Article

Transfer Factor of $^{137}$Cs in Several Fruit Tree Species Planted After Radioactive Fallout in Orchard in Fukushima Prefecture and the Effect of Topsoil Management on $^{137}$Cs Concentration in Persimmon Fruits

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We conducted a 3- to 5-year study of the transfer factors (TF) of $^{137}$Cs in Japanese chestnut, satsuma mandarin and Japanese persimmon trees planted 1 to 2 years after the Fukushima Dai-ichi Nuclear Power Plant accident. The TFs of these fruit trees were on the order of $10^{-4}$ and $10^{-3}$ across the several years and showed annual variations. Comparison of the TFs between two Japanese persimmon cultivars, ‘Hachiya’ and ‘Hiratanenashi,’ seemed to be higher TFs values of the fruit and leaves in the former than in the latter cultivar. We further investigated the effect of topsoil management (plowing, topsoil removal, and topsoil return) on $^{137}$Cs concentration in ‘Hachiya’ fruit and the planted soil. The soil $^{137}$Cs concentration in the topsoil removal treatment was lower than that in the plowing and topsoil return treatments, but the topsoil management had no effect on the $^{137}$Cs concentration of ‘Hachiya’ fruit in this experiment.

Key Words: Fukushima Dai-ichi Nuclear Power Plant Accident, transfer factor of caesium-137, topsoil management, fruit tree

1. Introduction

After the Fukushima Dai-ichi Nuclear Power Plant (FDNPP) accident in 2011, radionuclides were widely released across a large area, including Fukushima Prefecture, Japan. Fruit orchards were contaminated mainly by radioceasium released during the accident. At the time of the accident, most deciduous fruit trees, except for Japanese apricot, had not yet sprouted. Therefore, radioceasium contaminated only the branches and trunks of the deciduous fruit trees. In contrast, evergreen trees developed leaves at the time of the accident. In evergreen satsuma mandarin (Citrus unshiu Marcow.), the concentration of radioceasium was higher in the leaves than that in other organs; in particular, it was higher in old leaves that expanded before the accident than in new leaves that expanded after the accident. Tagami et al. reported that the concentration of radioceasium in newly emerged leaves was higher in evergreen trees than in deciduous trees. Furthermore, after the 2011 accident, radioceasium...
concentrations of several fruits, including satsuma mandarin, Japanese chestnut, and Japanese persimmon, in the contaminated orchards exceeded the official tolerance level, which was at the time 500 Bq/kg fresh weight (FW), but then lowered to 100 Bq/kg (FW) on April 1, 2012.4) To reduce radiocaesium concentration in fruit, tree bark in most deciduous fruit orchards in Fukushima Prefecture had been washed with a high pressure washer within a year after the accident.5) Washing the thirty-year-old Japanese persimmon trees with a high pressure washer significantly reduced, by approximately 29%, radiocaesium activity concentration in the fruit, and the decrease in radioactivity following bark wash continued in the following four growing seasons.6) However, it was estimated that a large amount of the radiocaesium migrated inward via the bark before the washing treatment was conducted.7) In fruit of Japanese chestnut trees that were contaminated by the radiocaesium deposition, the pruning has been reported no significant effects of radiocaesium concentration.8, 9) Although some radiocaesium on and in contaminated trees can be removed by treatments such as bark washing and pruning, such treatments fail to remove all the radiocaesium absorbed by the tree.

Antonopoulos-Domis et al.10) demonstrated that root uptake of radiocaesium accounted for a small fraction of the total contamination in leaves and fruit of trees planted before the Chernobyl accident, whereas the leaves of trees planted after the accident showed low levels of contamination. Takata et al.11) compared the radiocaesium concentration of peach trees planted in soil with different radiocaesium concentrations and concluded that radiocaesium in soil would have little effect on radiocaesium concentration of peach trees in an accident year. Sato et al.1) suggested that root uptake of radiocaesium was negligible in deciduous fruit trees contaminated before bud burst. These previous data suggest that transplantation of non-contaminated fruit trees is an effective method for production of fruit with safe radiocaesium levels. However, there is little information about the annual change in the transfer factor (TF) of radiocaesium across several years in non-contaminated fruit trees planted in orchards in Fukushima Prefecture. The TF of non-contaminated peach trees and grape vines cultivated in contaminated soil was $10^{-4}$ and $10^{-3}$, respectively, approximately 5 months after their transplantation.1) Information on the TF of other fruits across several years is required as a reference when replanting trees in orchards contaminated with radiocaesium.

