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Evaluation of radiocesium concentrations in new leaves of wild plants two years after the Fukushima Dai-ichi Nuclear Power Plant accident

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ABSTRACT

Radiocesium (^{137}Cs) transfer to plants immediately after the Fukushima Dai-ichi Nuclear Power Plant accident was investigated by collecting newly emerged leaf and soil samples between May 2011 and November 2012 from 20 sites in the Fukushima prefecture. Radiocesium concentrations in leaf and soil samples were measured to calculate concentration ratios (CR). Woody plants exhibited high CR values because ^{137}Cs deposited on stems and/or leaves were transferred to newly emerging tissues. The CR values in 2012 declined as compared to that in 2011. Exchangeable ^{137}Cs rates in soil (extraction rate) samples were measured at five sites. These rates decreased at four sites in 2012 and depended on environmental conditions and soil type. Both CR values and extraction rates decreased in 2012. However, CR values reflected the changes in extraction rates and characteristics of each species. Amaranthaceae, Chenopodiaceae, and Polygonaceae, which had been identified as Cs accumulators, presented no clear ^{137}Cs accumulation ability. In 2012, the perennial plant *Houttuynia cordata* and deciduous trees *Chengiopanax sciadophylloides* and *Acer crataegifolium* displayed high CR values, indicating that these species are ^{137}Cs accumulators and may be considered as potential species for phytoremediation.

1. Introduction

The great East Japan earthquake and the following tsunami caused a serious accident at the Fukushima Dai-ichi Nuclear Power Plant (F1NPP) on March 11, 2011, mainly resulting in radiocesium [^{134}Cs ($t_{1/2}$ = 2.1 year), ^{137}Cs ($t_{1/2}$ = 30 year)] and radioiodine emissions [^{131}I ($t_{1/2}$ = 8.1 d)] of approximately 1.3×10^{16} and 1.5×10^{17} Bq, respectively (Chino et al., 2011). In particular, ^{137}Cs contamination is a severe problem for mankind and ecosystems because of its relatively long half-life. In addition to affecting wild plants, ^{137}Cs deposited on fields and forests contaminated farm products and livestock through the food chain. The consumption of such contaminated foods is the principal cause of human exposure to radioactivity (Zhu and Smolders, 2000). Moreover, the resulting shipping restrictions regarding agricultural products and woods have inflicted serious economic damage to farmers. More than four years after the accident, there is a decrease in the contamination levels of agricultural products, but several edible forest products still exceed the regulated permissible levels in food [100 Bq/kg fresh weight (FW)] (MHLW, 2015; MAFF, 2015). Therefore, the uptake of ^{137}Cs by plants has changed with time depending on species and growing conditions. The reduction of radioactive contamination in agricultural fields and forests and the prediction of medium and long-term ^{137}Cs behavior rests on information on the characteristics of this behavior in vegetation (Yamaguchi et al., 2012). In addition, this information may find application in the

