Soil & Tillage Research 153 (2015) 76–85

Contents lists available at ScienceDirect

Soil & Tillage Research

journal homepage: www.elsevier.com/locate/still

Tillage can reduce the radiocesium contamination of soybean after the Fukushima Dai-ichi nuclear power plant accident

Yuta Hoshino, Tatsuya Higashi, Takahiro Ito, Masakazu Komatsuzaki *

Center for Field Science Research & Education, Ibaraki University, 3-21-1, Ami, Inashiki, Ibaraki 300-0393, Japan

ARTICLE INFO

Article history:
Received 4 January 2015
Received in revised form 5 April 2015
Accepted 6 May 2015

Keywords:
No-tillage
Plow
Rotary cultivator
Cover crop
Rye
Hairy vetch

ABSTRACT

A magnitude 9.0 earthquake and a subsequent large tsunami hit the northeastern coast of Japan on March 11, 2011. This resulted in serious damage to the reactors of the Fukushima Dai-ichi nuclear power plant (FDNPP), operated by the Tokyo Electric Power Company. Large amounts of radionuclides were released from the FDNPP, a proportion of which were deposited on the ground. In this study, we investigated soil radiocesium contamination of soybean fields in Ibaraki, approximately 170 km from the FDNPP. After the accident, we compared the radiocesium contamination in soybeans cultivated using different tillage systems and cover crop species. The different tillage systems were moldboard plow/rotary harrow (MP), rotary cultivation (RC), and no tillage (NT); the three types of winter cover crops were fallow weeds, rye, and hairy vetch; and for soybean production we used two rates of manure (0 and 1 Mg ha^{-1}). MP and RC reduced the radiocesium contamination ($^{134}Cs + ^{137}Cs$) in the 0–2.5 cm soil layer (509.7 Bq kg^{-1} for MP and 782.7 Bq kg^{-1} for RC), although NT left a large amount of radiocesium on the soil surface (1324.8 Bq kg^{-1}). The radiocesium concentration of the rye cover crop was significantly lower than hairy vetch and fallow during 3 years. In 2013, across the tillage system, radiocesium concentration of rye was only 3.4 Bq kg^{-1}, although those values were 17.7 Bq kg^{-1} for hairy vetch and 56.4 Bq kg^{-1}, for fallow. The radiocesium concentration in soybean grains was significantly lower in MP and RC than in NT from 2011 to 2013. In 2013, 3 years after the FDNPP accident, the radiocesium concentration of soybean grain was 14.8 Bq kg^{-1} for NT, although these values were 5.8 Bq kg^{-1} for MP and 6.5 Bq kg^{-1}, for RC. The transfer factor for soybean grain was significantly lower in MP and RC than in NT, although the transfer factor in NT also decreased each sampling year from 0.12 to 0.08 after the FDNPP accident. We conclude that despite numerous benefits of the NT system for environmental conservation, soil inversion by tillage significantly decreased the radiocesium contamination of crops. Thus, tillage inversion would be appropriate to counter measures after the nuclear accident.

1. Introduction

The nuclear accident at the Fukushima Dai-ichi Nuclear Power Plant (FDNPP) occurred as a consequence of the massive earthquake and associated tsunami that struck the Tohoku and northern Kanto regions of Japan on March 11, 2011. The released radioactive nuclides were deposited over a wide area of the Tohoku and Kanto regions. Ibaraki prefecture is located approximately 70–180 km southwest of the FDNPP and covers approximately 6096 km^2. Ami town is located approximately 170 km southwest of the FDNPP and the most serious radiocesium contamination was observed in the Ibaraki prefecture where the total radiocesium contamination in the soil was 78,000 Bq/m^2 on September 30, 2011 (Ibaraki Prefectural Government, 2011). However, the area is not necessary to take the protective measures for human life because the air radiation dose rate is very low compared with the limits specified by the human exposure regulation.