Takata et al.12) reported that the transfer rate of $^{137}$Cs in fig (shallow rooted) trees was higher when high concentration of $^{137}$Cs was located in surface soil than in deep soil. Transfer of $^{137}$Cs from soil to fruit is strongly influenced by the relationship between the depth of contaminated soil and the depth of root distribution. The concentration of $^{137}$Cs within the 3 cm of topsoil decreased from 84–94% in the first 7 months after deposition in 2011 to 41–75% in 2017.13) This result indicated that over time $^{137}$Cs migrated further down in the soil after the accident; the speed of $^{137}$Cs migration in orchards during the first 6 years after the accident was 0.44 to 0.97 cm/year.13) Since nursery stocks have a shallower root area than adult trees, nursery stocks may enhance $^{137}$Cs uptake from the soil. Therefore, topsoil management at the time of replanting may affect the transfer of $^{137}$Cs from soil to fruits.

To clarify the influence of root absorption on radiocaesium accumulation in fruit other than peach and grape in Fukushima Prefecture, we investigated the TF in several fruit trees (satsuma mandarin, Japanese chestnut, and Japanese persimmon) planted after radioactive fallout. Moreover, we studied the effects of different topsoil management practices on radiocaesium concentration and TF in persimmon fruit. These data will be useful in replanting of fruit trees in
contaminated areas affected by the FDNPP accident.

2. Materials and methods

2.1 Transfer factor of different fruit trees

2.1.1 Transplantation and cultivation management of uncontaminated fruit trees

Four-year-old satsuma mandarin (Citrus unshiu 'Nichinan No. 1') and three-year-old Japanese chestnut (Castanea crenata Sieold & Zucc. 'Porotan') trees were obtained from a greenhouse at the National Agriculture and Food Research Organization (NARO) Institute of Fruit Tree Science (Tsukuba, Ibaraki, Japan). The differences in TF were investigated between two-year-old Japanese persimmon Diospyros kaki Thunb. 'Hiratanenashi' grown at the NARO Institute of Fruit Tree Science (Higashihiroshima, Hiroshima, Japan) and approximately six-year-old D. kaki 'Hachiya' grown in Kyoto. None of the trees were contaminated with radiocaesium. In an experimental orchard of the Fruit Tree Research Center of Fukushima Agricultural Technology Center (FTRC), which is located approximately 65 km from the FDNPP, five trees of each satsuma mandarin, Japanese chestnut, and 'Hiratanenashi' were transplanted in May 2012, one year after the accident. Three trees of 'Hachiya' were transplanted in March 2013 in the same orchard. Fruit trees were transplanted in planting holes (diameter: approximately 70 cm, deep: approximately 20 cm) filled with the same soil. The soil type was fine-textured Brown Forest soil (Cambisol). Satsuma mandarin, Japanese chestnut, and 'Hiratanenashi' trees were fertilized with chemical fertilizer (N:P₂O₅:K₂O=8:8:5; Kumiaikasei-7; JA Higashihinon Kumiaisiryou Co. Ltd., Gunma, Japan) in October 2013 and 2015, with 400 g chemical fertilizer (N:P₂O₅:K₂O=16:10:14; S604; JCAM AGRI. Co. Ltd., Tokyo, Japan) in March 2017, and with 150 g each of the two chemical fertilizers (N:P₂O₅:K₂O=15:15:15; S555; JCAM AGRI. Co. Ltd., Tokyo, Japan and N:P₂O₅:K₂O=8:8:5; Kumiaikasei-7; JA Higashihinon Kumiaisiryou Co. Ltd., Gunma, Japan) in 2018. All trees were pruned once a year. Soil surface was controlled with weed sod culture. During the winter season, satsuma mandarin trees were covered with cheesecloth.

