Simultaneous Uptake and Translocation of Magnesium and Calcium in Barley (*Hordeum vulgare* L.) Roots

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Summary. The patterns of uptake and translocation of magnesium in different regions of the root are very similar to those of calcium. Once the endodermis has become suberized translocation of either ion to the shoot is greatly reduced and it is concluded that magnesium, like calcium, appears to move across the root cortex largely in the free space.

Introduction

In considering the mobility of essential mineral nutrients in plants it has long been accepted that magnesium is more mobile than calcium, the other major divalent nutrient cation. This is particularly evident in leaves where calcium is accumulated with increasing leaf age whilst magnesium, like potassium, is readily translocated in the phloem from the leaf to other growing plant parts (e.g. Oland, 1963; Schimansky, 1973). Such observations raise questions as to whether, in general, magnesium is more readily transported in the symplast than calcium and whether the poor mobility of calcium can be attributed to its inability to move in cytoplasmic pathways. For example there is evidence that calcium moves preferentially, although not exclusively, in the free space (apoplast) in its passage across the root (Robards *et al.*, 1973).

A technical problem that has hampered study of the uptake and translocation of magnesium is the difficulty in obtaining its short-lived radioisotope $^{28}\text{Mg}$. Since this could be produced at the Kernforschungsanlage, Jülich, we took the opportunity to measure simultaneously the uptake and translocation of labelled magnesium and calcium by segments of intact barley roots. The results are compared with those from earlier studies of calcium translocation (Robards *et al.*, 1973) by barley plants grown under similar conditions.

Methods

*Hordeum vulgare* (cv Midas) was grown in $\frac{1}{10}$ Hoagland’s solution ($\text{Ca}^{2+}$ 0.5 mM; $\text{Mg}^{2+}$ 0.2 mM) at a temperature of $23^\circ\text{C}$, relative humidity 60% and light intensity of 18,000 lux. The seedlings were used for uptake experiments when 14 days old, the longest roots being about 30 cm in length.

The uptake apparatus was the same as that described in Ferguson and Clarkson (1975), where segments (approximately 3.5 mm long) of intact seminal axes were sealed into slits cut across the diameter of a polythene tube. Nutrient solution (as above, adjusted to pH 5.7, and labelled with $^{28}\text{Mg}$ and $^{44}\text{Ca}$) was pumped through the tube containing the root segments, whilst the remaining roots of the experimental plants were in a non-radioactive solution of similar composition. A second seedling was also placed in the latter solution as a check on leakage and re-absorption of radioisotopes. The radioactivity found in the roots and shoot of the second plant was deducted from the experimental plant on a fresh weight basis (see Russell and Sanderson, 1967). The $^{28}\text{Mg}$ ($^{28}\text{MgCl}_2$) was produced in the cyclotron of the Institut fü r Kernphysik and obtained carrier-free, from the Institut für Nuklearchemie der Kernforschungsanlage, Jülich.

Each experiment was run from 20 to 24 h after which time the solutions were removed and the plants divided into shoot, roots and treated segment. The length and diameter of the treated segments were measured and all results were expressed in terms of the volume of the segment. The fresh weights of the roots and shoot were also obtained and then all tissues were ashed at $500^\circ\text{C}$, made up to 5 ml with 0.2 N HCl and immediately counted for $^{28}\text{Mg}$ in a Packard 2099 Gamma Spectrometer. After allowing the $^{28}\text{Mg}$ to decay (half-life 21.3 h), 4 ml of the solution was added to 10 ml of 'Instagel' and the mixture counted for $^{44}\text{Ca}$ in a Packard Liquid Scintillation Spectrometer.

