RELATION OF FERTILIZER AND LIGHT TREATMENTS TO THE TOP ROOT RATIO IN LETTUCE AND RADISH

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RELATION OF FERTILIZER AND LIGHT TREATMENTS

TO THE TOP/ROOT RATIO IN LETTUCE

AND RADISH

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THESIS

INTRODUCTION

The study of the effects of nutrient supply on the ratio of tops to roots in plants is of much interest to the horticulturist and considerable work has been done in attempting to determine whether the desirable increase in top/root ratio in a foliage crop or the desirable decrease in top/root ratio in a root crop may be secured through varying fertilizer treatments.

The effects of variations in length of daily light period on top/root ratio and the reasons for these effects are also of interest but much less work has been done on this phase of the subject. Recent suggestions of a practical use for artificial illumination in the growing of plants have occasioned this phase of the work.

It is the aim of this paper to present data in regard to the effects of various combinations of fertilizer and light treatments on the distribution of growth in tops and roots of lettuce and radish plants.

REVIEW OF LITERATURE

Several factors with regard to variations in nutrient supply and their effects on the distribution of growth in top and root have been studied in the past.

Sachs (19) showed that roots were shorter in nutrient solutions of higher concentrations, and Nobbe (15) showed that this same factor caused them to be more branched.

Moeller (13) found that more dilute nutrient solutions caused a decrease in actual root weight and at the same time caused a decrease of sixty percent in top/root ratio below that found in plants grown in more concentrated nutrient solutions with which he worked.

Tucker and von Seelhorst, (24) and Thiel (22) found that there were relatively more roots in soils with low moisture than in soils with high moisture, and also that there were more roots in soils having a low fertility than in those having high fertility, while von Seelhorst (20), working on rye, wheat, barley, peas, beans, and field beets, concluded that with high fertility, root systems were larger and descended more deeply into the soil.

Livingston, (12) working with wheat, found that increasing fertility by the use of stable manure caused an increase in root system due to an increase in secondary and not in primary roots. He also found that there was no increase in dry weight of roots in the fertilizer treatments.

Polle (17) found root systems more branched and with higher absolute weight in unfertilized soil.

Harris (9) found that tops and roots of plants grown in concentrated soil extract were greater in green weight, dry weight, and length. He also found that increased moisture and fertilizer, both had a positive effect on the ratio of tops to roots. Weights of roots in the dryest sand used were about three times the weights of tops attached to them, while in wet sand the tops and roots were about equal in weight. Increase in ratio due to fertilizer was caused chiefly by increase in actual weight of tops. More concentrated nutrient solution was found by Duley and Miller (5) to increase the ratio of tops to roots in corn plants. They found that this ratio increased as the plants grew older.

Brenchley and Jackson (2) state that of the plants nutrients tried, sodium nitrate was most effective in promoting root growth in barley and wheat plants. The effect of nitrates in solution was also studied by Turner (25) who found that in corn and barley, top/root ratios were increased as the concentrations of nitrates in the solutions were increased.

Tufts (23) drew the conclusion from work on nursery stock that pruning or cutting back of tops caused a decrease in root development. However correct this conclusion may be, the evidence which he presents to substantiate his contention must be considered insufficient for he quotes only coefficients of correlation between tops and roots in proof of it. A high coefficient of correlation between tops and roots of plants which were unpruned and another high coefficient of correlation between the tops and roots of the plants which were pruned does not indicate that pruning decreased root development, but simply indicates that within either one of these lots, the top growth nearly parallels root growth. The coefficients of correlation would still be very high if the pruning had greatly increased root growth, provided the weights of roots bore a rather constant relationship to the weights of the corresponding tops in that particular lot of plants. However, Chandler (3) gives figures to show that the dry weight of roots of severely pruned apple trees was 49.5 percent below the dry weight of roots of unpruned trees. Loomis (11), working on vegetable crops, found that severe root pruning had no permanent effect on the top/root ratio.

It may be seen from the foregoing review of literature that many workers have secured results which are apparently contradictory to the results found by other workers. In general, it may be said that no consistently significant effects have been produced by any practical fertilizer or cultural treatment.

Considerable data on the different effects of artificial illumination and shortened day on the growth of plants are available but very little of it pertains to the effects of varied length of daily light period on the distribution of growth in top and root.

The first experiments with varied light periods were those of Siemens (21) who found that electric light produced much the same effect as sunlight on plants and concluded that it could be used a s supplementary illumination.

