ABSORPTION OF WATER FROM ATMOSPHERES OF DIFFERENT HUMIDITY AND ITS TRANSPORT THROUGH PLANTS

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Summary

An intact plant was arranged so that the top and roots were sealed in separate flasks. In each flask the vapour pressure was maintained at a predetermined level so that a diffusion gradient favouring water movement either from roots to top or from top to roots was established.

With 1-year-old seedlings of short leaf pine (*Pinus echinata*) the absorption of moisture from one flask and its transfer through the plant to the other has been demonstrated, regardless of whether the gradient favoured movement in the direction of normal transpiration (positive transport) or in the opposite direction (negative transport). Absorption occurred from both saturated and unsaturated atmospheres.

The relevance of the results to the absorption of dew and of moisture from unsaturated atmospheres is discussed.

I. Introduction

In recent years a number of investigations have been made concerning the absorption of water by the leaves of plants, and its transfer through the plant to the medium in which the roots are located. In particular the work of Breazeale, McGeorge, and Breazeale (1950, 1951), Haines (1952), Breazeale and McGeorge (1953*a*, 1953*b*), and Duvdevani (unpublished data) can be cited as offering strong evidence for the existence of such movement. In general, these investigators placed the tops of the plants under study in a fogged, supersaturated atmosphere and observed accumulation of water in the vessel containing the roots. The fogging was achieved by the continuous operation of an atomizer or fine sprayer, so that droplets of water formed on the plants. Although the results of these investigations aroused some controversy, it would seem, as Haines (1952) pointed out, that the absorption and movement of water through the plant under these conditions was to be expected as a gradient of increasing diffusion pressure deficit† (DPD) existed from the environment surrounding the leaves to the environment surrounding the roots. The significance of these studies in relation to the absorption of dew by plants under natural conditions has been stressed, in particular by Duvdevani (unpublished data).

Stone, Went, and Young (1950) contributed to the subject in an experiment which demonstrated absorption of water from an unsaturated atmosphere. In their investigation, a small "Plexiglass" chamber was sealed around the top of 2-year-old Coulter pine seedlings, and water-saturated air blown into the chamber. The plants tested were growing in very dry soil, and to induce further water stress they had been exposed to forced ventilation for 48 hr prior to the tests. They were left in the chambers for 24 hr, at the end of which time the relative humidity, as determined by

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† Using the terminology of Meyer (1945).

a humidity sensor inside the chamber, was recorded. In most of the tests the humidity was reduced to a level equivalent to a DPD of more than 150 atm, and in one case to 230 atm. The authors concluded that DPD's of this magnitude existed in the plant and were responsible for the uptake of moisture. They did not measure soil moisture, and so could not determine whether or not the moisture was transported through the plant to the soil.

Theoretically it would be expected that the water would move into the soil as long as the DPD of the soil water was higher than the DPD of the water in the plant, and that transport of water from the atmosphere to the soil would occur whenever a DPD gradient favoured such transport.

In order to take this investigation one stage further, equipment was made up so that the top and roots of an intact plant could be placed independently in atmospheres of known vapour pressure (and hence of known DPD). By establishing DPD gradients at desired levels it was hoped to demonstrate transport of water through the plant in both directions.

II. Apparatus and Methods

The apparatus consisted of two cylindrical flasks, each 8 in. long and $1\frac{1}{2}$ in. in diameter, joined by a ground glass central junction so that the top projected into one flask and the roots into the other (see Fig. 1). The inner walls of the flasks were

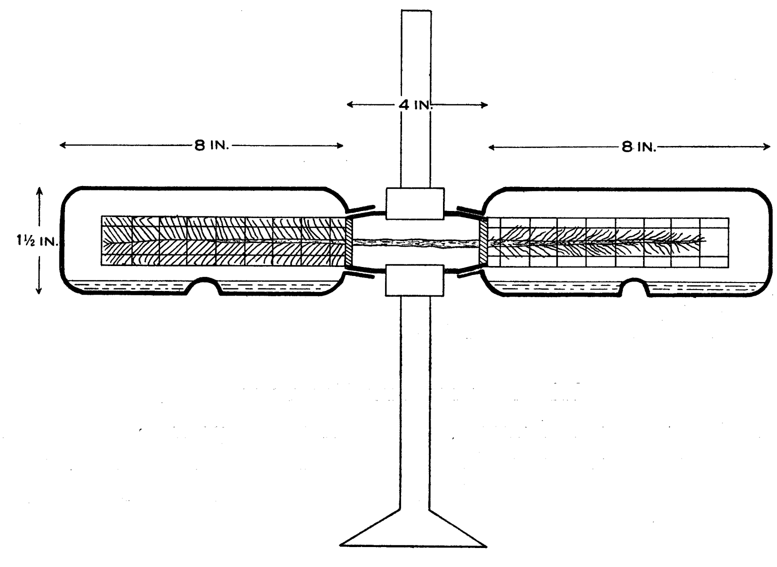

Fig. 1.—Diagrammatic view of apparatus. This whole unit was placed in a constant temperature water-bath for the determinations.

lined with filter paper which dipped into a reservoir of sodium chloride solution of known concentration at the bottom. A baffle midway along the bottom of each flask prevented undue movement of the solution during manipulation.

