Monthly Change in Radioactivity Concentration of $^{137}$Cs, $^{134}$Cs, and $^{40}$K of Paddy Soil and Rice Plants in Fukushima Prefecture

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Monthly fieldwork was conducted in the paddies of Fukushima Prefecture in 2016, to obtain samples of the paddy soil and rice plants. The monthly change in the radioactivity concentrations of $^{137}$Cs, $^{134}$Cs, and $^{40}$K of the samples was investigated, using a germanium semiconductor detector. Three-phase transfer factors (TFs) of $^{137}$Cs from the paddy soil to the roots (TF$_1$), from the roots to the leaves (TF$_2$), and from the leaves to the ears (TF$_3$) of rice plants were calculated. The results showed that the radioactivity concentration of $^{137}$Cs and $^{134}$Cs in the paddy soil varied seasonally, while the concentration of $^{40}$K showed an almost opposite seasonal change compared to $^{137}$Cs and $^{134}$Cs. The radioactivity concentration of $^{137}$Cs and $^{134}$Cs in the roots increased 60 days after planting, while the concentration of $^{40}$K decreased. Furthermore, the radioactivity concentration of $^{137}$Cs, $^{134}$Cs, and $^{40}$K in the leaves and ears decreased over time. Correlations of the TFs of $^{137}$Cs with the radioactivity concentration of $^{40}$K suggested that $^{137}$Cs and $^{40}$K were competitively absorbed by the roots, however, they were transported to the leaves and ears in the same manner. In conclusion, the transportation of $^{137}$Cs (TF$_2$ and TF$_3$) in rice plants was high despite the low absorption of $^{137}$Cs (TF$_1$) in the early stage of rice growth. Therefore, it is recommended that the potassium concentration in the paddy should be high during the early stage of growth to prevent radioactive cesium contamination.

Key Words: cesium, potassium, transfer factor, paddy soil, rice plant

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1. Introduction

The Fukushima Daiichi Nuclear Power Station (FDNPS) accident was caused by the East Japan Great Earthquake in March, 2011. Hydrogen explosions from the reactor released many radionuclides into the environment$^{1,2}$. There appeared medical, environmental, and social problems. In particular, $^{137}$Cs was released into the terrestrial environment, where it stays for the duration of its half-life 30.17 years which is a long time considering the length of an average human life. Cesium-134, whose half-life is 2.06 years, was also released in similar quantities to $^{137}$Cs$^3$. These radioactive Cs isotopes may contaminate agricultural products by replacing K because Cs and K have similar physical and chemical properties$^4$. Since agriculture is the key industry of Fukushima Prefecture, and rice is a Japanese staple food, it is very important to ensure food safety. In 2013, $^{137}$Cs contamination of rice in the private paddy in Fukushima City was observed and the cause of the contamination was investigated by the Japanese Society of...
Radiation Safety Management\(^5\). In later years, we studied the influence of variation in grain size distribution of the paddy soil and the depth distribution of radioactive Cs on the uptake thereof in rice plants in the same field\(^5^7\). The presence of exchangeable K in the paddy has been shown to prevent radioactive Cs from transferring into the rice plants\(^8^9\). Therefore, the dispersion of potassium chloride (KCl) in the paddy before planting has been recommended. We, however, wondered if a constant concentration of K is maintained in the paddy during the growth process of rice plants because the exchangeable K is water-soluble, and the irrigation water in the paddy is interchanged often during the growing of rice plants. Thus, to investigate the absorption of radioactive cesium by rice plants over a period of time, we conducted monthly fieldwork in the private farm paddies in Fukushima Prefecture. We collected samples seven times, from April 2016, before planting, to September 2016, before harvesting. We then monitored the rice plants’ growth and measured the radioactivity of \(^{137}\text{Cs},^{134}\text{Cs}, \text{and}^{40}\text{K}\) in the paddy soil and rice plants. In addition, to confirm the absorption of \(^{137}\text{Cs} \text{and}^{134}\text{Cs}\) into the rice plants and transportation in the rice plants, we calculated three phase transfer factors (TFs) of \(^{137}\text{Cs} \text{and}^{134}\text{Cs}\): from the soil to the roots (TF\(_1\)), from the roots to the leaves (TF\(_2\)), and from the leaves to the ears (TF\(_3\)). Note that the TF was originally defined as the division of radioactivity concentration between rice plants and soil\(^10\). To the best of our knowledge, this is the first study performing repeated sampling and analysis, over a period of six months in the same site and confirming the correlations between (A) and (B), as well as between (A) and (C), which represent:

(A): TF\(_1\), TF\(_2\), and TF\(_3\) of \(^{137}\text{Cs} \text{and}^{134}\text{Cs}\)
(B): the radioactivity concentration of \(^{40}\text{K}\) in the soil, root, and leaves, and
(C): the rice plants’ growth.

