A Recording Transpirometer.

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With two Figures in the Text.

AN instrument which will automatically record the amount of water lost by a transpiring plant is of great service in many physiological and ecological studies. Of such instruments the most practicable type is that in which the loss in weight is automatically registered by means of a balance provided with some special mechanism. A number of such instruments have been devised, mainly by workers in the United States, but either they have never been put upon the market or else their cost is very high.

The first accurate recording balance which could be satisfactorily used for measuring the transpiration of a potted plant appears to be that described by Anderson,[1] who was the first to use the method of balancing the scale-pans by means of metal balls released at intervals by an electrical device. This balance seems never to have been put upon the market, and obviously would be costly to reproduce.

Woods[2] has invented another type of transpirometer on the plan of a recording hygrometer, which does not seem to have come into use. The best-known type of recording instrument is that of Ganong,[3] which of late years has been somewhat modified, and is described in his book on Plant Physiology. In this instrument, which is very ingenious and convenient, the scale-pans, as in Anderson's balance, are kept in equilibrium by steel balls which are added when required. It has, however, two drawbacks: it is expensive, thus prohibiting the use of a number of instruments in comparative work, and it is adapted to one particular weight only, the steel balls weighing one gramme. The instrument thus only records the time-intervals required for the loss of one gramme of water; an interval which is

[1] Alex. P. Anderson: On a new Registering Balance. Minnesota Botanical Studies, Bull. 9, Pt. IV, 1894, p. 177.

[2] Bot. Gaz., xx, 1893, p. 473.

[3] Bot. Gaz., xxxix, 1905, p. 141.

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often too long in the case of slowly transpiring plants. Of course, balls of lighter weight can be used,[1] but they must be of one particular size to suit the valve-mechanism.

The apparatus here described is an attempt to provide an instrument of considerable accuracy at a comparatively low cost, since part of the apparatus should be available in every well-equipped physiological laboratory. It has the further advantage that the water-content of the soil is kept constant automatically, a point of considerable importance, since soil moisture affects the rate of transpiration.

The principle on which the apparatus is constructed is, like that of Anderson and of Ganong, the addition, at intervals, of a weight equivalent to that lost in transpiration; but the novelty lies in the use of *water-drops* instead of steel balls, the water being added directly to the soil. By this means the combined weight of plant and pot and soil is constantly brought back to its original amount, and the soil to its original degree of moisture.

The apparatus consists of four parts: (1) a water-reservoir with a tube supplying drops of water of constant size; (2) an electrical device consisting of two solenoids (hollow magnets), which draw a tube backwards or forwards when energized by currents of a suitable direction; (3) a balance (provided with a 'damper' to prevent undue oscillations), the pans of which bear cups of mercury into which platinum points dip; (4) a revolving drum with recording pen actuated electrically. The arrangement of the various parts is shown in the photograph (Fig. 1), where the apparatus is in duplicate, one recording the loss of water from a transpiring plant, the other the loss of water from a porous-cup evaporimeter.

The pot containing the plant is contained in one of Ganong's aluminium 'shells', roofed over by a sheet of indiarubber which surrounds the stem of the plant and is perforated for a glass tube, which projects free above and is embedded below in the soil.[2] This tube receives water from the dropper when the loss of weight by transpiration has risen to a certain prearranged value. The 'dropper' is a bent tube, provided with a stopcock to regulate the rate of flow of the drops, and connected with a reservoir in which the pressure of water is kept constant by an air tube which dips below the level of the water. The reservoir and tube are supported on a stand adjustable in height.

The tube which serves to catch the water passes, as described above, through two solenoids, and is provided with a funnel at one end, the other end projecting over a reservoir which catches the waste water. When an electric current passes through one solenoid the tube is drawn back;

[1] Transeau (Bot. Gaz., lii, 1911, p. 54) has made some modifications in this direction and has invented a ball-supplying mechanism to be used separately from the recording apparatus.

[2] This tube can be connected below with a small porous pot, so that the water supplied may be distributed more evenly to the soil.

