Use of rice seedlings to estimate uptake of radiocesium from soil to plants in Fukushima Prefecture

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The uptake of radiocesium to plants from the soil is affected by many environmental factors, and it is difficult to determine the contribution of uptake among these factors. In addition, these environmental factors should be investigated independently for each field. The aim of this study was to develop a practical and simple method for the estimate of uptake of radiocesium from soil to plants. Rice seedlings were used to estimate the root uptake of radiocesium from seven different soils. To confirm that the seedlings were the effective indicator, the concentration of ^{137}Cs in the seedlings was compared with that in brown rice and sunflower. The seedlings were cultivated for a week from germination in a phytotron and the concentrations of ^{137}Cs in the seedlings above ground were determined. To obtain brown rice and sunflower, rice and sunflower were cultivated either in a pot (1/5000 a Wagner pot, 4000 cm^3) placed in a glasshouse or in a paddy field in Fukushima prefecture for two to four months. The concentration of ^{137}Cs in the rice seedlings ranged from 150 to 1900 Bq kg^{-1}, and that in brown rice and sunflower ranged from 2 to 880 Bq kg^{-1} and from 580 to 3900 Bq kg^{-1}, respectively. The Spearman's rank correlation coefficient between the measured concentration of ^{137}Cs in rice seedlings and the measured concentration of ^{137}Cs in brown rice and sunflower was 1.0 ($p < 0.001$ and $p = 0.09$, respectively). This suggests that the use of rice seedlings in this experiment over a period of two weeks provides an effective indicator for the uptake of ^{137}Cs from soil to plants over a longer period of time.

Key Words: *brown rice, radiocesium, rice seedling, root uptake*

1. Introduction

Large amounts of radionuclides were released into the environment as a consequence of the accident at the Fukushima Daiichi Nuclear Power Plant (FNPP) that was triggered by the earthquake and subsequent tsunami on March 11, 2011[1) - 3)]. Since two isotopes of radiocesium (^{134}Cs and ^{137}Cs) have relatively long half-lives and have high biological availability[4)], the concentrations of radiocesium in agricultural fields were monitored by agencies within Fukushima Prefecture and by other organizations. In the aftermath of the accident, rice production has been restricted in the contaminated areas in which agricultural field soils contained more than 5000 Bq kg^{-1} of radiocesium.

Consequently, the concentrations of radiocesium in brown rice (unpolished rice) produced during 2011 were monitored, and the concentration of radiocesium in the brown rice was found to be markedly lower than the fixed provisional regulation value of 500 Bq kg^{-1} for 2011[5]. Nonetheless, elevated radiocesium concentrations, which exceeded the provisional regulation value, were found in brown rice produced in some paddy fields located in the northern part of Fukushima Prefecture[6]. In order to avoid food contamination, rice production in 2012 has been restricted in areas producing brown rice that had higher concentrations of radiocesium than the provisional regulation value.

The estimation of the uptake of radiocesium from the soil to the crops in contaminated fields is necessary before agricultural production can be resumed in the restricted areas. Although the uptake of radiocesium from soil to plants is affected by many environmental factors such as the concentrations of radiocesium, exchangeable potassium (K)[4) 7)] and the total K content[8] in the soil, and the sorption sites for cesium in the soil[9], it is difficult to determine the contribution of uptake among these factors. In addition, these environmental factors should be investigated independently for each field, a process that is both labor-intensive and time-consuming.

The aim of this study was to develop a practical and simple method for the estimation of uptake of radiocesium from soil to crops before harvesting. It is necessary to determine the uptake of radiocesium in plants from a field contaminated by the radiocesium released from FNPP without involving time-consuming processes. In this study, rice seedlings grown under the condition of high plant-density were used to estimate the uptake of ^{137}Cs from soil to plants. To confirm that the seedlings were the effective indicator, the concentration of ^{137}Cs in the seedlings was compared with that in brown rice and sunflower.

