MEASUREMENT OF PLANT GROWTH BY MEANS OF THE OPTICAL LEVER

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Introduction

The use of the optical lever principle for measuring small movements has been applied to plant experimentation, so far as indicated by published work, by relatively few persons. Bose[1] (1906) used the optical lever for measuring slight movements in plants. Miss Delf[2] (1916) employed an optical lever apparatus designed by Dr. F. F. Blackman for measuring minute movements in tissues associated with turgor changes. Very recently Wadsworth[3] (1932) has described a form of optical lever which has been used in certain sugar cane investigations.

Two simple forms of the optical lever have been constructed and used by the author for demonstrating and measuring growth in plants. Because of the simplicity of design and cheapness of construction, it has been thought advisable to publish a brief description of these instruments.

Description of the Apparatus

Figure 1-A illustrates the assembly of the apparatus as employed for making quantitative measurements on the growth of plants. A mirror (c) having a horizontal scratch in the middle of the silver backing is mounted on an axis coinciding with this scratch. The mirror is rotated on this horizontal axis by means of a short lever arm attached to the center of the back of the mirror. A cord-wire system connects the lever arm to the growing plant (i). The mirror is firmly supported by a clamp and ring stand with the potted plant resting upon the base of the ring stand (h_1).

A second ring stand (h_2) supports an inverted meter stick (l) to which is attached a piece of cardboard (j). This cardboard stop is perforated by a single hole which serves as a sighting aperture. The cardboard stop is attached to the meter stick by a rubber band in such a way as to allow the stop to be moved to any desired position on the meter stick.

When an experiment is to be conducted, the apparatus is set up on a firm base with the sighting aperture adjusted to a height equal to that of the mirror axis. If the eye is placed at the sighting aperture, a portion of the scale can be seen reflected in the mirror. The scale reading coinciding with the reference line scratched on the mirror is then re-

[1] Bose, J. C., 1906: Plant Response.

[2] Delf, E. Marion, 1916: Studies of protoplasmic permeability by measurement of rate of shrinkage of turgid tissues. I, influence of temperature on the permeability of protoplasm to water, Ann. Bot., **30**:283-310.

[3] Wadsworth, H. A., 1932: The optical lever as a tool in physiological studies, Plant Physiol., **7**:727-731.

"Proc. Ind. Acad. Sci., vol. 42, 1932 (1933)."