Results and Discussion

The pattern of translocation from the treated segment was very similar for magnesium and calcium (Table...
Table 1. Uptake and translocation of labelled-magnesium and -calcium by 3.5 mm segments of intact seminal axes of Barley over 24 h

<table>
<thead>
<tr>
<th>Ion</th>
<th>Distance from root tip</th>
<th>Translocated from segment (nmol ion mm⁻² segment)</th>
<th>Translocated treated segment (%</th>
<th>Total uptake</th>
<th>Translocated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ca²⁺</td>
<td>1 cm</td>
<td>0.98</td>
<td>2.18</td>
<td>45</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6 cm</td>
<td>1.50</td>
<td>0.57</td>
<td>72</td>
<td></td>
</tr>
<tr>
<td></td>
<td>30 cm (base)</td>
<td>0.08</td>
<td>2.53</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Mg²⁺</td>
<td>1 cm</td>
<td>0.48</td>
<td>0.60</td>
<td>56</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6 cm</td>
<td>0.65</td>
<td>0.22</td>
<td>75</td>
<td></td>
</tr>
<tr>
<td></td>
<td>30 cm (base)</td>
<td>0.06</td>
<td>1.69</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

1). Most translocation occurred from the apical regions of the root, with the highest proportion of that absorbed being translocated in the region approximately 6 cm behind the apex. This zone was apical to the emerging lateral roots. The "translocated" values for the 1 and 6 cm regions are the sum of the values for the shoot and the root system (other than the treated segment) and as such are a measure of movement across the endodermis. In the basal region, the "translocated" value is that of the shoot only since the treated segment was located in the extreme base of the root, and it is known that there is virtually no movement of calcium towards the root tip in the phloem (Marschner and Richter, 1974). There is a chance that this procedure may slightly underestimate the magnesium translocated from the treated segment because the extent to which magnesium, absorbed by the basal zone, moved in the phloem towards the root tip, in the presence of adequate external magnesium, was not determined. The amount of magnesium in the shoots was so small, however, that it seems improbable that large amounts could have been moved in this way. Thus, in the basal zones, only small amounts and proportions of the absorbed calcium and magnesium were translocated to other parts of the plant and it is assumed, therefore that there was little movement across the endodermis into the stele. There appeared to be a much larger amount of labelled calcium and magnesium associated with the basal treated segments than with the other zones; this may have been due to accumulation by bacteria on the root surface.

Earlier work has shown that calcium translocation is progressively reduced in zones of the root in which the endodermis has become suberized (Robards et al., 1973; Harrison-Murray and Clarkson, 1973; Ferguson and Clarkson, 1975). This development, which commences 8–12 cm from the tip of vigorously growing axes of barley, deposits hydrophobic suberin lamellae over the entire surface of the secondary cellulosic walls thus creating a barrier of high resistance to the direct passage of water and solutes from the apoplast to the plasmalemma of the endodermal cell. In the apical 8–12 cm from which calcium is readily translocated, it has been suggested that calcium moves radially in the apoplast to the endodermis where it is absorbed (see also Moore et al., 1965). After suberization, calcium is largely excluded from the stele, even though continuity of the symplast is maintained through the endodermal walls by plasmodesmata (Robards et al., 1973). It seems, therefore, that calcium is not transported effectively by the symplast thus contrasting with phosphate and potassium. We had anticipated that magnesium would be less affected than calcium by suberization and that it would move more freely in the symplast because of its greater phloem-mobility (Schimansky, 1973); it seems likely that it must pass through the plasmodesmata of companion cells to enter the phloem sieve tubes. In the event, the effect of suberization was similar with both ions and we conclude that neither moves across the symplast of the root in significant amounts and that effective translocation to the shoot occurs by movement towards the stele in a common apoplastic pathway in the apical portions of the roots. This interpretation is consistent with observations on the competitive inhibition of the translocation of the ions when barley plants were grown in solutions in which the ratio of calcium to magnesium varied (Lazaroff and Pitman, 1966). The absorption of the two ions by excised roots of *Zea mays* has also been found to be mutually inhibitory when they were supplied at a concentration of 2 mM or less (Maas and Ogata, 1971). The apparent reluctance of calcium and magnesium ions to move in the symplast of the root cannot be explained at present but may be due to their low activity in the cytoplasm where most divalent cations may be electrostatically bound or sequestered in some way.

We would like to thank Dr. F. Führ for his interest in this project and for the facilities provided for this work in the laboratory of the Arbeitsgruppe Radioagronomie der FKA, Jülich, and Dr. Ch. Schimansky for assistance with the preparation of the magnesium isotope.