2. Materials and Method

(1) Brown rice

a) Experiment 1

Rice plants (*Oryza sativa* L. cv. Hitomebore) were cultivated in a glasshouse at the Fukushima Agricultural Technology Centre, Koriyama, Japan. Four types of contaminated soils (Andosol, gray lowland soil, brown lowland soil and brown forest soil) were used in this experiment. The soils were collected from lysimeters, in which soil surface was contaminated by radiocesium released from FNPP, constructed in the Fukushima Agricultural Technology Centre in April 2011, and they were well homogenized before being used. The concentrations of ^{137}Cs are shown in Table 1. Soil of mass 3.5 kg was filled in a 1/5000 a Wagner pot (16 cm diameter, 20 cm height). Seedlings were transplanted to the Wagner pot on June 14, 2011, in four replicated pots per soil type. Fertilizer was applied at the rate of 0.7 g per pot, 0.3 g per pot, and 0.6 g per pot of N, P, and K, respectively, as basal dressing, and 0.2 g per pot of N as top-dressing. Brown rice was sampled on October 13, 2011.

b) Experiment 2

Rice plants (*Oryza sativa* L. cv. Hitomebore) were cultivated in the Wagner pots in the glasshouse. Two types of contaminated soils (sandy clay loam and gray lowland soil) were used in this experiment, and they were collected from paddy fields located in Nihonmatsu and Fukushima-shi, respectively, and well homogenized before being used. Seedlings were transplanted to the pots with the sandy clay loam on November 29, 2011, and to pots with the gray lowland soil on December 9, 2011, in three replicated pots per soil type. Fertilizer was applied at the rate of 0.1 g per pot of N and P, 0.5 g per pot of K as basal dressing, and 0.3 g per pot of N as top-dressing. Brown rice was sampled on April 9, 2012, and April 23, 2012, for the sandy clay loam and the gray lowland soils, respectively.

c) Experiment 3

Rice plants (*Oryza sativa* L. cv. Koshihikari) were cultivated in a paddy field in the Fukushima Agricultural Technology Centre. Seedlings were transplanted on May 30, 2011, in three replicated plots (4.4m × 4.7m for each plot). Fertilizer was applied at the rate of 5 g m^{-2}, 4 g m^{-2}, and 8 g m^{-2} of N, P, and K, respectively, as basal dressing, and 2 g m^{-2} of N as top-dressing. Brown rice was sampled on October 4, 2011.

(2) Sunflower

The soils used in experiment 1 were used in this case. Sunflower plants (*Helianthus annuus* L. cv. Sunrich orange) were cultivated in a glasshouse at the Fukushima

Agricultural Technology Centre. Seeds were seeded to the Wagner pots on June 8, 2011, in four replicated pots per soil type. Fertilizer was not applied as basal dressing, but 0.02 g per pot of N was applied as top-dressing. Sunflower was sampled on August 17, 2011.

(3) Rice seedlings

The soil samples used in this experiment were the same soils used in the brown rice experiments 1-3 and the sunflower experiment as mentioned above. The soil used in experiment 3 was collected over a depth of 0-15 cm from a paddy field on May 10, 2011 and well homogenized before being used.

Soil mass of 100 g was filled in a polyethylene cup (7.3 cm diameter, 7.5 cm height) to a height of 3 cm. Subsequently, 10 mg of N, P, Mg, and Ca, 2 mg of Fe, and 0.5 mg of Mn were added to the soil[10]. Fertilizer K was not added to the soil to avoid suppression of ^{137}Cs uptake by rice seedlings. Germinated rice seeds of mass 8 g were seeded directly in the soil, and they were covered by less-contaminated soil of 20 g. The less-contaminated soil was used to avoid direct contamination of leaf of rice seedling. The cups were placed inside a phytotron (LH-220S, Nippon Medical & Chemical Instruments Co., Ltd., Japan) at 30 °C under dark conditions. After emergence (three days after seeding), rice seedlings were grown in the phytotron at 30 °C for a photoperiod of 20 h. The photosynthetic photon flux density was 300 µmol m^{-2} s^{-1} as measured by a ML-020P PAR sensor (EKO Instruments Co. Ltd., Japan). Seven days after emergence, rice seedlings were cut at a height of 2 cm above soil and the leaf and leafsheath of rice seedlings were sampled.

(4) Measurement of ^{137}Cs concentration

Brown rice and rice seedling samples were dried for 48 h at 105 °C and 80 °C, respectively. The sunflower samples were dried in a lyophilizer. The concentration of ^{137}Cs was determined using a germanium detector with a multichannel analyzer system (Canberra, USA). The actual decay date was determined as August 1, 2012, using the half-life (i.e., decay constant) of the ^{137}Cs. The Spearman rank correlation coefficients of the collected data were obtained.