2. Materials and methods

2.1. Fieldwork

The sampling of the paddy soil and rice plants was conducted in two adjacent paddies in Fukushima Prefecture. Japonica rice (koshihikari) and glutinous rice (koganemochi) were privately cultured in the two paddies of 268 m\(^2\) and 182 m\(^2\), respectively. Seven samples were taken over a six-month period in 2016, namely April 26, May 18, June 15, July 5, August 2 and 24, and September 13. Fig. 1 shows the location of the paddies, approximately 60 km northwest from FDNPS. Soil samples from the top 5 cm of soil and a batch of rice plants were obtained at the center (J3, G3) and four corners (J1, J2, J4, J5, G1, G2, G4, G5) of each paddy. Only soil samples were collected on April 26 because the planting was only performed on May 12 (according to a personal communication with the farmer).

To observe the growth process of the rice plants, photographs were taken at a fixed-point every time. In addition, the plant height was measured manually and the SPAD (Soil and Plant Analyzer Development) values were measured by a SPAD-502Plus Chlorophyll Meter (Konica Minolta, Inc., Japan) at each sampling point. SPAD is primarily a business enterprise of the Ministry of Agriculture, Forestry and Fisheries (MAFF), and the meter is designed to manage the nutritional condition of crops by measuring the amount of chlorophyll. The plant heights and SPAD values were measured randomly.

![Fig. 1. Location of the fieldwork in Fukushima Prefecture (left) and the points of sampling and measurement of plant heights and SPAD values in the two adjacent paddies (right). In 2016, Japonica rice (koshihikari) was cultured in the larger paddy and glutinous rice (koganemochi) was grown in the smaller one.](image-url)
Three measurements were taken at each sampling point and the averages were calculated. Then, the average of the five sampling points was calculated for each paddy.

2.2. Sample preparation procedure

The paddy soil and rice plants were first dried at room temperature in the laboratory for a few days. The soil was passed through a 2 mm mesh sieve for a day to remove gravel and thereafter, it was dried completely in an oven at 105°C for a day. Before and after drying, the mass of the soil sample was measured by electronic balance, and the moisture ratio was calculated using the following equation (i). This is the same method that was used for our study in 20146).

\[
MR = \frac{M_{\text{total}} - M_{\text{soil}}}{M_{\text{total}}} \times 100 \tag{i}
\]

- \(MR\): moisture ratio of the soil sample (%)
- \(M_{\text{total}}\): the mass of the soil sample before drying in an oven (g)
- \(M_{\text{soil}}\): the mass of the soil sample after drying in an oven (g)

The rice plants were separated into roots, leaves, and ears, if ears had emerged, and the roots and leaves were chopped into small pieces. Both soil and rice plant samples were packed in U8 vessels (plastic container with inner diameter of 50 mm and height of 68 mm).

2.3. Radioactivity measurement

The radioactivity of \(^{137}\text{Cs}\), \(^{134}\text{Cs}\), and \(^{40}\text{K}\) for the samples, packed in U8 vessels, was measured using a germanium semiconductor detector (GEM 30-70, ORTEC). Fig. 2 shows the gamma-ray spectrum of the paddy soil sample (C1) collected on April 26, 2016. The gamma-ray energies of 662, 605, and 1460 keV correspond to \(^{137}\text{Cs}\), \(^{134}\text{Cs}\), and \(^{40}\text{K}\), respectively. We analyzed gamma-rays with a greater emission probability for \(^{134}\text{Cs}\), and the measurement was conducted until the count error of gamma-rays was less than 10%. In some rice plant samples, the radioactivity of \(^{137}\text{Cs}\) and \(^{134}\text{Cs}\) was too low to be measured. We estimated that \(^{137}\text{Cs}\) and \(^{134}\text{Cs}\) should be detectable, if the error in measurement decreased to less than 30% within a week. The radioactive decay was corrected, and the radioactivity concentration on the sampling date was calculated by the following equation (ii).