The plant was prepared by washing away the soil from around the roots (after the pot containing the plant had been saturated for 24 hr to facilitate washing). It was then sealed in the central tube with "Permagum"* and "Tackiwax"*, the roots dried as completely as possible with filter paper, and the roots and leaves wrapped loosely with an $\frac{1}{8}$-in. screen mesh to prevent the plant material from dipping into the solution or touching the sides of the flasks.

Prior to insertion, approximately 50 ml of sodium chloride solution of the desired concentration were added to each flask which was then stoppered, weighed to 0·01 g, and allowed to equilibrate for 24 hr in a constant temperature water-bath. As soon as the central unit containing the plant was ready, the flasks were removed from the bath, unstoppered, the plant material inserted, and the apparatus replaced in the bath. Loss of weight by the flasks during the insertion of the plant material did not exceed 0·02 g. At the conclusion of the determination the apparatus was removed from the bath, the plant material extracted and the flasks restoppered, dried, and reweighed to 0·01 g.

The plant was placed in nutrient solution for several days to make sure that death had not occurred during the determination. Change in weight of the flasks was used to determine the extent of water transfer from one flask to the other. During the transfer, loss of turgor in the plant occurred, and this was reflected in a greater gain by one flask than loss by the other. The difference between these amounts represented the degree of turgor loss. Data obtained by direct weighings of the central plant unit before and after each determination were used in the first few experiments to check the results from the flask weights, and to exclude the possibility of leaks in the system. This procedure was found to be unnecessary and was discontinued. No special lighting was provided for the tops of the plants. They received intermittent light from an incandescent light bulb, which comprised the heat source for the water-bath, and diffuse light from normal room illumination.

The constant temperature water-bath used in the experiments was held at 25·0°C and at this temperature was maintained constant to ±0·001°C. Temperature control of this order was very important to minimize the possibility of condensation of water on the plant surfaces. All the experiments were conducted in a constant temperature room, which made the attainment of this degree of temperature control much easier.

III. Results and Discussion

With this apparatus and procedure, two series of experiments were conducted: one with gradients favouring normal transpiration, referred to in this paper as positive transport, and the other with gradients favouring the movement of water in the opposite direction, referred to as negative transport. Two treatments were imposed in each series, the first involving a DPD gradient from 0 atm in one flask to 60 atm in the other, and the second involving a gradient from 15 atm to 60 atm. The former treatment was intended to confirm the results of the investigators who have worked in fogged atmospheres, except that in this case no droplets of water were present; and the latter was intended to extend the work of Stone, Went, and Young (1950) to cover water movement from the aerial environment through the plant to the root environment.

* Trade names for commercially available sealing compounds.

The plant material used was short leaf pine (*Pinus echinata*) of which a great number of 1-year-old seedlings of uniform size were available. Different plants were used in each experiment, and at insertion the weight of most of the plants was approximately 8 g. The standard period for the experiments was 7 days.

The data obtained from a series of 17 experiments are given in Tables 1 and 2. It is at once evident that both positive transport and negative transport have been demonstrated depending on the direction of the DPD gradient.

TABLE 1

TRANSPORT OBSERVED WHEN GRADIENT FAVOURED POSITIVE TRANSPORT

Wt. of Plant at Insertion (to nearest g)	DPD of Vapour (atm)		Change in Wt. of Flask (g)		Change in Wt. of Plant (by subtraction) (g)
	Roots	Tops	Roots	Tops	
12*	0	60	−4·81	+5·38	−0·57
8	0	60	−2·61	+2·84	−0·23
8	0	60	−2·88	+3·28	−0·40
8	0	60	−3·28	+3·81	−0·53
Means:	0	60	−2·9	+3·3	−0·4
8	15	60	−1·21	+2·29	−1·08
8	15	60	−1·28	+2·66	−1·38
8	15	60	−1·39	+2·42	−1·03
Means:	15	60	−1·3	+2·5	−1·2

* Results for this plant not included in means.

From Table 1 it is evident that appreciable amounts of water were transferred in both the 0–60 atm and 15–60 atm treatments. Total gain by the 60-atm flask was greater in the former case, as was to be expected from the relative steepness of the gradient. Loss from the 0-atm flask was, however, much greater than from the 15-atm flask and there was an associated decrease in the weight of the plant in the latter treatment. This can be explained when it is realized that the plants at insertion were turgid, and some dehydration had to occur in them before the DPD gradient could develop through the whole system. Thus, in the 0–60 atm treatment evaporation from the leaves of the plant into the 60-atm flask quickly resulted in the development of a DPD of several atmospheres in the plant and so enabled absorption of water through the roots from the 0-atm flask. In the 15–60 atm treatment, however, a DPD in excess of 15 atm had to develop in the plant before a gradient favouring absorption from the 15-atm flask existed. Hence the time taken for the development of this gradient would be expected to markedly reduce the time during which absorption from the 15-atm flask occurred, and hence the amount of total transfer in the 7-day test period.