Table 1 ^{137}Cs concentrations in soils used in this study.

Experiment	Soil type	^{137}Cs concentration (kBq kg^{-1})
1 and sunflower experiment	Andosol	30
	Gray lowland soil	18
	Brown lowland soil	20
	Brown forest soil	24
2	Sandy clay loam	1.9
	Gray lowland soil	4.5
3	Gray lowland soil	2.0

3. Results and discussion

The ^{137}Cs concentration in brown rice collected in experiments 1, 2, and 3 ranged from 88 to 880 Bq kg^{-1}, from 37 to 51 Bq kg^{-1}, and 2 Bq kg^{-1}, respectively (Figure 1). The ^{137}Cs concentration in sunflower ranged from 580 to 3800 Bq kg^{-1} (Figure 2). The ^{137}Cs concentration differences between soil types in experiment 1 and the sunflower experiment can be attributed to the differences in exchangeable K content and/or the sorption sites for cesium in soil. These details will be published elsewhere. The ^{137}Cs concentrations in rice seedlings cultivated in the soils used in experiments 1, 2, and 3 ranged from 610 to 1900 Bq kg^{-1}, from 220 to 550 Bq kg^{-1}, and 150 Bq kg^{-1}, respectively.

The correlations between the ^{137}Cs concentrations in brown rice and sunflower and that in rice seedlings were analyzed. The Spearman's rank correlation coefficients were 1.0 with significance levels of 0.1% for brown rice and 10% for sunflower. This suggests that the use of rice seedlings provides an effective proxy for the uptake of radiocesium from soil to plants.

The assessment using rice seedlings is less labor-intensive and faster compared with the experiments using brown rice and sunflower. The experimental time for the

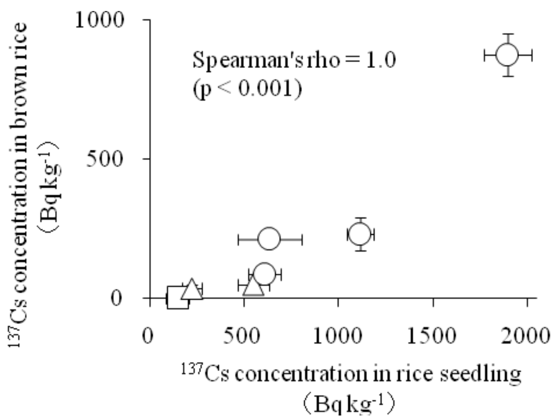

Figure 1 Correlation between the ^{137}Cs concentration in brown rice and that in rice seedlings (means ± standard deviation, n = 3-4). circle: experiment 1; triangle: experiment 2; square: experiment 3.

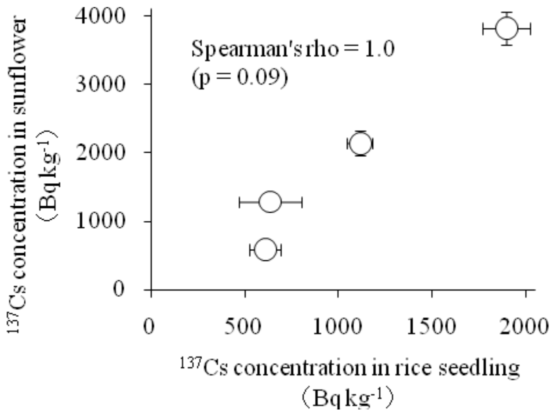

Figure 2 Correlation between ^{137}Cs concentration in sunflower and that in rice seedlings (means ± standard deviation, n = 3-4).

assessment using rice seedlings in this study was two weeks, including the time necessary for preparation of seeds before sowing (1 day), cultivation (10 days), post-sampling treatments (2 days), and measurement of ^{137}Cs concentration (1 day). In addition, the amount of soil used for rice seedling cultivation was 100 g while that for brown rice and sunflower was 3.5 kg. Soil used in the estimation should be sampled from few locations for each agricultural filed and well homogenized since the amount of soil used was small.

We conclude that the use of rice seedlings in this study is a practical and simple method for the estimation of uptake of radiocesium from soil to plants, being both less labor-intensive and time-consuming.

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