Short Communication

Inhibition of Phosphorus and Water Passage Across Intact Roots by Polyethylene Glycol and Phenylmercuric Acetate

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ABSTRACT

Application of polyethylene glycol or phenylmercuric acetate to intact bean (Phaseolus vulgaris L., cv. Red Wade) roots inhibited passage of phosphorus across the roots to the xylem. The same results occurred for foliar application of phenylmercuric acetate when time was allowed for absorption and distribution of the chemical in the plant. For both chemicals the inhibition of phosphorus was proportional to or greater than any accompanying restriction on water flow across the root.

The osmotic agent polyethylene glycol and the stomate regulator phenylmercuric acetate have been routinely used to affect the water economy of experimental plants. One or both of these compounds have, however, also been observed to alter plant growth (2, 8, 10), nutrition (3, 6), photosynthesis (11, 13), and various physical characteristics of the plant (6, 9, 10, 11). Enumeration of such effects is necessary to a critical evaluation of the chemicals. Helpful too would be information on whether the chemicals interfered directly with vital processes such as photosynthesis and nutrition, or whether such processes responded to water stress induced by the chemicals. In the current study the effects of PEG and PMA on phosphorus and water influx were measured with these points in mind.

MATERIALS AND METHODS

Measurements were made of phosphorus and water passage across intact bean (Phaseolus vulgaris L., cv. Red Wade) roots to the xylem. These measurements rested on earlier findings that the processes of water and phosphorus movement to the xylem were not linked (5). Phosphorus passage controlled amounts of the element delivered to the xylem stream and to the plant top, and was insensitive to water flow. Water determined degree of dilution of phosphorus in the xylem stream, but not quantitative delivery of the solute to the stream or to the plant top. This phenomenon was given excellent illustration by Sutcliffe (12).

Passage of phosphorus was determined by simply measuring the end product of such passage—the amount delivered at the plant top. Water flow, on the other hand, was estimated by measuring the phosphorus concentration of the xylem stream. To explain, both phosphorus and water passage could be expected to affect composition of the xylem stream, but in antipodal directions. Restriction of phosphorus passage, as experienced throughout this report, would reduce the ratio of solute to solvent and thus lower concentration of the xylem stream. The well documented effect of PMA and PEG of restricting water flow would have the opposite effect. The ratio of solute to solvent would be increased and the xylem stream concentration raised. The extent to which water flow countered the effects of phosphorus passage on stream concentration was used here as a relative criterion of water flow.

The measurement for phosphorus in the xylem stream was made in a trilayer environment control system described elsewhere (4). In brief, roots and foliage of test plants were maintained in carefully controlled functional environments while a section of the hypocotyl was held at 0°C. Radiophosphorus was added to the roots, and the amounts which completed passage to the xylem stream were noted by measuring the radioactivity of the chilled hypocotyl. The reading represented 32P in the xylem sap of the hypocotyl section as well as 32P which had moved laterally from the sap to peripheral tissues. Mathematical correction was possible for the extra-xylem fraction. Experiments with derooted plants in the manner described in reference 4 established that the extra-xylem fraction was not influenced by PMA or PEG in the xylem sap in the concentrations used here.

In all experiments the test bean plants were grown in a hydroponics medium under controlled environment regimes to provide healthy, uniform, rapidly growing plants. Plants were ready for testing after 13 days growth from seed, when the first trifoliate leaves were approximately 2 cm long. Plants were taken approximately midpoint in the photoperiod and sealed in the trilayer environment system, with roots in 50 ml of the growth solution. After a 30-min conditioning period, the solution was replaced in rapid sequence with distilled water and then with 50 ml of 0.1 mM KH2PO4, which yielded approximately 3000 cpm/ml. Radiosolutions also contained 0.3 mM Ca(NO3)2. Activity of the chilled stem was recorded over a 2-hr period following addition of the radiosolution. The amount of 32P which reached the plant top during the test period was determined at the conclusion of the run by severing the stem slightly above the solution meniscus and counting the radioactivity of the ashed top.