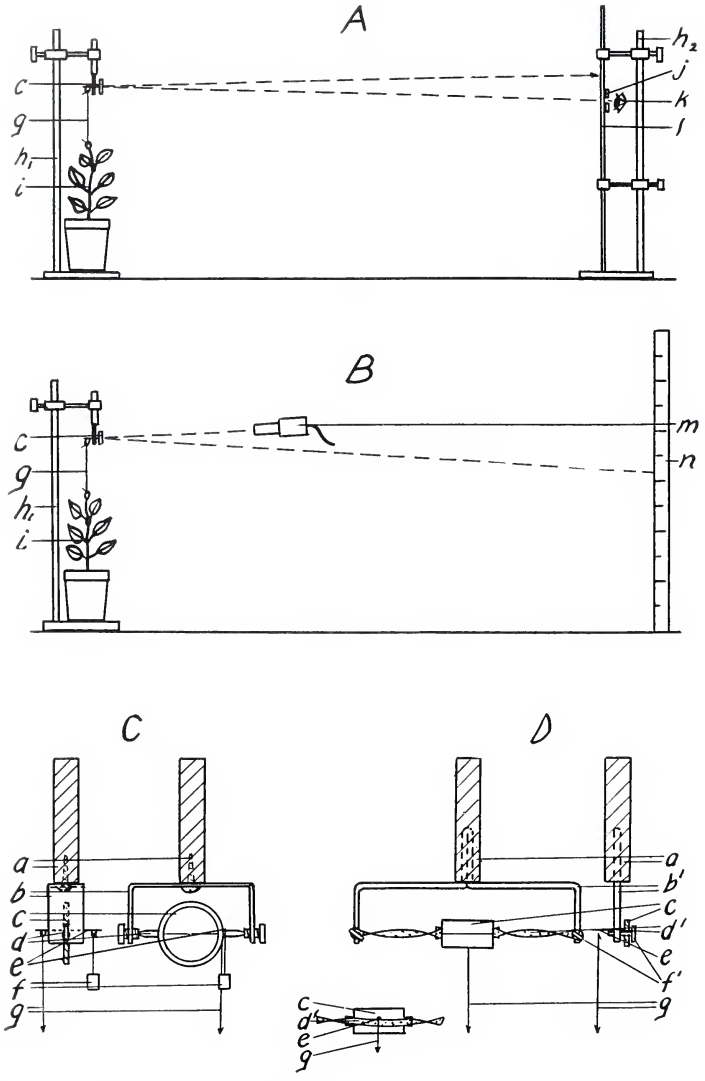

Fig. 1. Optical lever apparatus. (a) wooden handle, (b) metal frame, (b) heavy wire frame, (c) mirror, (d) mirror axis, (d) rubber band, (e) lever arm, (f) counter balance weight, (f) adjusting peg, (g) connecting cord leading to plant, (h_1) and (h_2) ring stands, (i) plant, (j) card board light stop with sighting aperture, (k) eye, (l) meter stick, (m) light source, and (n) large scale.

A—Apparatus set up for quantitative measurement.

B—Apparatus set up for lecture demonstration.

C—Pivot type of mirror detail.

D—Torsion type of mirror detail.

corded at intervals as an index of the growth of the plant. As the plant increases in length the mirror is rotated forward and the line of vision passes down the scale with double the rapidity of a material lever of the same dimensions. For small angles of rotation a straight meter scale may be employed without introducing serious error in the determination of the actual growth of the plant. When large angles are encountered, a curved scale greatly reduces the degree of error. (See Wadsworth, loc. cit.)

Modifications of the foregoing set up may include the substitution of a small telescope for the sighting aperture, or the use of a concentrated light beam and reflected spot of light as indicated in figure 1-B. This latter form of the apparatus is of particular value for lecture or other demonstrations, since very large magnifications can be secured and since the moving spot of light may be easily seen by a group.

Detailed views of the two different types of mirrors used are given in figures 1-C and 1-D. Figure 1-C represents the pivot form of the device, consisting of a small mirror (c) attached to a metal axis (d) pointed at each end. These metal points turn in metal bearings, which are supported by a metal and wood frame (b, a). Two short lever arms (e) fixed at right angles to the main axis serve for connecting the mirror with the plant (rear lever arm) and with the counterbalance weight (forward lever arm). A weight (f) is required of size sufficient to maintain a slight tension on the plant and to keep the connecting cord (g) taut.

The second type of mirror is illustrated by figure 1-D. In this type a twisted rubber band (d^1) is substituted for the horizontal metal axis. The rotation of the mirror (c) is secured by the torsion force of the rubber band. The magnitude of this force, and consequently the amount of tension exerted upon the plant, can be varied by the number of backward twists previously given the rubber band, and by the degree of tension placed upon the elastic band by the pegs (f^1). Different degrees of tension upon the plant can also be effected by the use of rubber bands of varied sizes. A small rubber band which, when broken in two, gave a tension upon the plant of 0.2 to 0.4 gm. was used for the experiments herein recorded. The rubber band is not permanently fastened to the mirror but is simply slipped through two wire loops cemented to the back of the mirror as indicated in the figure (Fig. 1-D). The mirror is mounted in a frame of heavy wire possessing sufficient rigidity to resist bending (b^1).

Illustrative Experiments

The results of certain experiments designed to demonstrate the use of the apparatus are given in figure 2. Potted bean and pea plants were employed, using both the pivot and the torsion types of mirror, and varied environmental conditions. All of the experiments were carried out in the greenhouse under conditions of natural winter illumination.

A short experiment was performed with a potted bean plant of about 25 cm. height under dull light conditions on a cloudy day (Fig. 2-A). The air temperature was maintained at approximately 19° C. The curve (b) of the same graph represents readings taken from another