\[
A = (C - B) \times S \times \frac{1}{D} \times \frac{100}{E} \times \frac{1}{\exp(-\lambda t)} \times \frac{1}{M} \tag{ii}
\]

- \(A\): the radioactivity concentration on the sampling day (Bq kg\(^{-1}\))
- \(C\): the counts per second of gamma-ray (cps) (= net counts/live time)
- \(B\): the counts per second of gamma-ray of \(^{40}\text{K}\) background (cps) (= 0.0053) for calculation of \(^{40}\text{K}\)
- \(S\): the correction constant of the sum effect of \(^{134}\text{Cs}\)

![Gamma-ray spectrum of the paddy soil sample (C1) collected on April 26, 2016, measured by a Ge semiconductor detector.](image-url)
\( D = \frac{C}{(A \times I/100)} \)  

**D**: the detection efficiency  
**C**: the counts per second of gamma-ray (cps) (= net counts/live time)  
**A**: the radioactivity on the measurement day (Bq)  

\[ A = A_0 \times \exp(-\lambda \times t) \]

**A**\(_0\): the verified radioactivity (Bq)  
**\( \lambda \)**: the decay constant (s\(^{-1}\)) (= 0.693/half-life)  
**t**: the elapsed time from verified to measurement day (s)  
**I**: the emission rate of gamma-ray (%)  

In addition, the sum effect of \(^{134}\)Cs was corrected and the background of \(^{40}\)K was subtracted. The sum effect arises because \(^{134}\)Cs emits cascade gamma-rays, unlike \(^{137}\)Cs that emits gamma-rays of a single energy. In particular, the emission rates of gamma-rays with energies of 605 keV and 795 keV are high. Therefore, these gamma-rays are coincidentally detected in the same moment, producing a single, high energy gamma-ray (1400 keV), which is called the sum peak. When the sum peak is detected, the intensity of the gamma-ray observed in the spectrum is underestimated, and consequently, the radioactivity concentration of \(^{134}\)Cs is also underestimated. To reduce the possibility of such a coincidence, the source should be placed far from the detector. Hence, the paddy soil samples from Fukushima, which were preserved in the laboratory, were measured at different distances from the detector by using a height-adjustable acrylic platform. The correction constant for the sum peak of \(^{134}\)Cs (605 keV) was calculated by the following equation (iv).

\[
S = \frac{C(\text{\(^{134}\)Cs/\(^{137}\)Cs}) \text{ at } 20 \text{ cm}}{C(\text{\(^{134}\)Cs/\(^{137}\)Cs}) \text{ at } 1 \text{ cm}}
\]  

**S**: the correction constant for the sum effect of \(^{134}\)Cs  
**C(\(^{134}\)Cs/\(^{137}\)Cs) at 20 cm**: the ratio of the counts per second of \(^{134}\)Cs to that of \(^{137}\)Cs when the source is placed 20 cm from the detector.  
**C(\(^{134}\)Cs/\(^{137}\)Cs) at 1 cm**: the ratio of the counts per second of \(^{134}\)Cs to that of \(^{137}\)Cs when the source is placed 1 cm from the detector.  

Concerning the background of \(^{40}\)K, we measured the background, and the cps of gamma-rays with an energy of 1460 keV (\(^{40}\)K) was estimated as 0.0053.

### 2.4. Calculation of transfer factors (TFs)

The transfer factors, \(TF_1\), \(TF_2\), and \(TF_3\), of \(^{137}\)Cs and \(^{134}\)Cs were calculated by the following equations (v).

\[
TF_1 = \frac{A(\text{roots})}{A(\text{soil})},
\]
\[
TF_2 = \frac{A(\text{leaves})}{A(\text{roots})},
\]
\[
TF_3 = \frac{A(\text{ears})}{A(\text{leaves})}
\]

**A(roots)**: the radioactivity concentration of paddy soil (Bq kg\(^{-1}\))  
**A(roots)**: the radioactivity concentration of rice roots (Bq kg\(^{-1}\))  
**A(leaves)**: the radioactivity concentration of rice leaves (Bq kg\(^{-1}\))  
**A(ears)**: the radioactivity concentration of rice ears (Bq kg\(^{-1}\))
$TF = \frac{A_{(ears)}}{A_{(soil)}} = TF_1 \times TF_2 \times TF_3$  \hspace{1cm} (vi)

