complete	Inter- mediate	14.2092	78.0	18.0241	72.1
	Short	15.1986	84.0	18.2653	73.1
	Long	19.3430	106.7	18.4954	74.0
Minus Potassium	Inter- mediate	10.5518	58 .3	11.1094	45.5
	Short	9.2293	51.0	12.6393	50 .6
	Long	11.9764	66.1	8.9104	40.5
linus Calcium	Inter- mediate	10.2780	56.8	12.0752	49.2
	Short	7,8848	43.5	12,4518	49.7

Table II - Dry weights of leaves and stems in three different types of solutions and under three light exposures. The increases that did appear, as in the case of short light plants when compared with intermediate light plants, are so slight that no significance can be assigned to the results.

The effect produced by lack of potassium, however, is of a different nature and probably due to some interference with normal activity of the plant. This will be taken up later in the discussion when the results of chemical analyses are presented.

Table III shows the distribution of the various carbohydrate fractions in all solutions in Series I. The simple sugars in the leaves for the three light conditions in the complete solution do not vary much. Long light plants, however, show highest values while intermediate and short light plants are about the same. The values for sucrose in the leaves of these plants are much higher than the simple sugar values and show considerable variation. Soluble dextrins and insoluble starches in these plants are low but show rather wide variations as a result of the three light conditions. Hemicellulose in plants grown in this solution is quite high except for short light which indicates that there may be a utilization of this material by the plants for cell wall construction. The values for all these fractions in the stems correspond to those in the leaves, but are usually lower than the leaf values. The simple sugars and soluble dextrins, however, are exceptions.

In the case of leaves of minus potassium plants there is a great difference in simple sugars, depending upon the light exposure; while sucrose values show much similarity to sucrose values in plants grown in the complete solution and under corresponding light exposures. For this solution high soluble dextrin and insoluble starch values are

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Table III - Carbohydrate distribution in pes plants growing in three types of culture solutions under

three light exposures. Series I

				Leaves					Stems		
Culture sol.	Light treat.	Simple	Sucrose	Sol. dextrin	Insol.	Hemi- cellulose	Simple	Sucrose	Sol. dextrin	Insol.	Hemi- cellulose
	Long	2.30	7.40	0.75	0.37	5.02	4.11	5.04	1.00	0.36	6.00
Complete	Inter.	2.02	5.80	.68	.20	5.00	2.35	4.49	•78	•10	4.82
	Short	2.07	4.68	•30	60.	2.65	1.05	1.15	.28	60.	2.65
	Long	1.70	7.30	•30	1.70	4.16	2.05	3.10	•46	.26	5.35
Minus	Inter.	1.35	6.85	.53	.42	3.78	1.88	4.10	.45	.48	5.50
Potassiu	Short	.72	3.70	•35	.35	3.15	00.1	2.89	.21	.20	5.68
	Long	2.55	4.80	•60	.92	4.20	06.1	6,11	•60	•30	2.65
Minus	Inter.	94	4.45	.29	.40	2.90	.95	4.00	•29	•34	5.30
Calcium	Short	12.	2.96	.25	.45	3.95	.50	• 50	.25	•14	2.85

found as compared with these values in complete solution plants. Hemicellulose values, while they show the same reduction in short light, do not show such marked changes as they do in plants grown in complete solution. Stems in this solution show the same trend as the leaves.

The calcium deficient plants, show in both stems and leaves, much reduced values for simple sugars as compared to the values for complete solution plants. High values for insoluble starch are found in these plants as well as in the potassium deficient plants.

The use of a table of ratios will facilitate a comparison of the various culture solutions as influenced by light exposures. In Table IV the various carbohydrate fractions have been combined as sugars and non-sugars and ratios computed, based on the values for plants in the complete solution growing in long light.

A study of Table IV shows that the production of sugars and non-sugars, in both leaves and stems of plants grown in the complete solution, is always decreased as the light period is shortened.

The potassium deficient plants, with one exception, show decreases in sugars and non-sugars in shortened light exposures to a greater extent than the complete plants. The leaves in long light do not show a decrease in the amount of non-sugars produced.

