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Absorption behavior of technetium and rhenium through plant roots

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Abstract. The absorption behavior of technetium (Tc) and rhenium (Re) through plant roots was studied using nutrient solution culture. Radish samples, grown in culture solutions for 20-30 days in a greenhouse, were transferred into plastic vessels containing nutrient solutions contaminated with multitracer solutions including ^{95m}Tc and ^{183}Re. The plant samples were grown individually for 1-7 days under laboratory conditions. The activities of radionuclides in nutrient solutions and oven-dried plant parts (roots, fleshy roots and leaves) were measured with Ge detecting systems. The concentrations of ^{95m}Tc and ^{183}Re in the nutrient solutions after harvesting the plants were almost the same as those in the initial solution, though about 2 mL of the nutrient solution was lost per day per plant pot due to transpiration. Possibly, the radionuclides were taken up with water through the plant roots. The distributions of Tc and Re in the plants showed no differences, thus, soluble Tc and Re absorption mechanisms by plant samples were the same. It is suggested that Re could be used as a geochemical tracer for Tc in soil environments.

1. INTRODUCTION

Among technetium isotopes, ^{99}Tc is of potential long-term importance in the earth's environment because it has a long half-life of 2.11×10^5 y and it is produced in the thermal fissions of ^{235}U and ^{239}Pu. The most stable chemical form of Tc in soil environments is TcO_4^- [1], which is considered to be highly mobile in biogeochemical cycles among nonnutrient elements [2]. Thus, knowledge of Tc behavior in the soil to plant systems is of special interest because of potential long-term radiological consequences. Determination of physicochemical forms of ^{99}Tc in soil and plant samples would advance understanding of its environmental behavior, but the amount of ^{99}Tc in the earth's environment is at ultra-trace levels even in soil [3], therefore, environmental ^{99}Tc forms are unclear.

Rhenium may be studied as a chemical analogue for Tc, which is just above Re in the periodic table. These two elements behave similarly in soil environments [1]. The amount of Re in the earth's environment is higher than that of ^{99}Tc; however, no data are available for terrestrial plant samples due to Re being one of the rarest elements in the earth's crust [4]. To measure Re, radiochemical neutron activation analysis has been used; however, these days, inductively coupled plasma mass spectrometry, ICP-MS [3, 5] is being widely applied.

We think that terrestrial plants might absorb Re at as high a rate as reported for Tc. Then, Re could be used as a chemical analogue for Tc in soil solution to plant systems if their uptake behaviors were the same, although no study from that viewpoint has been carried out yet. Therefore, we carried out a tracer experiment using a multitracer technique [6]. The Tc and Re uptake behaviors by plants and their distributions in plant parts were observed after growing radish plants in nutrient solution.

2. EXPERIMENTAL

2.1 Plant samples

Radish seedlings, 3 d after germination, were grown in a nutrient solution culture. The nutrient solution was prepared from a commercially available nutrient powder, HYPONeX®, by dissolving it in deionized water (1:1000 in weight). The plants were placed in a greenhouse, kept at 21˚C, and exposed to normal daylight condition for about 1 month. Then, each plant was transplanted to a 120-mL plastic vessel containing 40 or 60 mL of new nutrient solution contaminated with $^{95m}TcO_4^-$ and multitracers (short-lived radioisotopes) including $^{183}ReO_4^-$. The ^{95m}Tc used was prepared by irradiation of Nb in a cyclotron [7]. Details of the multitracer solution preparation method were described by Ambe [6]. In addition to ^{183}Re, the multitracer solution also contained ^{58}Co, ^{65}Zn, ^{75}Se, ^{83}Rb, ^{85}Sr, ^{88}Y, ^{102}Rh, ^{139}Ce, ^{143}Pm, ^{146}Gd, ^{173}Lu and ^{185}Os.

2.2 Sample treatment and radioactivity measurement

The plant samples were in contact with the solution through their fine roots. After 1, 3 and 7 d contact periods, the plants were carefully removed from the solution (n=3 for each sampling date). The nutrient solution was passed through a 0.22-µm filter. The radioactivities in the filtrate were measured using a Ge detecting system (Seiko EG&G Ortec). The fine roots were successively rinsed in plastic cups with deionized water and then the roots were gentry wiped with paper towels. Next, the plants were separated into three parts, that is, leaves, fleshy root and fine roots. The leaves and the fine roots were cut into 1-1.5 cm lengths and the fleshy root was sliced into disks approximately 1 mm thick. Each sample part was weighed (wet-weight), oven-dried at 60˚C for 72 h and weighed again (dry-weight). The activities of radioisotopes were measured with the Ge detecting system.

3. RESULTS AND DISCUSSION

3.1 Changes of TcO_4^- and ReO_4^- concentrations in the nutrient solution

Figure 1 plots the loss of nutrient solution per gram plant (wet) against sampling day. The plant samples absorbed the nutrient solution constantly. Weights of the plants increased only by 0.6g (raw weight), which corresponded to about 1% of the nutrient solution. Evaporation of the nutrient solution directly from the vessel would be negligible (less than 2%) because it was covered with a polystyrene foam

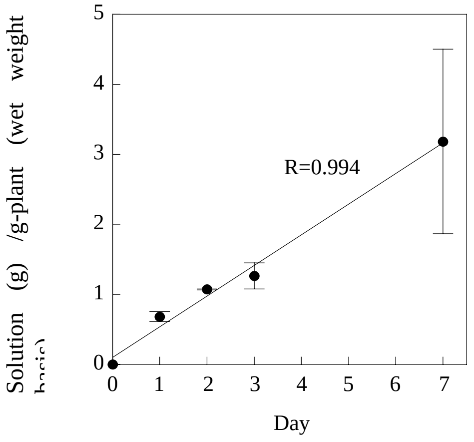

Figure 1. Loss of nutrient solution per plant weight (wet) plotted against sampling day.

board. Thus, we thought the reduction of nutrient solution volume is due to plant transpiration. About 0.43 g per gram plant per day on average were lost according to the measurements. The average fresh weight of the plants was about 4.9 g, thus, about 2 mL of water were absorbed by the plant everyday.

