SMITHSONIAN MISCELLANEOUS COLLECTIONS
VOLUME 96, NUMBER 3

PHOTOTROPIC RESPONSE AND CO_2 ASSIMILATION OF PLANTS IN POLARIZED LIGHT

BY
EARL S. JOHNSTON
Division of Radiation and Organisms, Smithsonian Institution

(PUBLICATION 3440)

CITY OF WASHINGTON
PUBLISHED BY THE SMITHSONIAN INSTITUTION
JULY 12, 1937

The Lord Baltimore Press
BALTIMORE, MD., U. S. A.

PHOTOTROPIC RESPONSE AND CO_2 ASSIMILATION OF PLANTS IN POLARIZED LIGHT

By EARL S. JOHNSTON

Division of Radiation and Organisms, Smithsonian Institution

From time to time articles both scientific and popular appear on the effects of polarized light on plants. Some years ago Semmens (1923) reported an increased velocity of seed germination in moonlight and suggested that the plane polarization of moonlight affected the diatase activity. Baly and Semmens (1924) reported an increased rate of hydrolysis of starches in plants exposed to polarized light. In a later paper Semmens (1930) characterizes plants grown in successive periods of darkness and polarized light by a disappearance of starch and other reserve products, such as glucosides, a temporary phototropism due to increased stem turgor, and a leaf fall with other signs of starvation. On the other hand, du Buy and Nuernbergk (1935) mention some unpublished experiments in which they found no difference in the bending of *Avena* coleoptiles toward polarized and nonpolarized light. Furthermore, Dastur and Asana (1932) indicate that the process of photosynthesis goes on as vigorously and regularly in polarized light as in ordinary light. Macht (1926) reports evidence of better growth of *Lupinus,* wheat, squash, and *Helianthus* seedlings in polarized light of a Mazda lamp than in his controls. Dastur and Gunjikar (1935) report that leaves of 12 different species clearly show a larger amount of energy absorbed from polarized light than from normal light of equal intensity. May (1924) conducted a number of experiments over a year to determine if there was a basis of fact regarding the seeding of crops during different phases of the moon. He found there was not enough difference in the general growth to be noticeable to the eye, certainly not enough upon which to found a theory. There is no evidence, as pointed out by Garner (1937), to show that the moon is capable of exerting any effect on crop plants other than those due to its action on illuminating conditions.

In a number of plant growth studies conducted at the Smithsonian Institution it has been necessary to direct beams of light on the plants by means of mirrors. Judging from some of the discussions in the literature one might raise the question as to the effect of polarized light on growth processes. Especially is this applicable to our studies on the growth of the oat coleoptile in monochromatic light reflected by a

mirror, and to CO_2 assimilation studies of wheat plants in which light intensities are increased by mirrors. The present paper discusses the phototropic response of the oat coleoptile and the CO_2 assimilation of young wheat plants in polarized light.

The general method of illuminating the plant by two opposing beams of light was used in the phototropic experiments. This balancing

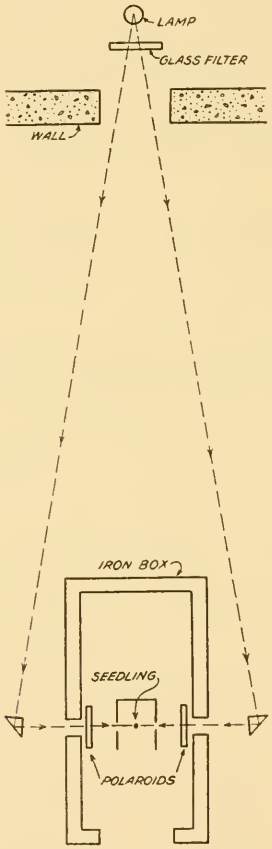

FIG. 1.—Diagram showing position of *Avena* coleoptile between two opposing beams of light which originate from a single source and are polarized at right angles to each other.

action of light on phototropic response has been discussed by Johnston (1934) and by Castle (1931). In the experiments here discussed a single light source was used. Two beams were reflected by right-angle prisms in such a manner that the first 0.5 to 1.0 mm of the tip of a coleoptile was illuminated from opposite sides. The general arrangement of apparatus is illustrated in figure 1.

The light source was a 1,000-lumens, 1.6-amperes street series lamp with a heat-resisting, heat-absorbing extra light shade Corning filter (2.75 mm). After being reflected by the prisms two beams of light entered an iron box (34.5 × 18.5 × 30 cm high) through two oppositely located side windows. In each window was fitted a Polaroid disk (4 cm diameter). Each beam of light then passed through a horizontal 0.5-mm slit in a brass shield and fell on the tip of a coleoptile placed midway between these shields. These shields were 4 cm apart. The small Erlenmeyer flask (50 ml) in which the oat seedling was growing rested on a small shelf which could be raised or lowered by means of a worm gear. With this arrangement the tip of a seedling could be accurately placed in the path of the narrow opposing beams of light. The total length of each light beam from the lamp to the mid point between the brass shields was 107 cm.

