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Radiocesium and radioiodine in soil particles agitated by agricultural practices: Field observation after the Fukushima nuclear accident

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ABSTRACT

Three weeks after the accident at the Fukushima Daiichi Nuclear Power Plant, we determined the activity concentrations of ^{131}I, ^{134}Cs and ^{137}Cs in atmospheric dust fugitively resuspended from soil particles due to soil surface perturbation by agricultural practices. The atmospheric concentrations of ^{131}I, ^{134}Cs and ^{137}Cs increased because of the agitation of soil particles by a hammer-knife mower and a rotary tiller. Coarse soil particles were primarily agitated by the perturbation of the soil surface of Andosols. For dust particles smaller than 10 μm, the resuspension factors of radiocesium during the operation of agricultural equipment were 16-times higher than those under background condition. Before tillage, most of the radionuclides accumulated within a few cm of the soil surface. Tillage diluted their concentration in the uppermost soil layer.

1. Introduction

Radionuclides released due to the Fukushima Daiichi Nuclear Power Plant accident were deposited onto the soil through rainfall from March 21 to 23, 2011 in Tsukuba, Ibaraki, Japan. The major components of the radionuclides were ^{131}I, ^{134}Cs and ^{137}Cs (Sanami et al., 2011). Agricultural practices that perturb the soil surface often transmit soil particles to the atmosphere. The loss of fertile surface soil particles caused by tillage erosion is a significant concern on sloping land (Govers et al., 1996). Soil surface loss has been traced by determining the concentration of ^{137}Cs derived from the global fallout of atmospheric nuclear tests conducted from the 1950s to the 1960s (Ritchie and McHenry, 1990). The fallout-derived ^{137}Cs can be used as a tracer for soil particles when Cs is strongly associated with 2:1 clay minerals in the soil. The resuspension of ^{137}Cs derived from domestic soil particles leads to elevated concentrations of ^{137}Cs in the air (Igarashi et al., 2003). The resuspension of soil particles is especially extensive from March to May, when spring storms perturb the surface soil of unplanted farmlands (Igarashi et al., 2001). Tsukada et al. (1991) reported that ^{129}I in the coarse fraction of aerosols (>1 μm) is primarily derived from resuspended soil particles. Before the Fukushima Daiichi Nuclear Power Plant accident, the contribution of domestic soil particles to the atmospheric radionuclide concentration was lower than that derived from dust transported from southern Mongolia and northeastern China (Fukuyama and Fujiwara, 2008). However, the accident changed the radionuclide concentration of local soils. The observed increase in the concentration of radionuclides in the soil after the accident may increase the internal radiation dose in farmers, due to their inhalation of contaminated soil dust. Soil particles stirred up from farmlands because of agricultural practices can be spread to the surrounding environment. Thus, the quantities of soil-derived radionuclides that are transmitted to the atmosphere during agricultural practices must be estimated.

To estimate the airborne radionuclide concentration of resuspended soil particles due to the contamination of the soil surface, the resuspension factor (RF in m^{-1}) is defined as the ratio of the volumetric activity concentration (Bq m^{-3}) of air to the activity density (Bq m^{-2}) at the soil surface (IAEA, 2010). The RF depends on a number of different environmental factors, such as the soil humidity (Wagenpfeil et al., 1999), wind speed (Holländer, 1994), and the time elapsed since the deposition of radionuclides (Rosner and Winkler, 2001). Anthropogenically enhanced soil perturbations increased the RF (Nicholson, 1988). For instance, Wagenpfeil et al. (1999) demonstrated that the RF increased by three orders of magnitude due to agricultural practices compared to wind-driven resuspension. Three weeks after the accident at the Fukushima Daiichi Nuclear Power Plant, we obtained field observed RF data during the cutting of wheat for green manure and tillage by determining radionuclide concentration in dust transmitted to the atmosphere and in soil. The purpose of this study is to determine the effects of

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agricultural practices on the resuspension of soil particles contaminated with radionuclides.

2. Experimental

2.1. Site description

Atmospheric dust and soil samples were collected from experimental farmland at the National Institute for Agro-Environmental Sciences, Tsukuba, Ibaraki, Japan. Tsukuba is approximately 165 km south-southwest of the Fukushima Daiichi Nuclear Power Plant. At the experimental site, the soil is classified as a Silandic Andosol (FAO, 2006), and the area of the experimental field is 944 m^2 (24.5 × 38.5 m, Fig. 1). Winter wheat (*Triticum aestivum* L.) for green manure was sown on November 16, 2010 in rows at a spacing and sowing density of 20 cm and 120 kg ha^{-1}, respectively. When the radioactive plume reached Tsukuba and the radionuclides were deposited on the ground by the rain from March 21 to 23 (Sanami et al., 2011), the wheat in the experimental field was 15 cm in height and had a ground coverage (by crop canopy) of 60–70%. On April 7, 2011 the aboveground plant bodies were cut using a hammer-knife mower (HMB1100, Kyoeisha, Toyokawa, Japan) with a cutting width and height of 110 cm and 2–3 cm, respectively. The aboveground dry matter yield was measured at nine subplots, each of which had an area of 1 m^2 (1 × 1 m). On the following day, the cut plant bodies were incorporated into the surface soil to a depth of approximately 15 cm using a rotary tiller (KJM180T, Kobashi type, Okayama, Japan) with a tillage width of 180 cm and a tillage blade rotating radius of 25 cm. The hammer-knife mower and rotary tiller used in this study were similar to those commonly used by farmers who work near the study site. Three weeks after the accident, major release of radionuclides from the reactor had been almost stopped (Kinoshita et al., 2011). Rainfall did not occur from April 1 to April 8, and thus the soil surface was dry. The average and maximum instantaneous wind speeds 2 m from the surface of the ground were measured 250 m from the observation field (National Institute for Agro-Environmental Sciences, 2012).