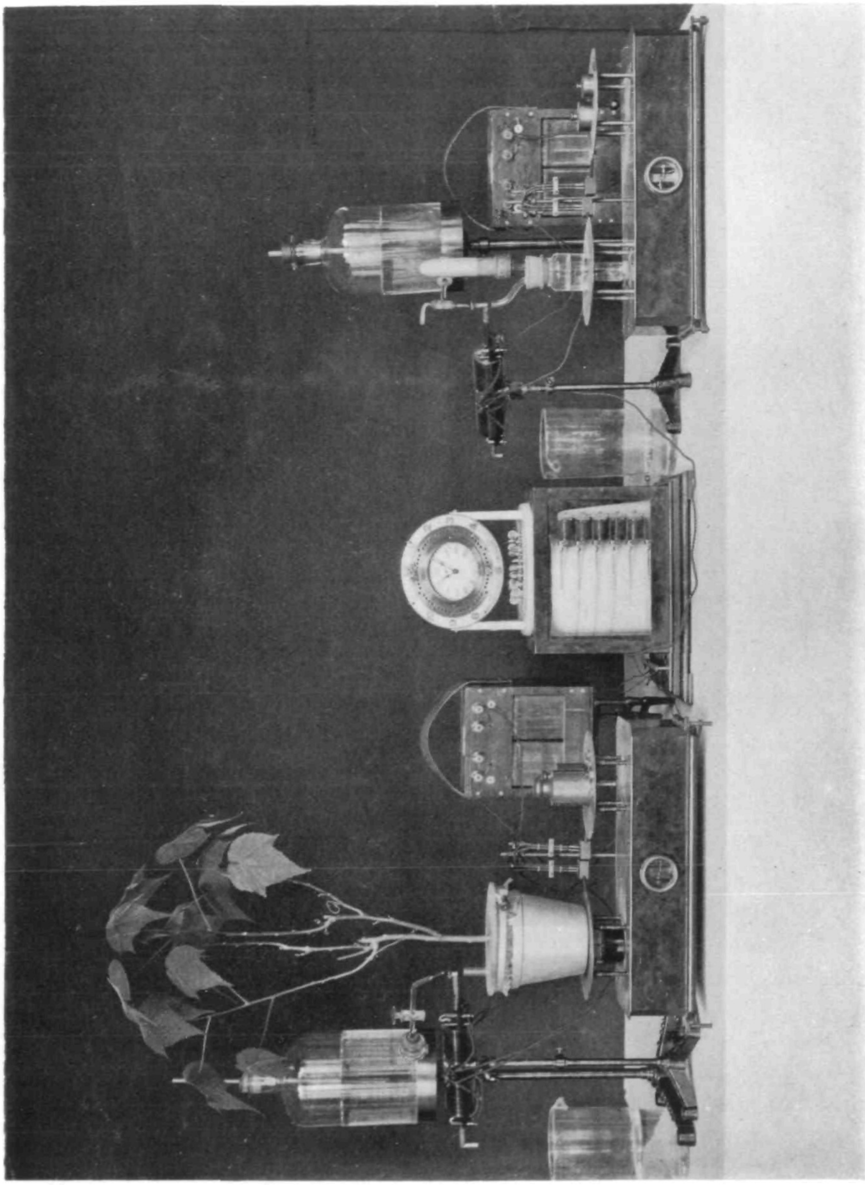

FIG. 1.

when the current passes through the other the tube is brought forward again. The tube is so placed that in its forward position the funnel stands immediately above the glass tube which is fixed in the soil of the pot, and the water-dropper is placed so as to deliver its series of regular drops into the funnel, whence they run to waste through the tube.

A balance of almost any type can be used provided that it is sufficiently sensitive and that it allows sufficient room above the scale-pan for the foliage of the plant. The balance employed in the apparatus photographed is of a simple, familiar type, with open pans supported below. This is sufficiently sensitive for ordinary work, but one with a bigger movement of the scale-pans, such as a large so-called physical balance, or Ganong's special transpiration balance, is more suitable for very accurate work. In any case, the balance must be provided with a 'damper' and an appliance for making contact as the pans rise. The damper is used to prevent the unduly large oscillations which would otherwise result from the fall of water into the pot, and from air-currents acting on the pans or plant. In the form of balance shown in the photograph, this purpose is accomplished in a very simple manner by attaching beneath one of the pans an aluminium disc which moves on a vessel containing some viscous fluid such as treacle or glycerine. In addition to this 'damper' there is attached to each pan a small vulcanite cup holding mercury. Above each cup stand a pair of platinum points, supported on the framework of the balance and in electrical connexion with the battery, the solenoids, and the recording pen.

When the apparatus is in use, the pot is placed on the left-hand scale-pan and is accurately counterbalanced, and the funnel of the solenoid tube and the dropper are placed immediately above the glass collecting-tube in the pot. As the plant transpires it loses weight, and the pan rises so that the left-hand pair of platinum points dip into the mercury in the cup attached to this pan; the electrical circuit is thus closed, with the result that the current passes through one of the solenoids and the metal tube with its funnel is drawn back. The water-drops are now free to fall into the glass tube fixed in the pot and so reach the soil. The addition of water to the pot continues until the increased weight in this pan causes the other pan with its attached mercury cup to rise and close another circuit. As a result, a current is sent through the other solenoid, which by its attraction brings back the tube to its forward position, and the water now runs again to waste. Every time the left-hand pan rises and closes the circuit, a portion of the current passes through the magnet of the recording pen, and so makes a vertical line on the revolving drum.