2.1.2 Sampling

The fruits and leaves were sampled at harvest. In the case of satsuma mandarin and Japanese persimmon, approximately 20 fruits were randomly collected from each tree. All Japanese chestnuts were collected from each tree when the nuts had matured. Approximately 50 leaves of Japanese persimmon were sampled from each tree. Satsuma mandarin and Japanese chestnuts were sampled annually from 2014 to 2016. The leaves of Japanese persimmon were sampled from 2014 to 2018 and the fruits from 2015 to 2018. All samples were washed with tap water and then wiped with paper towels. Only the edible sections were minced for measurement of 137Cs. Nuts and leaf samples were weighed and dried at 80°C to a constant weight. The dried samples were minced.

Soil samples were collected with a core sampler (diameter: 3.0 cm) in 2014, 2015, and 2016 from two points under the canopy approximately 50 cm from the trunk and at depths of 0–20 cm. In 2017 and 2018, soil samples were collected from four points per tree. Soil samples were air-dried and sieved through a 2 mm screen to remove plant residues. Part of the soil sample was dried at 105°C to a constant weight to calculate its water content.
2.1.3 Measurement of $^{137}\text{Cs}$

$^{137}\text{Cs}$ concentrations were measured by gamma-ray spectrometry with a high-purity germanium detector (GC2520-7500SL and GC4020-7500SL, CANBERRA, California, USA). $^{137}\text{Cs}$ concentration of the fruit was measured in a 0.7 L or 2 L Marinelli beaker, and that of the nuts, leaves, and soil was conducted in U-8 containers. The $^{137}\text{Cs}$ concentration was calculated as Bq/kg FW for fruit and leaf samples, and as Bq/kg dry weight (DW) for soil samples. Concentration uncertainties (relative standard deviations) of $^{137}\text{Cs}$ of fruit and leaves were maintained below 10%, whereas soil samples were measured until the concentration uncertainties were less than 5%. The values were corrected for radioactive decay using the date of sample collection.

Transfer factor of $^{137}\text{Cs}$, TF ($^{137}\text{Cs}$), of the fruit or leaves was calculated using the following equation:

$$\text{TF} (^{137}\text{Cs}) = \frac{^{137}\text{Cs concentration in mature fruit or leaves (Bq/kg FW)}}{^{137}\text{Cs concentration in soil (0–20cm) (Bq/kg DW)}}$$

2.2 Effect of topsoil management on the TF of Japanese persimmon

Three types of topsoil management, (1) plowing, (2) topsoil removal, and (3) topsoil return, were investigated at two sites (Site A and Site B).

(1) Plowing: The soil was plowed with a rotor. The contaminated topsoil was homogeneously mixed with the deeper soil. At the time of cultivation, the $^{137}\text{Cs}$ concentration of the soil was vertically averaged.

(2) Topsoil removal: After removing approximately 5 cm topsoil, the same amount of pit sand was added and the soil was plowed. This ensured that most of the contaminated soil was removed.

(3) Topsoil return: Approximately 5 cm topsoil was removed, and the soil was plowed with a rotor. After planting the trees, the removed topsoil was returned around each transplanted tree.

The contaminated topsoil was thus distributed on top of the soil.

2.2.1 Site A: Experimental orchard in the FTRC

In 2015, we prepared the location using the three different methods to plant the Japanese persimmon. In the (1) plowing treatment, the soil (at approximately 40 cm in deep) was inverted with a backhoe and plowed with a rotor (at approximately 15 cm in deep). In the (2) topsoil removal and (3) topsoil return treatments, the contaminated topsoil was removed. For the (2) topsoil removal treatment, the same amount of pit sand was added, and the soil was inverted with backhoe (at approximately 40 cm in deep) and cultivated with a rotor (at approximately 15 cm in deep). In the (3) topsoil return treatment, the soil was inverted and cultivated as described for treatment (2), but without the addition of clean soil. After transplantation of the trees, the removed topsoil was uniformly spread over the same location.

