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Uptake and retention of radio-caesium in earthworms cultured in soil contaminated by the Fukushima nuclear power plant accident

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ABSTRACT

To understand the effects of radionuclides on non-human biota and the environment, it is essential to study the intake and metabolism of radio-isotopes in earthworms which are among the most important soil organisms, and *Eisenia fetida*, which were used in this study, are known to be sufficiently sensitive to chemicals and representative of common earthworms. In this study, we assessed the concentration ratios, uptake and retention, absorbed dose rate, and distribution of radio-caesium in earthworms. The concentration ratios of ^{137}Cs (i.e., the concentrations of radio-caesium in earthworms relative to those in dry soil) were higher early in the culturing period and decreased gradually over the experimental period. ^{137}Cs taken up by *E. fetida* was cleared rapidly after the worms were cultured in radio-caesium-free soil, suggesting that the metabolism of radio-caesium in earthworms is very rapid. Autoradiography demonstrated that the concentration of radio-caesium within the digestive tract was as high as that in the soil, while radio-caesium in the body tissue was lower than radio-caesium in the soil and was almost uniformly distributed among earthworm tissues. The highest absorbed dose rate of total exposure to radio-caesium (^{137}Cs + ^{134}Cs) was calculated to be 1.9×10^3 (μGy/day) in the earthworms.

1. Introduction

There has been increasing concern about the effects of radiation and/or radionuclides on non-human biota. The International Commission on Radiological Protection (ICRP) has indicated the importance of this subject (ICRP, 2003, 2007), and other international authorities have also expressed interest in its study. To assess the effects of radiation on non-human biota and the overall environment, it is essential to estimate typical doses of radiation and to understand the metabolism of radionuclides. However, only limited data are available on the metabolism of radionuclides in non-human biota.

Earthworms are common soil organisms and play an important role in numerous soil processes (Lavelle et al., 1997). Earthworms are also recognized as ideal soil organisms for use in terrestrial ecotoxicological studies and have been used as indicator animals for contaminated land (Greig-Smith et al., 1992). The ICRP assigned the earthworm as a reference animal for assessing effects of radiation on the environment (ICRP Pub 108, 2009a).

Radio-cesium, mainly ^{137}Cs and ^{134}Cs, emits gamma and beta radiation with a relatively long half-life; these radio-isotopes are produced by the nuclear industry. A large amount of radio-caesium was emitted to the environment by the Tokyo Electric Power Company's Fukushima Daiichi nuclear power plant accident. The United Nations Scientific Committee on Atomic Radiation recently described in a report to the UN General Assembly that there is a potential risk to organisms in the areas of highest exposure, but this risk is difficult to quantify with the available information (UNSCEAR, 2013).

In this paper, we describe the uptake and retention of radio-caesium in genetically well-defined earthworms. The soils used were collected near the accident site. The distribution of radio-caesium in the earthworms and surrounding soil were examined by autoradiography, and absorbed dose rates were estimated.

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2. Materials and methods

2.1. Earthworms (Eisenia fetida)

The earthworms used in this study, *Eisenia fetida*, are known to be sufficiently sensitive to chemicals and representative of common earthworms (Fritzpatrick et al., 1996). This species is commonly found in soil and compost, standing manure heaps, and sewage filter beds (Janssen et al., 1996). The earthworms were obtained from the laboratory of Prof. Gamou, Kyorin University, and has had their genetic background determined previously (Suzuki et al., 2008). This species are slightly different at the allied species level from those in Japan, but will give standard data to be able to use for actual situations. Worms were maintained in a commercial leaf mold for plant culture (peat moss, Keiyo Co., Ltd.) and given oatmeal powder and water once or twice a month. Adult earthworms ($n = 95$) with an individual mass of 310–920 mg were selected and moved to a mixture of the commercial leaf-mold and rice-field or land soil containing radio-caesium. The worms were cultured in this medium for 1–36 days, and the worms were removed at scheduled time intervals for measurement or autoradiography.

