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Radiocaesium transfer from volcanic soils to Swiss chard, cabbage and sweet corn

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ABSTRACT

The root uptake of radiocaesium by different plant parts of Swiss chard *(Beta vulgaris* L. *var. cicla),* cabbage *(Brassica oleracea* L. *var. capitata)* and sweet corn *(Zea mays* L. *var. saccharata*) and the potential influence of K-fertilising on the transfer behaviour was studied in allophanic volcanic soils (umbric andosol and dystric fluvisol) in Chile under temperate climate and heavy rainfall conditions (~2660 mm y^{-1}) over several vegetation periods. The soils were spiked homogeneously to 0.20 m depth with 100 kBq ^{134}Cs m^{-2} and activity concentrations measured. The transfer factor (TF, on a dry mass basis) to Swiss chard had a clear exponential decrease within each crop year for both soil types, either K-fertilised or unfertilised. The highest values of the TFs to Swiss chard were at the beginning of the harvests, and the half-times of TF decrease ranged between 52 and 137 d for umbric andosol and between 40 and 164 d for dystric fluvisol. Over the five seasons there was no consistent ageing effect based on TF in either soil types for the three studied crops. The effect of ^{134}Cs foliar uptake by Swiss chard from resuspended soil was estimated to account for about 70% (external leaves) and 30% (internal leaves) increase in the TF for the K-unfertilised umbric andosol, and showed an ambiguous behaviour for the K-fertilised umbric andosol. Consequently foliar uptake does not explain the 370 and 500% increase of the TF to Swiss chard leaves determined during the third growing period in the umbric andosol without and with K-fertilisation, respectively. Therefore an uncertainty factor of 3–5 is recommended to be taken into account when using this parameter for dose calculations. The TF to Swiss chard was found to be higher than previously reported values. The TF to cabbage and sweet corn plant parts was found to be within the range of previously reported values. Normal K-fertilisation resulted in about 2.4-fold reduction in ^{134}Cs TF to Swiss chard, 2.3-fold to sweet corn and 3.0-fold to cabbage.

1. Introduction

Plant uptake of radionuclides from soil is an important entry into the human food chain contributing to internal radiation doses after deposition. Ingestion doses to people are due to direct intake of edible parts of plants or indirectly due to the use of plants as animal feed (Putyatin et al., 2006). Among the anthropogenic radionuclides, radiocaesium plays an important role because of its high environmental mobility and bioavailability, its long physical and ecological half-life and because it contributes significantly to the long-term radiation dose to man (Schimmack and Feria Márquez, 2006). According to Sanzharova et al. (2009) and IAEA (2010), the transfer of radionuclides into plant systems varies considerably depending on the bioavailability of the radionuclide in question, and is influenced by 6 main factors: the physical-chemical properties of the radionuclide, the properties during the fallout, time after deposition, plant species, cultivation practices, and soil properties. Specifically the soil-to-plant transfer of radiocaesium may vary over four orders of magnitude (IUR, 1989; IAEA, 2010; Voigt et al., 1996; Absalom et al., 1999). Therefore realistic values of transfer via root uptake and/or direct (re-)deposition are rather unreliable and are recommended to be determined in situ.

Within the Chilean territory, the highest areal activity density of global fallout ^{137}Cs (up to 5400 Bq m^{-2}) was observed in the River and Lake Regions, predominantly because of the high rainfall (1500–4000 mm y^{-1}) affecting these regions and additionally, because of their mid-latitudinal (39–43°S) positions (Schuller et al., 2002). The River and Lake Regions are important agricultural regions of Chile, high in production of milk and meat (ODEPA, 2012). Few data on long-lived anthropogenic radionuclide transfer factors (TFs) to edible crops for this area are available (Schuller et al., 1993, 2005) and knowledge on TF in the predominant allophanic (volcanic) soils in general is scarce. The objective here was to improve the data set on radiocaesium soil-to-

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crop TFs in less explored soil systems where the TFs are expected to deviate from global average values.

Preliminary results described the initial two year seasonal variation observed for the TF to Swiss chard (*Beta vulgaris* var. *cicla* L.) in the same allophanic soils in Chile (Schuller et al., 2005). Here we add to these previously published data three additional seasons and measurement of the time-course of TF for ^{134}Cs to the edible plants including cabbage (*Brassica oleracea* L. var. *capitata*) and sweet corn (*Zea mays* L. var. *saccharata*). All three crops are widely consumed by Chilean population and corn is used for livestock feed. We also investigated the influences of soil type, K-fertilisation, the contribution of rain splash and soil resuspension on soil-plant transfer behaviour.

2. Materials and methods

2.1. Study site

The site selected for the study is located at the Santa Rosa Experiment Station, Universidad Austral de Chile, Valdivia, River Region, Chile (39°47′S, 73°14′W). A detailed description of the site and soil characteristics was given in Schuller et al. (2005). Two allophanic soils characteristic for crop production in south-central Chile were selected: an umbric andosol (silty loam) and a dystric fluvisol (loam), the last one representative of soils flooded during autumn and winter and commonly cultivated after the flood period during late spring and summer for vegetable production (Fig. 1).