The platinum points can be raised or lowered by means of a simple screw arrangement, and so the apparatus can be set to respond to a small or a large number of drops. The loss of water from slowly transpiring plants is thus recorded as readily as that of more active ones. The actual weight of water lost corresponding to each mark on the record must of course be obtained by weighing the appropriate number of drops. The solenoids are provided with 'cut-outs', so that the current only passes momentarily at the time the points first make contact with the mercury. The solenoids and recording pen can be readily worked with two 2-volt accumulators in series; the interposition in the circuit of a short piece of manganin wire is useful in adjusting the strength of current, so that

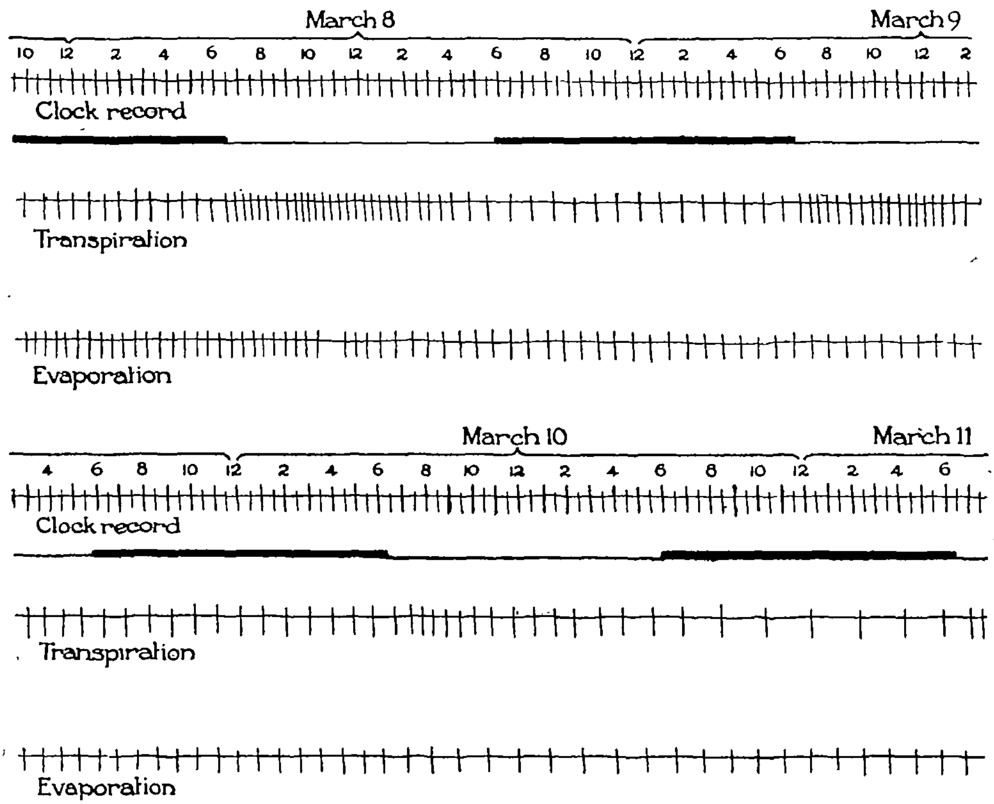

FIG. 2.

(The record has been cut into two and reduced to two-thirds.)

the movement of the tubes is not too rapid. The rate at which the drops fall can be controlled by the tap, and should be rather slow, as the 'damped' balance is naturally somewhat sluggish in movement. Distilled or filtered water is preferably used in the reservoir to avoid any sediment partially blocking the tube. There is a certain loss of soil-water by evaporation through the glass tube, but it is very small in amount; if necessary it can be measured and allowed for. A special thick-walled tube, ground flat at its orifice like a stalagmometer tube, can be used for dropping, but it is hardly necessary.

In the apparatus shown in the photograph, instead of a simple revolving drum, which is sufficient for ordinary purposes, there is a more elaborate drum (seen in the centre beneath the clock) with six pens, so that a number of comparative observations can be made. In this case a transpiring plant is being compared with the evaporation from a porous cup. A comparison of two such tracings enables one to eliminate the effect of such factors as humidity, temperature, air-currents, &c., which act directly on transpiration and evaporation alike.

A record obtained by this means is shown in the text (Fig. 2). The top line shows the time record, made by connecting a special clock (shown in the centre of the photograph (Fig. 1)) with a battery and one of the six pens mentioned above. The thick, long lines represent hours, the thin, short ones half-hours; the hours between sunset and sunrise are indicated by the black lines below them. The second line is the transpiration record, the lowest line that of the porous cup. The effect of light and darkness is brought out very sharply; while the transition from day to night has no effect on simple evaporation from the porous cup, the rate of transpiration is very much greater in the light, as is shown by the greater closeness of the vertical lines when the plant is illuminated. It will be noticed that the record shows that the rate of transpiration fell off as the experiment proceeded. In the absence of a record of simple evaporation under the same conditions, such a reduction might have been put down to some change in the plant. A glance at the lowest record shows that the evaporation from the porous cup is similarly reduced. In fact, while the experiment was started in warm dry weather, it was concluded in cold damp weather.[1]

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[1] By arrangement with the authors the various parts of the apparatus are supplied by Messrs. Baird and Tatlock, Cross Street, Hatton Garden, London, E.C.