Bailey, working with the electric light at Cornell, (1) showed that the light caused fifty percent improvement in lettuce over the checks in three weeks time after transplanting. He concluded that electric light could be used to advantage in the forcing of some crops as it caused better growth and earlier maturity. The effect of light on growth and earliness of lettuce was also observed by Rane(18). He found that added light caused some plants such as spinach and endive to run quickly to seed, while with the radishes, he concluded that proper watering was more beneficial than improper watering plus light. He worked with the incandescent lamp and found it superior to the electric arc light.

The incandescent gas light was used by Corbett. (4) He found the light caused earlier maturity in lettuce, earlier blooming in tomatoes, and a higher sugar content but loss of weight in roots in sugar beets.

Garner and Allard (6) worked on the effects of varied lengths of daily light period with special reference to their effects on vegetative growth and the initiation of the reproductive processes in plants. They found that sexual reproduction in plants would take place only under favorable length of day, which might be a long day or a short day, depending on the individual variety of the plant. Other than favorable length of day caused unfruitfulness. This was sometimes accompanied by unusual vegetative growth while at other times it resulted in dwarfism. They learned, too, that tuber formation in the Irish potato proceeded much more rapidly with a daily light period of ten hours than with light periods of either five or thirteen hours. (7) They also found that long day caused a higher content of reducing sugar in the plant.

Oakley and Westover (16) showed that the effects of varied day lengths on seedlings of some varieties of alfalfa were sufficiently different from the effects on other varieties to make it possible to identify alfalfa varieties by simply growing them under varied lengths of day and observing their behavior. Nightingale (14) concluded that the effects of varied day lengths were associated, in part at least, with the effects of light on synthesis of nitrogenous compounds from soluble nitrogen and the subsequent effect of this nitrogen on carbohydrate utilization. A speeding up of the time of blooming of Easter lilies was found by Hendricks and Harvey (10) to be correlated with an increase in carbohydrate content of the leaves when grown under continuous artificial light. They found a specificity in light intensities for blooming, which varied for different plants.

Working (26) found that light is a very essential factor in the production of new roots of asparabus and suggested that this may be due to a change in the carbohydrate gradient due to photosynthesis.

The effects of light treatments on the top/root ratio have not been studied very extensively for little published work on this phase of the subject could be found. In all other cases of the study of factors affecting top/root ratio, the actual individual ratios have not been calculated, the ratio of the average weight of tops to the average weight of roots having been used instead.

EXPLANATORY NOTES

All the plants in the following experiments were grown in new six-inch pots, each pot being supplied with drainage material and filled with loose soil which was then compacted slightly and watered. As soon as the plants were set the pots were plunged in sand in a bench, care being taken to distribute the treatments well throughout the bench to eliminate place effects. In order to keep soil moisture nearly constant, all watering was done with a measure so that each pot received the same amount of water.

The radishes used in these experiments were grown from seed furnished by Professor George E. Starr and consisted of a strain of the Scarlet Globe variety, specially selected for uniformity in growth and type. The plants were grown in flats and carefully selected when they were put into pots. The lettuce was grown from seed secured from Mr. Yonker of Grand Rapids and the variety was Grand Rapids Forcing. The seed was sown very thickly in flats and the plants carefully selected when they were pricked off into the bench. They were again selected when they were potted.

In harvesting, the tops were cut off at the ground surface and individual green weights secured immediately. Samples of the tops were taken for analysis and moisture determination.

The roots were carefully washed out in water, rinsed in clear water, and the excess moisture removed by leaving them between sheets of paper for a short time. The individual green weights were then determined, care being taken to record each root weight along with its corresponding top. Samples of the roots were also taken for chemical analysis and determination of the percentages of moisture in each lot.

In all the data presented, the average green weights of tops and roots in each of the lots are given along with the probable errors of these averages. The probable errors were computed by the formula: P. E. = standard deviation times .6745, when the standard deviation is $\frac{\Sigma d^2}{N}$. (Σd^2 indicates the sum of the squares of the individual deviations from the mean, and N stands for the number of plants in that treatment.)

In all cases the ratio of top to root was calculated for each plant separately and the average for each lot is shown in the tables along with its probable error as calculated by the formula just described.