2.2. Atmospheric dust

Atmospheric dust was collected using a high-volume air sampler (HV-500F, Shibata Scientific Technology LTD., Tokyo, Japan) equipped with an impactor, which removed 100% of particles larger than 10 μm. Particles smaller than 10 μm (Dust-10) were trapped on a glass fiber filter (GB-100R-100A, Shibata Scientific Technology LTD., Tokyo, Japan, filter efficiency is 99.99% for particles smaller than 0.3 μm) under an airflow rate of 500 L min^{-1}. The average particle concentration in the atmosphere during dust sampling was calculated by dividing the weight of trapped soil particles by the collected air volume. Particles of aerodynamic diameter less than 2.5 μm (PM 2.5) was collected using the filter-pack method (EMEP, 2001), and open-face filter holders (NL-O, NILU, Norway) were employed. The filter-pack set consisted of two stages. Specifically, the upstream stage consisted of a doughnut-shaped filter made of glass fiber supported with polytetrafluoroethylene (T60A20-H20, Tokyo Dylec, Japan) and an impactor, which was used to collect particles larger than PM 2.5 at an airflow rate of 20 L min^{-1}. In the second stage, a glass fiber filter with a collection efficiency of 96.4% for dioctyl phthalate particles with a diameter of 0.3 μm was supported with polytetrafluoroethylene (T60A20, Tokyo Dylec, Japan) and was used to collect PM 2.5. The locations of the dust sampling sites are shown in Fig. 1. Before operating the hammer-knife mower, atmospheric dust was sampled for 4 h at a height of 0.85 m from the ground surface. The dust samplers, which measured 1.6 m in height, were settled in the center of the field, and the air was vacuumed for 51 min during the cutting of wheat on April 7, 2011. On the following day, wheat was incorporated into the surface soil by a rotary tiller, and dust samples were collected in the center of the field at a height of 0.85 m for 30 min. Filters with trapped dust were carefully folded and packed into a plastic cylinder vessel (with an inner diameter of 10 mm and a height of 40 mm) for γ-ray counting. In addition to dust sampling to determine the radionuclide concentrations, the particle mass concentration in the air [particles with an aerodynamic diameter less than 10 μm (PM 10), PM 2.5 and total suspended particles] was measured for 4 min using a particle mass monitor (GT-331, Shibata Scientific Technology LTD., Tokyo, Japan), and the results of three repetitive measurements

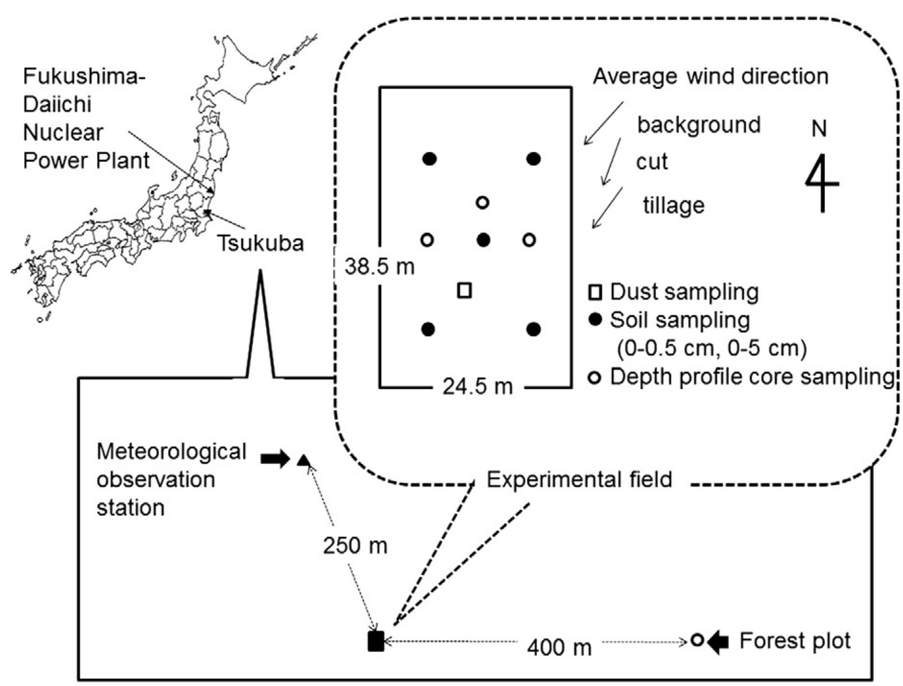

Fig. 1. Sampling location.