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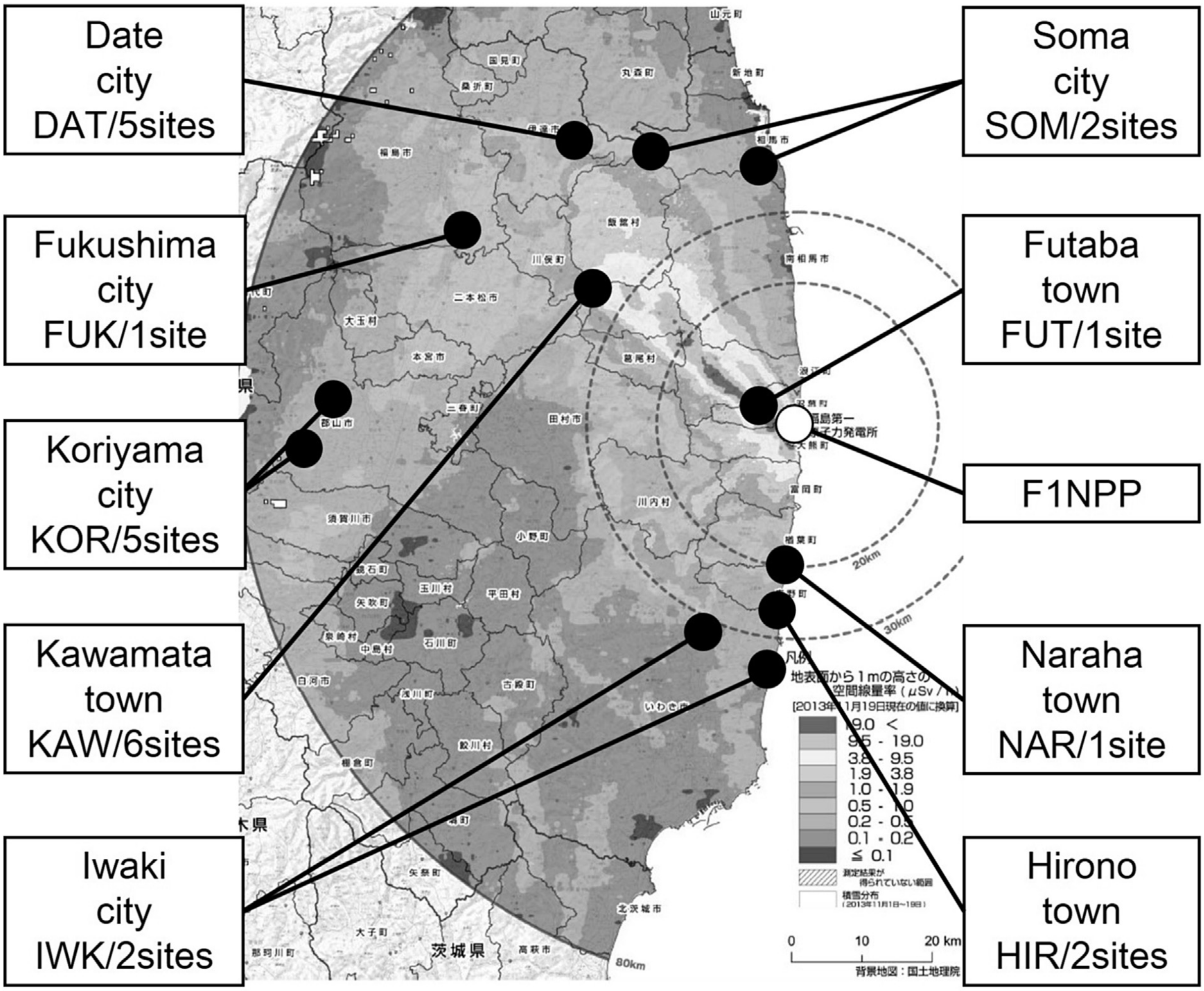

Fig. 1. Map of the sampling sites and F1NPP modified from NRA (2014).

development of phytoremediation technology, wherein special plants having high accumulation abilities absorb and remove ^{137}Cs from contaminated soils (Salt et al., 1995).

A ^{137}Cs transfer from soil to plants has been observed after the Chernobyl Nuclear Power Plant (ChNPP) accident mainly in Europe. Radiocesium accumulation abilities vary according to plant species. Some species of Amaranthaceae (Broadley et al., 1999; Dushenkov et al., 1999; Fuhrmann et al., 2003; Lasat et al., 1998) as well as Chenopodiaceae and Polygonaceae (Broadley and Willey, 1997) have proven potential ^{137}Cs accumulators. Furthermore, the physicochemical properties of the soils strongly affect ^{137}Cs accumulation (Ehlken and Kirchner, 2002; Tsukada and Hasegawa, 2002).

Cesium accumulation in plants had also been investigated in Japan prior to the F1NPP accident, particularly for the stable isotope ^{133}Cs and low-concentration ^{137}Cs derived from global fallout and the ChNPP accident (Kamei-Ishikawa et al., 2008; Tsukada and Nakamura, 1999). However, the behavior of ^{137}Cs just after a substantial deposition on the terrestrial ecosystem is unclear. In general, ^{137}Cs deposited on soil readily adheres to clay minerals; however, its bioavailability decreases with time (Dushenkov, 2003), demonstrating the importance of soil properties in ^{137}Cs accumulation in plants. Because the Japanese islands are located in the most active part of the Pacific Ring of Fire, andosol, a soil derived from volcanic ash, is widely distributed in Japan. This rare soil exhibits unique properties, such as low bulk density, high water-holding capacity, and high phosphate-fixing capacity (Takeda et al., 2013). Also, land use, climate, and rainfall patterns differ between Japan and Europe. Therefore, the knowledge obtained from investigations on the ChNPP accident needs to be carefully applied to the F1NPP accident (Yamaguchi et al., 2012). A continuous observation of the dynamics of ^{137}Cs immediately after the F1NPP accident is crucial.

The ^{137}Cs contamination of agricultural products has been studied and monitored directly after the F1NPP accident, but wild plants have attracted less attention (Mimura et al., 2014). Nonetheless, primary information collected about ^{137}Cs transfer for many plants may help with the decontamination of agricultural plants and handling of contaminated weeds (Yamashita et al., 2014). Moreover, identified ^{137}Cs accumulators may aid in soil phytoremediation.

Plant and soil samples were collected in Fukushima prefecture from May 2011 to November 2012 to obtain primary information on the characteristics of ^{137}Cs accumulation immediately after the accident.