Radioprotection, vol. **44**, n° 5 (2009) 365–369

DOI: 10.1051/radiopro/20095070

Root-uptake of ^{14}C derived from acetic acid by root vegetables

S. Ogiyama[1], H. Suzuki[2], K. Inubushi[3], H. Takeda[1] and S. Uchida[1]

[1] *Office of Biospheric Assessment for Waste Disposal, National Institute of Radiological Sciences, 263-8555 Chiba, Japan*
[2] *Graduate School of Pharmaceutical Sciences, Chiba University, 263-5522 Chiba, Japan*
[3] *Graduate School of Horticulture, Chiba University, 271-8510 Matsudo, Japan*

Abstract. Sand culture using radish (*Raphanus sativus* L.) and hydroponics using carrot (*Daucus carota* L.) were conducted to examine root-uptake of carbon and its assimilation in the form of ^{14}C-acetic acid. ^{14}C-acetic acid (1, 2-^{14}C, radioactivity: 74 kBq) was added to each pot. Radishes were grown under the dark conditions or the light conditions for 24 h. Carrot were grown under the light conditions after ^{14}C-acetic acid addition (radioactivity: 19 kBq). The ^{14}C radioactivity in each plant part was determined. The distribution of ^{14}C in the plants was visualized using autoradiography. For a comparison, autoradiography was also done using ^{22}Na. The results indicated that the root vegetables absorbed ^{14}C through the roots and assimilated it into the shoots and edible parts. However, the amount of ^{14}C-acetic acid absorbed by plants through the roots was considered to be very small. Absorption and assimilation of ^{14}C seemed to be carried out not because of uptake of ^{14}C-acetic acid but because of uptake of ^{14}C in inorganic forms with very low concentration. ^{14}C dominantly transferred to the plant parts where were physiologically active. ^{14}C movement in the plant did not have a close relation to water movement unlike ^{22}Na movement.

1. INTRODUCTION

Geological disposal of radioactive waste from nuclear facilities is planned to avoid radiation exposure to the general public. For safety assessment of geological disposal, it is necessary to clarify pathways on how these radioactive elements are transferred to edible plants. Carbon-14 (^{14}C, $t_{1/2} = 5.73 \times 10^3$ yrs) from radioactive waste is one of the most important radioactive nuclides for environmental assessment in the context of geological disposal. There are both organic and inorganic carbon forms in radioactive waste, and it has been reported that organic carbon in radioactive waste is mainly present as carboxylic acids such as acetic acid [1] while a major carbon source for plants has been generally thought to be carbon dioxide (CO_2) from air, which is assimilated by photosynthesis. For assessment of geological disposal, it is also necessary to clarify transfer of carbon from underground to plants. Past studies have reported that soybean and rice plants grown in a nutrient solution containing various radioactive nuclides, such as metal elements, accumulated them in the plant parts [2–4]. Also, radiotracer experiments on leaf vegetable [5] and root crops [6] have reported. However, little is known about carbon transfer to root vegetables from geological disposal of radioactive waste. The present study was conducted to examine root-uptake and assimilation of organic carbon by two root vegetables, radish and carrot, using ^{14}C nuclide in the form of acetic acid.

2. MATERIALS AND METHODS

Sand culture experiment using radish (*Raphanus sativus* L.) was done to examine root-uptake of ^{14}C derived from ^{14}C-acetic acid and ^{14}C assimilation to the edible parts, and hydroponics experiment using

Article published by EDP Sciences and available at http://www.radioprotection.org
or http://dx.doi.org/10.1051/radiopro/20095070

carrot (*Daucus carota* L.) was done to examine ^{14}C distribution in the plant and ^{14}C movement through roots. Hydroponics experiment was also done using ^{22}Na for a comparison.

