Effect of potassium application on root uptake of radiocesium in rice

Takashi SAITO[1)*], Satoru OHKOSHI[1)], Shigeto FUJIMURA[1)], Koji IWABUCHI[1)], Masaaki SAITO[1)], Tomoaki NEMOTO[1)], Mutsuto SATO[1)], Makoto SATO[1)], Kunio YOSHIOKA[1)], Hirofumi TSUKADA[2), 3)]

1) Fukushima Agricultural Technology Centre, 116 Shimonakamichi, Takakura-aza, Hiwada-machi, Koriyama-shi, Fukushima 9630531, Japan
2) Fukushima Future Center for Regional Revitalization, Fukushima University, 1 Kanayagawa, Fukushima 9601296, Japan
3) Department of Radioecology, Institute for Environmental Sciences, 1-7 Ienomae, Obuchi, Rokkasho, Aomori 0393212, Japan
*saito_takashi_01@pref.fukushima.lg.jp

After the Fukushima Daiichi Nuclear Power Plant accident that occurred in March 2011, the concentration of radiocesium in brown rice that has been produced in some area has exceeded the provisional regulation value. In order to decrease the concentration of radiocesium in brown rice, we investigated the effect of the application of potassium fertilizer in rice paddy fields on the root uptake of radiocesium. The observed concentration ratio of ^{134}Cs to ^{137}Cs was 0.81 at the time of sample collection, and the mean concentrations of radiocesium in the soils at depths of 0–5, 5–10, and 10–15 cm were 5879 Bq kg^{-1} DW, 3223 Bq kg^{-1} DW and 1835 Bq kg^{-1} DW, respectively. The results showed that the vertical distribution of radiocesium was not uniform, although the rice paddy fields had been plowed. The concentration of radiocesium at a depth of 0–5 cm in soil collected from the 5 different rice paddy fields was in the range of 2465–7823Bq kg^{-1} DW, showing an approximately 3-fold variation between the upper and lower limits of the range. The concentration of radiocesium in brown rice cultivated in 5 different fields, was in the range of 52–485 Bq kg^{-1}. The concentration of radiocesium in brown rice was found to be not correlated with that in the soil, and the soil-to-brown rice transfer factor was found to lie in the range of 0.0075–0.11. However, the radiocesium in brown rice decreased with an increase in exchangeable potassium in the soil. The concentration of radiocesium in brown rice also decreased from 370 to 138 Bq kg^{-1} upon the application of a top dressing of potassium fertilizer. Thus, the application of potassium fertilizer is shown to reduce the concentration of radiocesium in brown rice.

Keywords: *Radiocesium, Brown rice, Exchangeable potassium, Soil-to-brown rice transfer factor*

1. Objective

The magnitude 9.0 earthquake and the subsequent large tsunami that occurred on March 11, 2011, caused extensive damage to coastal areas in Tohoku, Japan. In particular, the cooling system of the Fukushima Daiichi Nuclear Power Plant (TEPCO, Tokyo Electric Power Company) was collapsed due to a tsunami in excess of 10 m and this resulted in several explosions in the four reactors of the plant. Large amounts of radioactive materials, mainly noble gas, ^{131}I, ^{134}Cs and ^{137}Cs, were released into atmosphere, and consequently, agricultural land and forest in Eastern Japan became contaminated.

Radiocesium is an important radionuclide that can be used for the assessment of radiation exposure to the public because it has a long half-live (^{134}Cs has a half-life of 2.06 y, and ^{137}Cs, 30.2 y), high transferability, and wide distribution in the environment. Because of their long half-lives, there is concern that radiocesium isotopes will remain on the surface of agricultural land and persist for a long time[1), 2)]. Therefore, we have started monitoring the radiocesium in soil and agricultural products collected from agricultural land in Fukushima prefecture, starting from March, 2011, and have investigated the distribution of radiocesium in farmland [3)]. Based on these data, Nuclear Emergency Response Headquarters showed planting areas of rice in all regions, except a 20-km exclusion zone and the deliberate evacuation zone (DEZ) in Fukushima prefecture. However, brown rice produced in some areas in Fukushima prefecture exceeded the provisional regulation value for agricultural crops at the times (>500 Bq kg^{-1}). Consequently, the planting of rice crops for the year 2012 has been restricted in these areas. In order to suppress radiocesium uptake in brown rice from contaminated fields, we investigated the distribution of radiocesium in experimental fields and examined the effect of using potassium fertilizer on the radiocesium uptake in brown rice.

