自然環境科学研究　Vol.29, 41 - 47 (2016 年)
Natural Environmental Science Research Vol.29, 41- 47 (2016)

Data and Notes　資料

Accumulation of radioactive cesium released from Fukushima Daiichi Nuclear Power Plant in wild plants grown on grassy plain

SASAKI Hideaki*, SAKAMOTO Shota* & SATO Kenji**

The Fukushima Daiichi Nuclear Power Plant accident released large amounts of radioactive substances into the environment and contaminated the soil of Tohoku and Kanto districts in Japan. Removal of radioactive materials from the environment is an urgent problem, and soil purification using plants is under consideration. This study monitored accumulation of radioactive cesium in wild plants grown on a grassy plain in Iwaki City, Fukushima Prefecture, to choose a plant species to use for the decontamination. Many plant species did not accumulate high levels of radioactive materials expect for *Lamium purpureum*, *Pueraria lobata*, *Taraxacum officinale*, *T. platycarpum*, and *Vicia sativa* subsp. *nigra*. These species accumulated 501 to 1,450 Bq/kg dry weight of ^{137}Cs in the shoots.

Keywords
wild plants, grassy plain, radioactive cesium, Fukushima Daiichi Nuclear Power Plant

Radioactive materials were released into the environment in large quantities after the accident at the Fukushima Daiichi Nuclear Power Plant in March of 2011, contaminating the soil of Tohoku and Kanto districts in Japan. According to calculations of the Tokyo Electric Power Company, approximately 9.0×10^{17} Bq of radioactive materials were released by the accident [1].

Plants are primary producers and can accumulate radioactive materials. Contamination of crops and wild plants is thus a major concern [2-4], but details are poorly understood. For example, a sunflower that accumulated high levels of radioactive materials was used to purify the polluted soil after the Chernobyl Nuclear Power Plant accident that occurred in 1986 in Russia [5-7]. However, a decontamination experiment using a sunflower performed by the Ministry of Agriculture, Forestry and Fisheries of Japan in 2011 was not successful [8].

In Fukushima, radioactive material accumulation in wild plants was investigated. It was reported that different plant species exhibited accumulation in different soil environments. High accumulation was observed in *Athyrium yokoscense* and *Dryopteris tokyoensis* grown in paddy fields, and in *Houttuynia cordata* grown in upland fields [9]. After the accident at the Fukushima Daiichi Nuclear Power Plant, an increasing number of farms have been abandoned in Fukushima. The total abandoned area reached 25,226 ha as of 2015, which is the largest in Japan [10]. Because abandoned farmland generally changes into grassy plains, it is important to investigate plants grown on such grassy plains. In this study, we monitored accumulation of radioactive cesium in wild plants grown on a grassy plain in Iwaki City, Fukushima Prefecture, to choose a plant species to use for the decontamination.

Twenty-nine species of seed plants and one pteridophyte species were collected in 2012 from a grassy plain belonging to Iwaki Meisei University in Fukushima Prefecture, Japan (Table 1). The site is approximately 45 km away from the Fukushima Daiichi Nuclear Power Plant (Fig. 1). Dominant species of this grassy plain were *Artemisia indica* var. *maximowiczii*, *Hypochaeris radicata*, *Miscanthus sinensis*, *Pueraria lobata*, *Solidago canadensis* var. *scabra*, and *Trifolium pretense* [11]. The concentration of ^{137}Cs in the soil of the Iwaki Meisei University was 2530 Bq/kg DW at

* College of Science and Engineering, Iwaki Meisei University, 5-5-1 Chuodai Iino, Iwaki, Fukushima, 970-8551 Japan
** College of Engineering, Nihon University, 1 Nakagawa, Tokusada, Tamuramachi, Koriyama, Fukushima, 963-8642 Japan

Table 1 Collection data of the wild plants grown on grassy plain of Iwaki Meisei University, Iwaki City, Fukushima used for radioactivity concentration analyses.