It should be noted that in no piece of work which has been published on this subject have the individual ratios or average ratios been calculated. It has always been taken for granted that the ratio of the average weight of tops to the average weight of roots was the same as the average ratio of tops to roots when these ratios were calculated individually. These quantities may or may not be equal. In other words, $\frac{\Sigma T}{N} \Big/ \frac{\Sigma R}{N}$ may or may not equal $\frac{\Sigma T/R}{N}$. These quotients will vary very widely, especially when the absolute ratios vary considerably along with rather wide variations in actual weights of tops and roots. A single example will suffice to draw attention to this difference.

	Weight of tops	Weight of roots	T/R calculated individually
	18	16	1.12
	10	2	5.00
Average	14	9	3.06

But 14/9 = 1.55

Here it is seen that the ratio of averages or $\frac{\Sigma T}{N} \Big/ \frac{\Sigma R}{N}$ is 1.55 while the average ratio, or $\frac{\Sigma T/R}{N}$ is 3.06. Extreme variations have been chosen here in order to accentuate the difference between average ratio and the ratio of averages, but the fact remains that there was not a case in the work done where these figures were exactly coincident.

The following procedure was employed in the analysis for carbohydrates.

Sampling.

The green material was immediately cut up finely with a knife and well mixed. A weighed beaker was filled with this material and again weighed. This was placed in an oven at 86° C. until the contents were thoroughly dry, weighed again, and the dry material saved for analysis.

Grinding.

The dry material was ground in a mortar until it would all pass through a 60-mesh screen. It was then placed in 8-oz. bottles and heated in the oven to drive off hygroscopic moisture.

Preparation of Extract.

One gram of the oven dry material was placed on a filter and washed six to eight times with successive portions of cold distilled water, the filtrate being caught in a 250 cc. volumetric flask. The residue was saved for starch analysis. The filtrate was clarified with dry lead sub-acetate, made up to volume, filtered. 200 cc. of this filtrate was transferred to a 250 cc. volumetric flask and de-leaded with dry sodium carbonate. It was then made up to volume and filtered again and the filtrate saved to furnish aliquots for sugars and for hydrolysis in the determination of total sugars.

Free-reducing sugars.

30 cc. of the $CuSO_4$ solution, 30 cc. of the alkaline tartrate solution, and 60 cc. of water were placed in a beaker and brought to boiling. 25 cc. of the water extract of the material under examination were then added and boiled two minutes, keeping the beaker covered with a watch glass. It was immediately filtered through a prepared, dried, and weighed gooch crucible, using suction. The oxide on the filter was washed with water at 60° C. and with a small quantity of alcohol. The gooch crucible was then placed in an oven for thirty minutes, cooled in a dessicator, and weighed. The quantity of cuprous oxide was then determined and the equivalent quantity of dextrose secured from Allihn's tables.

Total sugars.

50 cc. of the original sugar solution were pipetted off into a 100 cc. volumetric flask, neutralized with HCl, and 5 cc. of concentrated HCl added. This flask was then placed in a water bath at 60° C. and held there for fifteen minutes, removed, cooled, neutralized, and made up to volume. Determination of dextrose was made as in the case of free-reducing sugars, using 25 cc. of this solution.

Sucrose

The difference between total sugars and free-reducing sugars gives the amount of sucrose.

Starch.

The filter paper, holding the sugar-free solid residue, was punctured and the residue washed into a small beaker. This was held on a hot water bath for fifteen minutes and the contents stirred constantly, cooled, a solution containing .1 gram of taka-diastase added, and this solution incubated at 35° to 40° C. for 24 hours. It was then filtered into a 700 cc. Erlenmeyer flask, 8 cc. of concentrated HCl added in sufficient water to bring the volume up to about 150 cc. The flask was then connected to a reflux condenser and heated for 2.5 hours, cooled, neutralized with NaOH, clarified with lead sub-acetate, made up to 250 cc. volume and filtered. A 200 cc. portion of this filtrate was deleaded with Na_2CO_3, made up to volume, and filtered again. Determination of dextrose was made exactly the same as in the case of free-reducing sugars, using a 25 cc. aliquot of this solution.

Total polysaccharides.

A one-gram sample of the original dry material was placed on a filter and the sugars removed by washing several times with water at 30° to 40° C. The residue was then washed into a 700 cc. flask and hydrolyzed with HCl as in the case of starch determination. the clarification and deleading processes, and the determination of the amount of dextrose were identical with those employed in the determination of starch, after the starch had been hydrolyzed in a similar manner.

