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Radiological Sciences Department

September 15, 1953

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ABSTRACT

In Red Kidney bean plants grown at a pH of 6.0 in nutrient culture, there was no significant redistribution of cesium from the older leaves, whereas the younger leaves demonstrated retranslocation where concentration gradients existed. The concentration of cesium in the aerial portions of the plant is nearly proportional to the concentration of cesium added to the nutrient solution. The absorption of cesium tends to increase as the pH of the nutrient environment is decreased. Uptake efficiency for cesium with bean plants was 0.68, tomato 0.32, Russian thistle 0.05 and wheat 0.02. Barley plants can attain a concentration of cesium in the leaves only 0.13 times the concentration in an Ephrata fine sandy loam soil.

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THE UPTAKE AND TRANSLOCATION OF CESIUM BY PLANTS

INTRODUCTION

The uptake of cesium has been investigated by Collander[1] with special reference to the other members of the alkaline metal series. He found, with the eleven phanerogams studied, that there was very little variation in the uptake of cesium among the different species. It was also indicated that cesium is absorbed in much the same manner as potassium, and there appeared to be a fairly constant ionic ratio between cesium, rubidium and potassium absorbed. Pirson[2] has indicated that cesium may, in part, replace potassium for certain functions within the plant, but none of the functions were considered essential even though certain stimulative effects were noted.

Because cesium has not been shown to be essential for plant growth, most of the earlier investigations were concerned with its possible relationship to the essential elements. However, isotopes of cesium are among the principal long-lived products of nuclear fission and thus deserve some attention heretofore not accorded this element.

The purpose of the present investigation was to determine the effect of the factors of concentration, pH, and plant species on the uptake and retention of this element using nutrient solution cultures with Cs^{137} as a tracer. The results obtained from these experiments were compared with the maximum uptake obtained from a representative South Central Washington soil.

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MATERIALS AND METHODS

The detailed methods used in these studies have appeared previously.[3] Red Kidney bush beans (Phaseolus vulgaris) were used as the principal experimental plant. This seed was of pure stock obtained from the California Crop Improvement Association.* Other plants used were Rutgers tomatoes (Lycopersicum esculentum), White Russian wheat (Triticum vulgare) and Russian thistle (Salsola pestifer). The seed of the latter was collected locally. Plants were grown, six plants per culture, in a modified Hoagland's solution according to standard nutrient practice. The pH values of the solutions were maintained at 6.0 except where varied as an experimental condition. Carrier-free Cs^{137} (<0.0001 ppm Cs, final nutrient concentration) was used as a tracer in a concentration of about 10^{-4} μc/ml of nutrient solution. Except where varied as an experimental condition the concentration of stable cesium added to the nutrient solution was 1.0 ppm as CsCl. Plants were grown under greenhouse conditions except in those experiments indicated as having been conducted in a controlled-environment chamber.

Soil experiments were conducted using the Neubauer technique.[3, 4] One hundred Belsford Beardless barley seeds were planted in 100 gms of Ephrata fine sandy loam soil. This is a representative local soil which contains less than 100 ppm cesium by spectrographic analysis, is very low in nutrient elements especially nitrogen (0.6 mg N/gm of soil,) and has a pH of 7.6. The soil was prepared by addition of carrier-free Cs^{137} and well-mixed before planting. The aerial portions were harvested after 18 days.

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* University of California, Davis, California.

RESULTS

The Accumulation of Cesium by Plants

In order to determine the effect of a prolonged absorption period on the uptake of cesium by bean plants, an experiment was conducted in a constant environment apparatus for a 32-day period. The aerial temperatures were maintained at 29 $\pm$ 1.5^{o} C during the light hours and 24 $\pm$ 1° C during the dark hours with wet bulb temperatures of 22 $\pm$ 1° C and 20 $\pm$ 1° C, respectively, while the root environment was maintained constant at 26 $\pm$ 0.5^{o} C. The light source consisted of white and cool white fluorescent tubes in a 1:1 ratio and was operated for a 16-hour day length at 1300 $\pm$ 100 foot candles.

Beans plants were grown in six liter culture pans according to the previously described technique[3] with six plants per pan. Cultures were harvested every four days. At each time of harvest, the nutrient solutions were changed in the remaining pans. In addition to the nutrient salts, 1.0 ppm of cesium as CsCl and 1.06 x 10^{-4} μc of Cs^{137} per ml was added as a tracer. At the end of the 12th day, cesium was added to only half of the remaining cultures to allow a study to be made of the retention as well as the absorption of this ion. After the 28th day the plants had so completely filled the growth chamber that growth was somewhat erratic, and uptake results beyond this time are of doubtful significance.

