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Interception and transfer of wet-deposited ^{134}Cs to potato foliage and tubers

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ABSTRACT

Contamination levels on potato foliage and tubers were investigated by repeated sampling after multiple foliar contaminations of wet-deposited ^{134}Cs at five different growth stages in a micro-plot field experiment in three successive years. Application of the radionuclide early in the growing season (deposition date 19–27 June, growth stage II = plant establishment) resulted in low ^{134}Cs activity concentration in potato tubers across sampling occasions (mean 60, 25 and 115 Bq kg^{-1} dry weight (D.W.) for years 1, 2 and 3, respectively). Following radionuclide deposition in the middle of the growing season (15–24 July, growth stage III = tuber initiation), ^{134}Cs activity concentration in tubers across sampling occasions was found to be highest (mean 150, 850 and 660 Bq kg^{-1} D.W. for years 1, 2 and 3, respectively). When the radionuclide was sprayed on at later stages (5–7 August, growth stage IV = tuber bulking), ^{134}Cs activity concentrations in tubers across sampling dates decreased (mean 75, 310 and 395 Bq kg^{-1} D.W. for years 1, 2 and 3, respectively). Deposition in the second half of August (15–28 August, late growth stage IV and beginning of growth stage V = tuber maturation) resulted in yet lower ^{134}Cs activity concentration in tubers. Potato tubers may concentrate as much as up to 2 times more ^{134}Cs than foliage depending on deposition date of radionuclide.

1. Introduction

The Chernobyl disaster in 1986 and the nuclear accident at Fukushima Dai-ichi NPP in 2011 indicate that similar accidents resulting in contamination of large areas of terrestrial land may occur in the future. One consequence of accidental radionuclide release is contamination of agricultural land during the growing season, to a level making it impossible to utilise the food crops produced (Anspaugh et al., 2002). Following the Chernobyl and Fukushima accidents, a large amount of data were collected about radionuclide uptake from soil to plants, but there is still a shortage of information about the effect of radioactive fallout on agricultural crops growing during the deposition event. Agricultural crop production in the Northern hemisphere is cyclical, with different phases of crop development during the season from growth in spring and summer to ripening and harvest in autumn. Transfer of radionuclides to food is affected by whether the crops are used directly as fresh material, such as animal fodder and vegetables, or in processed form. If fallout occurs during vegetative development or crop ripening, the transport pathways of radionuclides may be short, with any deposited/intercepted by aboveground green parts of the plant being transferred directly to edible parts. Data obtained after previous nuclear accidents showed that the level of agricultural crop contamination by radionuclides may be determined by many factors, including time of the year at which radionuclide deposition occurs (Bengtsson et al., 2014). Among other factors, leaf area, above ground plant biomass and growth stage of the crop may be important (Kinnersley et al., 1997; Eriksson et al., 1998b; IAEA, 2010). Considerable fractions (more than 40%) of the applied cesium (Cs) deposited on the surface of the potato leaves may be transferred to the edible parts of plants when harvested a month after application of radioactivity (Oestling et al., 1989). The level of radionuclide interception and redistribution within the plant shortly after deposition differs depending on the growth stage of the crop, e.g. a well-developed crop may intercept a substantial part of the deposited radionuclides due to its large leaf area (Eriksson et al., 1998a, 1998b; Vandecasteele et al., 2001; Bengtsson et al., 2013, 2014).

The contamination of the crop depends strongly on the date of

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^{134}Cs application (Gerdung et al., 1999). Milk from grazing cows and vegetables such as potatoes are among the main food products that can be contaminated shortly after radionuclide fallout and thus contribute to the radiation dose on consumption (Lepicard and Dubreuil, 2001; Madoz-Escande et al., 2004). Potatoes are generally characterised by relatively low uptake of cesium from contaminated soil compared with other food crops (Strandberg, 1994; Tsukada and Nakamura, 1999). However, consumption of potatoes as a food product is high in many countries. In Sweden, consumption of potatoes (fresh and processed as e.g. crisps) in 2011 was 56.5 kg per capita (Jordbruksstatistisk årsbok, 2014).

Information about the relationship between level of crop contamination and timing of radionuclide deposition relative to crop growth stage is needed to predict whether the crops are suitable for human consumption. To our knowledge there are a few published experimental data (Voigt et al., 1991; Gerdung et al., 1999) showing transfer of wet-deposited cesium isotopes to potato foliage and tuber when radionuclide deposited at different stages of plant growth. Therefore in an experiment carried out during three consecutive years, retention of ^{134}Cs in potato foliage and transfer to the tubers was studied. The plants were grown in a micro-plot experiment under field conditions and artificial deposition of ^{134}Cs was applied by spraying a solution directly onto the potato foliage at different times during the growing season.

The aims of this study were to measure the interception and activity concentrations of wet deposited ^{134}Cs in potato foliage and tubers. Our starting hypothesis was that potato tuber contamination by ^{134}Cs is highest when radionuclide deposition occurs during growth stage III, i.e. tuber initiation, and growth stage IV, i.e. tuber bulking (beginning of tuber formation and accumulation of water, carbohydrates and nutrients within cells). We determined the change in ^{134}Cs activity concentration in foliage and tubers and ^{134}Cs transfer from deposition to foliage and tubers depending on deposition time at different sampling dates. We also determined the proportion of total ^{134}Cs activity allocated within foliage and tubers as a percentage of the amount of radionuclide applied per m^2. Data obtained could be used to predict possible levels of potato contamination by cesium in the event of radionuclide fallout.