Two three-year-old ‘Hachiya’ trees were transplanted at 1 m distance in one plot (4 m × 3 m), in March 2015. Each treatment consisted of three replications. The trees were cultivated in accordance with the methods recommended by the Fukushima Prefecture.

2.2.2 Site B: A farmer’s orchard in Date City (approximately 60 km northwest from FDNPP)

In 2015, the soil was prepared for each treatment in the same way as described for Site A, but the soil was not inverted with the backhoe and the depth of rotor cultivation was 10 cm. The soil surface was controlled with weed sod culture.

Three-year-old ‘Hachiya’ trees were transplanted in April 2015. Each plot (5 m × 3 m) had two trees at a 1 m distance, and each treatment included three replications. The trees were cultivated in accordance with the method recommended by the Fukushima Prefecture.
2.2.3 Sampling

Five fruits and approximately 50 leaves were sampled from each tree (Site A) and each of the two trees planted in one plot (Site B) and bunched. This was repeated for each replicate of each treatment. At Site A, leaf sampling commenced in 2015 and fruit collection in 2016. At Site B, sampling of the leaves and fruit started in 2015 and 2016, respectively; but in the plowing treatment, it was impossible to sample fruit. All samples were washed with tap water and then wiped with paper towels. The samples of fruit (edible parts) and leaves were weighed and dried at 80°C to constant weight. After drying, the fruit and leaf samples were crushed to a fine powder.

2.2.4 Measurement of $^{137}$Cs

$^{137}$Cs concentration was measured by the same method as described above. The fruit and leaf samples were analyzed in U-8 containers for more than 36,000 s and more than 14,400 s respectively. If $^{137}$Cs concentration in leaf samples was undetectable, the minimum value that could be detected (detection limit) was adopted as the measurement value. The $^{137}$Cs concentration was calculated as Bq/kg (FW).

2.3 Statistical analysis

Statistical analysis was performed using JMP13 (SAS, North Carolina, USA).

3. Results and discussion

3.1 TF of different fruit trees

The $^{137}$Cs concentration of the satsuma mandarin fruit and the surrounding soil ranged from 0.40 to 0.53 Bq/kg and from 1100 to 2904 Bq/kg, respectively. The TF in 2014, 2015, and 2016 was $3.0 \times 10^{-4} \pm 7.5 \times 10^{-5}$, $3.2 \times 10^{-4}$ and $1.9 \times 10^{-4} \pm 1.0 \times 10^{-4}$, respectively (Fig. 1). Across the 3 years, the TF of satsuma mandarins was similar. In 2011, Hiraoka et al. investigated the radiocaesium concentration (sum of $^{134}$Cs and $^{137}$Cs) of fruit in directly contaminated five-year-old satsuma manda-
chestnut trees, the radiocaesium concentration of nuts decreased annually from 29 to 2.9 Bq/kg from 2011 to 2013.\(^{17}\) The authors suggested that the TF value in their study might have been affected by the direct contamination of the aboveground parts of the chestnut trees. The amount of radiocaesium in the tree is increased by direct contamination from fallout and absorption by the roots. On the other hand, it is decreased by harvesting, defoliation, and pruning. In the present study, radiocaesium was absorbed only by the roots as the plants were not exposed to radioactive fallout. The TF of Japanese chestnut ranged from \(10^{-4}\) to \(10^{-3}\) when absorbed only from roots.

