Interaction of Rubidium or Sodium with Potassium in Absorption by Intact Sugar Beet Plants

ADEL M. EL-SHEIKH, T. C. BROYER, AND ALBERT ULRICH
Department of Soils and Plant Nutrition, University of California, Berkeley, California 94720

ABSTRACT
This study concerns the selective absorption of K and Rb or of K and Na by intact sugar beet (Beta vulgaris) plants from modified conventional nutrient solutions over an extended period of plant growth. Long term results agreed with those of short term experiments by other investigators using excised root systems and simple salt solutions. Potassium and Rb were mutually competitive in their absorption. High selectivity of K relative to Na absorption was observed. Sodium was excluded during the early growth period of sugar beets.

Most of the information about ion absorption has been obtained with excised root systems over very short time periods and with single salt solutions (4, 7). Results with excised root systems may or may not be extended to those of intact plants grown in complex nutrient solutions. Transport to and redistribution of minerals among the several organs of a plant, concurrent with growth and development, may significantly affect subsequent absorption of salts by roots from the multiple salt nutrient solutions. There is a need, therefore, for long term studies with intact plants supplied with complete nutrient solutions for comparison with those of a short time period in simple salt solutions in the study of the kinetics of ion absorption (1, 5). In the short time studies with either excised roots or intact plants it has been reported for simple salt solutions that K and Rb are mutually competitive on essentially equal terms, i.e., bound and transported by identical carrier sites (4, 5). In the absorption of Na and K by excised barley roots, Rains and Epstein (8, 9) postulated that a multiplicity of sites is concerned in transport of K and Na. In contrast, Jacobson et al. (7) postulated that there is a single common site for Na and K absorption. The present research concerns the influence of Na or Rb on K absorption from complex nutrient solutions. The rates of absorption of K as well as of the companion ions were determined from analyses of the culture solutions. Indirect evidence of carrier sites was observed.

MATERIALS AND METHODS
Beta vulgaris seeds, variety M.S. NB, X NB1, treated with Phygon-XL (2, 3-dichloro-1, 4-naphthoquinone) at the rate of 1%, were planted in vermiculite, and a basal nutrient solution lacking potassium was applied daily to an open pot system (3). When the seedlings were in the early two-leaf stage, they were carefully removed, and the roots were washed free of vermiculite. Individual seedlings were supported in a cork ring with nonabsorbent cotton and transferred at random, three per 20-liter tank, to solution cultures.

Two experiments were conducted concurrently: the first with Rb, the second with Na (Table 1). Each of the complementary cations was added as the sulfate. Five replicates per treatment were used, each in a completely randomized block design. The mineral composition of the solutions at transplanting was as follows: macronutrients in millimoles per liter; 0.5 MgSO4, 0.25 Ca(H2PO4)2, 1.875 Ca(NO3)2, and 0.125 CaCl2; micronutrients in milligrams per liter; 2.5 Fe, 0.25 B, 0.25 Mn, 0.05 Zn, 0.01 Cu, and 0.05 Mo. Iron was added as an FeCl3-EDTA complex (6). These nutrients were added again to the old solutions in the same amounts, 20 and 36 days after transplanting. Two K concentrations were applied in each experiment, a low-K treatment (1 meq/liter) and a high-K treatment (8 meq/liter). The low-K treatment allowed K deficiency symptoms to appear 3 to 4 weeks after transplanting while the high-K treatment supported favorable growth during a period of 42 days. The pH of the solutions was kept between 5.5 and 6.0 by the addition of 1.0 N H2SO4 or 1.0 N NH4OH as necessary.

Since the roots, especially the storage root, developed at different rates, solution volumes could not be practicably adjusted to the true initial volume, but were adjusted with distilled water to the initial pot level and sampled at 2-day intervals following transplantation. This deviation from the true volume does not affect the conclusions drawn, because differences of storage root size among different treatments were slight relative to the 20-liter solution volume; also, cation pairs for each treatment were proportionally affected. Analyses of the low-K media were made periodically up to 55 days, since K was added at transplanting time only. Analyses of the high-K media were made periodically up to 42 days only, the time when a second K addition of 4 meq/liter was necessary for the plant growth studies (3). Samples were kept at 4.5 C while awaiting analysis.

Potassium and Na were measured by means of the flame emission technique, except when the solutions contained Rb. Potassium was then determined by atomic absorption, since upon dilution Rb does not interfere with the K determination. Rubidium was determined by the atomic absorption technique after the addition of a high K concentration (50 meq/liter); this was particularly advantageous in the measurement of low Rb concentrations.

RESULTS AND DISCUSSION
Plants remained healthy as long as K was present in the culture solution. Potassium deficiency appeared first as a...
browning of the fibrous roots, which developed only after the K supply in the nutrient solution was quite depleted. Available sodium forestalls symptoms of K deficiency of tops and roots 

(3) and such an effect was noted in treatments 2, 3 and 4 (experiment 2).