Species	Life cycle	Collection dates
Magnoliophyta		
Dicotyledoneae		
Asterales		
Achillea millefolium	perennial	11 July 2012
**Artemisia indica* var. *maximowiczii*	perennial	16 April 2012
Aster microcephalus var. *ovatus*	perennial	7 November 2012
**Bidens pilosa* var. *pilosa*	annual	13 October 2012
Conyza canadensis	biennial	27 August 2012
Coreopsis lanceolata	perennial	4 August 2012
Erigeron annuus	annual	31 May 2012
E. philadelphicus	perennial	2 June 2012
E. strigosus	annual	11 July 2012
Gamochaeta coarctata	perennial	11 July 2012
**Hypochaeris radicata*	perennial	2 June 2012
**Petasites japonicus*	perennial	16 April 2012
Picris hieracioides subsp. *japonica*	annual	15 June 2012
**Solidago canadensis* var. *scabra*	perennial	8 June 2012
Sonchus asper	annual	31 May 2012
Taraxacum officinale	perennial	2 May 2012
T. platycarpum	perennial	24 April 2012
Youngia denticulata	biennial	7 November 2012
Lamiales		
Lamium purpureum	annual	2 May 2012
Mosla punctulata	annual	13 October 2012
Perilla frutescen var. *crispa*	annual	11 August 2012
**Veronica persica*	annual	2 May 2012
Fabales		
Lespedeza juncea var. *subsessilis*	perennial	26 June 2012
Pueraria lobata	perennial	8 May 2012
Trifolium pratense	perennial	2 June 2012
**Vicia sativa* subsp. *nigra*	annual	2 May 2012
V. villosa	annual	26 June 2012
Caryophyllales		
**Cerastium glomeratum*	annual	2 May 2012
Dianthus armeria	annual	26 June 2012
**Rumex acetosa*	perennial	24 April 2012
Stellaria uliginosa var. *undulata*	annual	8 June 2012
Plantaginales		
Plantago lanceolata	perennial	8 May 2012
Monocotyledoneae		
Poales		
Cyperus iria	annual	11 August 2012
**Dactylis glomerata*	perennial	15 June 2012
Digitaria timorensis	annual	18 September 2012
**Imperata cylindrica*	perennial	26 June 2012
Miscanthus sinensis	perennial	13 October 2012
**Poa annua*	annual	8 May 2012
Setaria faberi	annual	27 August 2012
S. glauca	annual	2 October 2012
Typhales		
Typha latifolia	perennial	2 October 2012
Pteridophyta		
Equisetopsida		
Equisetales		
Equisetum arvense	perennial	16 April 2012

*The values of these species refer in the article of Sasaki et al. [12].

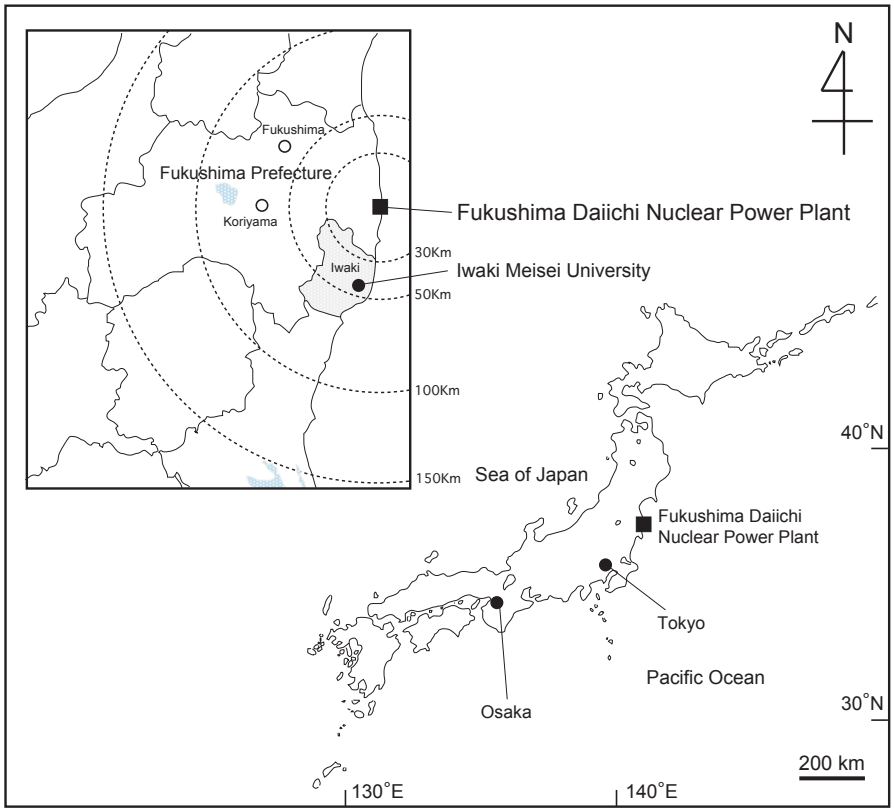

Fig. 1 Locations of the collection sites of wild plants investigated in the present study.

