Field Study on Transfer of Radioactive Cesium into Rice Plants Derived from Fukushima Daiichi Nuclear Power Station Accident

(福島第一原子力発電所事故由来の放射性セシウムの米への移行に関する実地調査)

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Since Fukushima Daiichi Nuclear Power Station (FDNPS) accident triggered by the East Japan Great Earthquake on March 11, 2011, much attentions to food contamination by radioactive cesium (Cs) have been gathered. So far, potassium (K) chloride is empirically known to have an effect to reduce the concentration of radioactive Cs in the rice plants, however, effect of other features of paddy soil and condition of rice plants on the transfer of radioactive Cs are not completely unraveled. Thus, this thesis is described about the field study conducted to clarify the cause of Cs-contamination of rice from various perspectives.

In the chapter 1, background information and objectives of the research are given as an introduction. In addition, the structure of the thesis itself is explained.

The chapter 2 is a part of methodology. The fieldwork was conducted in the private paddy in Fukushima Prefecture in 2014, 2016, and2018, which was located approximately 60 km northwest from FDNPS. This sampling site consisted of four adjacent paddies (field A, B, C, and D). The samples of paddy soil of surface 5 cm and a batch of rice plants were obtained at the center and four corners in each paddy. In the laboratory, after drying at room temperature for a few days, gravel was removed from the soil by dry sieving with 2 mm of mesh size. Then this soil sample containing grains less than 2 mm was completely dried at 105°C for a day by oven. The analysis of grain size distribution (GSD) was also performed by dry sieving classification. According to the method of classification of geomaterials for engineering purpose by Japanese Geotechnical Society, the soil was classified into clay and silt(–75 µm), fine sand (75 –250 µm), medium sand (250 –850 µm), and coarse sand (850 –2000 µm). The rice plants were separated into parts of roots, leaves, and unhulled rice after drying at room temperature for a few weeks. The samples were measured for the radioactivity of Cs-137, Cs-134, and K-40 by Ge semiconductor detector. Based on the results of radioactivity measurement, the transfer factor (TF) into rice plants from paddy soil was estimated. In addition, the soil samples were measured for the concentration of exchangeable sodium (Na), magnesium(Mg), K, and calcium(Ca)by ICP-AES.

In the chapters 3, a correlation between the GSD of paddy soil and TF of radioactive Cs into unhulled rice was discussed based on the results in 2014. The concentration of radioactive Cs did not influence the TF as the results indicated that the radioactivity concentration of Cs-137 was low in Paddy B where the TF was the highest in the four fields (**Fig. 1**). On the other hand, the radioactivity concentration of K-40 was the lowest in this paddy. As known well, K is chemically similar with Cs, and when the concentration of K is adequatein the paddy soil, radioactive Cs is not absorbed by rice plants. TF had a correlation with grain size distribution of paddy soil, in which the more the medium sand contained in the soil, the higher the TF of Cs-137 became, but the more clay and silt contained, the lower the TF of Cs-137 became(**Fig. 2**).It is conceivable that the radioactive Cs is fixed strongly in small grains, such as clay and silt, and not absorbed by rice plants, however, rice plants may use the radioactive cesium attached on large grains, such as medium sand, instead of K.

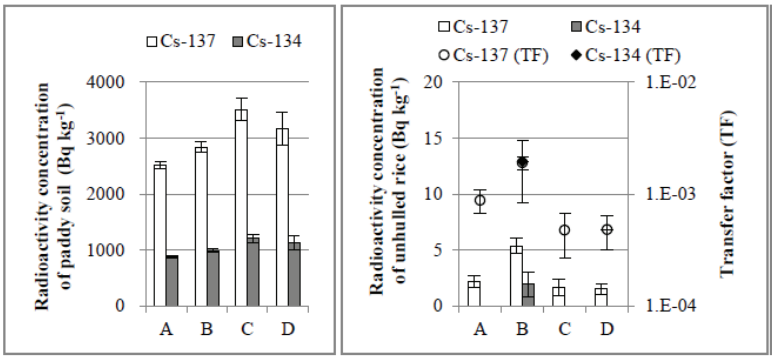

Fig. 1 Radioactivity concentration of paddy soil (left) and radioactivity concentration and TF of unhulled rice (right).

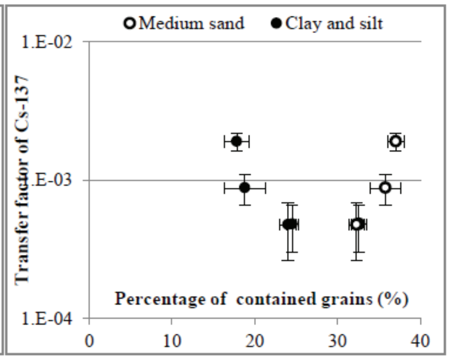

Fig. 2 Correlation between TF of Cs-137 and percentage of medium sand, and clay and silt contained in the paddy soil.

In the chapter 4, for further analysis of paddy soil obtained in 2014, the radioactivity and exchangeable cation concentration of clay and silt fraction were measured. The radioactivity concentration of Cs-137 and Cs-134 in clay and silt was 1.3 ~ 2 times higher than that of whole soil sample. But the tendency of radioactivity concentration was same with the result of whole soil sample (the radioactivity concentration is high in field C and D, but it is low in field A and B) (**Fig.3 (a)**). On the other hand, the concentration of exchangeable cation including Na, Mg, K and Ca, has an opposite trend (**Fig. 3 (b)**). There is a good proportional correlation between TF of Cs-137 and the inverse number of concentration of exchangeable K in the clay and silt when the concentration of exchangeable K is lower than a level (**Fig. 4**).