3. Results and discussion
3.1. Growth process of rice plants

Fig. 3 shows the photographic recording during the rice growing process. After planting on May 12, 2016, the rice plants grew up to 60 cm in two months, enough to mask the surface of the paddies. Some ear emergence was observed in both paddies on August 2, and ear formation for the rice plants was complete on August 24. The plant height was more than 100 cm and the rice plants were lodged on September 13. Fig. 4 shows the plant heights and SPAD values. Both Japonica and glutinous rice exhibited similar growth trends for the plant height, and the Japonica rice plants eventually became taller than the glutinous rice plants (Fig. 4(a)). On the other hand, the SPAD values for both rice species were the highest in the tilling stage, 30 days after planting, and decreased as the growth process continued. In particular, the SPAD values of Japonica rice showed a sharp reduction, while the SPAD values for both species were similar on August 24 (Fig. 4(b)).

3.2. Moisture ratio of paddy soil

Fig. 5 shows the moisture ratio for the paddy soil. The moisture ratio of the soil in both paddies, where Japonica and glutinous rice were cultured, was measured during the rice growing process. The moisture ratio decreased as the growth process continued, and the water level in the paddies was maintained at a low level. Japonica rice (koshihikari) and glutinous rice (koganemochi) were cultured in the larger and smaller paddies, respectively.
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Glutinous rice were cultured, was similar. It varied between 3% and 6% from April to September 2016. These values correspond to the moisture ratio measured in 2014\(^6\). Therefore, there is no difference in the moisture ratio of the paddy soil that could influence the mobility of the nuclides.

3.3. Radioactivity concentration of paddy soil and rice plants

The radioactivity concentration of \(^{137}\text{Cs}\), \(^{134}\text{Cs}\), and \(^{40}\text{K}\) for the paddy soil and rice plants was measured. Figs. 6–9 show the results for the paddy soil, roots, leaves, and ears, respectively. Based on the radioactivity concentration of \(^{137}\text{Cs}\) and \(^{134}\text{Cs}\) in the paddy soil obtained on April 26, before planting (Fig. 6), the decay curves of \(^{137}\text{Cs}\) and \(^{134}\text{Cs}\) were calculated by the following equation (vii).

\[
A = A_0 \times \exp(-\lambda \times t)
\]  

(vii)

\(A\): the radioactivity concentration on each sampling day

\(A_0\): the radioactivity concentration on April 26, 2016 (Bq kg\(^{-1}\))

\(\lambda\): the decay constant (s\(^{-1}\) (= 0.693/half-life))

\(t\): the elapsed time from April 26, 2016 (s)

The radioactivity concentration of \(^{137}\text{Cs}\) and \(^{134}\text{Cs}\) in the paddy soil decreased sharply (to less than 3000 Bq kg\(^{-1}\) in total for \(^{137}\text{Cs}\) and \(^{134}\text{Cs}\)) in comparison with the calculated values from June to the beginning of August, however, it increased at the end of August and became nearly the same (where Japonica rice was cultivated) or a little lower (where glutinous rice was cultivated) than the calculated value. One of the reasons the radioactivity concentration of \(^{137}\text{Cs}\) and \(^{134}\text{Cs}\) in the paddy soil decreased, is the absorption of \(^{137}\text{Cs}\) and \(^{134}\text{Cs}\) by the rice roots, from organic matter contained in the paddy soil, which formed by decomposition in the summer heat\(^{11}\). Furthermore, the increase in the radioactivity concentration of \(^{137}\text{Cs}\) and \(^{134}\text{Cs}\) in the paddy soil may be caused by the release of \(^{137}\text{Cs}\) and \(^{134}\text{Cs}\) by weathering rice roots.

On the other hand, the radioactivity concentration of \(^{40}\text{K}\) increased slightly and then returned to the original value as time elapsed. Although the change is small, the low natural abundance of \(^{40}\text{K}\) (0.0117%) implies that the change is actually quite large. Therefore, as reported in another study\(^{12}\), it is possible that K is released from the rice roots due to the accumulation of other cations.