0–5 cm in depth, 424 Bq/kg DW at 5–10 cm, 31 Bq/kg DW at 10–15 cm, and 5 Bq/kg DW at 15–20 cm [12].

Collected field materials were transported to the laboratory in polyethylene bags at 15–20°C to avoid damages during the transportation. Plant samples were washed with water and dried at room temperature. Dried samples were desiccated at 60°C for 48 h, pulverized using a mill, and placed in U-8 plastic vials (Φ56 mm × 68 mm high). The vials were stored in a desiccator until the measurement. Radioactive cesium (^{134}Cs, ^{137}Cs) and iodine (^{131}I) were measured using a GEM40P4-76 Ge semiconductor detector (Seiko EG & G, Tokyo, Japan). The measurements of the radioactive cesium and iodine concentrations showed a 3σ counting error.

The radioactive cesium concentrations of various taxa are shown in Fig. 2 and Fig. 3. Twelve species of plants reported by Sasaki et al. [12] were added to the list. All the 42 plant species studied, showed relatively low concentrations of radioactive cesium. Radioactive iodine ^{131}I was not detected in any samples. The accumulation levels in larger plants such as *Miscanthus sinensis* tended to be lower than those in smaller plants. Of *M. sinensis,* ^{137}Cs was not detected (ND) in the shoot and was at a concentration of 156 Bq/kg DW in the root. In contrast, a small plant *Lamium purpureum* accumulated 719 Bq/kg DW of ^{137}Cs in the shoot and 3,300 Bq/kg DW in the root. We believe that *L. purpureum* absorbed more radioactive cesium because of its small root system. Radioactive cesium was distributed within the top 10 cm of topsoil [12], and large-scale roots extending deep into the soil could not contact cesium. Overall, radioactive materials accumulated more in the roots than in the shoots. In the shoots, the ^{134}Cs level ranged from ND to 1,020 Bq/kg DW and ^{137}Cs level from ND to 1,450 Bq/kg DW (Fig. 2). In the roots, the ^{134}Cs level ranged from ND to 2,320 Bq/kg DW and ^{137}Cs level from ND to 3,300 Bq/kg DW (Fig. 3). These data suggested that seed plants generally do not easily transport radioactive cesium into their shoots.

The life cycle of the plants led to the difference in characteristics of the radiological accumulation (Fig. 4). Many perennial plants accumulated high concentrations of ^{137}Cs in the shoots. However, these plants did not accumulate high concentrations of ^{137}Cs in the roots. On the other hand, in the annual plants, ^{137}Cs concentrations

