

# ACCUMULATION OF POTASSIUM, CESIUM<sup>137</sup>, AND RUBIDIUM<sup>86</sup> IN BEAN PLANTS GROWN IN NUTRIENT SOLUTIONS<sup>1, 2</sup>

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In evaluating uptake into the biosphere of Cs<sup>137</sup> from fallout, frequent use has been made of a Cs<sup>137</sup>/K ratio (4, 10, 11). A similar ratio of Sr<sup>90</sup>/Ca has assumed importance in interpreting data on the uptake of Sr<sup>90</sup> (9, 13). The validity of the Cs<sup>137</sup>/K has been assumed from relatively small amounts of experimental data on the interaction of these two elements (1, 3, 11). Use of such ratios to evaluate hazards has been questioned by Kornberg (7, 8) on the basis of data obtained in this laboratory with isotopically labeled ion pairs.

Results described in this report deal with the simultaneous uptake of Cs<sup>137</sup> and potassium by plants. The results of similar experiments with Rb<sup>86</sup> and potassium are also reported.

## METHODS

*Phaseolus vulgaris* L. were grown by nutrient culture techniques in controlled environment growth chambers (12). The nutrient solution was prepared by a modified formula of Johnson et al (6). The macronutrient concentrations were: 2 mM Ca(NO<sub>2</sub>)<sub>2</sub>, 1 mM NH<sub>4</sub>H<sub>2</sub>PO<sub>4</sub>, 1 mM (NH<sub>4</sub>)<sub>2</sub>HPO<sub>4</sub>, and 0.5 mM MgSO<sub>4</sub>. Potassium was adjusted to concentrations from 0.07 to 20 mM by adding KNO<sub>3</sub>. Total nitrogen was held constant by adding NH<sub>4</sub>NO<sub>3</sub>. Micronutrients added were: Cl, B, Mn, Fe (added separately), Zn, Cu, and Mo at respective concentrations of 1.77, 0.27, 0.27, 0.22, 0.13, 0.03, and 0.01 ppm.

Cesium 137 was added uniformly to all culture media at a concentration of 0.8 microcuries per liter; the Rb<sup>86</sup> concentration was 0.4 microcurie per liter. Carrier cesium was added at concentrations of 0.02 or 0.2 mM (table I), and stable rubidium was 0.003 mM. Each treatment was triplicated with six plants per replicate. Seven-day-old seedlings were placed in the test solution and allowed to grow for 16 days. Nutrients were replaced every 3rd day with fresh solutions containing the initial concentrations of nutrients and radioisotopes. The pH was maintained between 6.0 and 6.3.

Plants were divided for analysis into stems, roots, and leaves with the latter divided according to age for some assays. Roots were blotted dry to remove

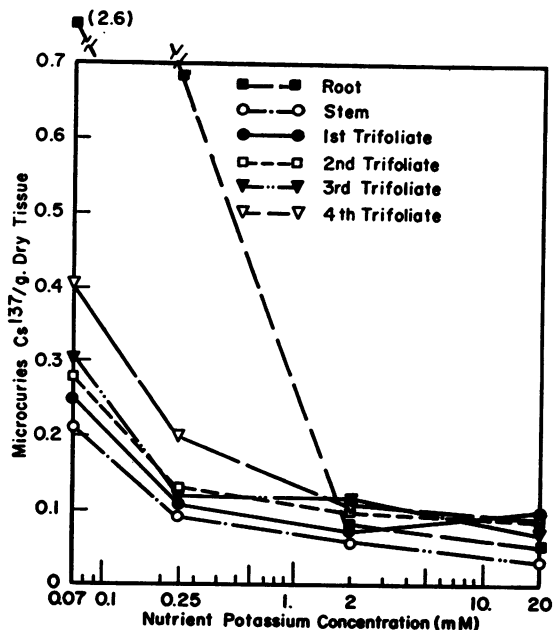
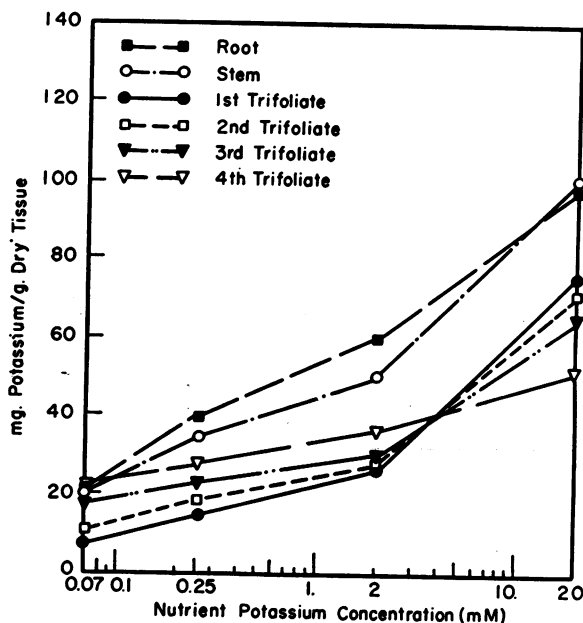