In the rice roots, the radioactivity concentration of \(^{40}\text{K}\) was more than 500 Bq kg\(^{-1}\), which is higher than that in the paddy soil (Figs. 6 and 7). The maximum value (more than 1000 Bq kg\(^{-1}\)) was observed in the tilling stage, one month
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Fig. 6. Monthly changes in the radioactivity concentration of $^{137}\text{Cs}$, $^{134}\text{Cs}$, and $^{40}\text{K}$ in the paddy soil where Japonica (a) and glutinous rice (b) were cultivated. Open and filled circles indicate the concentration of $^{137}\text{Cs}$ and $^{134}\text{Cs}$, respectively. Filled triangles indicate the concentration of $^{40}\text{K}$.

Fig. 7. Monthly changes in the radioactivity concentration of $^{137}\text{Cs}$, $^{134}\text{Cs}$, and $^{40}\text{K}$ in the roots of Japonica (a) and glutinous rice (b). Open and filled circles indicate the concentration of $^{137}\text{Cs}$ and $^{134}\text{Cs}$, respectively. Filled triangles indicate the concentration of $^{40}\text{K}$.
after planting, and thereafter, it decreased to less than 500 Bq kg$^{-1}$, which is the same level as that of the paddy soil. Although the radioactivity concentration of $^{40}$K increased in the harvesting stage, 120 days after planting, it did not exceed 1000 Bq kg$^{-1}$. On the other hand, the radioactivity concentration of $^{137}$Cs and $^{134}$Cs was primarily low and then increased as the plants grew. The maximum value of $^{137}$Cs and $^{134}$Cs, which was more than 3000 Bq kg$^{-1}$ in total, and close to the level in the paddy soil, was reached at the end of August, 100 days after planting. The rice roots primarily contained high concentrations of $^{40}$K but did not contain much $^{137}$Cs and $^{134}$Cs. These radioactivity concentrations approached the level observed in the paddy soil at the end of August. The period of absorption of K and radioactive Cs ($^{137}$Cs and $^{134}$Cs) by rice roots seemed to be different. Thus, there may be selective absorption of K by the roots in the early stage of rice growth.

In the rice leaves, the radioactivity concentration of $^{137}$Cs, $^{134}$Cs, and $^{40}$K was high at the initial stage, soon after planting, and remained high up to the tilling stage, in June (Fig. 8). The reason the concentration was initially high is that the transportation of $^{137}$Cs and $^{134}$Cs from the roots to the leaves might occur in the early growth stage of rice plants in spite of the low radioactivity concentrations of $^{137}$Cs and $^{134}$Cs in the roots. In particular, $^{134}$Cs was only detected within 60 days of planting (Figs. 8(a) and 8(b)), after 60 days the radioactivity concentration of $^{134}$Cs dropped below the detection limit (2 Bq kg$^{-1}$)$^7$. Initially, the radioactivity concentration of $^{40}$K was more than 500 Bq kg$^{-1}$ and higher than that in the paddy soil. The maximum value, which was more than 1000 Bq kg$^{-1}$, was observed in the tilling stage, 30 days after planting. Thereafter, the radioactivity concentration of $^{137}$Cs and $^{40}$K in the leaves of Japonica rice was maintained at approximately 10 and 900 Bq kg$^{-1}$, respectively. While that of glutinous rice was approximately 20 and 900 Bq kg$^{-1}$, respectively. The leaves...
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3.4. Correlations of transfer factors of $^{137}\text{Cs}$ and $^{134}\text{Cs}$ with radioactivity concentration of $^{40}\text{K}$

The transfer factors, $\text{TF}_1$, $\text{TF}_2$, and $\text{TF}_3$ of $^{137}\text{Cs}$ and $^{134}\text{Cs}$ were calculated and the results are shown in Figs. 10–12, respectively. The radioactivity concentration of $^{40}\text{K}$ in the paddy soil is slightly different, while $\text{TF}_1$ of $^{137}\text{Cs}$ and $^{134}\text{Cs}$ varied during rice growth (Fig. 10). These results suggest that the absorption of $^{137}\text{Cs}$ and $^{134}\text{Cs}$ by the rice roots occurred opposite to the concentration of $^{40}\text{K}$ in the soil. It was confirmed that the application of K in the early stage of growth is an important countermeasure for the contamination of rice by radioactive Cs$^{137}$. On the other hand, $\text{TF}_2$ and $\text{TF}_3$ of $^{137}\text{Cs}$ indicated a proportional relationship with the radioactivity concentration of $^{40}\text{K}$ in the roots and leaves of rice, respectively (Figs. 11 and 12). This suggests that the transportation of $^{137}\text{Cs}$ from the roots to the leaves and from the leaves to the ears occurred with that of $^{40}\text{K}$. Therefore, once radioactive Cs and K are absorbed, they may be treated in the same manner, due to their similar physical and chemical properties.

