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VII. 1. A Comparison of Technetium and Rhenium Uptake by Plants

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Introduction

Technetium-99 (^{99}Tc) is of potential long-term importance in environmental dose assessment because it has a long half-life of 2.11×10^5 y and it is produced by thermal neutron fissions of ^{235}U and ^{239}Pu giving a relatively high fission yield (ca. 6 %), similar to that of ^{137}Cs. The most stable chemical form of Tc in the surface environment is pertechnetate, TcO_4^-, which has a high geochemical mobility and availability for plants[1,2)].) The possible accumulation processes are Tc uptake with water mass flow (passive uptake) or active nutrient uptake (e.g., NO_3-, SO_4^{2-}, MoO_4^{2-} and $H_2PO_4^-$) by plants. A variety of transport proteins involved in anion uptake by plants might be involved in TcO_4- uptake[3)]. However, these simple and passive pathways with water mass flow or active nutrient uptake cannot explain Tc accumulation in plants since no specific Tc transport sites in plant cells have been observed; There should be another active pathway for Tc, but how Tc is taken up is unclear. The authors hypothesized that Tc is abosrbed as a counter taken-up as a counter ion in plants. Thus, a tracer experiment, growing plants in a nutrient solution culture, was carried out to compare the plant uptake behaviors of Tc and major cations and anions from nutrient solution.

Materials and Methods

Three days after germination, plant seedlings of cucumber (n=5), radish (n=3), and a type of Chinese cabbage commonly eaten in Asian countries, called as qing gin cai (n=4) were grown in a nutrient solution prepared from a commercially available nutrient powder, HYPONeX®, which was dissolved in deionized water (1:1000 in weight). The plants were placed in a greenhouse at 21 °C and exposed to normal daylight conditions for about 3 weeks. Then, each plant was transplanted to a 120-mL plastic vessel containing 80-mL of new nutrient solution with $^{95m}TcO_4$- and ReO_4- (a chemical analogue of Tc). The details of the apparatus were reported previously4). The plant samples were in contact with the solution through their fine roots for 3 days under normal daylight conditions.

After the contact, the nutrient solution was passed through a 0.22-μm filter and the concentrations of ^{95m}Tc in nutrient solutions were measured with an NaI(Tl) scintillation counter (Aloka, ARC-300). Concentrations of major elements (Na, K, Mg, Ca, P, and S) were measured by were ICP-OES, and Re and Cl were determined by ICP-MS. For plant samples, the fine roots were rinsed with deionized water and then the roots were gently wiped with paper towels. The plants were then separated into two to three parts, i.e., leaves, fleshy root and fine roots. The dried samples were placed in plastic tubes and the activity of ^{95m}Tc was measured with the NaI(Tl) scintillation counter.

Results and Discussion

In the nutrient solutions with three plant species (12 samples), concentrations of each major element, ^{95m}Tc and Re after cultivation (C) were compared with their initial concentrations (C_0) to show if the ion flux was greater than ($C/C_0<1$) or less than ($C/C_0>1$) water mass flow. After three days, relative concentrations (C/C_0) of Tc, K, Mg, Cl, and Re had excess ion fluxes, but other elements did not. The C/C_0 relationships for Na, K, Mg, Ca, P, S, Cl, and Re with C/C_0 for ^{95m}Tc are plotted in Fig. 1. High correlations of $R \geq 0.8$ ($p<0.01$) were apparent for K, Mg, Cl and Re. Rhenium is thought to be a chemical analogue of Tc, subsequently, C/C_0 for these elements were almost the same; indeed Re also showed high correlations with that of K ($R=0.92$, $p<0.01$). In radish plants, it was previously reported that Tc and Re behave similarly4).

As written above, fluxes in excess mass flow were measured for K^+ and Mg^{2+}. To adjust the ionic balance to a suitable condition, counter anions are needed; it is known that Cl^- acts as a counter ion during K^+ fluxes, contributing to turgor of leaves. If these plants had absorption selectivity for Cl^- as a counter anion for K^+ and Mg^{2+}, then ReO_4^- and TcO_4^- would be retained in the nutrient solutions; however, the plants showed active absorption of both elements. Since ReO_4^- and TcO_4^- are stable in a nutrient solution and readily available to the plant, these ions can pass through nutrient anion transporters on the root surface, and accompany the excess nutrient cation flow. Possibly, ReO_4^- and TcO_4^- ions acted as substitutes for Cl^-. The ionic radii of Cl^- and TcO_4^- in aqueous solutions are close, being 1.81 Å and 2.40 Å, respectively5); consequently they may act similarly. Though ReO_4^- data have not been reported, the ionic radius should be close to that of TcO_4^-.