FIG. 1. Accumulation of potassium in plant tissue.  
FIG. 2. Effect of increasing nutrient potassium on Cs<sup>137</sup> concentration in bean plants.

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excess nutrient solution. Samples were dried in an oven at 70° C for 48 hours, weighed, and digested in hot nitric acid. Digests were not permitted to go to dryness since some cesium salts decompose at relatively low temperatures which could result in loss of  $\text{Cs}^{137}$ . The digested materials were brought to volume, and aliquots plated and assayed for  $\text{Cs}^{137}$  or  $\text{Rb}^{86}$  using the thin mica end-window beta counters. Potassium concentrations were determined on the same digests with a Perkin-Elmer, Model 146, flame photometer using the lithium internal standard method described in the manufacturer's operating manual.

### RESULTS

By comparing figures 1 and 2, it is clear the concentrations of both potassium and cesium in the plants were influenced by external concentrations of potassium. With progressively increasing amounts of externally supplied potassium, the potassium content of the leaves increased while the  $\text{Cs}^{137}$  content decreased. The decrease in  $\text{Cs}^{137}$  content was most significant in young leaves while the largest potassium increase was in older leaves. Rates of change were greater at the lower potassium concentrations.

Potassium concentrations in roots and stems were generally greater than in leaf tissues. This difference was accentuated with higher concentrations of potassium in the substrate. There was less  $\text{Cs}^{137}$  in stems than in other tissues at all potassium levels. The  $\text{Cs}^{137}$  content of roots was exceedingly high at the low potassium levels, but with substrate potassium concentrations of 2 mM and higher,  $\text{Cs}^{137}$  concentrations were higher in leaves than in or on roots.

Dry weights of the various plant parts were maximum with 2 mM potassium in the substrate (table I). A toxic effect of cesium was clearly expressed through decreased dry weight, yellow older leaves, and abnormal root growth when 0.2 mM cesium and 0.07 mM potassium were in the substrate. Such a plant is shown on the left side of figure 3, but unfortunately the abundant adventitious roots, characteristic of cesium toxicity, are not clear in this photograph.



FIG. 3. Cesium toxicity symptoms after 16 days exposure to treatment.

Toxicity was not due to depressed potassium uptake. Data in parenthesis in table I show that those plants which were damaged contained at least as high a concentration of potassium in the leaves compared to those grown on less cesium. The lower potassium in roots and stems suggests that its distribution may be modified even though uptake is unaffected.

Data reported here are from experiments in which potassium was added as the nitrate with total nitrogen held constant in all cultures by adding ammonium nitrate. Corresponding experiments were also conducted using KCl with nitrogen supplied uniformly

TABLE I

WEIGHT AND POTASSIUM CONTENT OF PLANTS AS FUNCTION OF POTASSIUM CONCENTRATION

SUBSTRATE CONCENTRATIONS mM		GRAMS DRY WEIGHT (MG K/G DRY TISSUE SHOWN IN PARENTHESIS)					
K	Cs	ROOTS	STEMS	PRIMARY LEAVES	1ST & 2ND TRIF	3RD & 4TH TRIF	TOTAL PLANT
0.07	0.02	1.02 (21)	0.94 (21)	0.70 (12)	1.25 (10)	1.25 (21)	5.21 (17)
0.25	0.02	1.47 (40)	1.43 (35)	0.89 (19)	1.68 (18)	1.82 (26)	7.30 (28)
2.0	0.02	1.58	1.75	0.98	1.68	2.13	8.11
20.0	0.02	1.58	1.74	0.95	1.74	1.51	7.53
0.07	0.2	0.71 (12)	0.81 (14)	0.82 (14)	0.84 (17)	0.77 (22)	3.95 (16)

to all cultures in concentrations according to the basic formula. Under both conditions results were similar, indicating little or no interference by the chloride, ammonium, or nitrate ions.