The oats, *Avena sativa* Markton, were germinated at approximately 25° C. between glass plates covered with moist filter paper. The plates were so placed in a moisture chamber that the seedlings grew vertically. A careful selection of the seedlings was made for straightness when they had attained a length of 1 to 2 cm. One was then transferred to the small Erlenmeyer flask fitted with a cork stopper. It was supported by means of a little cotton in a small hole of the stopper. The flask was filled with distilled water so that the roots were entirely immersed. The seedlings were always handled in darkness or photographically red light. One Polaroid disk was so placed that the plane polarized light was parallel to the axis of the seedling. The other Polaroid was placed to give a beam of light polarized at right angles to this. The setting at right angles could easily be accomplished by observing the lamp filament through the two prisms and two Polaroids and rotating the one Polaroid until the transmitted light reached its minimum visibility. At this point the filament appeared a dark purple red in color.

By means of a specially constructed photocell a point was located between the slits of the two shields where the two beams were equally intense. At this point the seedlings either showed no phototropic bending or a very slight one after 2 to 3 hours. No change so far as the reactions of the coleoptile were concerned were noted when the Polaroids were rotated through an angle of 90° in order to reverse the polarity of the light striking the two sides of the tip. The difficulty in this procedure was to locate accurately the mid point of equal intensities. The seedling was more sensitive to small differences of light intensity than the photocell.

In order to overcome this difficulty, a slightly different method was used. The mid point of equal intensities was approximately located with the photocell and the seedling placed slightly to the left of this point. A distinct phototropic bending then occurred toward the left. Another seedling was placed to the right of the mid point and the bending then occurred toward the right. The right or left displacements were never greater than 0.75 cm. Consistent results were obtained in a series of such experiments in which a fresh seedling was used each time, no matter whether the light was polarized parallel or at right angles to the axis of the plant. No difference could be detected in the phototropic response of the seedling in regard to the plane of polarization of the light impinging on its tip when the Polaroids were placed in the two positions mentioned.

Calculations of intensities based on the lengths of light paths at points of maximum displacement of seedlings give a difference of slightly less than 3 percent as the maximum range. This clearly shows that if polarized light had a different effect on phototropism in one plane than in the other, as here used, such an effect is less than 3 percent. Crozier and Mangelsdorf (1924) found no difference in the phototropic efficiency of plane polarized and nonpolarized light of equal intensity on arthropods. The difference in phototropic effect of light depending on the plane of polarization which Castle (1934) found for the cells of *Phycomyces* is shown by him to be due to differences in the reflection losses at the cell surface. What Castle concludes for the growth of *Phycomyces* is undoubtedly true for the coleoptile of *Avena,* namely, that plane polarized light has no specific effect on its growth processes.

The disappearance of starch and signs of starvation of plants grown in polarized light, as reported by Semmens, would indicate serious disturbances in the photosynthetic mechanism of such plants. This would undoubtedly involve the CO_2 assimilation process. Because of the disagreement between the results of Semmens and those of Dastur and Asana it was thought worth while to determine the CO_2 uptake of wheat plants in polarized and nonpolarized light, especially since this was the experimental plant used by Hoover, Johnston, and Brackett (1933) and by Hoover (1937) in their CO_2 absorption studies.

In a series of experiments carried out by McAlister in which his recently described spectrographic method (1937, 1937 a) for CO_2 determination was used, little or no evidence was obtained that indicated a different rate of photosynthesis of wheat plants in polarized and nonpolarized light from a Mazda lamp.

Young wheat seedlings were grown under controlled conditions in the growth tube and exposed first to nonpolarized and then to polarized light. The light source was a 1,000-watt Mazda projection lamp used with a suitable water filter. Light polarized parallel to the plant axis was obtained by inserting a Polaroid disk between the plant and the lamp.

The Polaroid greatly reduced the light intensity and in order to reduce the intensity of the nonpolarized light to that of the polarized, a 200-mesh screen was inserted between the plant and the lamp. A small G. E. photocell foot-candle meter was used to approximate the intensities. Data from two such experiments are presented in table 1.

TABLE 1.—*Carbon Dioxide Assimilation of Young Wheat Seedlings in Nonpolarized and Polarized Light*

Date 1937	Light: Character	Light: Intensity: Foot-candles	Light: Intensity: Thermocouple reading with filter [a]	CO_2 assimilation (mm^3 10 min.)	CO_2 assimilation: Corrected
May 4	Nonpolarized	250	...	482	588
	Polarized	260	...	574	586
May 5	Nonpolarized	273	8.2	565	689
	Polarized	282	9.8	670	684

[a] With a Corning Aklo heat-resisting, heat-absorbing medium (2.46 mm) filter together with a 10-cm water filter, the wave-length distribution was restricted to about 3800-7800 A, which includes the major portion of the spectrum active in photosynthesis. These thermocouple readings were used in obtaining the corrected CO_2 assimilation.