We compared the TF of fruit between two varieties of Japanese persimmon cultivar, ‘Hachiya’ and ‘Hiratanenashi.’ The \(^{137}\)Cs concentration of ‘Hachiya’ fruit and the soil ranged from 0.39 to 3.53 Bq/kg and from 260 to 2,295 Bq/kg, respectively. The \(^{137}\)Cs concentration of ‘Hiratanenashi’ fruit and the soil ranged from 0.15 to 0.48 Bq/kg and from 692 to 1,660 Bq/kg, respectively. The TF of ‘Hachiya’ fruit from 2015 to 2018 was \(3.1 \times 10^{-3}\), \(5.3 \times 10^{-4}\)±\(2.6 \times 10^{-4}\), \(1.2 \times 10^{-3}\)±\(9.0 \times 10^{-4}\) and \(1.4 \times 10^{-3}\)±\(9.8 \times 10^{-4}\) respectively (Fig. 2), whereas the TF of ‘Hiratanenashi’ fruit was \(3.9 \times 10^{-4}\), \(1.9 \times 10^{-4}\), \(2.4 \times 10^{-4}\)±\(8.5 \times 10^{-5}\) and \(1.7 \times 10^{-4}\)±\(5.4 \times 10^{-5}\) respectively. The TF of ‘Hachiya’ fruit had a tendency to be higher than that of ‘Hiratanenashi’ fruit across the four years measured. This might be contributed to the stronger tree vigor and younger age of ‘Hiratanenashi’ trees compared with those of ‘Hachiya.’ The effect of tree vigor and/or tree age on the TF values remains unclear and demands further investigation. The TF of the leaves was higher than that of the fruit in both cultivars. The TF of ‘Hachiya’ fruit and leaves tended to be higher, although not significantly, in the beginning of the sampling period after transplanting.

We compared the difference in the TF among satsuma mandarin, Japanese chestnut, and Japanese persimmon (‘Hachiya’ and ‘Hiratanenashi’). Regard-
sium concentration in fruit was regardless of the radiocaecium concentration in topsoil. In 2016, the fruit TF in the plowing and topsoil return treatments was $5.8 \times 10^{-4} \pm 7.1 \times 10^{-5}$ and $5.7 \times 10^{-4} \pm 4.0 \times 10^{-4}$, respectively. In 2017, the TF of the plowing and topsoil return treatments was $7.6 \times 10^{-4} \pm 5.8 \times 10^{-4}$ and $7.3 \times 10^{-4} \pm 3.9 \times 10^{-4}$, respectively. There was no difference in TF between the plowing and topsoil return treatment, and the TF of the leaves was higher than that of the fruit in all topsoil treatments.

The concentration of $^{137}$Cs in the soil of the farmer’s orchard tended to be a little higher than that in the site A (Table 1, 3), except for the topsoil removal treatment. However, the difference in the concentration of $^{137}$Cs between Site A and B was not significant. The $^{137}$Cs concentration in the topsoil removal treatment in both 0–10, and 10–20 cm layers was the lowest at Site B. The $^{137}$Cs concentration in the top 10 cm of the soil tended to be lower in the topsoil removal treatment than in the plowing and topsoil return treatment (Table 3). The plowing treatment resulted in higher $^{137}$Cs concentration in the 10–20 cm soil layer compared with that of the topsoil return treatment. The TF of fruit from the topsoil return treatment in 2016 and 2017 was $5.3 \times 10^{-4}$ and $3.1 \times 10^{-4} \pm 2.5 \times 10^{-5}$, respectively (Table 4). We could not harvest any fruit in the plowing treatment in 2016. However, the TF of the fruit in 2017 was $5.4 \times 10^{-4} \pm 4.7 \times 10^{-4}$. In site B, the two topsoil management methods plowing and topsoil return produced almost the same TF values. In a previous study, the topsoil management treatment that affected the radiocaesium distribution in the soil