At the time of the FDNPP accident, radionuclide deposition of ^{129m}Te, ^{129}Te, ^{131}I, ^{132}Te, ^{132}I, ^{134}Cs, ^{136}Cs, ^{137}Cs, ^{140}Ba, and ^{140}La were identified in the soil of Fukushima Prefecture (Endo et al., 2013). The short-lived radionuclides such as ^{129m}Te, ^{129}Te, ^{131}I, ^{132}Te, ^{132}I, ^{136}Cs, ^{140}Ba, and ^{140}La decayed for several months following their deposition. However, the long-lived radionuclides ^{134}Cs (half-life of 2.06 years) and ^{137}Cs (half-life of 30.2 years) are serious contaminants, following such an accident, to which humans face internal and external exposure for many months. In particular, ^{134}Cs and ^{137}Cs lead to internal exposure through consumption of crops since cesium and potassium are both group one metals and

* Corresponding author. Tel.: +81 298 88 8707; fax +81 298 88 8707.
E-mail addresses: 15am307h@vc.ibaraki.ac.jp (Y. Hoshino), emhgc2015@yahoo.co.jp (T. Higashi), t.ito@mx.ibaraki.ac.jp (T. Ito), komachan@mx.ibaraki.ac.jp (M. Komatsuzaki).

http://dx.doi.org/10.1016/j.still.2015.05.005
0167-1987/

are thus easily taken up by plants (Absalom et al., 1999; Yamaguchi et al., 2012a,b).

The chemistry of ^{137}Cs in soil is well understood (Davis, 1963; Schulz et al., 1960; Yamaguchi et al., 2012a,b). After an initial deposition of radioactivity on the soil surface, immediate and strong adsorption of ionized cesium into clay particle occurs (Staunton and Roubaud, 1997; Tamura, 1964). In the case of the FDNPP accident, radionuclides were largely released on March 15 and 21, 2011. Most radioactive fallout is presumed to have deposited on the ground immediately (Morino et al., 2011) and to have concentrated in the surface layers.

Agricultural soils were highly contaminated by the deposited radionuclides after the FDNPP accident, and soil distributions have been intensively discussed by many researchers (Harada and Nonaka, 2012; Kato et al., 2012; Shiozawa et al., 2011). Kato et al. (2012) reported that >86% of the total radiocesium was absorbed in the upper 2.0 cm of the soil profile. Because a high clay content increased the aggregate stability of topsoil, increasing water infiltration due to aggregate stability enhanced ^{137}Cs transport into deeper horizons of the soil profile. Harada and Nonaka (2012) measured radiocesium distribution in a paddy field and found that higher concentrations of radioactivity were generally found in shallow soils, although soil inversion by tillage displaced the radioactivity to deeper soil layers.

Soil tillage is performed with the goal of improving soil structure and quality. Moldboard plowing (MP), a conventional tillage system, turns the topsoil into the deep soil layer and thoroughly incorporates surface crop residues into the bottom of the tilled area such that crop residues cannot be found on the surface. However, in Japan, >80% of cultivated crop land is tilled by the rotary cultivator (RC) (Moriizumi et al., 1995), where soil is cultivated with a rotary blade and crop residues are mixed with soil but are not completely covered by soil. This system is simple and easy for farmers, particularly Asian farmers whose farming scale is relatively small, and it results in an appropriate seedbed without great weed pressure. However, limited information is available on radioactive distributions in soil under various tillage systems such as moldboard plow, rotary cultivator, and minimum tillage.

The transfer factor coefficient (TF) from soil to crop in Japan after the FDNPP accident have been intensively discussed for paddy rice (Endo et al., 2013), forages, and bamboo (Ramzaev et al., 2013). Kamei-Ishikawa et al. (2008) reported the TF estimate using ^{133}Cs for vegetables and field crops including soybean. The TF values were $1.5 \times 10^{-2} - 7.2 \times 10^{-3}$ for soybean, suggesting relatively high TF values compared with those of other vegetable and field crops. Rigol et al. (2008) also reported the TFs after the Chernobyl accident in various agricultural soils subjected to several agricultural treatments (disking, ploughing, fertilizing, and liming). However, the effects of different tillage systems on the TFs for soybean production were not well examined after the FNDPP accident.