Daily precipitation was recorded during the years 2001–2005 at the Meteorological Station, Universidad Austral de Chile (Huber, 2006), located about 1 km distant from the experimental fields. In the River Region, intense rainfall occurs mostly between April and September corresponding to autumn and winter seasons. The annual precipitation amounts documented during the observation period were 2246, 3140, 2406, 2509 and 2984 mm for the years 2001–2005, respectively. The mean value of the annual rainfall registered from 1960 to 2005 in the area was 2295 mm y^{-1} (Huber, 2006), which is lower than in most years of the experiment.

2.2. Experimental design

Table 1 summarises the experiments performed and is a complement to the reported experimental design described by Schuller et al. (2005). The plots size was estimated to allow the collection of three replicates (each from 1/3 of the plot) for each crop type and soil treatment. During the three last growing seasons a small cabbage plot was installed on one extreme of each chard plot (see Fig. 1).

2.3. Soil contamination and sampling

The physical and chemical characteristics of the two soils were determined by standard methods (Hartge and Horn, 1992; Sadzawka, 1990) at the Institute for Agriculture and Soil Engineering, Universidad Austral de Chile, and are given elsewhere (Schuller et al., 2005). The ^{134}Cs soil-liquid distribution coefficient (K_d, L kg^{-1}) and Radiocaesium Interception Potential (RIP, $mmol_c$ kg^{-1}) as a measure for bioavailability of radiocaesium for the different soils and K-fertilisation treatments were determined at the Laboratory of Soil Fertility and Soil Biology, Katholieke University Leuven, Belgium.

Both soils selected for the study were very nutrient poor (Schuller et al., 2005). Therefore, the soils were fertilised annually, adding similar P and N amounts as used in local crop cultivation practices with triple superphosphate (all plots) 60 kg P ha^{-1}, sodium nitrate (all plots) 90 kg N ha^{-1}, potassium sulphate (only plots treated with ^{134}Cs + K) 90 kg K ha^{-1}.

Soil labelling with ^{134}Cs was necessary because the mass activity density (Bq kg^{-1}) of global fallout ^{137}Cs in plants was close to the detection limit. The detailed design of the plots and the radiocaesium labelling procedures were described by Schuller et al. (2005). Briefly, the upper 0.20 m soil layer was removed from each plot and sieved. The umbric andosol plots were labelled in November 14th, 2000, and the dystric fluvisol plots in January 3rd, 2001 with 100 kBq ^{134}Cs m^{-2} each

Table 1
Experimental design.

Soil type	Crop type	Treatment	Vegetation period (y)
Umbric andosol	Swiss chard	Cs + Pr[a]	5
		Cs + K + Pr	5
		Control	5
		Control + K	5
		Cs without Pr	2
		Cs + K without Pr	2
	Sweet corn	Cs + Pr	5
		Cs + K + Pr	5
		Control	5
		Control + K	5
	Cabbage	Cs + Pr	3
		Cs + K + Pr	3
		Control	3
		Control + K	3
Dystric fluvisol	Swiss chard	Cs + Pr	5
		Cs + K + Pr	5
		Control	5
		Control + K	5
	Sweet corn	Cs + Pr	5
		Cs + K + Pr	5
		Control	5
		Control + K	5
	Cabbage	Cs + Pr	3
		Cs + K + Pr	3

[a] Pr = Thin 0.02 m protection soil layer (without ^{134}Cs labelling) against contaminated soil deposition on leaves.

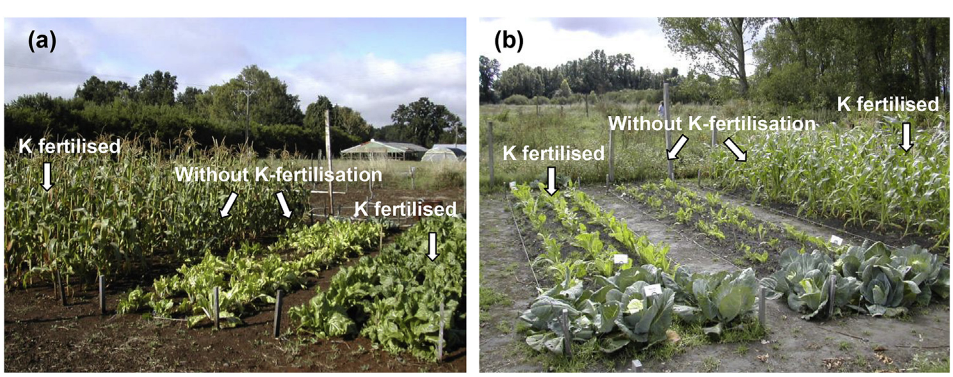

Fig. 1. Plots installed on the umbric andosol (a) and dystric fluvisol (b).