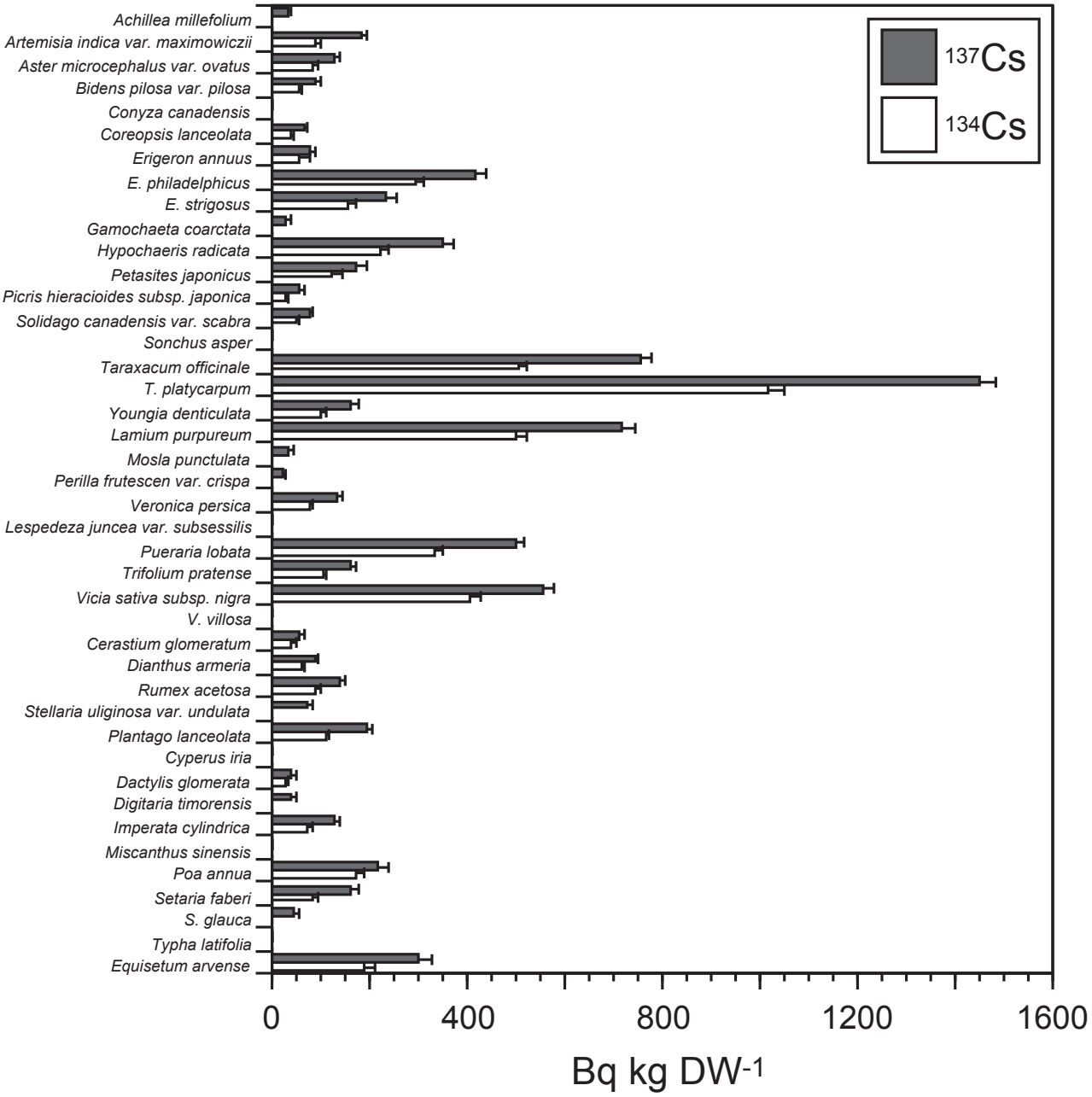

Fig. 2 Radioactivity concentrations of ^{134}Cs and ^{137}Cs in the shoots of wild plants grown in Iwaki City, Fukushima.