Treatments were as follows: (a) PMA or PEG 600 in the radiosolution; (b) PMA or PEG 600 in the growth solution 24

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1 Storrs Agricultural Experiment Station Technical Contribution No. 546.
2 Abbreviations: PEG: polyethylene glycol; PMA: phenylmercuric acetate.
Fig. 1. Effect of root application of PEG on $^{32}$P and water passage across roots of intact plants. PEG was introduced at the beginning (graphs a and b) or 24 hr before the test period (graphs c and d). Total amount of isotope delivered to the plant top (graphs a and c) reflected passage of isotope across the root. Dilution or concentration of the xylem sap throughout the 2-hr test period (graphs b and d) reflected the extent to which water flow was influenced relative to $^{32}$P passage. LSD (0.05) values are given as bars.

Fig. 2. Effect of root application of PMA on $^{32}$P and water passage across roots of intact plants. Other criteria are as in Figure 1.

Fig. 3. Effect of foliar application of PMA on $^{32}$P and water passage across roots of intact plants. Other criteria are as in Figure 1.
hr before the test, and also in the radiosolution; (e) PMA sprayed on the foliage immediately before the test; (d) PMA applied to the foliage 24 hr before the test. Concentration of PMA in the radiosolution or the growth medium was 1.0 \( \mu M \), and that sprayed to the foliage was 0.1 \( \mu M \). PEG was added in quantities to produce an osmotic potential of \(-4.0\) bars.

RESULTS

PEG applied to roots reduced centripetal passage of radiophosphorus across the roots as evidenced by lower amounts of isotope delivered to the plant tops (Fig. 1, a and c). The length of time that roots were exposed to PEG was not a factor, since inhibition of phosphorus passage occurred whether PEG was added immediately before the test (Fig. 1a) or for a 24-hr period before the test (Fig. 1c).

The extent to which water flow was influenced by PEG relative to the effect on phosphorus passage is shown by the xylem sap concentrations in Figure 1, b and d. Concentration of sap was significantly lower for PEG-treated plants compared with untreated checks, indicating that any restriction of water flow was proportionately less than that on phosphorus passage. The time of introduction of PEG had no bearing on these results.

Results for PMA resembled those described for PEG. Exposure of roots to PMA restricted the passage of radiophosphorus to the xylem as noted by the reduced delivery of isotope to the plant top (Fig. 2, a and c). The time of introduction of PMA had no influence on these results.

The effect of PMA on water flow is shown by the xylem sap values. Sap concentrations were lower for plants treated with PMA at zero time (Fig. 2b), indicating that any restriction of water flow was less than that of phosphorus passage. When roots were pre-exposed to PMA for 24 hr sap concentrations remained unchanged (Fig. 2d), indicating that the restriction on water passage approximated that on phosphorus passage.

PMA was also applied to the foliage, and these results were conditioned by the time allotted for absorption and internal distribution of the chemical. When this interval was negligible and PMA was applied immediately before the test, \(^{32}\)P passage across the root was not affected (Fig. 3a). Water flow, however, was restricted as indicated by an elevated concentration of xylem sap for treated plants (Fig. 3b). This restriction undoubtedly reflected stomate closure by PMA rather than a response by the root. Where PMA was applied to the foliage 24 hr before the test, allowing time for absorption and distribution to the root, phosphorus passage to the xylem was restricted (Fig. 3c). Water flow was also restricted to the same approximate degree as phosphorus so that little change occurred in the concentration of the xylem sap (Fig. 3d).

DISCUSSION

The water regulators PEG and PMA inhibited passage of phosphorus into the plant, and this restriction was equal to or greater than that exerted on water. The question arises whether phosphorus reacted to the chemicals directly or to the water stress induced by the chemicals. It is necessary here to distinguish between water stress throughout the plant as a whole, and more specifically, stress in the plasmalemmas of the root cells which mediate passage of ions into the plant (5, 7). It seems unlikely that a general condition of water stress was prerequisite to inhibition of phosphorus passage, since inhibition occurred when PEG and PMA were allowed insufficient time to seriously affect plant water (when chemicals were added at zero time). This argument would not necessarily hold, however, for root cells in close contact with the root bath. A more immediate induction of water stress could be expected here which, according to Crafts (1), could decrease the free energy of the cell membranes and inhibit passage across them.

LITERATURE CITED