2. Materials and methods

(1) Experimental Fields

This test was performed in the north area in Fukushima Prefecture. These fields are relatively high contamination level of radiocesium in rice paddy fields have been planted in Fukushima Prefecture.

The subsoil water from the mountain. is used as the irrigation water in rice paddy fields and surface runoff from forests into the paddy fields when heavy rain was falling (Fig. 1). The cultivator of five fields was same and cropping history was managed for a long time. Thus, we selected these fields.

(2) Cultural method

Plowing, pudding, and transplanting were performed on May 3, May 8, and May 15, 2011, respectively. Planting density was 18.5 hill m^{-2} (30×18 cm). Fertilizer (g m^{-2}) was applied at Sites 1-5 in the proportion 5.2:12.8:4.0 (N-P_2O_5-K_2O) on May 3, 2011. In addition, fertilizer was applied at Sites 4 and 5 through top dressing in the proportion 0:1.2:1.2, on July 25, 2011. Application of rice straw and compost has not been performed for the past 10 years.

(3) Sample collection and preparation

The soil in the rice paddy field was classified as Stagnic Anthrosols in WRB [4)]. Soil core samples (at depth of 0–15 cm) were collected on October 2, 2011, from 5 experimental rice paddy fields, after the cultivation of the rice plant using a stainless steel soil auger 30 cm in length and 5 cm in diameter (Fig.1). In order to determine the soil-to-brown rice transfer factor, we collected soil from the vicinity of the rice plants. From each field, 5 soil samples were collected and categorized into 3 groups according to the depth from which they were obtained (0– 5 cm, 5 –10 cm, 10 –15 cm). The inside of the soil auger was lined with a transparent polyvinyl chloride (PVC) tube for isolating soil samples and protecting against contamination. After the soil samples were air-dried for 21 days, the soil in each sample was properly mixed and sieved through a 2-mm sieve before analysis. Brown rice was collected from the 5 rice paddy fields after soil sampling and five brown rice samples at each field were collected from some location with soil. They dried at 40 ℃ for one day. After the unhulled rice was subjected to threshing, it was sieved through a 1.80-mm sieve, and grains that remained on the sieve were used for the analysis.

(4) Sample analysis

The dried soil and brown rice were compressed into cylindrical polystyrene containers (inside diameter: 5.0 cm; outer diameter: 5.6 cm; height: 6.8 cm). The concentration of radiocesium in the soil and brown rice were measured using a Ge gamma-ray detector connected to a multichannel analyzer system by counting for 2000s. Exchangeable potassium was extracted using the semimicro-Schollenberger method, and its concentrations were measured with an atomic absorption spectrophotometer.

3. Results and discussion

(1) Vertical distributions of radiocesium in 5 rice paddy fields

Root uptake of radiocesium depends on their vertical distribution in actual rooting zone in soils. Fallout from the Fukushima accident was deposited on the surface soil of the soil. Soils in rice paddy fields are commonly cultivated to the depth of about 15 cm before planting and after harvesting of rice plants every year. The vertical distributions of radiocesium concentration in paddy soils are shown in Fig. 2. The mean concentrations of radiocesium at 3 depths (0–5, 5–10 and 10–15 cm in depth) were 5879 Bq kg^{-1} DW (4701–6749 Bq kg^{-1} DW), 3233 Bq kg^{-1} DW (2674–3692 Bq kg^{-1} DW) and 1835 Bq kg^{-1} DW (1185–2893 Bq kg^{-1} DW), respectively. The results showed that the vertical distribution was not uniform, although the rice paddy fields had been plowed. However, we investigated the vertical distribution of radioactive cesium after plowing of farmland in the same district [5]. The vertical distribution of radioactive cesium in the plowed layer at 0–15 cm depth was homogeneously mixed. The concentration gradient of radiocesium was observed in the rice paddy fields because the clay fraction in the paddy soil was accumulated on surface by pudding. In addition, we suppose that polluted water flowing out of the forest had been integrated into the paddy since this field is in the path of forest runoff water.

(2) Horizontal distributions of radiocesium in 5 paddy fields

After the Fukushima accident occurred, the distribution of the radiocesium concentration in contaminated farmland has been investigated. However, the horizontal distributions of radiocesium within a field have not been reported as yet. Therefore, we investigated the horizontal distributions of radiocesium in 5 different rice paddy fields. The concentrations of radiocesium at a soil depth of 0–5 cm collected from 5 rice paddy fields were 4514– 6786 Bq kg^{-1} DW, 2465– 6392 Bq kg^{-1} DW, 4401–6442 Bq kg^{-1} DW, 5823– 7680 Bq kg^{-1} DW and 4567–7823 Bq kg^{-1} DW, respectively, showing approximately 3-fold variations, even though the paddy fiels had been sufficiently plowed (Fig.3). We investigated the horizontal distribution of radioactive cesium after plowing farmland in the same district. The horizontal distribution of radiocesium in the surface layer (0–2.5 cm) varied by a factor of about 2. In order to evaluate the uptake by rice plants accurately, it is necessary to measure the concentration of radiocesium in the soil around the root distribution.