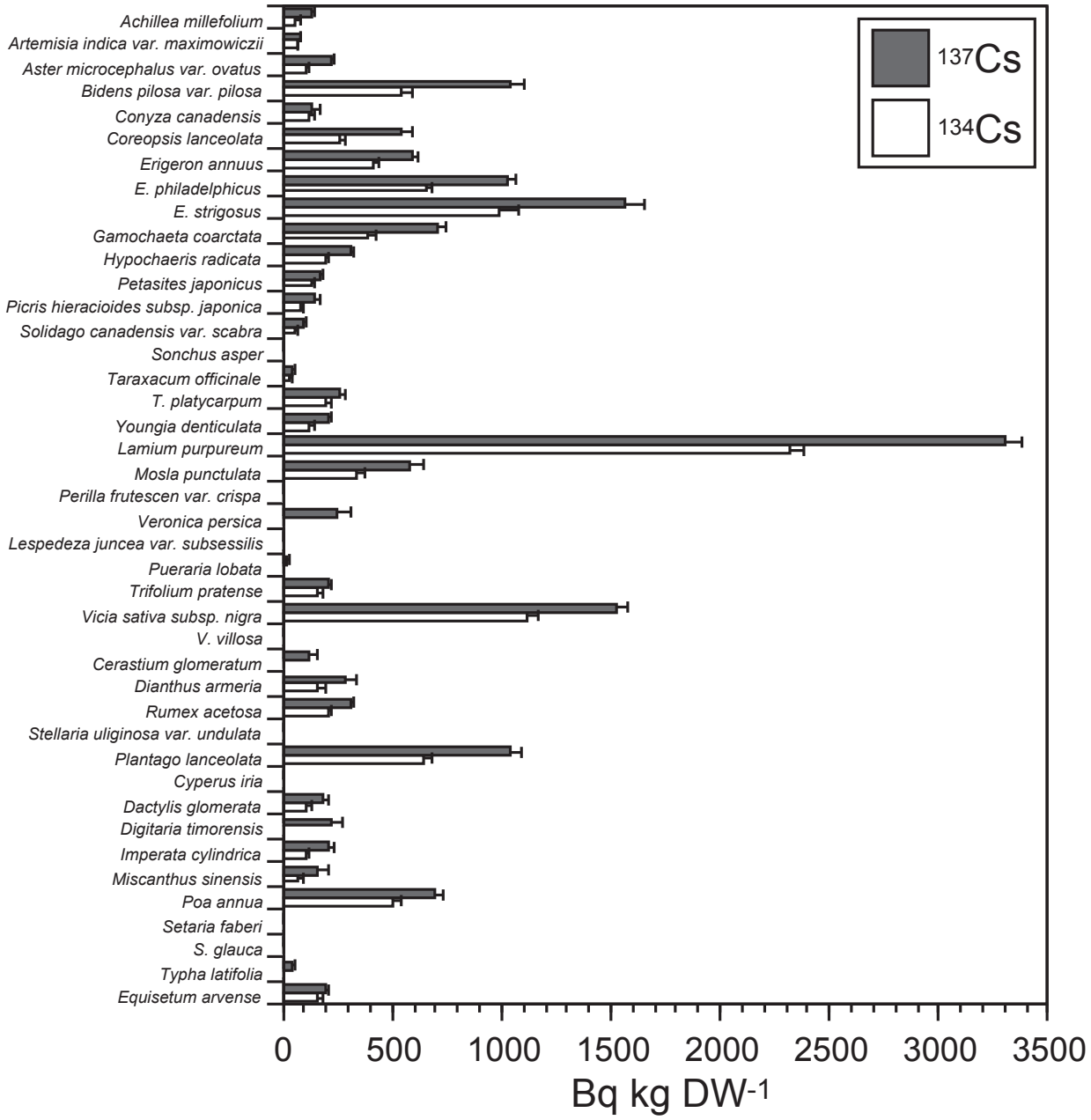

Fig. 3 Radioactivity concentrations of ^{134}Cs and ^{137}Cs in the roots of wild plants grown in Iwaki City, Fukushima.

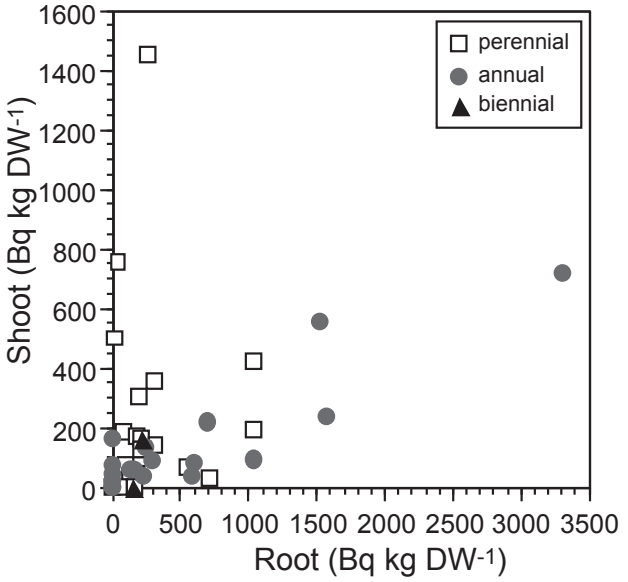

Fig. 4 Correlation of ^{137}Cs concentrations between the shoots and roots.

in the shoots and in the roots were directly proportional and relatively well correlated.

