The uptake and storage of caesium and strontium by spring wheat – a modelling study based on a field experiment

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INTRODUCTION

The highest risk for contamination of arable crops and thereby the food chain is when deposition occurs during the growing season (Anspaugh et al., 2002), when there is a higher transfer of radionuclides from atmosphere-to-plant than from soil-to-plant. Thus, the Fukushima Dai-ichi accident could have had more severe consequences for the security of the food production 2011 if it had occurred later in the growing season. The aims were i) to model and quantify the storage dynamics of 134Cs and 85Sr in wheat grains after wet-deposition and ii) to analyze the sensitivity of the storage of radionuclides to crop development, soil and radionuclide properties as well as to weather conditions.

MATERIALS AND METHODS

Tracey model description

We extended the dynamic model Tracey (figure 1, Gärdenäs et al. 2009) describing cycling of trace elements (TE), in this case radionuclides, in terrestrial ecosystems with high temporal resolution (1 day). The extension consisted of descriptions for contamination by wet-deposition, interception, and foliar uptake and adaptations to agricultural systems. The model is a multi-compartmental model in which fluxes and storage of radionuclides are described for different plant parts (leaves, stem, roots and seeds) and for several soil layers. Each soil layer includes six radionuclide pools; three pools belong to soil organic matter (slowly and quickly decomposing litter as well as humus) and one to the biomass (roots), the other two soil pools are radionuclides dissolved in soil water solution and radionuclides absorbed to soil particles.

The radionuclide fluxes are driven either by water or carbon fluxes, the latter two fluxes are simulated with an external dynamic model, the biogeophysical ecosystem model called CoupModel (Jansson and Karlberg, 2004) and provided to Tracey as driving forces. Tracey contains two alternative root uptake descriptions, one driven by transpiration and one by growth.

Tracey model application on spring wheat

The extended Tracey was calibrated against data from the wet-deposition experiment at Ultuna, central Sweden (Bengtsson et al. 2013). 134Cs and 85Sr were deposited on spring wheat at six growth, from tillering to full ripening, stages in 2010 and 2011.
The sensitivity for different radionuclide, plant, and soil properties were assessed by Monte Carlo simulations using the sensitivity toolbox Eikos. One thousand simulations were made for each of the 48 scenarios (2 radionuclides, 2 root uptake approaches, 6 deposition treatments, 2 years). The simulated dynamics of grains’ storage of radionuclides were accepted if the simulated values were within the 95% confidence interval of the measured values at all available samplings of a deposition treatment. The model does not distinguish between radionuclides in the grain and radionuclides in the husk, the grain shell, while the measurements do not distinguish between radionuclides intercepted (on the grain and husk surface) and internal in the grain or husk. Thus for comparison of the measurements with the simulations we used the sum of the measured activity concentration in grain and husk and the sum of the simulated intercepted and internal content of radionuclides ($TE_{Seed} + TE_{IntSeed}$, figure 1). Both were expressed as amounts per unit soil surface (Bq m⁻²).
RESULTS AND CONCLUSIONS

A ten percentage of all 134Cs and 85Sr simulations were accepted. Highest percentage of accepted simulations was found for the scenarios with deposition shortly before harvest, indicating that the added model descriptions of deposition and interception performed well. The model mimicked well that the grain and husk storage of radionuclides increased exponentially the later in the growing season the deposition took place; the storage of radionuclides when deposited at full ripening was 250 times higher than the storage when deposition took place at tillering. When deposition takes place before flowering only a few promille of the deposited amounts were found on and in the grains and husks at harvest (average of simulations 0.2 % of deposited Cs and Sr). With flowering, the average percentage increases to 2.2 and 2.1 % of deposited Cs and Sr respectively. The highest percentages of radionuclides simulated in and on the grains and husks at harvest were found when deposition took place shortly before harvest; 7.6 and 8.7 % of deposited Cs and Sr (Bengtsson et al. 2013). According to the measurements about one third of that was in and on the grains.

The model results confirmed that foliar uptake i.e. direct atmosphere-plant transfer, fully dominates total plant uptake when deposition takes place during the growing season. The estimated accumulated foliar uptake formed on average 99% of the Cs and 93% of Sr total plant uptake. We identified the governing factors of radionuclide storage in grains and how they varied with growth stage; the stem and leaves fixation rates dominate before flowering; the flowers/grain fixation rates dominate between flowering and ripening; and the interception retention capacity of the grains dominates from full ripening. Root uptake and soil properties were not important for the storage in grains and husks. Rain events, especially, those within a week after deposition caused significant weathering. Cs was more likely to be washed-off than Sr was. On the other hand, Cs was reallocated from leaves and stem to grain in a much higher degree than Sr was.

We conclude that Tracey can accurately simulate the storage dynamics of radionuclides in plant parts that are a major ingredient in human food. We showed the dependency of the storage dynamics on the radionuclide, local weather, growth and soil conditions. The model and results can be used to tailor counter-measures to local conditions in the case of a radioactive deposition and to improve preparedness for radioactive deposition on growing crops.

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