(3) Concentration of radiocesium in brown rice and the soil-to-brown rice transfer factor

The concentration of radiocesium in brown rice in contaminated 5 rice paddy fields were determined to be 230–397 Bq kg^{-1}, 278–485 Bq kg^{-1}, 158–281 Bq kg^{-1}, 52–115 Bq kg^{-1} and 92–-137 Bq kg^{-1} DW, respectively (Fig.4). These data were below the provisional regulation value. In 2011, the radiocesium level in 99.8 % of the brown rice produced in Fukushima was below the limit of 500 Bq kg^{-1} [6]. However, the brown rice cultivated in the experimental field had relatively higher values. The soil-to-brown rice transfer factor is a simple but important parameter that can be used to estimate the concentrations of radionuclides in plants from different fields. The transfer factor generally shows a very wide range of variation. Therefore, it seems reasonable that the parameter used for the estimation of the transfer of the nuclides should be evaluated under site-specific condition. As shown by the data list Table 1, the geometric mean of the transfer factor of radiocesium in brown rice obtained in this study was 0.014–0.094 in 5 rice paddy fields, which indicates 7-fold variations between the upper and lower limits of the range. The transfer factor of soil-to-brown rice was in the range of 0.0075–0.11. Tsukada et al. and Komamura et al. reported that the geometric mean of the soil-to-plant transfer factor of polished rice in rice paddy fields, which were determined by the fallout depositions derived from the nuclear weapons tests, as 0.0016 and 0.0030, respectively [7, 8]. The observed variations were large in the same and in a nearby field, and they were higher than previously reported values. The difference from previous values can be attributed to the aging periods of radiocesium after being deposited onto the soil.

(4) Relationship between radiocesium concentration in brown rice and exchangeable potassium in the soil

Potassium is an important essential element in a plants physiology, and it is supplemented by the application of fertilizers to agricultural soils. Other researchers have reported that the transfer factor of ^{137}Cs decreased with increasing concentrations of potassium in soils [9-11]. Kato et.al. reported that the soil-to-plant transfer factor of radiocesium decreased with increasing concentrations of exchangeable potassium in soils [12]. For this reason, we have shown in Fig.5, the relationship between the exchange able potassium exchange in soil and the concentration of radioactive cesium in brown rice. There was a high correlation (R= 0.87) between the concentration of radioactive cesium in brown rice and the exchangeable potassium in the soil. Further, the average radiocesium concentration in brown rice also decreased from 370 to 138 Bq kg^{-1} with the application of potassium fertilizer through top dressing. Hence, it is clear that the application of potassium fertilizer reduces the concentration of radiocesium in brown rice.

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Table 1 Soil-to-brown rice transfer factor of radiocesium

No.	Transfer factor		Number of samples
	Geometric mean	Range	
Site 1	0.053	0.049-0.063	5
Site 2	0.094	0.075-0.11	5
Site 3	0.039	0.027-0.053	5
Site 4	0.014	0.0075-0.019	5
Site 5	0.018	0.014-0.021	5