Results from similar experiments using  $Rb^{86}$  instead of  $Cs^{137}$  are shown in figure 4. Plant concentrations of potassium were essentially as in figure 1 and are thus not shown. As with  $Cs^{137}$ , the concentration of  $Rb^{86}$  in the various plant parts decreased as

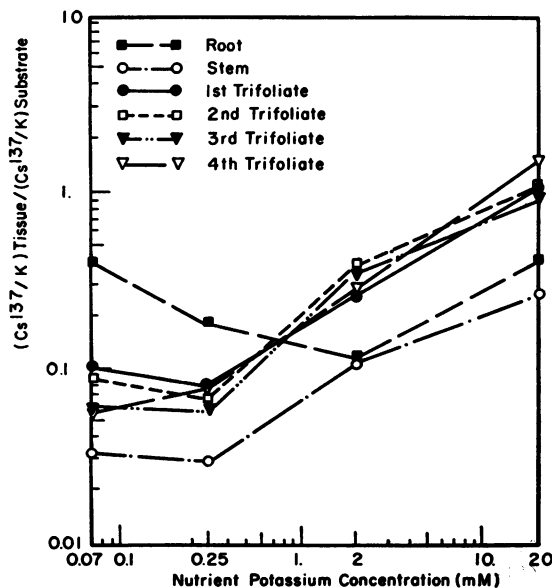
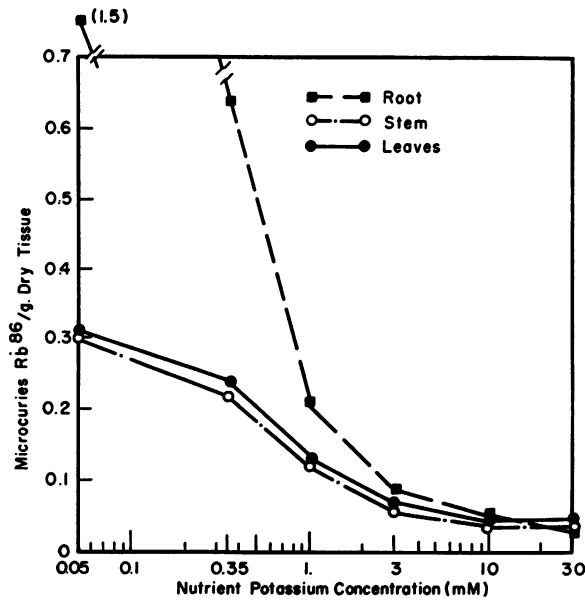


FIG. 4. Effect of increasing nutrient potassium on the uptake of  $Rb^{86}$  by plants.

FIG. 5. Effect of increasing potassium on DF values for  $Cs^{137}/K$ .

concentrations of potassium in the substrate and plants increased. The considerably higher  $Rb^{86}$  content of the roots as compared to stems and leaves at the lower potassium nutrient levels, was also similar to that obtained with  $Cs^{137}$ .

## DISCUSSION

The study of differential uptake by plants of cesium and potassium was facilitated by following the ratio of cesium to potassium in the plant tissues relative to the ratio in the substrate. We have chosen to use the term "discrimination factor" (DF), i.e.,  $(Cs^{137}/K)$  plant/ $(Cs^{137}/K)$  substrate, because it is descriptive and has previously been defined (2). Values greater than one indicate discrimination against potassium, and values less than one indicate discrimination against cesium. This term and similar expressions (observed ratio and distribution factor) have been used by other investigators (2, 4, 11) to compare concentrations in the organism with those in the substrate. The same value is obtained if one divides the percentage of  $Cs^{137}$  taken up by the percentage of potassium taken up.