The plants were divided into samples as follows: roots, stems and petioles, primary leaves, axillary trifoliate leaves, and the original trifoliate leaves along the main stem.

Figure 1 indicates that, for those plants which received cesium the full 32 days, all leaves tended to attain about the same concentration of cesium. This is particularly apparent for the primary and initial trifoliate leaves. The axillary trifoliate leaves were in a rapid stage of

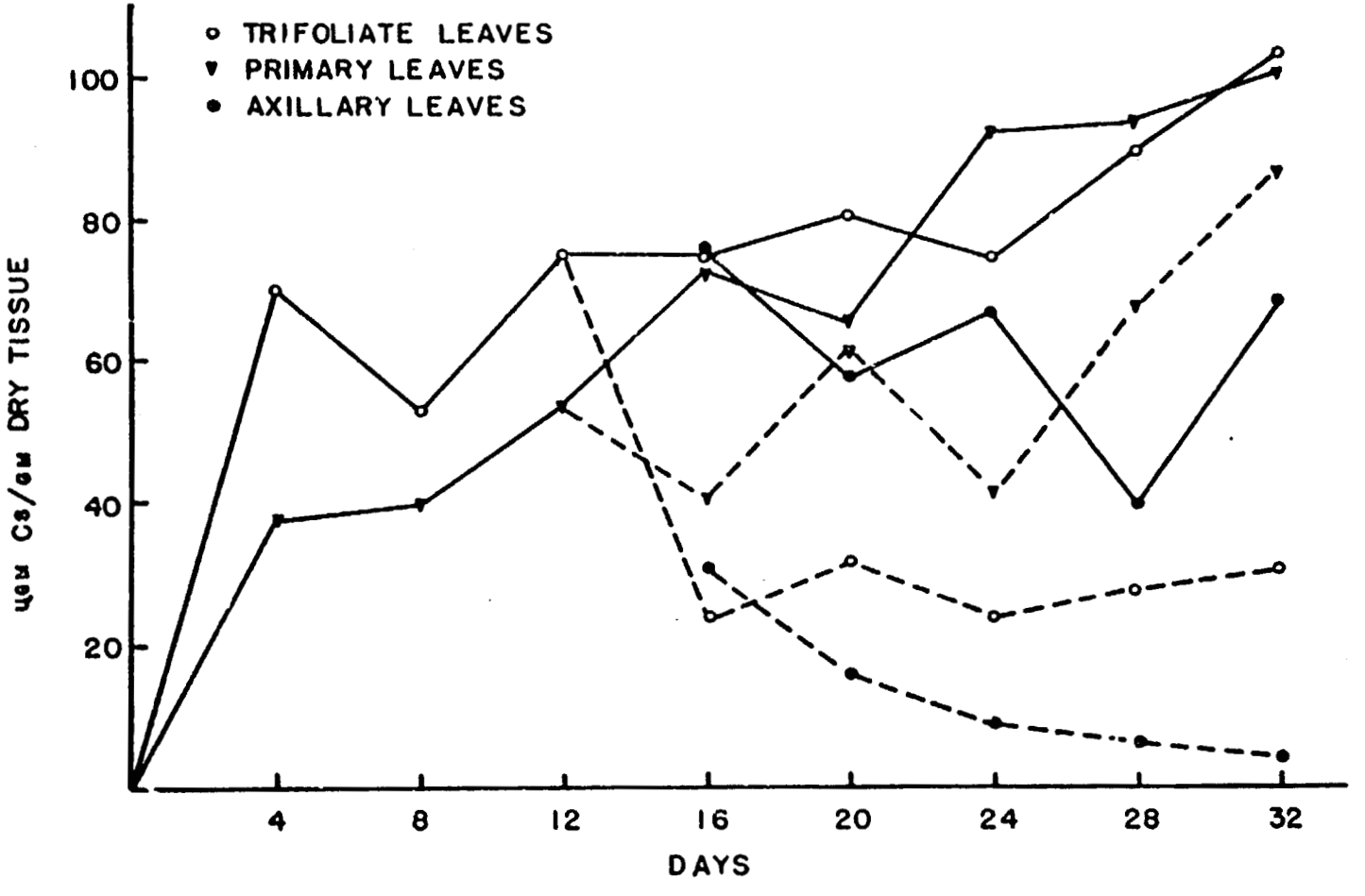

FIGURE 1

The concentration of cesium in tissues of plants grown in a nutrient solution containing 1.0 ppm cesium as CsCl at pH 6.0. The dotted lines represent those cultures from which the cesium was removed at the 12th day. Each point is the average of 6 plants from one culture.