Calcium deficient plants show the same response to shortened light exposures as the other two types of cultures, and the values are lower than the corresponding ones in minus potassium plants.

The results for deficient solutions in this Series indicate that the absence of either potassium or calcium interferes with photosynthesis, regardless of the light exposure, and are thus in accord with

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Table IV - Percentage of sugars and non-sugars in leaves and stems of plants of Series I. Ratios on .

basis of long light complete solution plants.

2 11			Let	AVes			Ste	sme	
Culture Sol.	Light treat.	Sugars	Ratio	Non-sugars	Ratio	Sugars	Ratio	Non-sugars	Ratio
	Long	9.70	100.0	6.14	0.001	9.14	100.0	7.36	100.0
Complete	Inter.	7.82	80.5	5,88	95.4	6.84	75.4	5.70	77.4
	Short	6.74	69.5	3,03	49.5	2.20	24.0	3.02	41.0
	Long	00.6	92.8	6.16	1.001	5.12	57.9	6.05	82.5
Minus	Inter.	8.20	84.5	4.53	72.4	5.88	64.5	6.43	87.2
Intession	Short	4.41	44.5	3,85	62.7	3.90	42.5	6.08	82.5
	Long	7.25	74.6	5.60	5.10	8.00	87.6	3.56	48.2
Minus	Inter.	5.39	55.5	3.60	58.6	4.95	54.1	3.93	53.7
UT 1 D TRO	Short	3,66	38.1	4.82	8.67	1.00	10.9	5.25	44.1

the findings of Gruzit and Hibbard (10). The nature of this interference will be discussed after the results of Series II are reported.

SERIES II

On November 17, 1931, a second Series of cultures were placed in the same type of culture solutions and under similar light conditions as Series I. These plants were just three weeks old at the time of change and had received the same treatment as those in Series I before being placed in the deficient solutions. Thus, there was a difference of one week in the age of the plants in the two Series at the time they were introduced to deficient solutions and changed light conditions.

With the exception of long light, which was the same in both Series of cultures, there was a difference in the amount of light naturally occurring. This was due to the season of the year and could not be avoided. The plants grown in the spring probably receive more sunlight than the fall grown plants, especially in the case of intermediate light plants.

Due to these differences in the age of plants and light conditions, the two Series of cultures are not duplicates and one can not be considered as a check on the results of the other. The plants of Series I were somewhat older than those of Series II and had produced a considerable number of blossoms and pods. Thus, some of the carbohydrates had gone into pod construction and are not shown in the analyses reported. However, the results are of value in that they exhibit similar effects and certain trends are established that make it possible to draw certain conclusions.

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Long Light.

1. Complete:

plants 34 inches tall, leaves dark green, few blossoms, but no pods present, roots long and apparently healthy.

2. Minus Potassium:

plants 34 inches tall, color similar to complete plants, but lower leaves showed gray patches on the margins, few shoots at base of the plants, fewer blossoms than complete plants, no pods present, roots shorter than those of plants in complete solution, but healthy in appearance.

3. Minus Calcium:

plants 20 inches high, but all dried, red patches very apparent in leaves and a few patches were present on the stems, no blossoms or pods present, roots short and very much branched, several shoots, two to four inches long, at the base of the plants.

Intermediate Light.

1. Complete:

plants 30 inches tall, small leaves, light green in color especially at the top of the plants, few blossoms and no pods present, roots long and healthy, no shoots at base of the plants. 2. Minus Potassium:

plants 30 inches tall, leaves light green in color and showing dried margins, few blossoms and no pods present, roots shorter than those in complete solution, intermediate light.

3. Minus Calcium:

plants 22 inches tall, but leaves wilted and showing red patches already described, no blossoms or pods present, roots short and yellow, many shoots at base, four to six inches long, and these also showing red patches.

Short Light.

1. Complete:

plants 30 inches tall, healthy but leaves light green in color, no blossoms or pods present, roots healthy and no shoots at base of the plants.

2. Minus Potassium:

plants 28 inches tall, leaves small and very light green in color, margins show grayish patches, no blossoms or pods present, roots short and a few shoots four inches long at base of the plants.