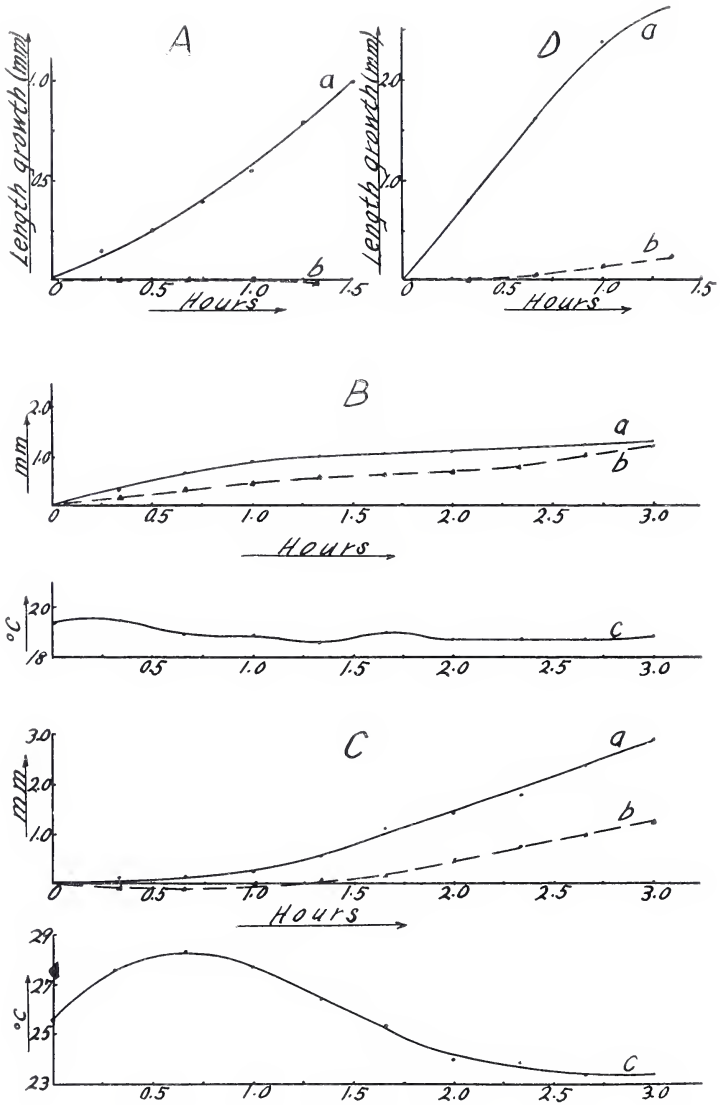

Fig. 2.

Fig. 2. A—Growth curves for a young bean plant and a control. a = plotted data for the young bean plant. b = plotted data for the control with the connecting cord anchored to the pot instead of fastened to a plant. Data obtained with the pivot type of mirror.

B—Growth curves for young pea seedlings. a = plant 3.5 cm. high. b = plant 4 cm. high. c = air-temperature curve.

C—Growth curves for bean plants. a = plant 30 cm. high. b = plant 33 cm. high. c = air-temperature curve.

D—Growth curves for irrigated and unirrigated bean plants. a = irrigated plant. b = unirrigated plant. Data for graphs B, C, and D were obtained with the torsion type of mirror.

experiment upon a dummy plant in order to discover whether any incidental changes in length of the braided silk connecting cord were sufficient to introduce appreciable error. An examination of this figure shows that such changes are evidently slight. This conclusion was substantiated by an experiment conducted for six hours with a similar result.

Two sets of duplicate curves are shown in figures 2-B and 2-C together with curves representing the prevailing air temperatures. It is evident that the growth in length of similar pea or bean plant does not take place at identical rates under the same environmental conditions, but that the forms of the individual growth curves are much alike. The curves shown in figure 2-C are of especial interest since they show slight or negative growth at high temperatures, accompanied by high light intensities, and more rapid growth with falling temperature and a lower light intensity.

A further experiment (Fig. 2-D) was conducted in order to demonstrate the relation of plant growth and the available soil moisture supply. Two similar potted bean plants growing in soil with a dry appearance were chosen. One pot was set in a pan of water and subirrigated for 10 minutes. The soil of the second pot was allowed to remain dry. This soil was not dry enough, however, to cause the plant to show signs of wilting. Growth records taken over a short period of time demonstrate an extremely rapid growth rate for the irrigated plant (a) as contrasted with the very slow rate for the unirrigated plant (b).

Concluding Remarks

The apparatus herein described has proved useful for both demonstrating and measuring length growth in plants. If proper precautions are taken in carrying out the experiments to avoid (1) excessive tension and injury to the plant, (2) heliotropic curvatures due to uneven illumination, (3) strong air currents, and (4) changes in the length of the connecting cord (oiled braided silk cord is recommended), satisfactory results may be obtained under a variety of environmental conditions.