Table 1 Effect of topsoil management on the $^{137}$Cs concentration of different soil layer at FTRC (Site A)

| year | treatment          | $^{137}$Cs concentration (Bq/kg DW) |
|------|--------------------|-------------------------------------|
|      |                    | 0-10 cm | 10-20 cm |
| 2015 | Plowing            | 816.5 b | 913.3 a  |
|      | Topsoil removal    | 196.5 b | 168.0 b  |
|      | Topsoil return     | 1680.5 a| 166.9 b  |
|      | **                 | **      | **       |
| 2016 | Plowing            | 958.3 ab| 729.5 a  |
|      | Topsoil removal    | 185.6 b | 150.8 b  |
|      | Topsoil return     | 2193.5 a| 125.2 b  |
|      | *                  | *       |          |
| 2017 | Plowing            | 1498.5 a| 1087.8 a |
|      | Topsoil removal    | 209.0 b | 300.2 b  |
|      | Topsoil return     | 1519.1 a| 149.8 b  |
|      | *                  | *       | **       |

Values are the mean of 3 replicates. Different letters indicate significant differences between soil treatment in each layer in same year at $P \leq 0.05$ by Tukey–Kramer test. * and ** show significant difference at the 0.05 and 0.01 level respectively. When planting trees in 2015, we managed the ground surface in three ways. The 20 cm topsoil layer was collected at harvesting time in each year. The soil layer was divided into halves vertically.

Table 2 Effect of topsoil management on the $^{137}$Cs concentration and TF in leaf and fruit of Japanese persimmon ‘Hachiya’ at FTRC (Site A)

| organ  | treatment          | $^{137}$Cs concentration (Bq/kg FW) | $^{137}$Cs TF |
|--------|--------------------|-------------------------------------|--------------|
|        |                    | 2015 | 2016 | 2017 | 2015 | 2016 | 2017 |
| Leaf   | Plowing            | 4.1  | 2.8  | 1.8  | $5.2 \times 10^{-3}$ b | $3.3 \times 10^{-3}$ b | $1.4 \times 10^{-3}$ b |
|        | Topsoil removal    | 5.3  | 3.3  | 1.3  | $2.9 \times 10^{-3}$ a | $2.0 \times 10^{-3}$ a | $5.9 \times 10^{-3}$ a |
|        | Topsoil return     | 4.1  | 3.3  | 1.3  | $4.5 \times 10^{-3}$ b | $3.2 \times 10^{-3}$ b | $1.8 \times 10^{-3}$ b |
|        | n.s.               | n.s. | n.s. | n.s. | **             | **             | n.s.     |
| Fruit  | Plowing            | 0.5  | 0.9  | 0.9  | $5.8 \times 10^{-4}$ b | $7.6 \times 10^{-4}$ b |           |
|        | Topsoil removal    | 0.5  | 0.8  | 0.8  | $3.1 \times 10^{-4}$ a | $4.3 \times 10^{-4}$ a |           |
|        | Topsoil return     | 0.6  | 0.5  | 0.5  | $5.7 \times 10^{-4}$ b | $7.3 \times 10^{-4}$ b |           |
|        | n.s.               | n.s. | n.s. | n.s. | **             | **             |           |

Values are the mean of 3 replicates. Different letters indicate significant differences between soil treatment in same year at $P \leq 0.05$ by Tukey–Kramer test. ** show significant difference at the 0.01 level respectively. n.s. indicate non-significant differences between soil treatment in same year. The 20 cm topsoil layer was collected at harvesting time in each year.
or the compost applied with conventional practice did not affect the radiocaesium concentration in the fruit of apple trees for at least 4 years since the nuclear power plant accident. Similarly, there was no difference in the $^{137}$Cs concentration of the leaf and fruit of the Japanese persimmon trees between different topsoil management treatments in this research.

### 4. Conclusions

1. We investigated the TF in fruit and leaf of satsuma mandarin, Japanese chestnut, and Japanese persimmon, which were planted in an orchard after the radioactive fallout. The TFs of these fruit trees were on the order of $10^{-4}$ and $10^{-3}$ across the several years.

2. The comparison of the TF between the two Japanese persimmon cultivars revealed higher TF in ‘Hachiya’ fruit and leaves than in ‘Hiratanenashi.’