3. Minus Calcium:

plants 20 inches tall, but all of them dried, leaves show abundance of red patches, no blossoms or pods present, roots short and branched, no shoots at base.

EXPERIMENTAL RESULTS

The plants of Series II were harvested, The leaves and stems were separated and dried in exactly the same manner of those of Series I. In addition, the roots of these plants were also taken. The dry weights of all parts of the plants in the different types of solutions and under different light exposures were obtained, and ratios calculated based on long light complete solution plants. These values are recorded in Table V.

From this Table it is seen that in the complete solution there is a decrease in weight in all parts of the plant as the light exposure is decreased, thus agreeing with the results of the first Series.

The leaves of minus potassium plants in this Series again show an increase in weight in long light as compared with the leaves in the complete solution. In intermediate light plants, however, there is a decrease in weight in stems and roots as well as in leaves when compared with the plants in complete solution. All parts of the plants under short light show a slight increase in weight over those in complete solution under similar light conditions. The difference is considered too small to be significant.

Calcium deficient plants show a decrease in weight in all light exposures as compared to plants in complete solution, but the most significant decrease occurs in the case of long light. The differences between minus potassium and minus calcium plants are in no case significant.

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Table V - Dry weights of leaves, stems and roots in three types of culture solutions and under three light exposures. Series II

	1	Le	aves	St	ems	Ro	ots
Culture	Light	Dry wt.	Ratio	Dry wt.	Ratio	Dry wt.	Ratio
solution	treatment	grams		grams		grams	
	Long	14.1813	100.0	14.7973	100.0	7.1582	100.0
Complete	Inter.	11.6406	82.0	7.4328	50.2	5.7434	79 .7
	Short	6.7895	47.8	5.2974	35.8	3.3134	46.0
	Long	18.6200	131.0	21.2706	144.0	6.4284	89.4
Linus	Inter.	10.0427	70 .7	7.1690	48.4	4.2191	58.6
Potassium	Short	7.3650	52 . 2	5.3282	36.0	3.4574	43.8
	Long	11.5134	B1.0	9.7937	63.9	3.9293	54.6
Linu s	Inter.	10.8754	76.5	7.0318	47.5	3.4520	47.9
Calcium	Short	6.7383	47.4	4.8346	32.7	2.8973	40.3

In plants in deficient solutions under all $li_{\mathcal{E}}ht$ exposures the greatest variations in dry weight occur in the stems which indicates that translocation of materials has been influenced in some manner by the treatments given.

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In the case of short exposures to light, the light and not the nutrient solution is clearly the limiting factor. The plants are not receiving enough light to enable them to function in a normal manner, therefore under these conditions, variations in weight due to culture solutions are not apparent. Under other light exposures, however, the effects of nutrient conditions can be readily seen.

The distribution of the carbohydrate fractions in the plants of Series II is shown in Table VI. The results obtained for plants in complete solution and under long light again may be considered as a control and compared to those values obtained from plants growing in deficient solution. Here, as in Series I, we find that all fractions are decreased in value as the light exposure is shortened and that the greatest variations are found in the amount of sucrose produced. The amounts of all fractions, except dextrin and hemicellulose, are usually greater in the leaves than in the stems. This is especially true in the case of short light plants. In long light the stems may show slightly higher values than the leaves and this is probably due to a greater abundance of material available for translocation under this condition. In other light conditions the plants probably are not able to manufacture a supply of food much in excess of their immediate needs, and consequently there is a smaller supply available for translocation and storage, thus giving low values for carbohydrates in the stems.

Table VI - Carbohydrete distribution in pes plants growing in three types of culture solutions and under