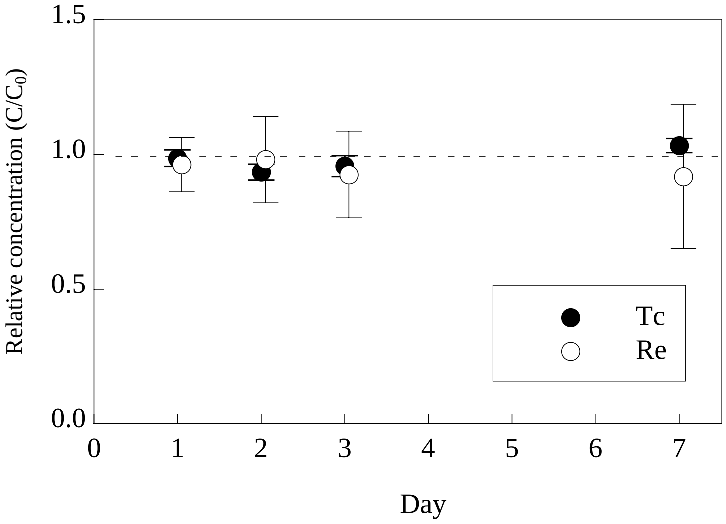

Figure 2. Relative concentration ratio (C/C_0) of ^{95m}Tc and ^{183}Re in nutrient solution with radish plants.

The relative concentration ratios for ^{95m}Tc and ^{183}Re in the nutrient solution obtained after and before (C/C_0) the 7 d exposure period are shown in Figure 2. The ratios of ^{95m}Tc and ^{183}Re for the samples of Day-1 to Day-7 did not change. The absorption rates of Re and Tc by the plant were almost the same as water uptake. From these results, we assumed that ReO_4^- uptake mechanisms are the same as those of TcO_4^-, and the plants cannot recognize any difference between ReO_4^- and TcO_4^-.

3.2 Tc and Re in radish

Distribution ratios of radionuclides, defined as 'activity in a plant part' divided by 'total absorbed activity', are shown in Figure 3 for the samples collected on Day-7 after the transplanting. The distribution ratios for ^{95m}Tc in leaves, fleshy root and fine roots were 0.54±0.04, 0.39±0.02 and 0.07±0.02, respectively. For ^{183}Re, the same ratios were 0.61±0.16, 0.39±0.02 and 0.03±0.08. These results showed the distributions of Tc and Re in the plants are almost the same; presumably, Tc and Re behave similarly in radish plants.

Then, behaviors of other elements were examined. The ratios for rare earth elements (REEs) in both tracer experiments showed that almost all of the absorbed REEs were distributed to the fine roots, thus, their behaviors were not the same as those for Tc and Re. The distribution patterns of Se and the REEs were similar. For Os, a higher distribution ratio was found in fine roots than in leaves, although the concentrations in the nutrient solution did not change like those of Tc and Re did. The distribution ratios for Co, Zn, Rb, and Sr tended to increase in the fleshy root. Our results implied that other elements should not be used as a chemical analogue of Tc because their distributions are different in radish plants.

From these results, we concluded Re could be used as a chemical analogue of Tc in soil solution for plant uptake. However, soil is generally used as a buffer in soil-to-plant systems, thus, the TFs of Tc and Re would not be the same because their physicochemical behaviors are slightly different especially in soil under waterlogged conditions. Further studies are needed to identify the physico-chemical forms of Tc and Re in soil environments.

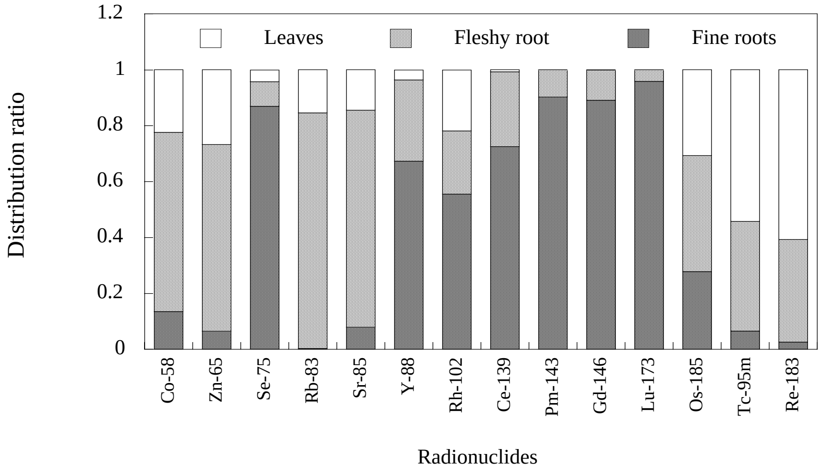

Figure 3. Distribution ratio of radionuclides in radish collected at Day-7.

Acknowledgments

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