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growth during the latter half of the experimental period and the slight reduction in concentration of cesium during this period may be attributable to a dilution by growth. A different relationship was found between the leaves of plants grown in cultures from which the cesium was removed after the 12th day. In this series the primary leaves, the oldest leaves, maintained about the concentration present at the 12th day. The initial trifoliate leaves decreased in cesium concentration after the removal of cesium, and the concentration did not stabilize until maximum growth was attained at the 16th day. The axillary trifoliate leaves, the youngest leaves, indicated a progressive decrease in concentration between the 16th and 32nd day.

This decrease in concentration, evidenced by the initial and axillary trifoliate leaves of plants deprived of cesium after the 12-day absorption period, seems to be mostly a dilution by growth. It appears that there is little redistribution of cesium from the older leaves under the above conditions even when favorable concentration gradients exist.

This is further amplified in Figure 2. The primary leaves from plants deprived of cesium after the 12th day retained essentially the absolute amount of cesium they possessed the 12th day. These leaves are, of course, no longer growing and are approaching senescence. The initial trifoliate leaves, which are still actively metabolizing but have grown very little after the 16th day, exhibit a decrease in the absolute content of cesium. This decrease is partially compensated for by an increase in the absolute cesium content of the axillary leaves which are actively growing. This seems to indicate that in tissues of low metabolic activity cesium exchange is small; but in tissues actively metabolizing the exchange is significant.