A plant that accumulates high amounts of radioactive materials in the shoot is desirable for the decontamination. Removal of the roots requires time, labor, and money in comparison with mowing. In this study, *Lamium purpureum*, *Pueraria lobata*, *Taraxacum officinale*, *T. platycarpum*, and *Vicia sativa* subsp. *nigra* accumulated high concentrations of radioactive cesium in the shoots. These species accumulated 501 to 1,450 Bq/kg dry weight of ^{137}Cs in the shoots. These plants are common on grassy plains of Fukushima Prefecture. We will further examine the possibility of using these species for the decontamination.

References

1) Tokyo Electric Power Company： “Estimate of the radiological burst size to the atmosphere in the Fukushima Daiichi Nuclear Power Plant accident” (2012), (Tokyo Electric Power Company, Tokyo). (In Japanese).
2) Oshita, S., Kawagoe, Y., Yasunaga, E., Takada, D., Nakanishi, T., Tanoi, K., Makino, Y. & Sasaki, H.：Radioisotopes 60, 329-333 (2011). (In Japanese).
3) Sakamoto, F., Ohnuki, T., Kozai, N., Igarashi, S., Yamasaki, S., Yoshida, Z. & Tanaka, S.：Trans. Atomic Energy Soc. Jpn. 11, 1-7 (2012). (In Japanese).
4) Tanoi, K., Hashimoto, K., Sakurai, K., Nihei, N., Ono, Y. & Nakanishi, T.：Radioisotopes 60, 317-322 (2011). (In Japanese).
5) Dushenkov, S., Mikheev, A., Prokhnevsky, A., Ruchiko, M. & Sorochinsky, B.：Environ. Sci. Technol. 33, 469-475 (1999).
6) Massas, I., Skarlou, V. & Haidouti, C.：J. Environ. Radioact. 59, 245-255 (2002).
7) Soudek, P., Valenová, Š., Vavříková, Z. & Vaněk, T.：J. Environ. Radioact. 88, 236-250 (2006).
8) Ministry of Agriculture, Forestry and Fisheries of Japan：Press Release on September 14, 2011, http://www.s.affrc.go.jp/docs/press/110914.htm (accessed 27 October 2016). (In Japanese).
9) Yamashita, J., Enomoto, T., Yamada, M., Ono, T., Hanafusa, T., Nagamatsu, T., Sonoda, S. & Yamamoto, Y.：J. Plant Res. 127, 11-22 (2014).
10) Statistics Division, Planning and Coordination Department, Fukushima Prefecture Government: “Agricultural and forestry census in 2015, Management investigation into agriculture and forestry business” (2015), (Fukushima Prefecture Government, Fukushima) (In Japanese).
11) Takahashi, Y., Sasaki, H. & Iwata, E.：Fukusihima seibutsu 53, 33-39 (2010). (In Japanese).
12) Sasaki, H., Shirato, S., Tahara, T., Sato, K. & Takenaka, H.：Microbes Environ. 28, 466-469 (2013).

草原に生育する野生植物における福島第一原子力発電所から放出された放射性セシウムの蓄積

佐々木秀明[1]・坂本祥太[1]・佐藤健二[2]

福島第一原子力発電所事故は，環境中へ大量の放射性物質を放出し，東北地方と関東地方の土壌を汚染した． 環境からの放射性物質の除去は喫緊の課題であり，現在，植物による土壌の浄化が検討されている．本研究では，除染に使用する植物種の選定のために，福島県いわき市の草原に生育する 42 種の種子植物と 1 種のシダ植物の放射性セシウムの蓄積量を調査した．調査した多くの植物種では高濃度に放射性セシウムを蓄積していなかったが，ヒメオドリコソ

ウ（*Lamium purpureum*），クズ（*Pueraria lobata*），セイヨウタンポポ（*Taraxacum officinale*），カントウタンポポ（*T. platycarpum*），ヤハズエンドウ（*Vicia sativa* subsp. *nigra*）に高濃度の放射性セシウム蓄積が観察された．これらの種は，茎葉部に放射性セシウム 137 を 1 kg あたり 501—1,450 Bq の濃度で蓄積していた．

キーワード
野生植物，草原，放射性セシウム，福島第一原子力発電所

(Received: July 7, 2016; Accepted: October 28, 2016)

[1] 〒 970-8551　福島県いわき市中央台飯野 5-5-1　いわき明星大学科学技術学部
[2] 〒 963-8642　福島県郡山市田村町徳定中河原 1　日本大学工学部