3.5. Correlations of transfer factors of $^{137}\text{Cs}$ and $^{134}\text{Cs}$ with the growth process of rice plants

Figs. 13 and 14 show the correlations of the three TFs with the plant heights and SPAD values, respectively. $\text{TF}_1$ of $^{137}\text{Cs}$ and $^{134}\text{Cs}$ increased exponentially with the plant height (Figs.
Fig. 10. Correlations between radioactivity concentration of $^{40}$K in the paddy soil and transfer factor of $^{137}$Cs and $^{134}$Cs from the paddy soil to the rice roots (TF$_1$) for Japonica (a) and (c), and glutinous rice (b) and (d), respectively.

Fig. 11. Correlation between radioactivity concentration of $^{40}$K in the rice roots and transfer factor of $^{137}$Cs from the roots to the rice leaves (TF$_2$) for Japonica (left) and glutinous rice (right).

Fig. 12. Correlation between radioactivity concentration of $^{40}$K in the rice leaves and the transfer factor of $^{137}$Cs from the leaves to the rice ears (TF$_3$) for Japonica rice (left) and glutinous rice (right).
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$^{137}$Cs and $^{134}$Cs from the soil to the roots (TF$_1$) (a, b, c, d), transfer factors of $^{137}$Cs from the roots to the leaves (TF$_2$) (e, f), and from the leaves to the ears (TF$_3$) (g, h) of Japonica (left) and glutinous rice (right).

TF$_1$ of $^{134}$Cs increased exponentially with the SPAD value (Figs. 14(e) and 14(f)). TF$_3$ of $^{137}$Cs for the glutinous rice was barely proportional with the SPAD value (Fig. 14(h)).

When the rice plants grew, the plant height increased and the SPAD value decreased. Consequently, the absorption of $^{137}$Cs by the roots increased, but the transportations of $^{137}$Cs from the roots to the leaves, and from the leaves to the ears decreased. These findings suggest that the $^{137}$Cs which was...
initially absorbed, was likely transferred into the upper parts of the rice plants, while the $^{137}$Cs which was absorbed as the rice plants grew, might accumulate in the roots. At present, this observation cannot be explained.

3.6. Change of transfer factor of $^{137}$Cs from the paddy soil to the rice ears

Fig. 15 shows the total transfer factor (TF) of $^{137}$Cs from the paddy soil to the ears. The TF of $^{137}$Cs for both Japonica and glutinous rice was highest in the ear emergence stage, in early August, of rice plant growth. This suggests that transportation of radioactive Cs into the ears occurred in the early stage of growth. However, radioactive Cs was not transferred very well toward the harvesting stage of growth.

4. Conclusion

The monthly change in radioactivity concentration of $^{137}$Cs, $^{134}$Cs, and $^{40}$K for the paddy soil and rice plants in Fukushima Prefecture in 2016 was assessed. The radioactivity concentration of $^{137}$Cs, $^{134}$Cs, and $^{40}$K in the paddy soil varied seasonally, during the growth of the rice plants. The three TFs of $^{137}$Cs and $^{134}$Cs exhibited various correlations with the radioactivity concentration of $^{40}$K and the growth of rice plants, as indicated by the change in plant height and the SPAD value. It was confirmed that radioactive Cs is absorbed by the roots in the later stage of rice growth, when the absorption of $^{40}$K decrease. However, both Cs and K were transported to the leaves and the ears of rice in the same manner. Furthermore, correlations of the TFs of $^{137}$Cs and $^{134}$Cs with the growth of rice plants suggested that radioactive Cs was increasingly absorbed with the continued growth of the rice plants. Although the transportation of $^{137}$Cs occurred easily in the initial stage of growth, it was unlikely to be transported to the upper parts of rice plants. Therefore, the absorption and transportation of radioactive Cs in the early growth process should be prevented. Additionally it was confirmed that the application of K in the early stage of growth is an important countermeasure for the contamination of rice by radioactive Cs. Furthermore, this paper also confirmed that the transportation of $^{137}$Cs occurs easily, despite the lower absorption of $^{137}$Cs in the early growth stage of the rice plant.

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