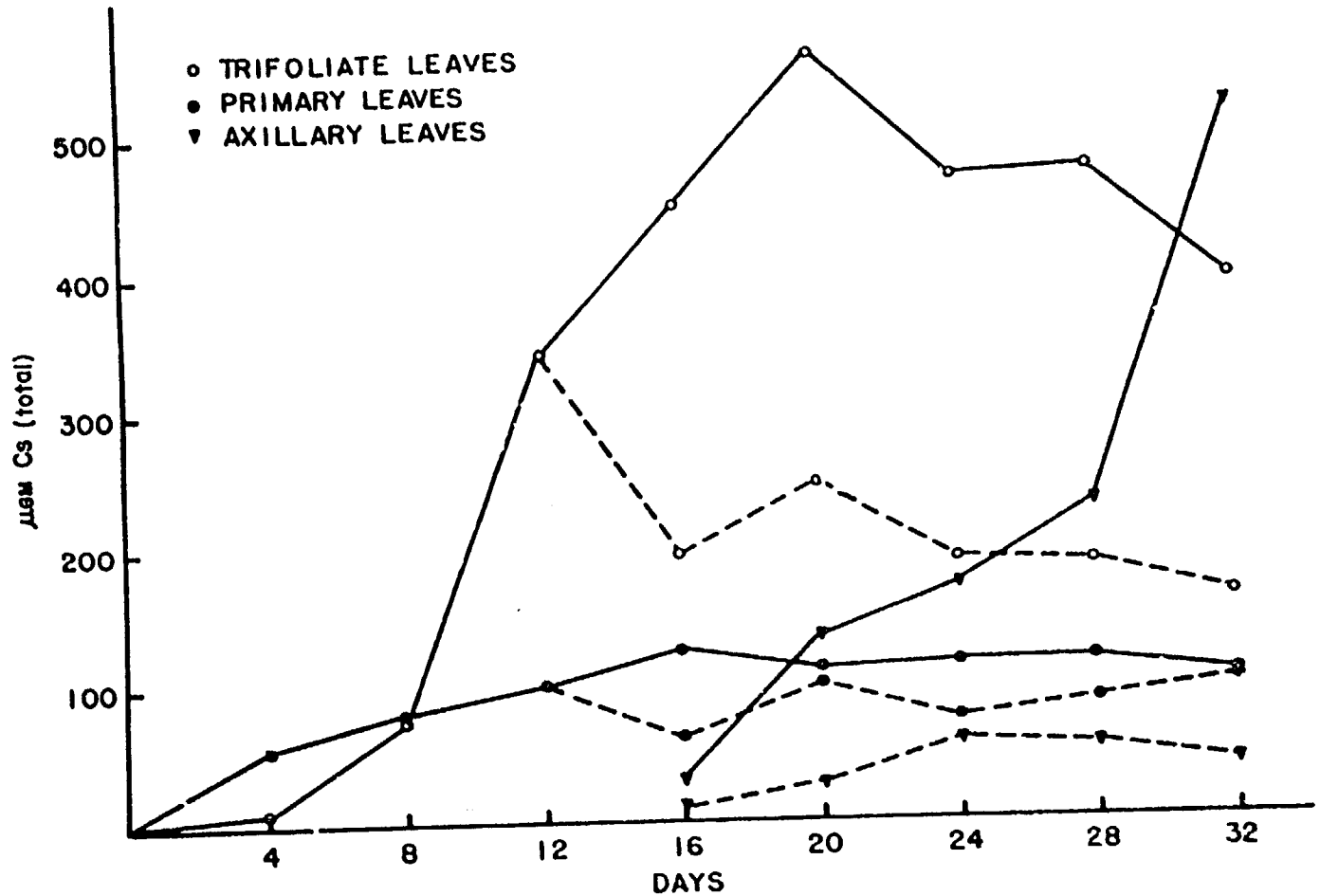

FIGURE 2

The total amount of cesium in tissues of bean plants grown in a nutrient solution containing 1.0 ppm cesium as CsCl at pH 6.0. The dotted lines represent those cultures from which the cesium was removed at the 12th day. Each point is the average of 6 plants from one culture.

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The Effect of Concentration on Cesium Uptake

To determine the effect of cesium concentration on the uptake of this ion, an experiment was conducted over a range of concentrations from 0.001 to 100 ppm. Bean plants were grown in the nutrient solution for 12 days at a pH of 6.0. During the last four days of the experiment, cesium was added as CsCl with 1.1×10^{-4} μc of Cs^{137}/ml as a tracer.

It can be seen from Figure 3 that the uptake of cesium by the leaves of the bean plant is proportional to the concentration added to the nutrient solution. Also, the amount of absorbed and adsorbed cesium, associated with the roots is proportional to the concentration added to the nutrient solution and is somewhat greater than the concentration in the leaves.

It was found that the cesium associated with roots killed by drying is nearly the same within experimental error as that associated with living roots. This relationship holds only if a few drops of saturated phenol solution have been added to the nutrient solution containing the dead roots. If no phenol is added, the concentration of cesium associated with the roots is often doubled due, no doubt, to microfloral accumulation. Thus, a large portion of the cesium associated with the roots must be adsorbed cesium.

The total accumulation associated with the root as well as the uptake into the aerial portions follows the proportional relationship observed for other elements.[3] However, certain minor irregularities exist. When the data are plotted on a concentration basis as a leaf:root ratio it is found that a greater proportion of the cesium associated with the roots is absorbed into the aerial portions of the plant at the higher concentrations of nutrient cesium. This relationship is shown in Figure 3.