three light exposures. Series II

2011		1		Leaves					Stems		
Culture Sol.	Light treat.	Simple	Sucrose	Sol. dextrin	Insol.	Hemi- cellulose	Simple	Sucrose	Sol. dextrin	Insol.	Hemi- cellulose
1.000	Long	4.30	5.40	0.40	0.40	4.52	4.60	5.81	0.52	0.42	6.00
Complete	Inter.	2.45	2,87	•28	.30	4.20	1.09	2.47	•51	60.	5.62
	Short	1.25	2.43	.20	.25	3.89	•80	•60	.40	60.	5.02
	Long	1.15	4.24	.35	1.10	5.21	1.67	1.59	•10	.14	6.05
Minus	Inter.	1.10	3.20	.24	.14	3.25	1.50	1.63	.10	.10	4.62
ntespior	Short	1.00	8.15	•50	.23	5.37	.45	1.47	.14	.14	4.82
	Long	1.79	11.5	•55	•30	1.00	1.09	3.27	.40	•30	2.20
Minus	Inter.	1.77	3.12	.52	.40	1.00	1.05	2.25	.44	.40	1.40
IMTOTRO	Short	•52	2.30	.47	.50	3.30	.94	1.23	.39	.50	1.14

In the plants growing in minus potassium solution there is a marked falling off in the amounts of simple sugars and sucrose formed and the decline is more pronounced as the light period is shortened. After exposure to long light, however, it is shown that insoluble starch and hemicellulose accumulate in the leaves. Evidently these plants are able to produce a certain amount of material that is changed into insoluble forms and then are unable to reconvert them into materials that can be moved. The stems of these plants show a decrease in these two fractions, especially in the case of insoluble starch.

Plants in minus calcium solutions show a great reduction in all fractions under all light conditions, with the exception of hemicellulose in the leaves of short light plants. This value for hemicellulose, however, is below the corresponding one in complete solution plants. Reed (21), Miller (15) Duccar (5), and others have ascribed to calcium a role in translocation of carbohydrates and have not considered it as important in the synthesis of these products. It should be borne in mind, however, that because of the difficulty in separating the two processes, a statement that calcium functions in one process and does not function in the other, can hardly be made. The results, reported here, indicate that calcium is important in the process of translocation and that it also has a very vital function in the synthesis of carbohydrates. When calcium is lacking very low values are obtained for simple sugars, sucrose, and hemicellulose in the leaves. The stems also show correspond-It seems likely that these plants have not been able ing decreases. to produce any appreciable quantities of food and have been forced to call upon the materials already made and stored before the period of deficiency

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a lack of calcium. Thus, destructive or katabolic processes are taking place. That this may have happened is indicated by the fact that the amount of sugars is somewhat reduced and the amount of non-sugars is greatly reduced. The fact that the plants were gradually dying and the manner of the dying process also lends support to this view. Reserve material probably could not be broken down rapidly enough to supply the needs of the plant, therefore, death from starvation occurs in those parts more remote from the food supply. This was shown by the death of tendrils and young leaves and also by the failure of plants to produce blossoms.

The results of the analyses of the roots of plants in this Series are shown in Table VII. The values for sugars are quite low, but non-sugars, the bulk of which is hemicellulose, are quite high, regardless of the culture solution and light exposure. The results have little value other than to point out the small amounts of sugars and the abundance of non-sugars present in all types of culture solution and under all light exposures.

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Ratios Table VII - Percentage of sugars and non-sugars in lecves, stems and roots of plants of Series II.

on basis of long light complete solution plants.

and the second second		10 m 10	Tes	TVOS			St	ems	2	2	Root	02	
Culture Sol.	Light treat.	Sugars	Ratio	Non-sugars	Ratio	Sugars	Ratio	Non-sugars	Ratio	Sugars	Retio	Non- sugars	Ratio
	Long	9.72	100.0	5.32	100.0	10.40	100.0	6.94	100.0	1.39	100.0	7.49	100.0
Complete	Inter.	5.33	55.1	4.79	5.16	3.58	39.3	6.22	0.06	1.90	136.7	8.75	117.0
	Short	3.68	37.8	4.34	81.7	1.40	16.4	5.51	62.3	.65	46.7	7.72	103.0
	Long	5.39	55.7	6.62	125.0	3.62	35.2	6.29	90.2	1.47	100.8	7.54	1.101
Minus	Inter.	4.30	44.7	3.68	68.4	3,14	34.4	4,83	69.69	1.67	101.4	7.82	104.5
POTASSIU	Short	3.15	32.5	4.12	2*44	1.92	20.3	5.10	73.6	.64	46.7	7.32	99.8
	Long	4.90	50.4	1.90	35.8	4.36	47.7	2.90	41.7	1.40	100.0	7.50	100.0
Minus	Inter.	4.90	50.4	1.92	36.2	3.30	36.1	2.25	32.3	1.35	99.8	1.85	104.8
mioran	Short	2.85	29.4	4.29	80.9	2.18	24.0	2.04	29.5	.67	49.0	7.29	97.2