2.1 Sand culture experiment using radish

The sand culture experiment for radish was done to determine carbon root-uptake by the plant and assimilation to the edible parts. Radish seedlings were transplanted to individual experimental pots that were filled with sterilized sand (400 g and 70% water saturation point) and they were cultivated in artificial light conditions (10 k Lux for 16 h/day). Ten mL of liquid fertilizer (containing NH_4NO_3-N at 80 mg L^{-1}, $Ca(NO_3)_2$-N at 70 mg L^{-1}, NaH_2PO_4-P at 10 mg L^{-1}, K_2SO_4-K at 100 mg L^{-1}, $Ca(NO_3)$-Ca at 100 mg L^{-1}, and $MgSO_4$-Mg at 30 mg L^{-1}) were added every 2 days for 23 days. At 23 days after transplanting ^{14}C-acetic acid (1, 2-^{14}C) was mixed with liquid fertilizer (radioactivity: 74 kBq) and added to each pot. Radish plants were grown for 24 h in the phytotron (23 °C, relative humidity; 40%) under the dark conditions or the light conditions (artificial light, 10 k Lux). After the plants were carefully removed from the pots, the distributions of ^{14}C in the plant shoot, root, and edible parts were visualized by the autoradiography using an imaging analyzer. The separate parts were combusted and made inorganic solutions using a sample oxidizer for measurement of the ^{14}C radioactivity using a liquid scintillation counter.

2.2 Hydroponics experiment using carrot

The set-up for the pot experiment using hydroponics is shown in Figure 1. It had an upper pot and a lower pot. A plug pot was used as the upper pot, and it contained sterilized wet sand. The lower pot was a polyethylene beaker filled with water (180 mL) and covered with aluminum foil to reflect light. One plant was raised from a seed in the upper pot and cultivated in artificial light conditions (10 k Lux for 16 h/day). Liquid fertilizer (1 mL) was added to the upper pot every 3 days until the roots had grown long enough to pass through the center opening in the bottom of the upper pot. Then, liquid fertilizer (5 mL) was added to the lower pot every 2 days. ^{14}C-acetic acid (1, 2-^{14}C), was added to the lower pot to give a radioactivity of 19 kBq. Thus, the upper pot covered the upper half of the root (upper root), and the lower half of the root (lower root) was the part that had passed through the opening and was soaked in the culture solution.

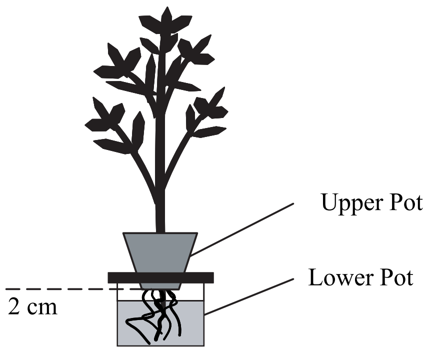

Figure 1. Hydroponics experiment set-up.

After addition of the ^{14}C-acetic acid, carrot seedling was cultivated in a phytotron for 24 h (artificial light, 10 k Lux for 16 h; 23 °C, relative humidity; 40%). The solution level in the lower pot was adjusted every 2 days to keep it 2 cm below the bottom of the upper pot in order for each plant to take up air via the roots. The plants were separated into shoot, upper roots, and lower roots after carefully removing them from the pots. The distributions of ^{14}C in the plants were visualized by the autoradiography. The autoradiography was also done using carrot seedling and ^{22}Na for a comparison.

3. RESULTS AND DISCUSSION

3.1 Results of sand culture experiment using radish

Specimens and autoradiography images of radish grown in the sand culture experiment are shown in Figure 2. Both radishes grown under the dark and light conditions had clear autoradiography images for their roots. Although most shoots had faint images, radish grown under the light conditions had relatively clear autoradiography images compared with those of shoots grown under the dark conditions. The images of both radish shoots were clear for the emerging leaves. The images of radish shoots grown under the light conditions were also clear for relatively young leaf where photosynthesis was actively carried out. The edible part of radish grown under the light conditions had clear images, but that under the dark conditions did not. However, there was no significant difference in ^{14}C radioactivity from actual measurements between the edible part of plants grown under the dark conditions and those grown under the light conditions due to the individual variances. Average total radioactivity was 1.2 ± 0.5 KBq in whole plant. The mean ^{14}C radioactivity in the radish edible parts was 377 Bq (180 Bq g^{-1} on a fresh weight basis). This value corresponded to 0.51% of the added radioactivity to the experimental pot.