EXPERIMENTAL DATA

EXPERIMENT I.

Effects of Good and Poor Soils, and of Single and Cumulative applications of Fertilizers on Shoot/Root Ratio in Lettuce and Radish.

Lettuce was sown broadcast in flats on October 14, 1924, pricked off on October 20, and transplanted into pots on November 7. Radishes were sown on October 20 and were potted on November 7. The radishes grown in poor soil were sown December 15, 1924, and potted January 13, 1925. The lettuce was harvested February 9, 1925. The first crop of radishes was harvested December 15, 1924 and the second crop on February 19, 1925.

Two kinds of soil were used in this experiment. The good soil consisted of five parts of loam, thoroughly mixed with one part of coarse sand. The poor soil consisted of five parts of coarse sand, mixed with one part of loam.

The data secured are presented in Tables I and II. It will be observed from the results shown in Table I on lettuce, that lots 1, 3, and 7 have top/root ratios which are apparently higher in the good soil than in the poor soil, while in lots 5, 9, 11, and 13, the reverse is true. Since these effects of good and poor soils are inconsistent and insignificant as determined by their probable errors, no generalizations as to differences in soils may be made.

In comparing fertilizer treatments, the top/root ratios in lots 13 and 14, both of which received potassium fertilizer, are lower than in any other treatment of the series. This difference is significant, while there are no significant differences among any of the other treatments.

In every case shown in Table II, the ratio of tops to roots in radishes is less in poor soil than in good soil, but in no instance is this difference sign-ificant.

Lot No. 5, which was grown in good soil and fertilized with potassium, had a top/root ratio which was apparently lower than the top/root ratios in any of the other good soil treatments of this series. The same holds true for the potassium treatment in poor soil, Lot No. 6. Again, these differences cannot be relied upon as furnishing conclusive evidence of fertilizer effects since their probable errors destroy their significance.

Table I. Effects of different soils and soil treatments on shoot/root ratio in lettuce.

Lot	Kind of soil	No. of plants	Fertilizer treatments (1)	Av. green weight tops (grams)	Av. green weight roots (grams)	Av. ratio top/root R=1
1	Good	20	None	61.0 ± 2.21	19.9 ± .30	3.06 ± .64
2	Poor	20	None	63.5 ± 2.57	27.0 ± .95	2.35 ± .47
3	Good	19	$Ca(NO_3)_2$	96.6 ± 2.70	23.8 ± 1.22	4.06 ± .86
4	Poor	20	"	100.0 ± 3.21	25.1 ± 1.03	3.98 ± 1.06
5	Good	20	$CaH_4(PO_4)_2$	63.4 ± 2.56	29.5 ± 1.24	2.11 ± .71
6	Poor	18	"	74.1 ± 4.01	34.4 ± 1.40	2.15 ± .49
7	Good	20	$CaH_4(PO_4)_2$ plus --	107.0 ± 2.95	27.2 ± 1.09	3.96 ± .34
8	Poor	20	--$Ca(NO_3)_2$	108.9 ± 3.29	32.0 ± 1.19	3.41 ± .59
9	Good	20	$CaH_4(PO_4)_2$ plus -- (2)	99.6 ± 3.12	25.6 ± 1.05	3.89 ± .71
10	Poor	17	--$Ca(NO_3)_2$ Cumulative	113.8 ± 4.97	24.1 ± 1.19	4.72 ± 1.08
11	Good	20	$Ca(NO_3)_2$ Cumulative(2)	89.6 ± 2.70	25.8 ± 1.22	3.47 ± 1.02
12	Poor	20	" " "	87.9 ± 3.79	20.2 ± .86	4.35 ± 1.47
13	Good	13	KCl	61.8 ± 2.33	40.6 ± 1.26	1.52 ± .30
14	Poor	11	KCl	51.0 ± 2.75	32.4 ± 1.23	1.57 ± .22

(1) All fertilizers applied in solution at the rate of one gram per pot.
(2) Applied in one-fourth portions November 7, November 19, December 1, and December 13.

Table II. Effects of different soils and fertilizer treatments on shoot/root ratio in radishes.

