

ART. XLVI.—*Growth or Evolution of Structure in Seedlings*; by
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THE continuous absorption of oxygen, and formation of carbonic acid, is an essential condition of evolution of structure, both in plants and in animals.

The above proposition in so far as it relates to animals will probably be admitted by all; the opposite opinion is, however, commonly held as regards plants; yet we propose to show that in these organisms, as in animals, growth as applied to evolution of structure, or organization of material provided is inseparably connected with oxidation.

The discussion of the proposition in question necessarily involves a preliminary review of the character of the gases exhaled from various plants. Commencing with the lower organisms as fungi, the uniform testimony is that these plants at all times expire carbonic acid, while it is chiefly in the higher plants, and especially in those which contain chlorophyl or green coloring matter that carbonic acid is absorbed and oxygen exhaled. The inquiry then in reality narrows itself down to the examination of the growth of chlorophyl-bearing plants.

Regarding these plants the statement is made and received, that they change their action according as they are examined in the light or in the dark, exhaling oxygen under the first condition, and carbonic acid under the second. Various explanations of this change of action have been given, that generally accepted accounting for it on the hypothesis of the absorption

of carbonic acid by the roots, and its exhalation by the leaves when light is no longer present.

The change, on the contrary, appears to arise out of the fact that two essentially different operations have been confounded, viz: the actual growth or evolution of structures in the plant, and the decomposition of carbonic acid by the leaves under the influence of the light, to provide the gum or other materials that are to be organized. These two factors are separated by Prof. J. W. Draper in his discussion of the conditions of growth in plants. We propose to show that by adopting this proposition of two distinct operations in the higher plants, all the apparent discrepancies regarding the growth of these plants are explained.

The growth of seedlings in the dark offering conditions in which the act of growth or evolution of structure is accomplished without the collateral decomposition of carbonic acid, I arranged two series of experiments in which growth under this condition might be studied and compared with a similar growth in the light. That the experiments might continue over a sufficient period of time to furnish reliable comparative results, I selected peas as the subject of trial, since these seeds contain sufficient material to support the growth of seedlings for a couple of weeks.

To secure as far as possible uniformity of conditions between the dark and light series, and also to facilitate the separation, cleansing and weighing of the roots, each pea was planted in a glass cylinder, one inch in diameter and six inches long. These cylinders were loosely closed below by a cork, and filled to within half an inch of the top with fine earth or vegetable mould. They were then placed erect in a covered tin box or tube-stand, in such a manner that the lower end dipped into water contained in the box, while the whole of the cylinder except the top was kept in the dark. Thus the first condition for germination, viz., darkness, was secured; the second, warmth, was supplied by the external temperature, which varied from 70° to 80° F., while regularity and uniformity in the supply of moisture in both series was secured by having a box of cylinders or tubes for each and keeping the level of the water the same in both. The supply of oxygen was also equal and uniform, since the upper part of each tube presented a similar opening to the air.

Thus prepared, one box containing five cylinders was kept in a dark closet, while a second similar in all respects was placed in a window of the adjoining room, where it was exposed to direct sunlight five or six hours every day. To each tube a light wooden rod thirty inches in length was attached, and on this the growth of the seedling was marked every twelve hours.

The hours selected were 7 A. M. and 7 P. M. I thus obtained the night and day, or dark and light growth of every seedling, as long as those in the dark grew. The seeds were planted on June 1st, and appeared above the ground on June 6th, when the measurements were commenced. In each series one seed failed to germinate; the record consequently is for four plants in each, and the history of the evolution of structures is as follows:

Evolution of structure in the dark.—In Table I. the seeds are designated as A, B, C, D, and each column shows the date on which leaves and lateral growths appeared. These constitute periods in the development of the plants, which are indicated by the numbers 1, 2, 3, 4, 5, 6. The weight of each seed is given in milligrammes.

Table I.—*Seedlings grown in the dark.*

Weight of seed.	A. 431.	B. 436.	C. 456.	D. 500.
Period 1,	7th day.	7th day.	7th day.	7th day.
" 2,	8th "	9th "	9th "	8th "
" 3,	10th "	10th "	11th "	10th "
" 4,	12th "	12th "	13th "	12th "
" 5,	14th "	15th "	15th "	14th "
" 6,	17th "	18th "	18th "	17th "

A glance at the above shows the uniformity as regards time with which the structures were evolved in each plant. It also indicates for each plant an equality in the number of periods of evolution, viz., 6, notwithstanding the difference in the weights of the seeds; and suggests that the power of evolution of structure in seedlings resides in the germ alone.