In Table 2, results of the experiments in which the direction of the DPD gradient favoured negative transport are given. In this case the gains in weight by the 60-atm flasks were about two-thirds as great as in the former series of experiments, and the order of the gain in the 60–0 atm treatment was about one-third greater than in the 60–15 atm treatment.

Although no quantitive data on leaf and root surface areas were obtained, the order of difference in weight gain by the 60-atm flasks in the two series of experiments suggests that a smaller evaporating surface of the roots may have been of importance in this connection. Within the negative transport series the differences in gains by the 60-atm flasks would again seem to be mainly a result of the relative steepness of the gradients.

Table 2

TRANSPORT OBSERVED WHEN GRADIENT FAVOURED NEGATIVE TRANSPORT

Wt. of Plant at Insertion (to nearest g)	DPD of Vapour (atm)		Change in Wt. of Flask (g)		Change in Wt. of Plant (by subtraction) (g)
	Roots	Tops	Roots	Tops	
8	60	0	+2·12	−0·20	−1·92
8	60	0	+2·52	−0·63	−1·89
8	60	0	+3·54	−0·88	−2·66
8	60	0	+2·68	−0·50	−2·18
Means:	60	0	+2·7	−0·5	−2·2
5*	60	15	+0·92	−0·12	−0·80
8	60	15	+1·70	−0·37	−1·33
8	60	15	+2·07	−0·43	−1·64
8	60	15	+1·82	−0·44	−1·38
8	60	15	+1·92	−0·43	−1·49
8	60	15	+1·77	−0·28	−1·49
Means:	60	15	+1·9	−0·4	−1·5

* Results for this plant not included in means.

From Table 2 it can be seen that the losses by the 0- and 15-atm flasks were much less than in the positive transport series, and the loss of turgor by the plants during the experiments was much more pronounced. Whereas in the positive transport series, dehydration of the plant only proceeded until a DPD developed of sufficient magnitude to enable absorption of water through the roots, in this series it appears that the plant as a whole was dehydrated until a DPD of the order of 60 atm was developed.* This indicates that the steepest part of the gradient was not at the root surface, but at the leaf surface. In normal transpiration (and in the

* Confirmatory evidence on this point has been obtained by the author (unpublished data) from a separate experiment. With similar seedlings to those used in this investigation the loss of weight from a turgid plant dehydrated to 60 atm was of the same order as that observed here.

positive transport series reported above), the steepest part of the gradient is at the leaf surface and it would be expected that the opposite would be true under conditions favouring negative transport. That this does not apply suggests that the cutinized epidermis of a leaf is much less permeable to water than the suberized epidermis of a root, at least in the seedlings used in this study.

The fact that the whole plant had to be dehydrated to approximately 60 atm before a gradient existed favouring absorption through the leaves explains the relatively small quantities of water absorbed from the 0- and 15-atm flasks in these treatments. Much of the period of the experiment would have been occupied with the development within the plant of a DPD high enough to cause absorption, and the time available for absorption would have been proportionately reduced. Had plants already dehydrated to 60 atm been used it could be expected that loss in the low tension flasks would be of the same order as gain by the high tension flasks. In practice, attempts to introduce dehydrated plants failed because of the degree of root mortality which followed rapid desiccation during the preparation of the material.

In conclusion it may be stated that these experiments have demonstrated that water has been absorbed from one flask and transported through the plant to the other flask, along gradients of DPD, regardless of whether the gradient has favoured positive transport or negative transport. In both cases absorption has occurred not only from an atmosphere of 100 per cent. relative humidity, but also from an unsaturated atmosphere.

This mechanism may have some significance in nature. In the first place it lends support to the hypothesis (put forward by the investigators cited above) that dew can be absorbed by plants, because in all but very wet soils, gradients favouring absorption would exist. Secondly it indicates that moisture may be absorbed from an unsaturated atmosphere so long as there is a favourable gradient. Such conditions can be expected to occur in areas of suboptimal rainfall, and particularly in semi-arid and arid regions, where humidity levels reach quite high values at night, even if dews do not occur. In these regions plants persist for protracted periods in very dry soil, and the DPD of the soil moisture may be of the order of several hundred atmospheres (Burr 1914; Alway, McDole, and Trumbull 1919). It is conceivable that DPD gradients favouring negative transport could develop, and water may move along these gradients from the atmosphere to the plant, and possibly through the plant to the soil. To what extent such transport could benefit plants is a matter for physiological study. The actual amounts of water involved under natural conditions have yet to be determined but it seems that even small amounts of additional water would be of benefit to plants growing in areas of low rainfall.

IV. Acknowledgments

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