A Microautoradiographic Study of Ca$^{45}$ and S$^{35}$ Distribution in the Intact Bean Root

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Summary. Microautoradiographic techniques were used to determine the distribution of Ca$^{45}$ and S$^{35}$ in regions of the bean root where anatomical features may influence the processes of ion uptake and translocation. Root tissue from intact plants was prepared by methods that preserve both soluble and insoluble Ca and S. Ca$^{45}$ distribution was determined after 1 hour and 15 min of uptake, after 2 efflux periods, and after replacement by non-tracer Ca. S$^{35}$ distribution was determined after 1 hour and 15 min of uptake.

The quantity of Ca$^{45}$ that entered the root was greater than the quantity of S$^{35}$. Ca$^{45}$ concentration within the root increased with linear distance from the 8-mm level behind the tip. The pathways of Ca and S across the cortex appeared to be different since Ca$^{45}$ was particularly associated with cell walls and S$^{35}$ was distributed more evenly through the cells. There was no evidence that the endodermis was a diffusion barrier for Ca; the small parenchyma cells associated with conducting elements acquired a high concentration of Ca$^{45}$ and thus appear to be implicated in absorption and perhaps in transfer to the xylem. The evidence suggests that the endodermis may have been a barrier for S, but if so, certain parenchyma cells inside the stele, especially at xylem poles, were equally involved. The region from 30 to 80 mm from the tip appeared to participate in Ca uptake and transfer to the xylem; because of tissue immaturity the 8-mm region, which contained the least Ca$^{45}$, was thought not to translocate to the shoot. Deposition of Ca$^{45}$ in oxalate crystals represented almost complete immobilization. Calcium oxalate metabolism was most active in the 30-mm region of secondary roots and in their small branches. S$^{35}$-labelled nuclei occurred in the cortex 2.5 to 3 mm behind the root tip.

Introduction

Though it has been extensively studied the uptake and transport of mineral ions by plant roots is still far from being understood. This is true not only because of the complexity of the processes involved but also because direct methods for study are difficult to devise. Most of what is known about uptake and transport in roots has been extrapolated from studies of single cells, isolated tissues, or lower organisms.

Currently, ion uptake by the root is believed to consist of two phases, a passive one involving diffusion, mass flow, or exchange adsorption, and an active one dependent on metabolic energy. Since neither the sites of the two phases nor the interrelationships between them have been defined for the intact root the transverse pathway of an ion through the root is unknown.
Considerable evidence suggests that a tissue barrier to passive movement exists within the root and that its location governs the transverse route of an ion (see reviews of Steward and Sutcliffe, 1959; Russell and Barber, 1960; Sutcliffe, 1962). Priestley (1920), extending the earlier work of de Lavison, showed that dyes that were incapable of passing through protoplasm could penetrate the root only as far as the endodermis. He suggested, therefore, that substances move into the root along cell walls as far as the endodermis where the impermeable radial walls would necessitate movement into the protoplasm. This idea anticipated the current view that ions move passively in the cortex through cell walls to the stele boundary where they undergo metabolic uptake. A recent modification of the ideas concerning the site of metabolic uptake proposes that parenchyma cells within the stele surrounding the conducting tissue must actively accumulate sufficient amounts of an ion before it is released into the xylem (Branton and Jacobson, 1962a).

A different view of the transverse path is that ions move across the root via plasmodesmata in the cytoplasm rather than in the cell wall (Arisz, 1956). Some proponents of symplastic movement hold that active uptake occurs at the stele boundary (Crafts and Broyer, 1938; Wiersum, 1947), others that it occurs near the root surface (Lundegardh, 1954; D. E. Williams, 1962).

Additional complexities in the study of ion uptake and transport arise because of the differentiation of tissues in the longitudinal direction of the root. Many conclusions concerning ion uptake and transport have been based only upon data for the tip segment of the root and failed to credit the possibility that in an intact plant these processes may well be affected by the transition from meristematic to vacuolated cells, the maturation of conducting tissues, the development of a suberized endodermis, and the penetration of the endodermis by branch roots. The present study was begun with the idea that if sufficient autoradiographic resolution for water-soluble substances could be obtained the determination of ion distribution at various developmental levels of the root would help to resolve some of the uncertainties of ion uptake and translocation in intact plants.

Materials and Methods

Bean plants (Phaseolus vulgaris cv. Red Kidney) were grown in an aerated half-strength Hoagland-type solution (Ca concentration 0.0025 M) under controlled conditions of light, temperature, and humidity (S. F. Biddulph, 1956). These conditions insured production of plants with normal salt nutrition and fairly high transpiration rates.

Ca45 Experiments. Root segments for the Ca45 experiments were harvested from plants receiving the following treatments: (1) About 2 hours after the beginning of the light period the plant was transferred from unlabelled nutrient to a Ca45-labelled (Ca45 concentration ca. 1.5 mc/ml) Hoagland solution of the same strength