Lot	Kind of soil	No. of plants	Fertilizer treatment (1)	Av. green weight tops, (grams)	Av. green weight roots, (grams)	Av. Ratio, T/R R= 1
1	Good	12	None	3.7 ± .19	6.2 ± .18	.52 ± .08
2	Poor	15	None	3.2 ± .15	6.3 ± .21	.42 ± .06
3	Good	12	$Ca(NO_3)_2$	3.5 ± .18	6.9 ± .13	.55 ± .15
4	Poor	15	$Ca(NO_3)_2$	5.6 ± .32	14.2 ± .75	.41 ± .08
5	Good	12	KCl	3.7 ± .24	7.7 ± .36	.47 ± .10
6	Poor	15	KCl	2.8 ± .13	8.0 ± .36	.37 ± .07
7	Good	12	$Ca(NO_3)_2$ KCl	3.9 ± .32	7.4 ± .27	.53 ± .14
8	Poor	15	$Ca(NO_3)_2$ KCl	3.6 ± .16	9.5 ± .35	.39 ± .06
9	Good	6	$CaH_4(PO_4)_2$	4.2 ± .22	8.0 ± .57	.52 ± .06
10	Poor	15	$CaH_4(PO_4)_2$	4.2 ± .24	9.1 ± .57	.51 ± .21

(1) All fertilizers applied in solution at the rate of one gram per pot.

EXPERIMENT II.

Effects of the Time of Application of Fertilizers on Shoot/Root Ratio in Lettuce.

Lettuce was sown broadcast in flats on January 22, 1925, pricked off February 2, and put into pots on February 26, and was harvested April 22.

The soil used in this experiment consisted of a mixture of one part of sand to two parts of loam. The individual fertilizer treatments and the results secured from them are shown in Table III.

From the data given, the time of application of fertilizers appears to have had no signficiant effect on the top/root ratio. When the probable errors are not considered there appears to be a slight increase in ratio due to later applications of nitrogen, while later applic-ations of phosphorus appear to cause a decrease in ratio, but in no instance shown, are these increases or decreases significant.

Table III. Effects of the time of application of fertilizers on shoot/root ratio in lettuce.

Lot	No. of plants	Fertilizer treatment (1)	Av. green weight tops, (grams)	Av. green weight roots, (grams)	Av. ratio T/R R=1
1	9	$Ca(NO_3)_2$ at the start	49.1 ± 2.86	35.7 ± .47	1.89 ± .33
2	9	" 12 days later	52.5 ± 2.75	25.4 ± .82	2.25 ± .26
3	11	" 24 days later	68.5 ± 2.89	25.4 ± 1.11	2.82 ± .57
4	11	" 36 days later	47.6 ± 2.46	21.0 ± 1.00	2.42 ± .59
5	11	$CaH_4(PO_4)_2$ at the start	24.2 ± 1.35	16.1 ± 1.01	1.58 ± .37
6	10	" 15 days later	21.9 ± .65	15.4 ± .82	1.48 ± .19
7	11	" 30 days later	19.9 ± 1.02	14.7 ± .58	1.35 ± .15
8	10	" $Ca(NO_3)_2$ at start	52.8 ± 2.88	29.7 ± 2.16	1.92 ± .44
9	11	" " 15 days later	52.4 ± 3.22	26.2 ± 1.16	2.03 ± .34
10	9	" " 30 days later	70.5 ± 4.56	28.1 ± .74	2.46 ± .36

(1) All fertilizers applied dry and washed into the soil with water. Application at the rate of one gram of each fertilizer per pot.

EXPERIMENT III.

Effects of Variations in Daily Light Period on Shoot/Root ratio in Lettuce and Radish.

The plans for this experiment included a study of the effects of full and cumulative applications of fertilizers on lettuce, full applications of fertilizers on radishes, and the effects of prolonged and shortened light periods on both lettuce and radishes.

Lettuce was sown October 10, 1925, pricked off October 17, potted November 5, and harvested January 4, 1926. Radishes were sown October 24, potted November 4, and harvested December 15, 1925.

In order to study the effects of extended and of shortened light periods, the following set-up of apparatus was employed. Three 1000-watt, 110 volt, nitrogen-filled incandescent electric lamps, covered by Benjamin reflectors, were hung at a height of four feet two inches above a bench, 5' x 21'. These lamps were approximately 1600 candle power each. They were lighted at dusk and turned off automatically at 11 o'clock P. M. The plants under these lamps were exposed to light for a 15½ hour period each day.