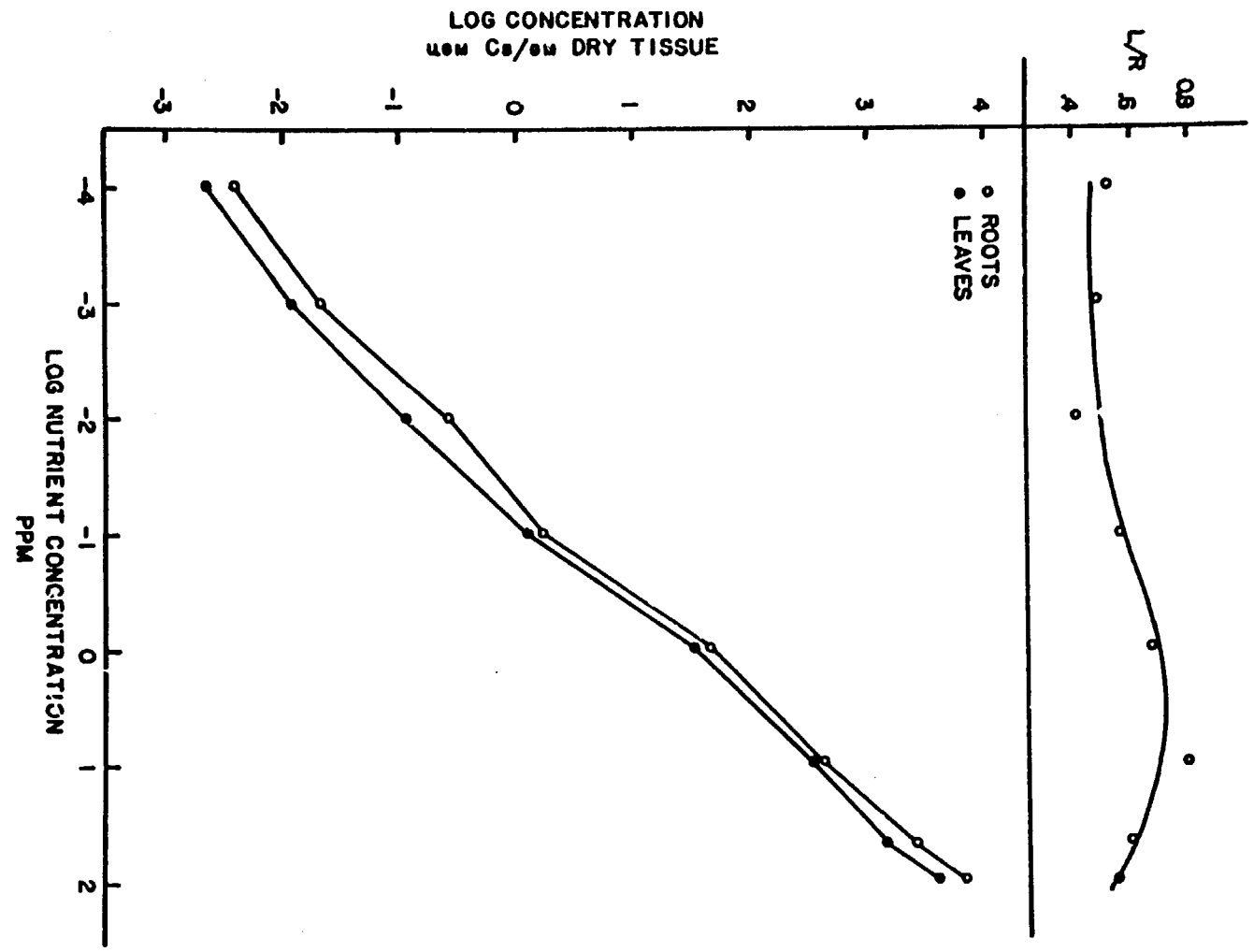

FIGURE 3

The uptake of cesium from a nutrient solution containing several concentration of cesium at pH 6.0. Each point represents the average of duplicate cultures of 6 plants each. The upper curve represents the leaf:root ratio for this same experiment.