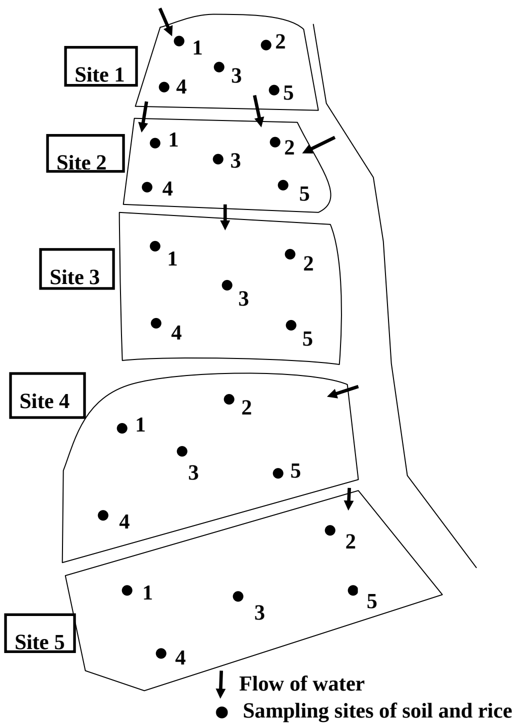

Fig.1 Sampling sites of soil and rice

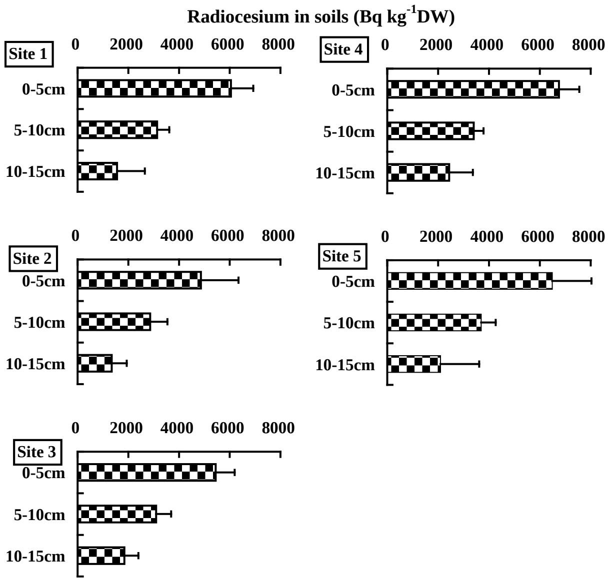

Fig.2 Vertical distribution of radiocesium in 5 paddy fields

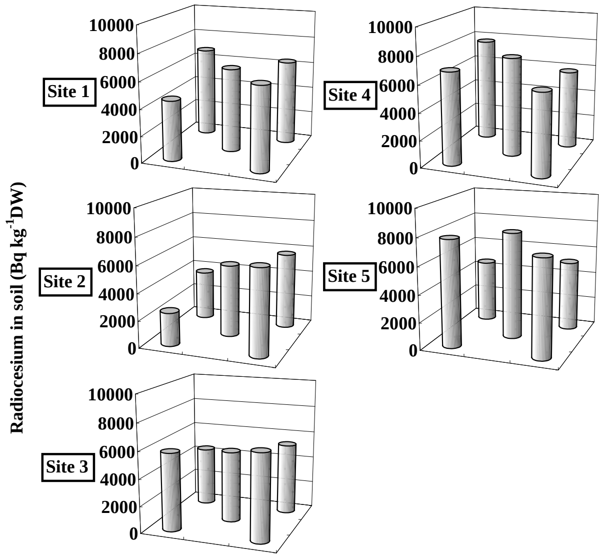

Fig.3 Horizontal distribution of radiocesium in 5 paddy fields

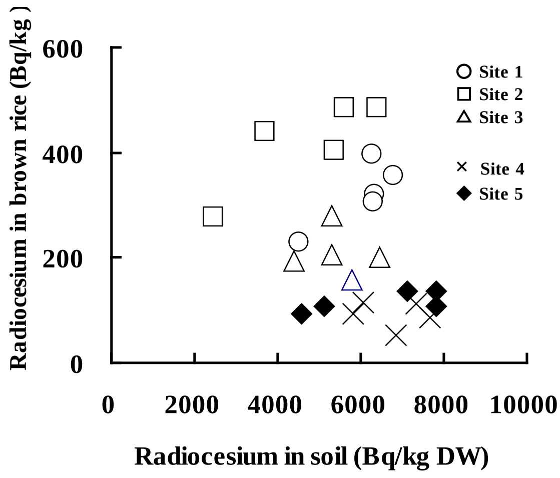

Fig.4 Relation ship between radiocesium concentration in brown rice and soil

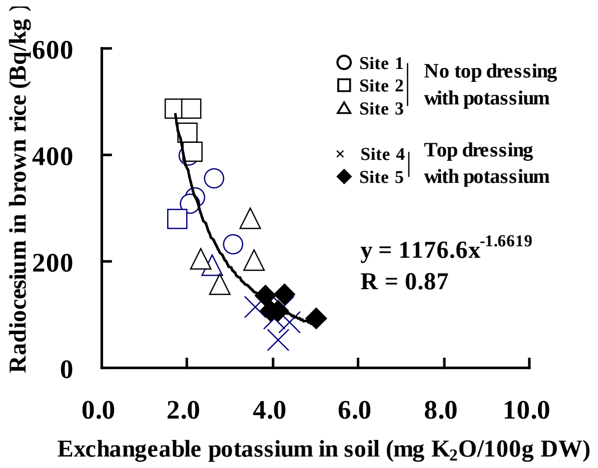

Fig.5 Relationship between radiocesium concentration in brown rice and exchangeable potassium in the soil