The plants in another series were given a shortened daylight period. These were covered at night with beaverboard boxes, 8' long, 5' wide, and 3½' high. These boxes were painted black on the inside and were fitted with four 1" x 3" light-proof ventilation holes at each end. They were lowered over the plants at 4:00 P. M. and removed at 9:00 A. M., thus giving the plants seven hours of light daily. After December 1, the boxes were set on at 3:00 P. M. and taken off at 9:00 A. M., decreasing the daily light period to six hours. The treatments with the data secured on each are shown in Tables IV and V.

It should be noted in Table IV, that in comparison of lots 1 and 6, neither receiving fertilizer but lot 1 having a longer daylight period, the top weights are practically equal, there being no significant increase due to the extra light. The decided increase in root weight under long day causes an apparent decrease of the top/root ratio from 4.12 in lot 6 to .80 in lot 1, but this decrease is also insignficant. However, these wide, though insignificant variations, may be indicative of some significant variations which might be found to exist if a sufficiently large number of plants were used so as to materially reduce the probable errors.

The actual weight of tops is very greatly increased by the addition of fertilizers but in all cases

except in lot 3, the root increases so nearly parallel the increases in tops that there are no significant differences in ratios among the lots which received fertilizers.

In lots 6 and 7 (Table IV), neither of which received fertilizer, there is a decrease in top weight under the short day. However, the tops under short day plus fertilizer are larger than the tops of plants under normal day or long day where no fertilizer was applied.

The results shown in Table V on radishes agree quite consistently with the results on lettuce, so far as light and fertilizers affect the top/root ratios, except the comparatively low ratio in the lot having long day and no fertilizer, lot 1. There are no significant differences in ratios due to fertilizers alone.

Potassium applied alone very materially decreased top weight of radishes as compared with lots receiving nitrogen, but a slight decrease in roots paralleling these decreases in tops destroyed the significance of this effect on the ratios.

It should be noted that the actual weight of tops of lettuce plants under short day plus nitrogen is practically equal to the weight of tops of plants under normal day.

Table IV. Effects of prolonged and shortened light periods on shoot/root ratio of lettuce, under various fertilizer treatments.

Lot	Length of day	No. of plants	Fertilizer treatment (1)	Av. green weight tops, (grams)	Av. green weight roots, (grams)	Av. ratio T/R R=1
1	Long	21	None	11.2 ± .32	14.5 ± .63	.80 ± .09
2	Long	21	$Ca(NO_3)_2$	49.8 ± 1.52	19.8 ± .98	2.83 ± .75
3	Long	21	$Ca(NO_3)_2$ Cumulative (2)	54.2 ± 2.17	11.3 ± .59	5.10 ± 1.48
4	Long	21	$CaH_4(PO_4)_2$ plus $Ca(NO_3)_2$	58.8 ± 1.49	15.1 ± .54	4.09 ± .72
5	Long	21	$CaH_4(PO_4)_2$ plus $Ca(NO_3)_2$ Cumulative (2)	75.2 ± 1.71	21.6 ± .81	4.97 ± 1.25
6	Normal	15	None	11.0 ± .58	3.8 ± .30	4.12 ± 2.35
7	Short	20	None	8.15 ± .31	1.4 ± .126	7.49 ± 3.58
8	Short	22	$Ca(NO_3)_2$	15.13 ± .57	1.5 ± .11	9.98 ± 3.92
9	Short	22	$Ca(NO_3)_2$ Cumulative (2)	13.4 ± .57	1.7 ± .14	9.35 ± 2.52

(1) All fertilizers applied in solution at the rate of one gram of each fertilizer per pot.

(2) Applied in one-fourth portions November 5, November 17, November 29, and December 11.

Table V. Effects of prolonged and shortened light periods on shoot/root ratio of radishes under various fertilizer treatments.

Lot	Length of day	No. of plants	Fertilizer treatment (1)	Av. green weight tops, (grams)	Av. green weight roots, (grams)	Av. ratio, T/R R=1
1	Long	22	None	3.52 ± .09	7.02 ± .25	.53 ± .01
2	Long	21	$Ca(NO_3)_2$	7.58 ± .45	11.88 ± .48	.55 ± .17
3	Long	22	KCl	3.56 ± .12	6.14 ± .38	.65 ± .17
4	Long	22	$Ca(NO_3)_2$ KCl	8.36 ± .42	12.32 ± .51	.76 ± .24
5	Normal	15	None	2.05 ± .04	3.24 ± .18	.73 ± .19
6	Short	16	None	1.59 ± .09	1.07 ± .13	1.76 ± .57
7	Short	16	$Ca(NO_3)_2$	2.21 ± .18	1.07 ± .11	2.49 ± .86
8	Short	14	KCl	1.61 ± .10	1.15 ± .12	1.81 ± .64

(1) Fertilizers applied in solution at the rate of one gram per pot.