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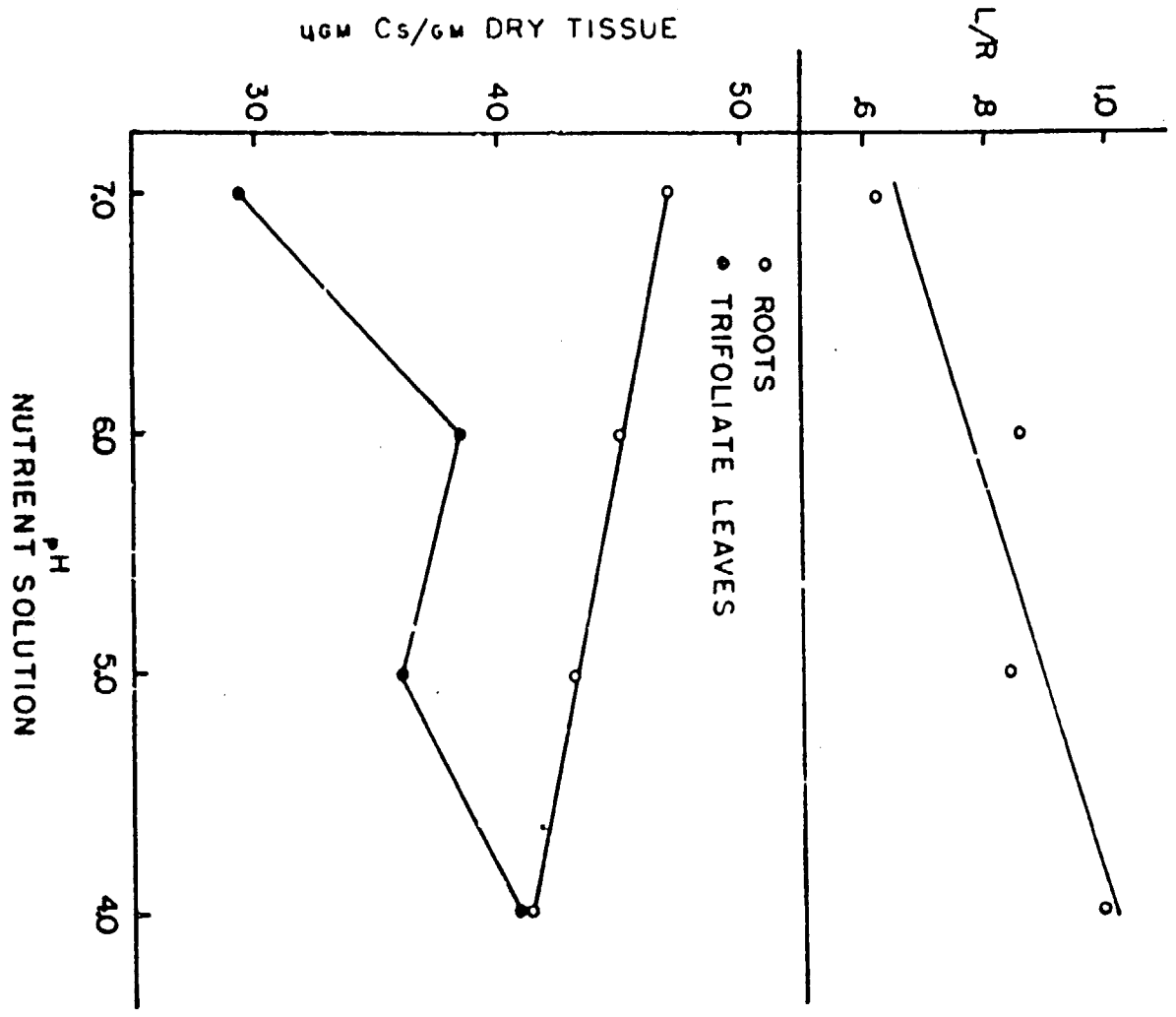

FIGURE 4

The uptake of cesium from a nutrient solution containing 1.0 ppm of cesium at 4 pH levels. Each point represents the average of duplicate cultures of 6 plants each. The upper curve represents the leaf:root ratio for the samc experiment.

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The Effect of pH on the Uptake of Cesium

The effect of pH on the uptake of cesium was studied in an experiment using Red Kidney bean plants. The plants were grown for 12 days in nutrient cultures adjusted to the indicated pH. During the last four days of the experiment, 1.0 ppm of cesium as CsCl was added to the nutrient solution with 1.1×10^{-4} μc/ml of Cs^{137} as a tracer.

The results, as indicated in Figure 4, show that a greater accumulation of cesium occurs on the roots at pH 7.0 than at pH 4.0. This must be the result of an effect of pH on adsorption of the ion, either directly or indirectly, since cesium solubility would be little affected by the pH in this nutrient solution. The uptake into the trifoliate leaves, conversely, is less at pH 4.0. This indicates that either cesium is less available at pH 7.0 or the roots are less permeable. If the leaf:root ratios are considered, as in Figure 4, it is obvious that a greater uptake efficiency is exhibited at pH 4.0 than at the other pH values studied. These results conform to a general trend observed for other fission elements.[3]

The Response of Different Plants to Cesium Uptake

The uptake of cesium was determined for Red Kidney beans, tomatoes, wheat and Russian thistle. The plants were started at different times so that all the species would have an adequate tissue sample at the time of harvest and all could be exposed to the experimental conditions at the same time. During the last four days of the experiment, the plants were transferred to nutrient solutions containing 1.0 ppm cesium as CsCl and 1.1×10^{-4} μc/ml of Cs^{137} as a tracer at a pH of 6.0.