The present study investigated the effects of tillage system, cover crop, and manure input on radioactive Cs uptake by soybean in Ibaraki, and the effects of tillage systems on Cs distribution in the soil profile after the FDNPP accident

2. Materials and methods

2.1. Study site

This experiment was conducted at a field study site in the humid subtropics on a volcanic soil located in the Japanese province of Kanto. The study site (36°1′57.7″N, 140°12′43.6″E) was 170 km from the FDNPP (Fig. 1) and was conducted from 2011 to 2013. The Mean monthly temperature and precipitation ranged from 2.4 to 27.7 °C and from 1.0 mm to 358.0 mm (1299 mm year^{-1})

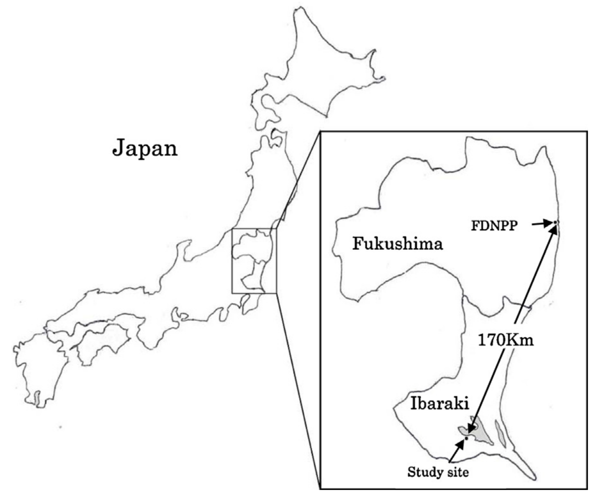

Fig. 1. Location of the test field in Ami Ibaraki prefecture. The test field is 170 km southeast of Fukushima Dai-ichi Nuclear Power Plant.

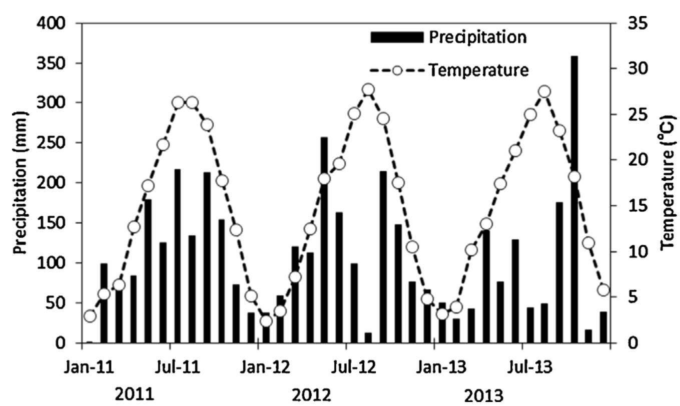

Fig. 2. Monthly temperature (line with markers) and precipitation (columns) at the study site (2011–2013).

during 2011–2013 (Fig. 2), respectively. According to the national survey regarding the radioactive Cs, although the ^{134}Cs was not observed in the soil in Ibaraki Prefecture, the ^{137}Cs was observed only at a concentration of 5–7 Bq kg^{-1} in 1999 because of a global fallout before the FDNPP accident (Yamaguchi et al., 2012a,b). The soil was an Andisol with a sandy-loam texture in the upper surface horizon and gradually changing to clay with depth. It had a mean pH of 6.5, a mean bulk density of 0.80 g cm^{-3}, and a soil carbon content of 3.37%.

In the split plot experimental design replicated four times, tillage system was the variable in the main plots, cover crop species were sub-plots and the level of manure application were sub-sub-plots. The study covered 72 plots of 16 m^2 each.

The tillage systems were as follows: no tillage (NT), moldboard plowing (MP), and rotary cultivation (RC). Preparatory work was conducted as follows: MP, moldboard plow (25–30 cm deep), rotary cultivation and sowing; RC (15 cm deep) and sowing; and NT, no tillage and sowing. Cover crop species were winter rye (*Secale cereal*), hairy vetch (*Vicia villosa* Roth), and fallow (native weeds). Manure input levels were 1 Mg ha^{-1} (20 kg N ha^{-1}) and no input (0 kg N ha^{-1}).

2.2. Farming practice

The cover crop was sown by hand on November 10, 2010. The seeding rate was 100 kg ha^{-1} for rye and 50 kg ha^{-1} for hairy vetch.