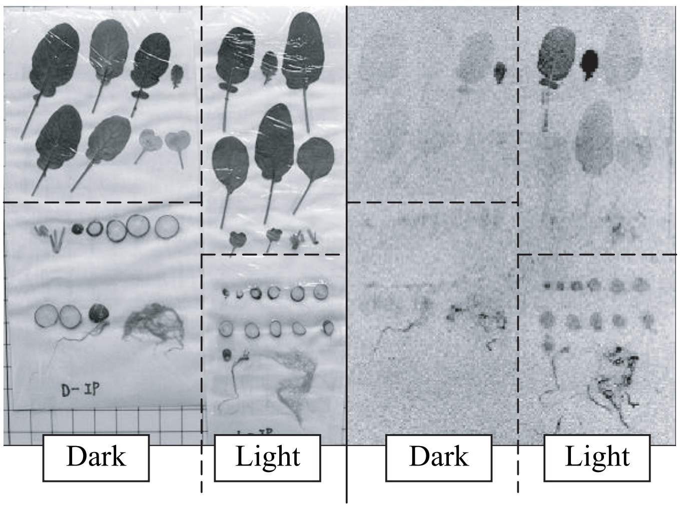

Figure 2. Specimens and autoradiography images for radish grown under the dark and the light conditions. Upper image, shoot; bottom image, root and edible parts (cross section).

Percentage distribution of the ^{14}C radioactivity in whole radish grown under the dark and the light conditions in the sand culture experiment is shown in Figure 3. There was no significant difference between the roots of radish grown under both conditions. Percentage distribution the ^{14}C radioactivity in the roots showed the highest distribution with approximately 55% in both whole plants. The activity in the shoots showed approximately 12% of the total activity of the plant grown under the dark conditions while the activity of shoots of the plant grown under the light conditions showed approximately 29%. Percentage distribution of the ^{14}C radioactivity in edible parts of radish grown under dark conditions was higher than that of radish grown under the light conditions. For the terms of relation between shoots and edible parts, ^{14}C dominantly transferred to the plant parts where photosynthesis was actively carried out under the light conditions, but was not under the dark conditions.

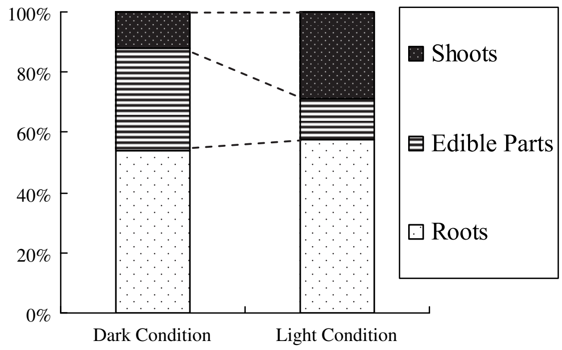

Figure 3. Percentage distribution of the ^{14}C radioactivity in whole radish grown under the dark and the light conditions.

3.2 Results of hydroponics experiment using carrot

Specimens and autoradiography images for carrot seedlings in the pot hydroponics experiment are shown in Figure 4. A clear image was observed in plants cultured with ^{14}C labeled solution at the shoot and lower root which was soaked in the culture solution. However, the upper root which was not soaked in the culture solution was not clearly imaged by autoradiography. Some fraction of ^{14}C was adsorbed on the lower root surface and not all the radioactivity levels were actually caused by ^{14}C assimilation in the lower roots. In the preliminary experiment using chromatographies (data not shown), ^{14}C-acetic acid was not found in the ethanol extracts of the plant. Therefore, it seemed that ^{14}C-acetic acid itself was not taken up so much by the plant through roots. Inorganic carbon such as HCO_3^{-} transformed from ^{14}C-acetic acid by microorganisms attached to the root would be taken up by plants through the roots, and some fraction of ^{14}C would be assimilated into the shoots by photosynthesis. Not much ^{14}C transferred upward in the plants, suggesting a discrimination of ^{14}C at the root surface during absorption of various elements from the culture medium [7]. A clear autoradiography image was observed using ^{22}Na for the whole carrot seedling, even in the upper root. The distribution of radioactivity using ^{22}Na generally agreed with water distribution in the plants but that using ^{14}C-acetic acid did not.