An examination of Figure 5 indicates that a difference does exist between plants in their ability to accumulate cesium both in the aerial portions and associated with the roots. On a concentration basis it can

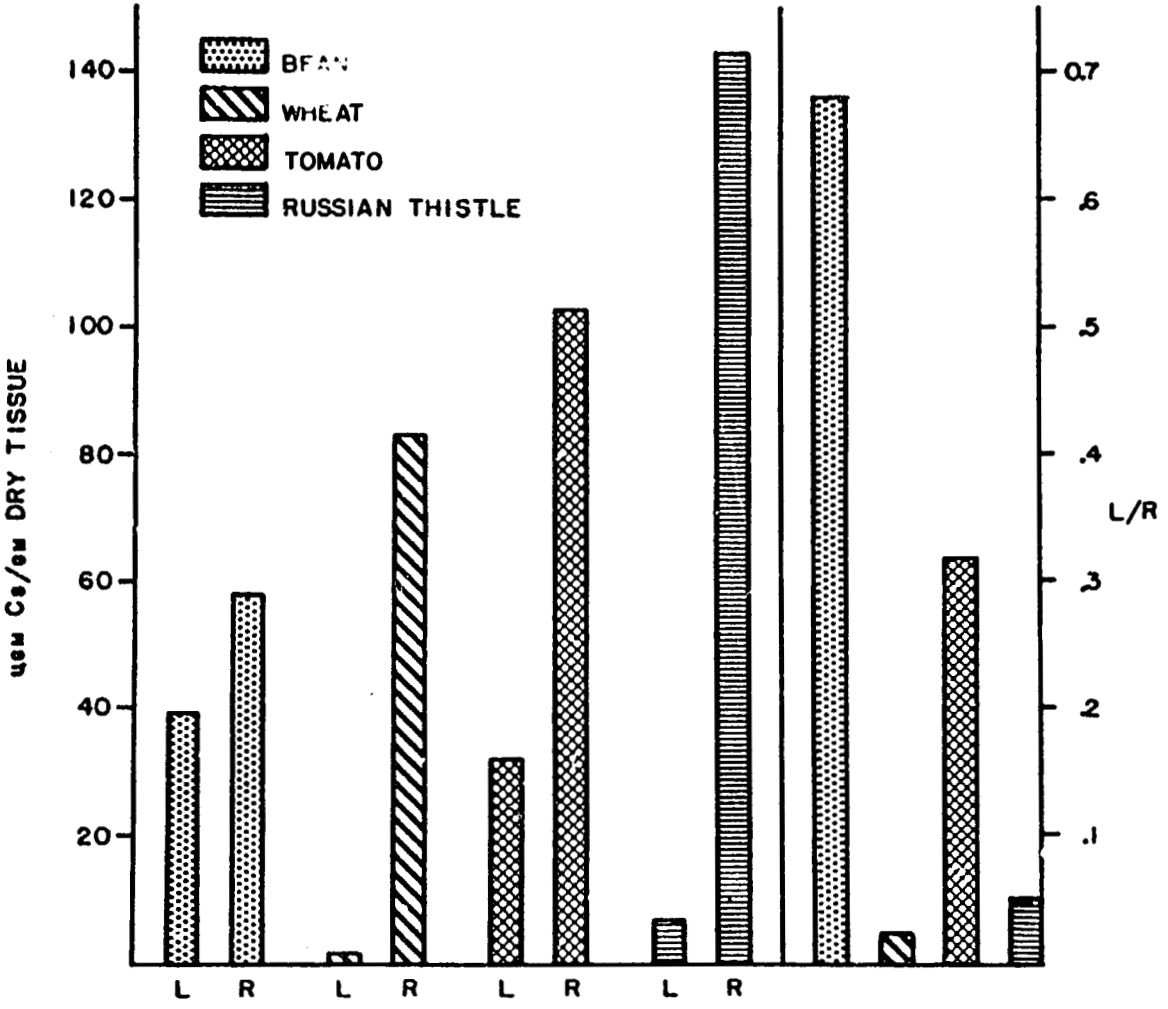

FIGURE 5

The uptake of cesium by four different plants from a nutrient solution containing 1.0 ppm cesium at a pH of 6.0. The leaf:root ratios are listed at the right. Each bar is the average of duplicate cultures of 6 plants each.

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be seen that the bean accumulates the greatest amount of cesium in its leaves with tomato, Russian thistle and wheat following in that order. The concentration of cesium accumulated on the roots is greatest for Russian thistle with tomato, wheat and bean following in that order. The concentration of cesium associated with the roots is in no way correlated with the mass of the root; it may, however, be dependent on the total area of the root.

The cesium associated with the root must be in large measure, adsorbed cesium, especially in the case of wheat, tomato and Russian thistle where the root accumulation so far exceeds the leaf concentration. This will undoubtedly affect the uptake of this element, since the Russian thistle plant has a cesium concentration in the root microenvironment about 2.5 times as great as the bean. When leaf:root ratios are calculated as an indication of uptake efficiency, bean shows the greatest efficiency with a leaf:root ratio of 0.68. Tomato 0.32, Russian thistle 0.048 and wheat 0.021 follow in order of decreasing uptake efficiency.