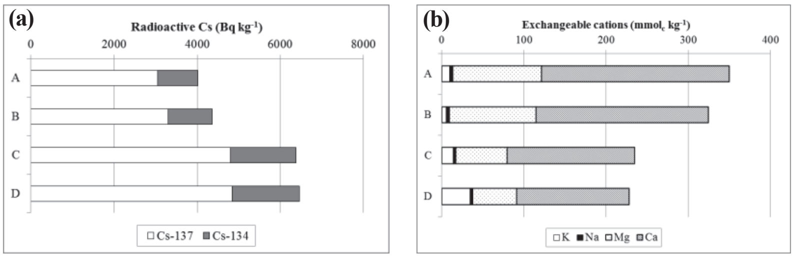

Fig. 3 (a) Radioactivity concentration of Cs-137 and Cs-134 and **(b)** concentration of exchangeable cations (K, Na, Mg and Ca) in the clay and silt.

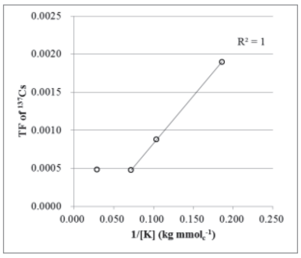

Fig. 4 Correlation between TF of Cs-137 and inverse number of concentration of exchangeable K in clay and silt.

In the chapter 5, the correlation between three phase TFs and radioactivity concentration of K-40 in each place (**Fig. 5**), and between three phase TFs and growth of rice plants, such as plant height and SPAD value was discussed. The three phase TFs was defined as the ratio of radioactivity concentration of Cs-137 (TF_1: roots/soil, TF_2: leaves/roots, and TF_3: ears/leaves). There was a very opposite relation between TFs and concentration of K-40 depending on the transfer phase of Cs-137. When Cs-137 is absorbed from soil by roots, K-40 in soil is competitive, but when Cs-137 is transported from roots to leaves, or from leaves to ears, K-40 in roots, or in leaves is corporative.

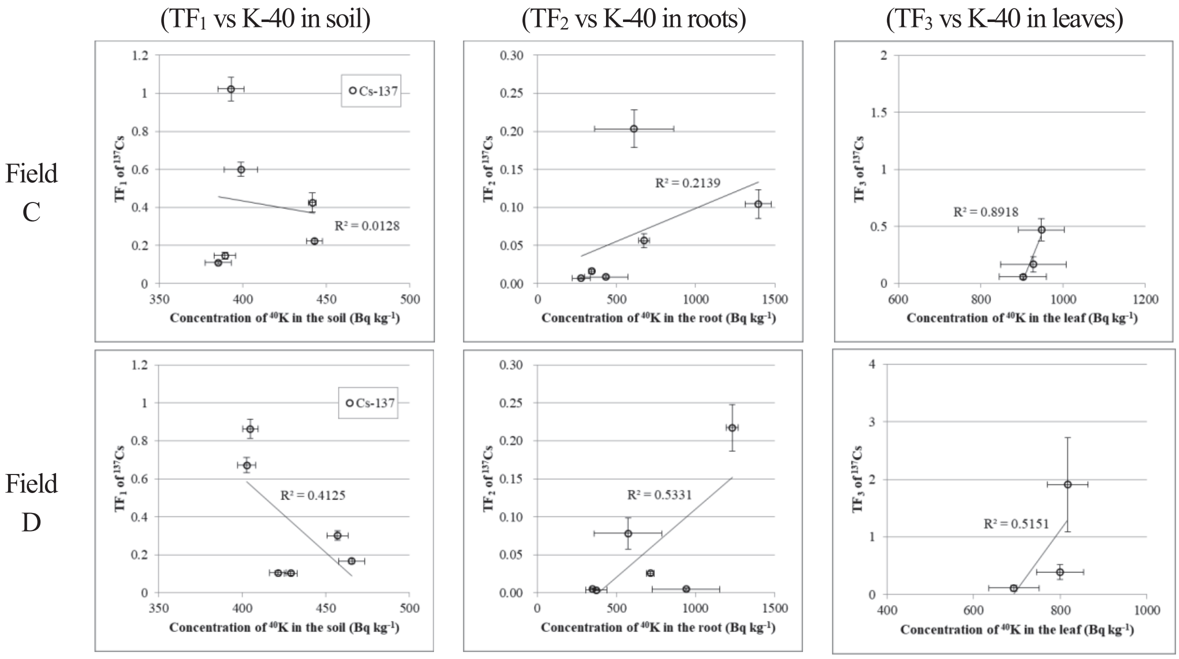

Fig. 5 Correlation between $TF_{1,2,3}$ and radioactivity concentration of K40 in soil, roots, leaves.

In the chapter 6, yearly changes of the radioactivity concentration of Cs-137 and Cs-134 of the paddy soil was discussed. Comparison of the radioactivity concentration among 2014, 2016, and 2018 indicated that radioactive Cs decreased following its half-life.

At last, a conclusion is drawn about the transfer of radioactive Cs into rice plants in the chapter 7.

Note: the content of chapter 3 was published in "Radiation Safety Management", and chapter 5 is now under revision in "Radiation Safety Management".