2. Material and methods

2.1. Experiment description

The experiment was carried out at the Uppsala Näs experimental station (59°49′N, 17°40′E, 10 m above sea level) during the growing seasons in 1990, 1991 and 1992 (denoted here year 1, year 2 and year 3). Potato foliage was experimentally exposed to radioactive fallout of ^{134}Cs at different times and growth stage during the growing season. The experiment (Fig. 1) was designed to minimise the risk of cross-contamination during radionuclide deposition and to avoid interference from neighbouring plots during sampling. A fertiliser dose of (kg/ha) 96 N, 42 P and 78 K was applied in spring of each year (Eriksson et al., 1998a, 1998b). The potato variety 'Maria', a medium-early variety, was used in all years, with planting on 30, 29 and 25 May in years 1, 2 and 3, respectively. Three potato tubers were placed diagonally in each of four 0.25 m^2 micro-plots. The micro-plot experiment method was described by Fredriksson et al. (1969). There were different blocks of micro-plot deposited each year. ^{134}Cs was deposited on each block on the same day (randomized block designs). The topsoil at the site was a loamy sand (0–25 cm), and the subsoil was a silty sand to about 1 m depth. It took about 3–4 weeks before the first leaves emerged above the surface (Fig. 1).

The precipitation collected at the experimental site during growing period was 181 mm in year 1 and 236 mm in year 2. For year 3 precipitation was 220 mm (data from SLU's (Ultuna) climate station located 7 km from the experimental site). The precipitation was relative lower in May and June (16–48 mm) but was intensive in July and part of August. The total annual mean of rainfall at the Ultuna station was 527 mm (Alexandersson and Eggertsson Karlström, 2001). No additional artificial precipitation was given during the experiment period.

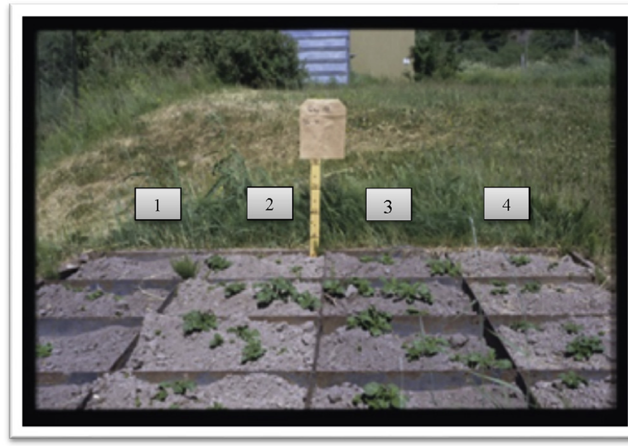

Fig. 1. Experimental layout, in which three potato tubers were placed diagonally in each 0.25 m^2 microplot. Microplots in each row (1, 2, 3 and 4) were treated in the same way (Fredriksson, 1969).

The mean air temperature during growing period for all tree years was 10 °C in May, 15 °C in June and 16 °C in August. In year 2 the temperature during May and June were lower while in year 3 the temperature was higher than normal. The yearly annual mean temperature from the Ultuna climate station was 5.1 °C (Alexandersson and Eggertsson Karlström, 2001).

2.2. Radionuclide deposition

The first deposition in each year was made 3–4 weeks after the potatoes had been planted in the soil and when the first 2–4 leaves were emerging. The radionuclide in the wet artificial deposition was ^{134}Cs. In all three years, a higher nuclide concentration was used on the first deposition occasion due to the plots being used for long observation periods. Early deposition and late sampling were compensated for by larger deposition to ensure good measurements. Deposition dates for years 1–3 are shown in Table 1.

The artificial deposition solution was prepared by mixing radionuclide with 0.1 N HCl, then diluting with water up to 0.25 L volume. The solution was sprayed in a manner similar to a shower of small raindrops on the potato crop, corresponding to 1 mm applied for each plot. To keep the tracer within the correct plot, this operation was carried out in aluminium frames, which protected each plot up to a height of 1 m. These frames were kept in place for one day after the deposition event to counteract the influence of weather conditions. The soil concentration of ^{137}Cs after the Chernobyl accident in 1986 was 35 kBq/m^2 at the study site, but there was little ^{134}Cs remaining when the experiments started.

Potato foliage was sampled by cutting off a leaf about 5 cm above the ground. When the potato tubers were ready for sampling, this was done on the same day as leaf sampling. Tubers were dug from the soil and washed before analysis. The first potato leaf was sampled on 29 June, 2 days after deposition, in year 1, on 23 July, 34 days after deposition, in year 2 and on 26 June, 15 days after deposition, in year 3. The first potato tubers were harvested on 8 August, 42 days after deposition in year 1, on 23 July, 34 days after