The character of the evolution in the six periods shows a steady improvement or progression.

In the first, the growth consists of the formation close to the stem of two partially developed pale yellow leaves.

The second period is similar to the first, except that the leaves are a little larger.

The third presents a pair of small yellow leaves close to the main stem, from between which a lateral stem or twig about one inch long projects, and bears at its extremity a second pair of imperfectly developed yellow leaves, from between which a small tendril about a sixteenth of an inch long is given off.

The fourth resembles the third, the lateral twig being longer, and the tendril three times as long as in the third.

The fifth is like the fourth, except that the tendril bifurcates.

The sixth is similar to the fifth, except that the tendril trifurcates.

Stem, leaves, twigs, tendrils of various degrees of complexity, all are evolved by the force pre-existing in the germ without the assistance of light.

*Evolution of structure in the light.*Table II.—*Seedlings grown in the light.*

Weight of seed.	E. 288.	F. 426.	G. 462.	H. 544.
Period 1,	—	6th day.	—	6th day.
“ 2,	7th day.	7th “	7th day.	7th “
“ 3,	8th “	8th “	8th “	9th “
“ 4,	12th “	9th “	10th “	10th “
“ 5,	15th “	11th “	14th “	12th “
“ 6,	— “	13th “	— “	14th “

Table II. was obtained in the same manner as Table I, the columns representing the days on which lateral growths and leaves appeared. Though there is not the same uniformity as in Table I, the periods are identical in both as regards the visible character of the evolution. Nothing appears in the second that did not pre-exist in the first, and in the case of the seeds E and G the evolution is even deficient as regards the first and the sixth periods.

While the general character of the evolution in both series is similar, certain minor differences exist. In II. the leaves and tendrils are many times larger than in I, and they with the whole plant are of a bright green color, instead of the sickly pale yellow of I; but the light has not developed any new structure; it has only perfected those which pre-existed, and converted other substances into chlorophyl which is not an organized body.

Not only did the plants in the two series present similarities in evolution of structure, but the average weight of dry plant in each was very nearly the same, for:

455 of seeds in the dark produced 184 of dry plant, while
 455 “ “ light “ 215 “ “

A comparison of the parts below the ground with those above (both being dried at 212° F.) shows that the proportion of root to total weight of plant was also nearly identical; being,

25 of root for 100 of plant in the dark, and
 23 “ “ 100 “ light.

The close similarity in the evolution of visible structure in the light and in the dark, the small difference in the total weights of the plants grown in the same time in both series, and the close approximation in the proportional weight of root to plant, all justify the conclusion, that the growth in darkness and in light closely resemble each other, and that it is proper to reason as regards the nature of the action from the first to the second.

Another interesting fact which lends support to the opinion that the process of growth in seedlings developed in the dark

is very similar to that occurring in those grown in the light, is the character of the excrements thrown out by the roots. It is well known that many plants so poison the soil that the same plants cannot be made to grow therein until the poisonous excretions from the roots of the first crop have been destroyed by oxidation. In the case of peas this poisoning of the soil takes place in a very marked manner, and I have found that in the pots in which peas have been grown in the dark, the soil is so poisoned by the excrements from the roots that a second crop fails to sprout. Does it not follow, that since in the two series with which I experimented, the excrements from the roots possessed the same poisoning action, the processes in the plants from which these excrements arose must have been similar?

There remains an important argument concerning which nothing has thus far been said. It is to be derived from the consideration of the rate of growth in the light series during various periods of the day of twenty-four hours. If the evolution of structure in a plant in daylight is the result of the action of light, that evolution should occur entirely, or almost entirely during the day. If on the contrary it is independent of the light, it should go on at a uniform rate as in plants in the dark.

For the elucidation of this portion of the subject, I present the following tables; the first of which shows the growth by night, 7 P. M. to 7 A. M. of the seedlings in the dark series, compared with their growth by day, 7 A. M. to 7 P. M. The measurements were taken from the sixth to the twentieth of the month, the day on which growth ceased in the dark series.

Table III.—*Seedlings grown in the dark.*

	Night growth.	Day growth.
No. 1	12 $\frac{3}{4}$ inches.	14 inches.
No. 2	13 $\frac{1}{4}$ "	13 "
No. 3	11 $\frac{3}{4}$ "	11 $\frac{3}{8}$ "
No. 4	12 $\frac{5}{8}$ "	11 $\frac{3}{8}$ "
Average,	12 $\frac{5}{8}$ "	12 $\frac{3}{8}$ "

The total day growth and night growth under these circumstances are nearly equal, though there is a slight excess in favor of the night, amounting as the table shows, to $\frac{2}{8}$ of an inch in 12 inches.