The carbohydrate analyses of samples from some of the lots of lettuce in this experiment are given in Table VI. Samples for analysis were taken in the forenoon. Both tops and roots of plants grown under normal day, lot 6, or long day, lots 1, 2, and 3, are fairly high in all substances for which they were analyzed, while the quantities of free-reducing sugars, total sugars, sucrose, and starch were practically negligible in the short day plants. The percentage of total polysaccharides in short day plants was very materially reduced also. The actual quantities of total polysaccharides in these plants were very much less than the percentages in the table indicate, since the plants themselves were very much smaller than the plants grown under long day.

Table VI. Carbohydrate Analyses of Lettuce Plants in Experiment III.

		Lettuce tops						Lettuce roots					
Lot	Length of day	Water per gram dry weight	Free-reducing sugars	Total sugars	Sucrose	Starch	Total polysaccharides	Water per gram dry weight	Free-reducing sugars	Total sugars	Sucrose	Starch	Total polysaccharides
		grams	p.ct.	p.ct.	p.ct.	p.ct.	p.ct.	grams	p.ct.	p.ct.	p.ct.	p.ct.	p.ct
1	Long	10.9	3.0	19.2	16.1	10.6	12.6	8.43	.7	14.8	14.1	0	6.3
2	Long	15.6	5.1	20.4	15.3	.65	12.7	13.26	1.0	15.6	15.6	1.3	10.0
3	Long	27.5	3.5	15.8	12.3	0	12.7	9.08	2.8	13.8	13.8	1.4	10.8
6	Normal	16.5	2.3	11.4	9.1	.15	12.9	6.03	1.7	10.3	10.3	.7	9.9
7	Short	23.6	0	0	0	0	4.6	3.82	0	0	0	.4	3.5
8	Short	29.3	0	0	0	0	3.5	4.72	0	0	0	0	2.6
9	Short	18.3	0	0	0	0	2.3	5.82	0	0	0	0	1.9

DISCUSSION AND CONCLUSIONS

The value of any treatment used in plant culture may depend not alone on the actual amount of growth which it makes in a plant but also on the distribution of that growth as regards top and root. It is very evident that if some treatment were available which, when applied to a crop of lettuce, would increase the top/root ratio by increasing the growth of tops relative to the roots, this treatment would be valuable to the lettuce grower. On the other hand, if some treatment should cause the reverse effect on a root crop, it too would be of practical importance in vegetable growing.

Data presented in this paper indicate that under the conditions of these experiments, fertilizers per se, or the time of their application, or light treatments, exert very little significant effect on the top/root ratio in either a positive or negative direction. The nearest approach to a significant effect is in the case of potash, which in one case on lettuce, decreased the top/root ratio significantly and in all other cases where it was used, decreases were indicated although mathematically insignificant. The variations in the ratios due to the special light treatments, though apparently large, are found to be unreliable when tested mathematically. They may be indicative of real variations which would have existed if the lots had contained a sufficient number of plants.

It is true that previous investigators have reported changes in the top/root ratio which were accounted real and used for drawing conclusions, but the method used generally in the determination of the ratios--that of using average weights of shoots and roots and not the average ratios with their probable errors--would seem at fault, rendering the results of doubtful value. Variations in the relative weights of tops and roots and consequently in the shoot/root ratios, when the plants are grown in soil, are very great, even under the best controlled conditions. These conditions demand an application of the most rigid mathematical tests, namely that of taking individual matched weights of tops and roots and from these deriving the average ratios and their probable errors.

SUMMARY

Data are presented which show that under the conditions of these experiments, the top/root ratios in lettuce and radish are comparatively constant figures so far as the effects of nutrients or their time of application are concerned.

Prolonged and shortened light periods produced apparent effects on top/root ratio but these effects were found to be insignificant when tested mathmetically.