The absorbed ^{95m}Tc distributions and concentration factors ("Tc concentration in a plant part [Bq g^{-1}-dry]" / "Tc in the initial nutrient solution [Bq mL^{-1}]") in plant parts are shown in Fig. 2. The concentration factors of 41-77 for leaves and 33-56 for fine roots were observed after 3 d contact. The data were similar to those reported previously[4) when they were calculated on a wet weight basis. Since dry weights of leaves and fine roots were different, distribution ratio, which is defined as "Tc content in a plant part" divided by "total absorbed Tc" was calculated and the results are also shown in Fig. 2. Although these plants made contact with the nutrient solution through fine roots, most of the Tc was found in the upper parts, especially in the leaves. In plants, TcO_4^- and ReO_4^- can move up through the xylem. They would be accompanied by K^+ or other cations, and finally Tc and Re would be translocated to the leaves, where their chemical forms would be changed to organic forms6). Through this active uptake mechanism together with the passive uptake with water mass flow or active nutrient uptake, Tc could be highly accumulated in plants, though it is not an essential element.

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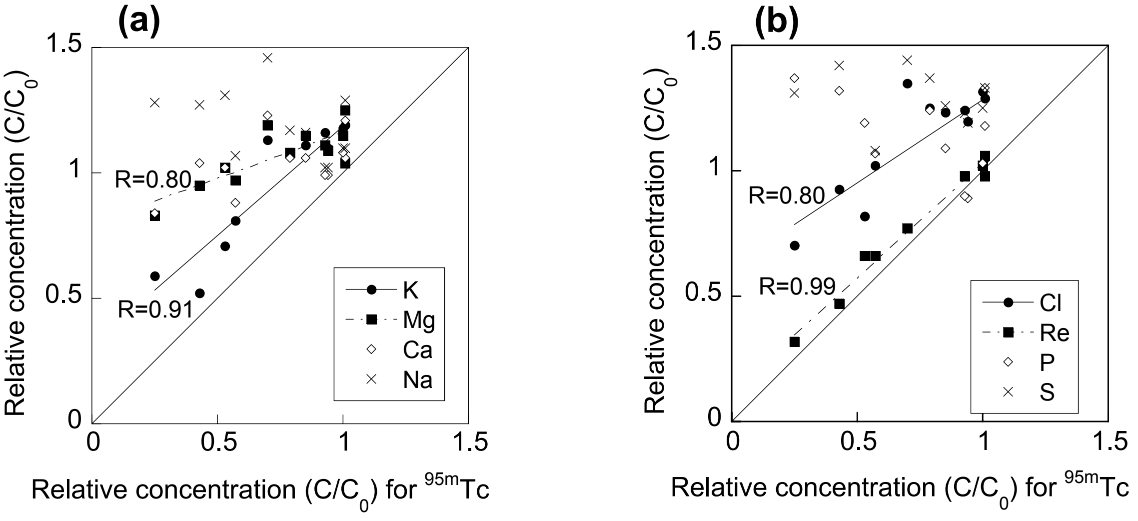

Figure 1. Relationships between concentration ratios (C/C_0) of ^{95m}Tc and (C/C_0) of (a) K, Ca, Na and Mg, (b) Cl, Re, S and P, which remained in nutrient solution after 3 d contact with three plant species (n=12). Lines for K, Mg, Cl and Re show correlation curves.

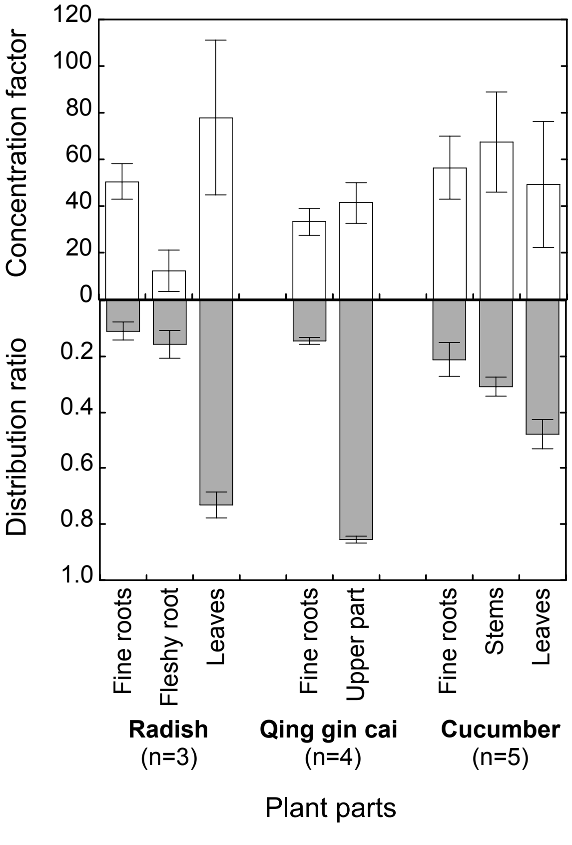

Figure 2. Distribution ratio of absorbed Tc in plant body and concentration factors after 3 d contact (n=3-5). Error bars show 1 s.d. of replicates.