In figure 5, the DF is plotted as a function of substrate potassium. It is clear that the degree of discrimination between  $Cs^{137}$  and potassium in aerial parts is not uniform. For plant parts other than roots, the DF rises about tenfold with a 200-fold increase in substrate potassium. The rise in DF is tempered by the increased potassium uptake over the range of substrate concentrations studied. However, the combined increase of potassium and decrease of  $Cs^{137}$  is not great enough to keep the ratio of these in the plant comparable with the ratio in the substrate. Thus, it seems that the uptake of these two ions is in part non-competitive. These results appear to disagree with those of Collander (1). This may be a consequence of the wider range of concentrations used in the present study.

Figures 1 and 2 show that potassium and cesium concentrations of leaves varied with age or position on the plant. The position relationship was changed by varying the potassium in the nutrient solution. The young top leaves of plants grown in low nutrient potassium contained higher potassium and cesium concentrations than did lower and older leaves. When nutrient potassium became excessive, a reverse relationship was observed with the higher potassium concentration in the older leaves. This same reversal was not noted for cesium.

This reversal with increasing potassium is easily explained on the basis of a relationship between interleaf transport and availability of freshly absorbed material from the root. If abundant potassium is available from roots, little translocation of this element from old to new tissue is observed. It can even be visualized as a detoxification process with all cells continuing to deposit excess potassium in their vacuolar spaces and thus building the concentration in older tissues. When potassium is limiting, it is translocated from existing tissue to supply demands for

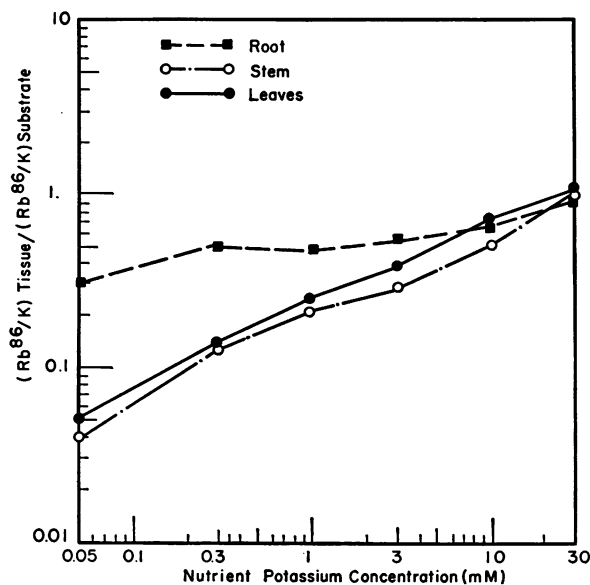


FIG. 6. Effect of increasing substrate potassium on DF values for  $Rb^{86}/K$ .

growth as suggested by Janssen (5). This interpretation also correlates well with the tissue studies of Steward and Millar (14) and Sutcliffe (15) who observed a higher concentration of  $Cs^{137}$  in vacuolated non-growing cells than in growing cells of carrot.

The relationships between  $Rb^{86}$  and potassium were similar to those between  $Cs^{137}$  and potassium. This is most easily seen by comparing figures 5 and 6. Although the DF factors for the two pairs are similar at the potassium concentration tested, there is less evidence of intra-plant selection between  $Rb-K$  than between  $Cs-K$ . This can be concluded from figure 6 by the closeness of the stem and leaf values.

It is important to note that the efficiency of uptake, i.e., DF value, for  $Cs^{137}$  with respect to potassium, is not uniform. Failure of the plant to take up these ions in a fixed proportion to their concentrations in the substrate means that prediction of  $Cs^{137}$  concentration in the biosphere on the basis of a  $Cs^{137}/K$  ratio in the soil is potentially in error. The fact that soil tends to buffer against extremes in concentration of ions available for uptake may well prevent the observation of the extreme changes in DF values as noted here. Precise predictions of plant uptake of  $Cs^{137}$  can be achieved only by evaluating isotope uptake from important soils in a given area.

#### SUMMARY

Adding potassium to the nutrient substrate reduced  $Cs^{137}$  and  $Rb^{86}$  uptake by bean plants less than expected from an assumed physiological equivalence of these ions. Plants discriminated against cesium at low potassium nutrient concentrations, but with in-

creasing substrate potassium, this discrimination diminished. Discrimination of  $Rb^{86}$  from potassium approximated that observed for  $Cs^{137}$ . Potential errors from the use of ratios in predicting uptake of  $Cs^{137}$  were discussed.

Some toxicity was noted when significant quantities of non-radioactive cesium were in the nutrient solution.

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