3. $^{137}$Cs concentration of the soil layer varied with the topsoil management method. The topsoil removal treatment reduced the $^{137}$Cs concentration in the top 10 cm soil in comparison with the plowing treatment, but it had no effect on $^{137}$Cs concentration of the fruit.

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### Table 3  Effect of topsoil management on the $^{137}$Cs concentration of different soil layer at farmer’s orchard (Site B)

| year | treatment       | $^{137}$Cs concentration (Bq/kg DW) | 0-10 cm | 10-20 cm |
|------|-----------------|-------------------------------------|---------|----------|
| 2016 | Plowing         | 2948.1 a                           | 660.9 a |          |
|      | Tops soil removal| 560.4 b                            | 421.1 b |          |
|      | Tops soil return | 3514.6 a                           | 197.9 b |          |
|      |                 | *                                   | **      |          |
| 2017 | Plowing         | 2951.4 a                           | 1324.7  |          |
|      | Tops soil removal| 183.8 b                            | 43.8    |          |
|      | Tops soil return | 3353.5 a                           | 141.5   |          |
|      |                 | *                                   | n.s.    |          |

Values are the mean of 3 replicates. Different letters indicate significant differences between soil treatment in each layer in same year at $P \leq 0.05$ by Tukey–Kramer test. * and ** show significant difference at the 0.05 and 0.01 level respectively. n.s. indicate non-significant differences between soil treatment in same year. When planting trees in 2015, we managed the ground surface in three ways. The 20 cm topsoil layer was collected at harvesting time in each year. The soil layer was divided into halves vertically.

### Table 4  Effect of topsoil management on the $^{137}$Cs concentration and TF in leaf and fruit of Japanese persimmon ‘Hachiya’ at farmer’s orchard (Site B)

| organ | treatment       | $^{137}$Cs concentration (Bq/kg FW) | 2016 | 2017 | 2016 | 2017 |
|-------|-----------------|-------------------------------------|------|------|------|------|
| Leaf  | Plowing         | 3.4                                 | 4.1  | 2.0×10^{-3} b | 2.5×10^{-3} b |
|       | Tops soil removal | 2.5                                | 1.3  | 8.6×10^{-3} a | 1.2×10^{-2} a |
|       | Tops soil return | 3.6                                | 2.5  | 1.9×10^{-3} b | 1.4×10^{-3} b |
|       |                 | n.s.                                | n.s. |      |      |      |
| Fruit | Plowing         | 0.8                                 | 0.8  | 5.4×10^{-4} b |
|       | Tops soil removal | 0.4                                | 0.4  | 1.0×10^{-3} a | 6.4×10^{-3} a |
|       | Tops soil return | 0.9                                | 0.8  | 5.3×10^{-4} b | 3.1×10^{-4} b |

Values are the mean of 3 replicates. Different letters indicate significant differences between soil treatment in same year at $P \leq 0.05$ by Tukey–Kramer test. * and ** show significant difference at the 0.05 and 0.01 level respectively. n.s. indicate non-significant differences between soil treatment in same year. The 20 cm topsoil layer was collected at harvesting time in each year.
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要 旨

福島県においてフォールアウト後に樹園地に植栽した数種の果樹の移行係数とカキ果実の$^{137}$Cs濃度に及ぼす表土処理方法の影響

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福島県内の樹園地において、東京電力福島第一原子力発電所の事故1～2年後に植栽したクリ、温州ミカン、カキの$^{137}$Csの移行係数の経年変化を3～5年に間調査した。調査年によってばらつきは認められたが、移行係数はどの果樹においても$10^{-4}$～$10^{-3}$の範囲であった。カキ'飼床'と'平核無'の移行係数を比較したところ、'飼床'は'平核無'よりも高い傾向がみられた。'飼床'で表土処理方法(耕転、表土剥ぎおよび表土反し)を比較したところ、表土剥ぎ区の土壌の$^{137}$Cs濃度は他の2区よりも低かったが果実の$^{137}$Cs濃度に有意な差はみられなかった。