Spatial variations in radioactive Cs of soil and crop within a field in Fukushima, Japan

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A large amount of radioactive cesium (^{134}Cs and ^{137}Cs, RCs) was released into the atmosphere and deposited widely onto the eastern Japan due to the accident at the Tokyo Electric Power Company's Fukushima Dai-ichi Nuclear Power Plant in March 2011. The monitoring of RCs activity concentration in soil and food has been conducted since the accident. In monitoring for agricultural fields, samples are taken from the same fields each year, but the activity concentrations can fluctuate due to factors other than the physical decay. One factor is inhomogeneous distribution of RCs in soil and crop within a field. Accordingly, sampling errors caused by the spatial variations must be considered to determine how much the monitoring values fluctuate. We investigated the spatial variations in the RCs activity concentrations in soil and broccoli (*Brassica oleracea* var. *italica*) within a field in Fukushima, Japan.

The field is plowed every year. The area was 1,350 m^2. Broccoli and soil samples (n = 37) were taken at 10 m intervals in November 2024. The coordinates of the sampling points were recorded using an RTK-GNSS system. Soils were collected from both sides for broccoli samples to a depth of approximately 15 cm and composited into one sample. The soil samples were air-dried and sieved through a 2 mm sieve. The buds of broccoli were cut, dried for 48 h at 80 °C, and ground using a blender. ^{137}Cs activity concentrations were determined using a germanium semiconductor detector. Transfer factors (TF) of ^{137}Cs from air-dried soil to dried buds were calculated. Semi-variogram was analyzed with the GS+ software, and the spatial distribution map was created using ordinary kriging or inverse distance weighting with the ArcGIS software.

The max values of ^{137}Cs activity concentrations in soil and broccoli bud were 923 and 32.8 Bq/ kg dry weight, respectively (Table 1). Coefficient of variation (CV) for the activity concentration in soil was approximately 20 %. The CVs of broccoli bud and TF were greater than 20 % and larger than the soil CV. The semi-variogram analysis presented that the activity concentrations in soil and broccoli bud were randomly distributed, whereas TF showed a spatial correlation with a range of 11.7 m. Soil ^{137}Cs distribution might be related to the cropping direction because only one ridge showed high activity concentrations although the reason was unclear. There was no correlation between the activity concentrations in soil and in broccoli bud, suggesting that other factors affected the transfer of ^{137}Cs, such as phytoavailable potassium content. We estimated how much the mean could fluctuate due to the spatial variations in the envelope sampling (5 points sampling), a widely applied method. The results showed that there were 24 % and 36 % variations in the activity concentrations of soil and broccoli bud, respectively, and 31 % variation in TF. These results indicate that the means in 5 points sampling can fluctuate several times due to the spatial variations even in a cultivated field.

Table 1. Descriptive statistics of ^{137}Cs in soil and broccoli buds.

	^{137}Cs in soil (Bq/kg dry soil)	^{137}Cs in broccoli bud (Bq/kg dry weight)	Transfer factor
Min	496	8.55	0.0152
Max	923	32.8	0.0426
Mean	681	16.4	0.0243
Coefficient of variation (%)	19.4	28.8	24.8