Soil Studies

In order to properly evaluate the hazard potentials of radioactive isotopes of cesium for plants growing in soil, a study was conducted to determine the maximum uptake of Cs^{137} from an Ephrata fine sandy loam. The Neubauer seedling technique[3,4] was used as previously described. The plants were grown for 18 days in a water bath at 24 $\pm$ 1° C under artificial light. This consisted of a ratio of one daylight fluorescent tube to three white fluorescent tubes at 1,000 $\pm$ 50 foot candles.

It was found (Table I) that barley was able to remove only about 0.10 per cent (average of six cultures) of the Cs^{137} from a given volume of Ephrata fine sandy loam soil. Since the plants were grown long enough to exhaust the nutrient elements from the soil, this datum may be interpreted

as the maximum percentage of Cs^{137} added to this soil which can be removed by barley plants before nutrient conditions limit absorption. It was also calculated that the barley plant was able to accumulate in its leaves a concentration of cerium about 0.13 times the concentration in the soil, on a dry weight basis.

DISCUSSION

In previous studies with strontium[3] it was found expedient to express the uptake data as leaf:root ratios. This was because massive accumulations of strontium were found associated with the roots which were in no way dependent on metabolic absorption. These accumulations were of such magnitude as to be of prime importance in influencing the uptake of stontium. Root accumulations as great as those observed with strontium were not found in the present studies with cesium. This was to be expected on the basis of adsorptive properties of the cesium ion and the solubility of its compounds.

TABLE I

The Uptake of Cs^{137} from an Ephrata Fine Sandy Loam Soil by Barley Plants, Using the Neubauer Seedling Technique.

μc/gm soil	Dry wt. Leaves (gm)	Cs Conc. Factor $\frac{\text{Leaf conc.}}{\text{Soil conc.}}$	% to total soil Cs absorbed into aerial portions
0.01	1.118	0.13	.091
	1.009	.09	.075
0.05	1.059	.15	.11
	1.038	.14	.11
0.10	1.057	.15	.12
	1.040	.14	.11

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However, it was found with dead root experiments that concentrations of cesium 6-7 times greater than that in the nutrient solution were adsorbed on dead bean roots in sterile solution. This is within limits of error, the same as found on live roots. It is obviously incorrect to infer that all the cesium associated with the roots of live plants grown in nutrient solutions is adsorbed. Nevertheless, a sufficiently high ratio of adsorbed to absorbed cesium apparently exists on the roots so that the total root concentration of cesium approximates the actual cesium concentration to which the absorptive mechanism is exposed. Thus the use of the leaf:root ratio is a valid approximation of relative uptake efficiency.

The effect of adsorbed root cesium on uptake is particularly important when comparing the ability of various species of plants to absorb cesium. Thus we find that the bean has about a six times greater concentration of cesium in its leaves than does Russian thistle. But when the accumulation of cesium associated with the roots is taken into consideration as the source of cesium available for absorption into the aerial portions of the plant, it can be seen that the bean can absorb almost 14 times as much cesium as the Russian thistle on a dry weight concentration basis when exposed to the same relative concentration associated with the root. It was also found when studying effect of pH on cesium uptake that if the data are expressed as leaf:root ratios they will more nearly conform to trends observed with other elements under similar conditions; namely, that as the acidity increases the absorptive efficiency also increases.

Root adsorption is even more important when comparing the uptake of cesium with other fission products. For instance, heavy accumulations of strontium are found on the roots of plants grown in nutrient solutions containing strontium and a correspondingly heavy uptake occurs. Cesium forms only a light accumulation of the root and is associated

with a smaller uptake. If, however, the wheat plants were exposed to the same concentration of cesium and strontium in the microenvironment of the root, the uptake of the two elements would be very nearly the same.

Such considerations are necessary in attempting to apply nutrient culture data to nutrient environments where mobility of the ion is more restricted, as in a soil. This correlation may be accomplished in a practical sense by first establishing the maximum uptake of a particular element which will occur from a given soil under a given set of conditions. This maximum uptake value can then be modified by those factors known to influence absorption which have been determined in a quantitative sense by nutrient culture studies.

ACKNOWLEDGMENTS

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