In Table IV. the growth of the light series is given in the same manner, by day and by night, for the same time, viz: to June 20th. The thermometric and hygrometric conditions in both series were very similar, as indicated by the dry and wet bulb thermometers suspended in the vicinity of each set of tubes.

Table IV.—*Seedlings grown in the light.*

	Night growth.	Day growth.
No. 5	3 $\frac{1}{4}$ inches.	4 inches.
No. 6	8 “	7 “
No. 7	5 $\frac{1}{4}$ “	4 $\frac{1}{2}$ “
No. 8	9 $\frac{1}{2}$ “	8 $\frac{1}{2}$ “
	Average, 6 $\frac{1}{2}$ “	Average, 6 “

In the average, and throughout the table, with a single exception, not only is the uniformity in the rate of growth during the day and night shown, but the slight excess of night growth found in the series kept in the dark is likewise copied. We must therefore accept the conclusion, that the act of growth or evolution of structure is independent of light, and that the manner of growth during the day is similar to that at night.

It will be noticed that the total average height attained in the light is only about half that in the dark series. The explanation of this we have already seen in the fact, that in the former the leaves and tendrils were much larger than in the latter, while the dry weights were nearly the same. The material of the seed in the light series was consumed in extending these surfaces, while in the dark series it was spent in lengthening the stem.

Having established the continuous character of growth in seedlings, and the similarity of rate and nature of the process by night and by day, and admitting that at night plants throw off carbonic acid, it is not improbable that this carbonic acid arises, not from mechanical absorption by the roots, and vaporization by the leaves, but as a direct result or concomitant of the act or process of evolution of structure.

To put the matter in the clearest form, let us first understand what growth is. It appears in all cases to consist in the evolution or production of cells from those already existing. According as the circumstances under which the cells are produced vary, so does the tissue ultimately produced vary. Cells formed in woody fibre become wood. Cells formed in muscle in their turn form muscles, but the starting point of the process in every instance is the formation of new cells.

If now we examine the evolution of cells under the simplest conditions, as for example in the fermentation that attends the manufacture of alcohol, we find that with the evolution of the torulæ cells carbonic acid is produced. The two results are intimately connected, and it is proper to suppose that since the carbonic acid has arisen along with the new cells, the latter operation must in some way involve a process of oxidation. Accepting the hypothesis that oxidation is attendant on these processes of cell growth under the simplest conditions, we pass

to the examination of what occurs in the lower forms of vegetable organisms found in the air.

The Fungi, and indeed all plants that are not green, with a few exceptions, exhale carbonic acid and never exhale oxygen. In this case, in which cell production often occurs with such marvelous rapidity, the carbonic acid must have arisen as a consequent of the cell growth. It is improbable that it has been absorbed by roots and exhaled from the structures, either in these plants or in those produced during fermentation. In the latter there never are any roots, and in the former, even where roots are present, they bear a small proportion to the whole plant. The quantity of moisture exhaled by such growths is also insignificant, and out of proportion to the carbonic acid evolved. We must, therefore, in this case decline to accept the root absorption hypothesis, and admit that the carbonic acid has arisen as a result of the cell growth in the plant.

Passing to the chlorophyl-bearing plants, we find that in the Phanerogamia it is only the green parts that at any time exhale oxygen, and then only under the influence of sunshine. The other parts of the plant above the ground, that are not green, viz., the stem, twigs, flowers, etc., are at all times, day and night, exhaling carbonic acid. The whole history of the plant, from the time the seed is planted to its death, is a continuous story of oxidation, *except when sunlight is falling on the leaves.* The seed is put into the ground and during germination oxygen is absorbed and carbonic acid exhaled. If the seedling is kept in the dark, oxygen is never exhaled, only carbonic acid, and the plant not only grows, but all visible structures except flowers are formed in a rudimentary condition. In the light the growth during the night time is attended by the evolution of carbonic acid, while during the day time the bark of the stem and branches is throwing off carbonic acid. When flowers and seeds form, the evolution of carbonic acid attending this highest act of which the plant is capable, is often greater than that produced at any time in many animals.

Everything in the history of plants, therefore, tends to show that the evolution of their structures is inseparably attended by the formation of carbonic acid, and it seems impossible, when we consider the evolution alone, to arrive at any other opinion than that already expressed—that, *all living things, whether plant or animal, absorb oxygen and evolve carbonic acid, or some other oxidized substance, as an essential condition of the evolution of their structures.*

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