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LITERATURE CITED

1. Bailey, L. H., Preliminary studies of the influence of the electric arc light upon greenhouse plants. Cornell Univ. Agr. Exp. Sta. Bul 30, 1891. Second report upon electro-horticulture. Cornell Univ. Agr. Exp. Sta. Bul. 42, 1891. Third report upon electro-horticulture. Cornell Univ. Agr. Exp. Sta. Bul. 55, 1893.

2. Brenchley, W. E., and Jackson, V. G., Root development in barley and wheat under different conditions of growth. Ann. Bot. 35:533-556. 1921.

3. Chandler, W. H., Results of some experiments in pruning fruit trees. Cornell Agr. Exp. Sta. Bul. 415, 1923.

4. Corbett, L. C., A study of the effect of incandescent gas-light on plant growth. West. Va. Agr. Exp. Sta. Bul 62, 1899.

5. Duley, F. L., and Miller, M. F. Effect of varying the nutrient supply upon the growth and character of the corn plant at different stages of growth. Mo. Agr. Exp. Sta. Res. Bul. 42, 1921.

6. Garner, W. W., and Allard, H. A., Effects of relative length of day and night and other factors of the environment on growth and reproduction in plants. Jour. Agr. Res. 18:553, 1920.

7. -----Further studies in photoperiodism. Jour. Agr. Res. 23:871, 1923.

8. Garner, W. W., Bacon, C. W., and Allard, H. A., Photoperiodism in relation to H-ion concentration of the cell sap and carbohydrate content of the plant. Jour. Agr. Res. 27:119, 1924.

9. Harris, F. S., Effect of soil moisture, plant food, and age on the ratio of tops to roots in plants. Am. Soc. Agron. 6:65, 1913.

10. Hendricks, E., and Harvey, R. B., Growth of plants in artificial light. Bot. Gaz. 77:330, 1924.

11. Loomis, W. E., Studies in transplanting of vegetable plants. Cornell Univ. Agr. Exp. Sta. Memoir 87, 1925.

12. Livingston, B. E., Note on the relation between the growth of roots and of tops in wheat. Bot. Gaz. 41:139, also 40:178, 1906.

13. Moeller, H., Beitrage zur Kenntniss der Verzwergung. Land. Jahrb. 13:167-173. 1865.

14. Nightingale, G. T., Light in relation to the growth and chemical composition of some horticultural plants. Proc. Amer. Soc'y. of Hort. Sci. 1922:18.

15. Nobbe, F., Uber die feinere Verastelung der Pflanzen wurzeln. Landw. Vers. Stat. 4:212-224, 1862.

16. Oakley, R. A., and Westover, H. L., Effect of length of day on seedlings of alfalfa. Jour. Agr. Res. 21:599, 1921.

17. Polle, R., Uber den Einfluss Verschieder hohen Wasserge halts, Verschiedener Dungung, und Festigheit des bodens auf die Wierzel ent wichlung, des Werzens und der Graste im easter Vegetationestadium. Jour. Fur. Landw., bd. 58, 297-345., 1910.

18. Rane, F. W., Electrohorticulture. W. Va. Agr. Exp. Sta. Bul. 37, 1894.

19. Sachs, J. von, Handbuch der Experimental Physiologie der Pflanzen. p. 177, 1865.

20. Seelhorst, C. von, Beobachtungen uber die Zahl und den Tiefgang der Wurzeln verscheidener Dungung des Bodens. Jour. Landw. 50:91-104. 1902.

21. Siemens, C. W., On the influence of electric light upon vegetation and on certain physical principles involved. Proc. Roy. Soc. (London) 30:210-219, 1880.

22. Thiel, Hugo, Der Text zu den Wandtafel fur den Naturwissenschaftlichen Unterricht. IV Serie, Bewurzelung, Berlin, 1876.

23. Tufts, T. W., Pruning young deciduous fruit trees. Calif. Agr. Exp. Sta. Bul. 313, 1919.

24. Tucker, G. M., and Seelhorst, C. von, Der Einfluss der Wassergehalt und der Reichteum des Bodens auf die Ausbelung der Wurzeln und der obsoer-idischen Organe der Hoferpflanze ausuben. Jahr. Landw. bd. 46. x. 52-63, 1898.

25. Turner, T. W., Studies of the mechanism of the physiological effects of certain mineral salts in altering the ratio of top growth to root growth in seed plants. Am. Jour. Bot. 9:415, 1922.

26. Working, E. B., Physical and chemical factors in the growth of asparagus. Ariz. Agr. Exp. Sta. Tech. Bul. 5, 1924.