THE ROLE OF TRANSPIRATION IN THE ABSORPTION AND TRANSLOCATION OF MINERAL SALTS IN PLANTS

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Cotton and bean plants were grown in solution culture and during the light period one set was kept in a mineral nutrient solution and another set in distilled water. During the dark period the treatment of two sets was reversed. The concentration of culture solution was such in which the plants grow slightly less well than plants growing in full concentration. This presumably prevented the accumulation of minerals in the root. The height and dry weights of the plants of both the sets were determined at the end of the experiments. The observation indicated that higher transpiration rate during the period of mineral salt availability is responsible for greater absorption of salts and better growth.

Introduction

The precise role of transpiration in the upward translocation of mineral salts in plants has been a subject of considerable discussion. It is known that inorganic ions absorbed by the roots are translocated upwards predominantly in xylem, although the specific chennels in xylem, that is, the cell types through which the bulk of this movement takes place, have never been delineated with certainty. However, it is reasonably probable that most of the ions are carried along by solvent drag forces through the walls and lumina of the tracheids, and, in such species as contain trachea, through these cells as well. It follows from this view that an increase in transpiration rate, to the extent that it accelerates the movement of water upwards through these tracheary elements, should similarly increase the rate of transfer of ion from the roots to the shoots.

By exposing corn and bean plants to different humidities to make them vary in the rate of transpiration, Freeland[1] and Wright[2] demonstrated that an increase in the absorption of water resulted in an increase in the mineral uptake. Hylmo[3] has also shown that the degree of absorption of calcium is directly proportional to the amount of water transported in the transpiration stream. The importance of metabolic activities of the root in salt absorption could be taken as one of primary controlling factors but the subsequent movement of solute up into the shoot might be still with the transpiration stream. The experiments of Broyer and Hoagland[4] are very important in this respect. They supplied mineral nutrients to three series of barley plants according to the following plan: (1) plants were supplied mineral nutrients during a 12-hour dark period each 24 hours; (2) a set of plants were supplied with mineral nutrients during the 12 hours of light each day; (3) a third set of plants was supplied with mineral nutrients continuously. At the end of three weeks the concentration of different salts in the roots and shoots as determined.

They concluded, "On the whole, the amount of ions absorbed were roughly the same whether the nutrients were available during the day or only during the night". The concentration of salts in the plants getting nutrients continuously was roughly double that of plants in the other series. Contrary to the first concept, these results suggest that most of the salts absorbed are translocated into the shoot, regardless of the rate of transpiration.

In view of above mentioned conflicting reports it was considered that further studies of this classic problem should be carried out in the light of modern concept of 'outer space' and 'inner space' present in the root.

Materials and Methods

Cotton plants (*Gossypium hirsutum L.*) and bean plants (*Phaseolus vulgaris* L.) were used in all the experiments reported in this investigation. Seeds were separated in uniform size lits. After soaking for one hour in distilled water the seeds were placed in culture dishes on moist vermiculite for germination. The culture dishes were placed in an incubator at 35°C. Cotton seeds sprouted by the fourth day and bean seeds sprouted by the seventh day after sowing. Cotton seedlings of uniform size were transferred in one-quart Mason jars fitted with a cork lid having two holes, one for receiving the aerator and the other for fixing the plants. The jars were placed in a controlled environment room and connected to a compressed air manifold. Sylvania F. 96, TB/CW cool white fluorescent tubes, supplemented with Ken Rad 60-w tungsten bulbs, were used for illumination. The illumination intensity at the top of the plants was about 1000. F.C. A light period of 12-hours at 80°F. was alternated with a 12-hour dark period at 70°F. The relative humidity of the room ranged between 30 and 40 per cent. Mineral nutrient solution was supplied according to the Hoagland'. formulation and concentrations given by Meyer *et al*,[5] were taken as full concentration for the purpose of dilution in later experiments. Micronutrients were added according to the formulation of Arnon[6] and iron was supplied in the form of ferric-potassium ethylenediamine tetraacetate.[7]

Experiments and Results

Prior to selecting the concentration of Hoagland solution used in this experiment, a series of cotton plants were grown in full, half, quarter, and one-eighth concentration of the macrometabolic elements. Full concentrations of micrometabolic elements are iron were added in each dilution. This was done in order to find out the critical concentration of culture solution which was slightly growth-limiting for cotton plants. Analysis of the growth of these plants showed that those growing in the half concentration grow only slightly less well than the plants growing in full concentration, but much better than the plants growing in one-fourth or one-eighth concentrations.

Cotton plants growing in one-quart Mason jars, in full concentration of culture solution, having at least five fully expanded leaves were matched together according to the size and number of leaves. One plant of every pair was kept in one-half of the normal concentration of culture solution during the light period, while the other was kept in distilled water. During the dark period this treatment was reversed between the plants of each pair. In this way, one set of plants was in one-half of the normal concentration of Hoagland solution during the light period and in distilled water during the dark period. The other set of plants was in distilled water during the light period and in one-half of the concentration of nutrient solution during the night. The differentiation in the rates of the growth between the two sets of plants became apparent after 20 days of the treatment. After 40 days the plants were harvested and their dry weights were determined. The observations are given in Table 1.

TABLE 1.—HEIGHT AND DRY WEIGHTS OF COTTON PLANTS SUPPLIED WITH MINERAL IONS DURING DAY OR NIGHT ONLY.