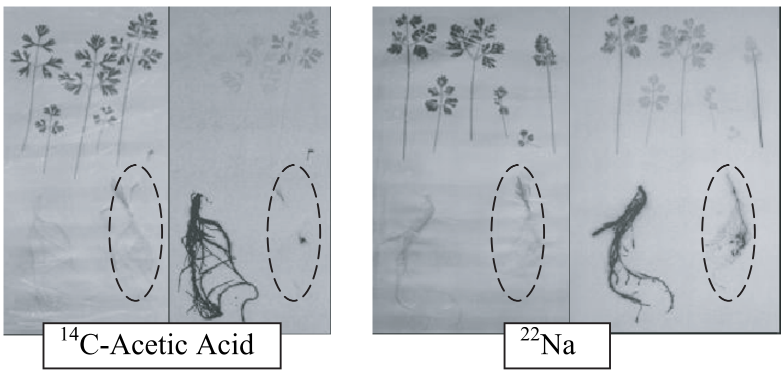

Figure 4. Specimens and autoradiography images for carrot seedlings (^{14}C addition, left; ^{22}Na addition, right). Upper image, Shoot; bottom left image; lower root; bottom right image, upper root.

4. CONCLUSIONS

The results of the present study indicated that the root vegetables absorbed ^{14}C through the roots and assimilated it into the shoots and edible parts. However, the amount of ^{14}C acetic acid absorbed by plants through the roots was considered to be very small compared with added ^{14}C. Absorption and assimilation of ^{14}C seemed to be carried out not because of uptake of ^{14}C-acetic acid but because of uptake of ^{14}C in inorganic forms such as HCO_3^{-} with very low concentration. ^{14}C dominantly transferred to the plant parts where were physiologically active. ^{14}C movement in the plant did not have a close relation to water movement unlike ^{22}Na movement.

^{14}C acetic acid is one of the major components released from ordinary portland cement with is used in solidification for radioactive waste disposal [1], but clarifying its pathways would be difficult because ^{14}C from radioactive waste would transform to inorganic forms. Therefore, it should be very careful to clarify its pathways for maintaining public health safety and reliable assessment of radiation exposure. To understand the fate of radioactive nuclides for environmental assessment of waste disposals, it is important to monitor the fate of ^{14}C associated not only with water movement but also with transformations to other chemical formulas such as inorganic forms even when it is in the soil.

Acknowledgments

This work has been partially supported by the Agency of Natural Resources and Energy, the Ministry of Economy, Trade, and Industry (METI) Japan.

References

[1] Kaneko, S., Tanabe, H., Sasoh, M., Takahashi, R., Shibani, T., and Tateyama, S., *Mat. Res. Soc. Symp. Proc.*, **757** (2003) 621–626.
[2] Anbe S., Ohkubo Y., Kobayashi Y., Iwamoto M., Maeda H., and Yanokura M., *RIKEN Review*, **13** (1996) 17–18.
[3] Muramatsu, Y., Uchida, S., and Ohmomo, Y., *J. Radiat. Res*. **34** (1993) 214–220.
[4] Muramatsu, Y., Uchida, S., Sumiya, Y., Ohmomo, Y., and Obata, H., *Water Air Soil Pollut.* **45** (1981) 157–171.
[5] Ban-nai, T., Muramatsu, Y., and Yanagisawa, K., *J. Radiat. Res*. **36** (1995) 143–154.
[6] Ban-nai, T., Muramatsu, Y., and Yanagisawa, K., *J. Radioanal. Nucl. Chem.* **241** (1999) 529–531.
[7] Momoshima N., Tjahaja P., and Takashima Y., *Radioisotopes* **40** (1991) 64–66.