2.2. Soil and ^{137}Cs activity

Organic surface soils at depths of 3–5 cm were collected with a hand scoop from the O layer, consisting of decomposed organic material, and the A layer, the mineral horizon containing substantial humus and dark color soil, in both a rice paddy field and in a land with weeds between the road and a cryptomeria forest in Fukushima Prefecture. The locations at which soils were collected are shown in Fig. 1. For experimental exposure of the earthworms, these radioactive soils were mixed with an equal mass of the commercial leaf mold described above. These two mixed soils are referred as soil A, using soil collected from the rice paddy field, and soil B, using soil collected from the land with weeds, hereafter. Bulk specific gravity, moisture content, and radioactive concentration of ^{137}Cs for soils A and B were 0.4 and 1.0 g/cm^3, 68% and 73% (mass basis), and 49.1 and 162.4 Bq/g dry mass, respectively. The Ministry of Agriculture, Forestry and Fisheries reported in Agriculture, Forestry and Fisheries Research Council that the concentration of ^{137}Cs for agricultural field soils in Fukushima Prefecture were from undetectable to 203,000 Bq/kg (203Bq/g) (http://www.s.affrc.go.jp/docs/map/240323.htm, accessed February 22nd). Therefore these soils used in this study were in the range of the value reported by the Ministry of Agriculture, Forestry and Fisheries and representative of the soil in Fukushima prefecture.

2.3. Activity measurement

All five earthworms were removed from soil A at 1, 2, 6, and 36 days after culturing; all five worms were removed from soil B at 1, 2, 4, 7, 14, and 22 days after culturing. 20 earthworms were cultured in the soil containing radioactive caesium for 1 week and were then transferred to radio-caesium-free soil to evaluate the clearance of radio-caesium from the worm's body. After removal from culturing, the earthworms were weighed and washed to remove soil from the body surface, placed into a vessel (cell culture dish, BD Falcon), and stored in a freezer at −20 °C. The radioactivity of each worm was measured using a p-type high-purity germanium detector (Model IGC3019, Princeton Gamma Tech) with a multi-channel analyzer (Model 7600, SEIKO EG&G). The counting efficiency of the detector was determined by constructing a relative efficiency curve using a certified mixed radionuclide gamma-ray reference source (5054QB, Japan Radioisotope Ass.) containing ^{57}Co (122.1 keV), ^{137}Cs (661.7 keV), and ^{60}Co (1173 and 1332 keV). A few dead worms were used to check the counting efficiency with their body position. We found that in any position the counting efficiency was almost the same value. For every measurement, we used one efficiency curve, which was normalized to the 1460 keV gamma ray peak from a ^{40}K in KCl placed in the same type of vessel.

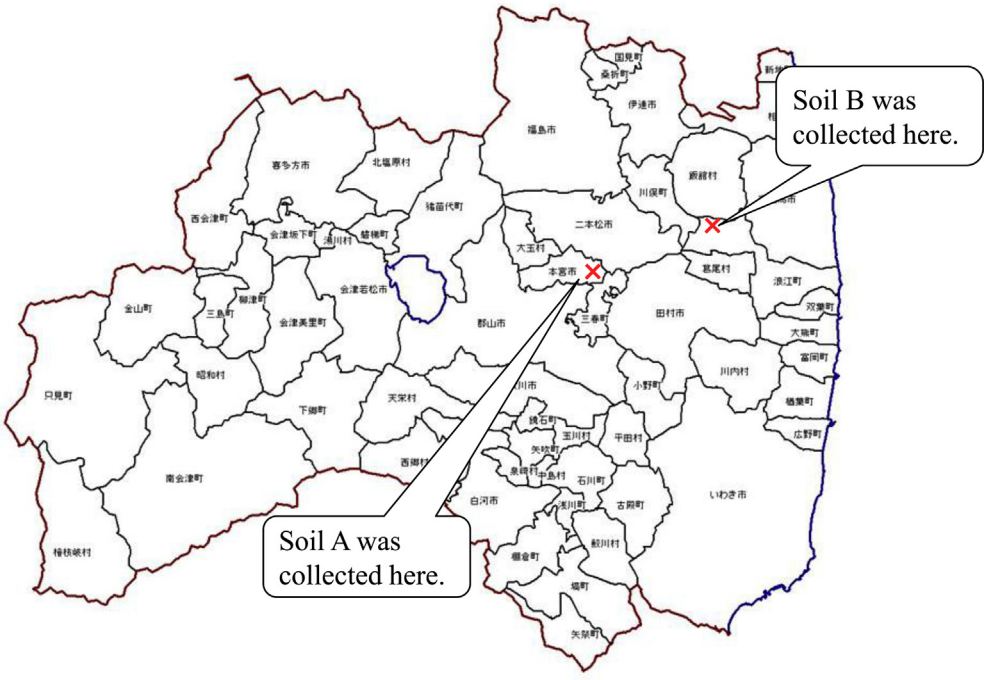

Fig. 1. Map of Fukushima Prefecture. The locations where the soils were collected are shown.