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Most workers agree in assigning to potassium the role of aiding in the condensation processes rather than in modifying translocation. It is not intended that this work should be taken as a direct contradiction of that idea. The plants in these experiments probably had stored enough potassium to enable them to carry on condensation processes for the length of time they were in deficient solutions, but the supply may not have been in excess of such needs. Plants are known to have the ability to transport potassium to those points where it is needed most, therefore the potassium in these plants may have been concentrated in synthesizing regions and none of it left for translocation purposes. It is merely suggested here that potassium may also play an important part in translocation as well as in condensation processes.

Flants in the minus calcium solution show a decrease in the production of sugars and non-sugars in both leaves and stems as compared to the values of corresponding light conditions in complete solution plants. The values are also lower than those in potassium deficient plants. Variations between long and intermediate light plants are not significant, but the fractions in short light are probably significantly lower than those in the other solutions. The stems of all calcium deficient plants show variations that follow the same general order as those in complete and minus potassium stems. The values for long and intermediate light plants are again approximately the same, but short light plants show quite a large decrease from the corresponding values in the other two types of solutions.

The good growth and the apparently healthy condition of the plants before they were placed in deficient solutions indicated that the supply of calcium was adequate all growth processes. It is generally observed that calcium is not easily moved in plants after it has once been laid down. This being the case, the plants would not be able to use the calcium in translocation of materials and a deficiency of calcium in the nutrient solution would likely be manifested in the amount of reserve materials in the stems of the deficient plants. The results give support to this view in every case. In addition, there is also a considerable decrease in the amount of sugars formed which indicates that the plants have had difficulty in synthesizing the more soluble carbohydrates.

The general appearance of the plants indicated that little if any growth had taken place while in the deficient solution. The height of the plants, as compared with those in complete and minus potassium solutions, suggested also that little if any growth had occurred.

If these plants have not had enough calcium to provide for growth there probably was less to provide for translocation, therefore, it seems logical to conclude that a disturbance in translocation would take place. The results seem to show that this is the correct conclusion. The data do not permit any positive statement in regard to the function of calcium in the synthesis of carbohydrates, but a relationship is seemingly indicated. Further work toward this end would probably yield valuable information.

The low values for short light plants can probably be best explained by the fact that plants are synthesizing very little because of the reduced light supply and in addition are suffering from •

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a lack of calcium. Thus, destructive or katabolic processes are taking place. That this may have happened is indicated by the fact that the amount of sugars is somewhat reduced and the amount of non-sugars is greatly reduced. The fact that the plants were gradually dying and the marner of the dying process also lends support to this view. Resorve material probably could not be broken down repidly enough to supply the needs of the plant, therefore, death from starvation occurs in those parts more remote from the food supply. This was shown by the doubt of tendrils and young leaves and also by the failure of plants to produce blocsoms.

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2. The data show that length of light exposure directly influences the amount of dry matter produced by the plants.

3. A deficiency of potassium may cause an increase in the weight of leaves produced by plants exposed to light for long periods but not in weight of stems.

4. Short and intermediate light exposures coupled with the lack of potassium produce a much reduced dry weight as compared with that of plants in a complete solution.

5. A deficiency of calcium produces a reduction in dry weight under all light conditions.

6. The production of carbohydrates is influenced by the length of light exposure.

7. Translocation of carbohydrates may be influenced by lack of potassium in plants growing in long light. Such plants show an increase of hemicellulose and insoluble starch in the leaves when compared with plants in complete solution.

8. Production of carbohydrates in all other light exposures is decreased by lack of potassium.

9. Lack of calcium tends to produce a reduction in the amount of carbohydrates formed and transported under all light conditions.
10. It is suggested that plants in calcium deficient solutions and under short light exposures break down products elaborated before the period of deficiency began, to supply the necessary energy to maintain life until death sets in.

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