**Rubidium-Potassium.** Culture solution analyses indicate that Rb absorption was similar to that of K. Such a conclusion was reached earlier by Epstein (4), using excised barley roots, and by Collander (2), using intact plants. However, Collander's results were based on plant composition and carried out under quite different conditions of plant culture than those used here. The absorption curves here, for Rb and K with time, were congruent for sugar beets when both cations were supplied at equal concentrations in the culture medium (Fig. 1A). As the ratio of Rb to K supply increased, Rb absorption increased and K decreased (Fig. 1, B, C). Conversely, as the ratio of K to Rb supply increased, the K absorption increased and Rb decreased (Fig. 1D).

If Rb acts as though it were identical to K, the absorption of either element at any sampling date would depend on its individual concentration as well as on that of the complementary ion. The ratio of K or of Rb to (Rb + K) in the initial nutrient solution would then determine the theoretical absorption ratio. At the theoretical value of 0.5 (K 1.0, Rb 1.0 meq/liter) and of 0.33 (K 1.0, Rb 2.0 meq/liter) the observed K absorption ratios

---

**Table I. Alkali Cation Concentrations in Nutrient Solutions**

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Treatment</th>
<th>K</th>
<th>Na</th>
<th>Rb</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1.0</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1.0</td>
<td>2.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>1.0</td>
<td>4.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>8.0</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>1.0</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1.0</td>
<td>0.25</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>1.0</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>1.0</td>
<td>8.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>8.0</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>8.0</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>8.0</td>
<td>8.0</td>
<td></td>
</tr>
</tbody>
</table>

---

**Fig. 1.** The absorption of K and Rb from solutions containing different concentrations of these ions. Initial supplies in milliequivalents per liter were: A: K 1.0, Rb 1.0; B: K 1.0, Rb 2.0; C: K 1.0, Rb 4.0; D: K 8, Rb 1.0. Total volume of each culture solution was 20 liters. Each value is an average of four replicates.

**Fig. 2.** Effect of Na on K absorption from culture solutions low or high in K. Total volume of each culture solution was 20 liters. Each value is an average of four replicates. Subscripts represent milliequivalents of Na per liter supplied.
K concentration of meq nearly depleted in Sodium had been between the due probably ratios (Fig. 4.1A, B). The only disagreement between the initial supply ratio K/(K + Rb) of 0.20 (for K 1.0, Rb 4.0 meq/liter) and the observed absorption ratio of 0.29 (Fig. 1C) is probably due to a toxic effect of the high Rb concentration on the root tissues. When K supply greatly exceeded that of Rb (for K 8.0, Rb 1.0 meq/liter), the observed absorption ratio agreed exactly with the theoretical value of 0.89 (Fig. 1D).

Sodium-Potassium. Sodium had no effect on K absorption (Fig. 2), whereas K strongly inhibited Na absorption (Fig. 3). Relationships between Na and K absorption are further illustrated in Figure 4. High selectivity for absorption of K relative to Na is apparent over a wide range of Na concentrations. Sodium was rapidly absorbed only after the K concentration had been depleted to a large extent (Figs. 3, 4).

Over the range of 0.25 to 1.0 meq of Na per liter, Na was absorbed only when K concentration was so low that it was nearly depleted in the supply medium. At 8 meq of Na and 1 meq of K per liter, little Na was absorbed while a low residual K concentration remained in the culture solution (Fig. 4C). At high concentrations of Na and K supply, Na was absorbed to a considerable extent in the presence of K (Fig. 4D).

The interaction of K and Na is different from that of K and Rb. Therefore, the K and Na relationship is not a simple competitive interference. The data, however, do not allow an unequivocal interpretation with respect to the relationship between K and Na absorption. Since an inhibiting effect of K on Na absorption has been demonstrated (Fig. 3), there are currently only two relevant modes of transport to be considered. One possibility is that a single common mechanism is responsible for K and Na absorption, with a much greater affinity for K than for Na (7). A high Na concentration rather than a high ratio of Na/K is needed for Na absorption (comparison of Figs. 4A and 4B with Figs. 4D and 4C). The second possibility is that two mechanisms are implicated in the absorption of K and Na (8, 9). The first mechanism presumably has a high affinity for K and is not effective for Na in the presence of K (Fig. 4, A and B). This mechanism would be available for Na absorption after K is completely depleted. The second mechanism presumably is not highly selective, transporting Na as well as...
K (Fig. 4, C and D), and operates at high Na and K concentrations.

Apparently, under the present conditions, the second mechanism was not effective for Na absorption during the first 20 to 25 days of growth (Fig. 4, C and D), a point of interest that should be examined further.

From the present data we conclude that the growth of plants in complete nutrient solutions over a long time period provides a useful method of studying ion absorption by entire plants. Information about ion absorption derived from excised root studies alone remains incomplete until confirmed with intact plants. In this respect K and Rb were found to be mutually competitive in their absorption, and a high selectivity of K relative to Na absorption was observed. Sodium was excluded during the early growth period of sugar beets.

LITERATURE CITED