In such experiments it is important that light and not the CO_2 of the air surrounding the plants be the limiting factor. In order to make sure this was the case, additional readings of CO_2 uptake were taken on May 5 at higher intensities in nonpolarized light. The CO_2 uptake at 700-800 foot-candles was found to be 1060 mm^3 per 10-minute interval. It therefore appears certain that at the lower intensities used in these experiments light and not CO_2 was the limiting factor.

Although the experiments on this phase of the work were not many and for 10-minute intervals, yet because of the extreme accuracy and quickness of this optical method of determining the CO_2 absorption by plants, it may safely be concluded that polarized light has no effect upon the uptake of CO_2. There is the possibility, although it does not seem probable, that if the plants were grown for long periods in polarized light some secondary effects on the CO_2 assimilation might appear. The measurements indicate a difference of approxi-

mately 1 percent, but since it is assumed that the thermocouple-filter system measures the light effective in photosynthesis equally accurately in the two cases, it is well to bear in mind that a greater photosynthetic efficiency may exist in one light than in the other. This may be the case because of the difference in color of the light after it passes through the Polaroid. Pollard (1936) has noted the wave-length distribution characteristics of the Polaroid. Because the light transmitted is somewhat different in wave-length distribution from the screened Mazda light, accurate comparisons are exceedingly difficult.

In summarizing, it may be concluded from the experimental evidence here presented that polarized light has no effect other than that of ordinary light in phototropism of *Avena* Markton. If there is a difference it is less than the 3 percent accuracy of the experimental technique. Also, there is little evidence that polarized light acts any differently from nonpolarized light of equal intensity and similar wave-length distribution in the process of CO_2 assimilation.

LITERATURE CITED

Baly, E. C. C., and Semmens, E. S.
1924. The selective photochemical action of polarized light. I. The hydrolysis of starch. Proc. Roy. Soc. London, ser. B, vol. 97, pp. 250-253.

Castle, E. S.
1931. The phototropic sensitivity of *Phycomyces* as related to wave-length. Journ. Gen. Physiol., vol. 14, pp. 701-711.

Castle, E. S.
1934. The phototropic effect of polarized light. Journ. Gen. Physiol., vol. 17, pp. 751-762.

Crozier, W. J., and Mangelsdorf, A. F.
1924. A note on the relative photosensory effect of polarized light. Journ. Gen. Physiol., vol. 6, no. 6, pp. 703-706.

Dastur, R. H., and Asana, R. D.
1932. Effect of plane-polarized light on the formation of carbohydrates in leaves. Ann. Bot., vol. 46, pp. 879-891.

Dastur, R. H., and Gunjikar, L. K.
1935. Energy absorbed by leaves in normal and plane polarized light. Ann. Bot., vol. 49, pp. 273-281.

du Buy, H. G., and Nuernbergk, E. L.
1935. Phototropismus und Wachstum den Pflanzen (dritter Teil). Ergebn. Biol., vol. 12, pp. 325-543.

Garner, W. W.
1937. Do the phases of the moon affect plant growth? (Mimeographed.) Bur. Plant Ind., U. S. Dep. Agr., February.

Hoover, W. H.
1937. The dependence of carbon dioxide assimilation in a higher plant on wave length of radiation. Smithsonian Misc. Coll., vol. 95, no. 21, pp. 1-13.

Hoover, W. H., Johnston, Earl S., and Brackett, F. S.
1933. Carbon dioxide assimilation in a higher plant. Smithsonian Misc. Coll., vol. 87, no. 16, pp. 1-19.
Johnston, Earl S.
1934. Phototropic sensitivity in relation to wave length. Smithsonian Misc. Coll., vol. 92, no. 11, pp. 1-17.
Macht, David I.
1926. Concerning the influence of polarized light on the growth of seedlings. Journ. Gen. Physiol., vol. 10, no. 1, pp. 41-52.
May, D. W.
1924. The moon theory. Porto Rico Agr. Exp. Stat., Agr. Ext. Notes (mimeographed), no. 65, Feb. 15.
McAlister, E. D.
1937. Spectrographic method for determining the carbon dioxide exchange between an organism and its surroundings. Plant Phys., vol. 12, pp. 213-215.
1937 a. Time course of photosynthesis for a higher plant. Smithsonian Misc. Coll., vol. 95, no. 24, pp. 1-17.
Pollard, A. F. C.
1936. Polarization of light and some technical applications. Nature, vol. 138, no. 3486, pp. 311-314.
Semmens, Elizabeth Sidney
1923. Effect of moonlight on the germination of seeds. Nature, vol. 111, pp. 49-50.
1930. Hydrolysis in the living plant by polarized light. Bot. Gaz., vol. 90, pp. 412-426.