Plant	Height (in cm.)		Dry weights (in g.)	
	Day,—Water Night,—Solution	Day,—Solution Night,—Water	Day,—Water Night,—Solution	Day,—Solution Night,—Water
1.	20.0	22.5	2.09	3.69
2.	17.5	31.5	1.86	7.60
3.	20.5	37.4	3.03	11.22
4.	20.0	32.4	2.79	9.52
5.	25.0	30.5	3.57	5.91
6.	21.0	30.0	2.35	4.34
7.	21.0	25.5	3.12	4.23
8.	22.0	24.0	2.79	3.75
9.	21.4	29.0	1.93	4.37
10.	19.5	32.0	2.02	7.93
Mean:	20.75	29.48	2.54	6.25

Bean seedlings of uniform size were transplanted to one gallon crocks containing distilled water or culture solution. Each crock was covered by a tygon-painted lid of mesonite having one inlet for aerator and three holes for fixing three bean plants. Half of the crocks were filled with distilled water and the others with quarter normal concentration of culture solution. Day and night alternating treatment of the plants was the same as mentioned in previous experiment. The experiment was performed in a green house and the transfer of plants from culture solution to distilled water and *vice versa* was carried out at sun-rise and sunset. Preliminary experiment for the selection of slightly growth-limiting concentration of culture solution in bean plants showed that one fourth concentration is most suitable for this purpose. Therefore one-fourth concentration of macrometabolic elements and full concentrations of micrometabolic elements and iron were used in the experiments with beans.

The differentiation in the rates of growth between the two sets became apparent after ten days of the treatment. Plants were harvested after 20 days of the treatment and their dry weights were determined. The observations are presented in Table 2.

TABLE 2.—HEIGHT AND DRY WEIGHTS OF BEAN PLANTS SUPPLIED WITH MINERAL IONS DURING DAY ONLY OR NIGHT ONLY.

Plants	Height (in cm.)		Dry weights (in g.)	
	Day—Night Water, Solution	Day—Night Solution, Water	Day—Night Water, Solution	Day—Night Solution, Water
1.	28.9	36.0	2.36	3.59
2.	24.0	50.5	1.88	3.42
3.	34.6	37.8	1.83	4.62
4.	26.4	41.5	1.97	3.57
5.	31.5	39.0	1.71	3.00
6.	33.0	60.5	2.10	4.20
7.	26.8	52.5	2.00	3.85
8.	26.0	40.2	1.70	3.31
9.	29.5	44.0	2.11	3.35
10.	20.0	48.0	2.01	3.63
11.	31.0	36.5	1.91	3.55
Mean:	29.15	44.22	1.96	3.64

Discussion

The results of previous experiments show that the plants kept in culture solution during the day and in distilled water during the night exhibit better growth in comparison with the plants treated *vice versa*. The difference between the height and dry weights of the two sets are quite significant. Preliminary experiments performed in order to find out concentrations of Hoagland solution which were slightly growth-limiting for cotton and bean plants provide critical knowledge on which later experiments were based.

In some other experiments a series of bean plants was kept in full concentrations of culture solution and alternating treatment of day and night was given but any significant difference was not noticed in height or dry weight of the plants belonging to different series. In these experiments, as in that of Broyer and Hoagland's,[4] a series of plants are kept in full concentration of culture solution during the night and in distilled water during the day. It is likely that an amount of minerals will be accumulated metabolically by active transport in 'inner space' sufficient for optimal growth of the shoot even during the period in distilled water. Root 'outer space' of course contains approximately the same concentration of mineral ions as the external solution. Thus at the end of the nutrient solution period the roots of the plants will probably be saturated, and this may constitute an excess of ion with regard to the mineral requirement of the shoot at that time. Subsequently, when the plants are placed in distilled water, the metabolically absorbed fraction of ions as well as the ions present in 'outer space' become available for translocation to the shoot, and shoots are supplied with minerals irrespective of the mineral present in the external solution. It appears reasonable, therefore, that Broyer and Hoagland[4] might not have found any difference in growth between the two series of plants, treated *vice versa*. In those experiments where a series of plants were kept in the sub-optimal concentration of culture solution during the night and in distilled water during the day the amount of minerals accumulated metabolically by active transport in 'inner space' is not sufficient for optimal growth of the shoot. Therefore, even when plants are placed in distilled water, the fraction of ions present in 'outer space' and 'inner space' of the roots become available for upward translocation but the amount is not sufficient for optimal growth.

A comparison between the day and the night rates of respiration of bean plants in a green house showed that the rate of transpiration during the day was about ten times that at night under the conditions prevailing at the time of experiment. The results given in Tables 1 and 2 clearly indicate that the availability of ions in the shoot expressed in terms of shoot length and dry weight, is greater in the plants kept in culture solution during the day. This strongly suggests that high rates of transpiration promote the translocation of ions. Low rates of transpiration, occurring during only the period of time that mineral salts are available, has a growth-limiting effect. It may be concluded that transpiration facilitates the translocation of mineral ions.

Summary

A series of experiments were performed to study the effect of transpiration on the absorption and translocation of mineral ions in cotton and bean plants. During the light period one set of plants was kept in a mineral nutrient solution and another set in distilled water. During the dark period the treatment of the two sets was reversed. For these experiments the mineral nutrient solutions were adjusted to a concentration in which the plants grow slightly less well than plants growing on full concentration. This presumably avoids ion accumulation in the 'outer' and 'inner spaces' of the roots to the extent that they would be available for translocation during the period when the plants are kept in distilled water. Plants kept in mineral nutrient solution during the period of rapid transpiration (day) grew much better than the plants kept in mineral solution during the night period of low transpiration.

Results of these experiments strongly suggest that a higher rate of transpiration during the period of mineral salt availability is responsible for greater rate of translocation. Conversely, a low rate of transpiration during the period of mineral salt availability may be growth-limiting.

References

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