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Study on the radioactivity and soil-to-plant transfer factor of ^{226}Ra, ^{234}U and ^{238}U radionuclides in irrigated farms from the northwestern Saudi Arabia

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ABSTRACT

The present study addresses the soil-to-plant transfer factors (TFs) of ^{226}Ra, ^{234}U and ^{238}U for 13 types of vegetables and agricultural crops planted under semi-arid environment in the northwestern part of Saudi Arabia. Crop plants along with plant-growing soils were collected from selected farms, which are irrigated from the non-renewable Saq aquifer, and investigated for their radioactivity content by means of alpha spectrometry after applying a radiochemical separation procedure. Hence, TF data for plant roots, green parts (stem and leaves) and fruits were calculated and contrasted to those reported in the literature. Substantial differences were observed in the TFs of Ra and U radioisotopes among plant species. In crop fruits, eggplant exhibited the highest uptake of ^{226}Ra (TF value of 0.11), while beans (0.16) have the highest TF for ^{234}U and ^{238}U. The geometric mean TF values indicated that the crop roots tend to accumulate Ra and U about four to six-folds higher than fruits. The relation between TF values and soil concentrations showed a weak correlation. Activity ratios between radionuclides in crop plants indicated the preferential translocation of U in fruits than Ra even though Ra is more available for root uptake. The fruit/root (F/R) ratios obtained for the investigated plants shown that pepper had the smallest F/R ratios (0.07 ± 0.01, 0.12 ± 0.02 and 0.11 ± 0.02 for ^{226}Ra, ^{234}U and ^{238}U, respectively), while the highest F/R ratios were observed in potatoes (0.71 ± 0.15, 0.44 ± 0.10 and 0.40 ± 0.08 for ^{226}Ra, ^{234}U and ^{238}U, respectively). The TF and F/R ratios data of natural radionuclides in the study region can hopefully improve the scientific knowledge for future studies.

1. Introduction

Various amounts of naturally occurring radionuclides present in soil can ultimately find their way into human food via their uptake by plant rooting system (IAEA, 1994). By accumulation in the edible part of plants, these radionuclides contribute to the total internal radiation dose received by humans (Sheppard and Evenden, 1988; Bunzl and Trautmannsheimer, 1999; Pulhani et al., 2005). Therefore, understanding the behavior of natural radionuclides in soil-plant environmental system is essential for improving the radiological assessment (Vera Tomé et al., 2003) and building the scientific knowledge of the migration of natural radioactive sources into cultivated plants and vegetables, which ultimately improve the dose assessment and enhance the estimation of radiation hazard to human.

The uptake of natural radionuclides by plants is also of high importance in assessing the pathways of radionuclides into the environment and evaluating their impact of releases. The uptake of radionuclides from soil to plants is widely measured by the transfer factor (TF), which serves as a prediction for the amount of radionuclide accumulates in the plant. However, TF data for a given radionuclide can vary considerably from plant to another and from environment to another, depending on the soil physical and chemical characteristics, the radionuclide behavior in soil and plant, and the environmental changes (Martinez-Aguirre and

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Perianez, 1998; Bettencourt et al., 1988). And thus, considerable differences in the uptake and translocation of natural radionuclides could arise among different plant species. Therefore, gathering new data on regional TFs for plants and agricultural crops from uninvestigated environments would definitely improve the scientific knowledge of the mechanisms and factors that affect transfer of long-lived natural radionuclides into the environment. Besides to that, regional TF data form a baseline for conducting accurate radiometric investigations and radiological assessments in a particular environment.

Environmental radioactivity measurements concerned about soil-to-plant TFs have mainly been devoted to anthropogenic radionuclides. Little attention was paid to determine the TF values of natural radionuclides within arid or semi-arid environments, which form about one-third of the land surface of earth. Moreover, studies that have been carried out on soil-to-plant TFs of natural radionuclides were mostly conducted in other environments (IAEA, 1994; Bunzl and Trautmannsheimer, 1999; Pulhani et al., 2005; Al-Kharouf et al., 2008; Al-Masri et al., 2008). This motivates us to carry out this study with the aim of determining the transfer of natural radionuclides from soil to vegetables and crop plants grown in the semi-arid environment of the Arabian Peninsula as there are no previous studies have been performed in this part of the world. The present work was dedicated to addressing the soil and plant natural radioactivity and hence estimate their radiological impact on crop plants.

Specifically, this paper reports the radioactivity levels of radium and uranium isotopes in cultivated soils and 13 different crop plant species grown on farms, which are irrigated from fossil groundwater of the Saq aquifer, in a semi-arid environment in the vicinity of Tabuk city in the northwestern Saudi Arabia. ^{226}Ra, ^{234}U and ^{238}U activity concentrations of the collected samples were determined by alpha spectrometry technique. The aim was to gather data on background radioactivity in soil and crop plants and hence calculate the transference of radionuclides between them. The TFs are necessary parameters used in environmental radiological impact assessment which are not available in the study area yet. Thus, these parameters for ^{226}Ra, ^{234}U and ^{238}U radionuclides in the sandy soils of the study area were presented, discussed and contrasted to those reported in other countries. The work was also expanded to study correlations between the measured radionuclides and hence compare their behavior and fractionation in the soil-plant system. Hopefully, the present study will initiate a scientific effort toward establishing baseline radioactivity levels in the different environments of this country. Moreover, the conclusions derived from this study should give valuable information on the fate of these radionuclides within the investigated environment and also on their behavior within similar environments.

2. Experimental

2.1. Area of study

The area of study is composed of eight farms located in the semi-arid climatic environment of Tabuk, Saudi Arabia between lat. 28° 00′ and 29° 00′ N and long. 36° 00′ and 36° 30′ E. The area lies within the sedimentary cover of the Arabian Peninsula and forms one of the most suitable places for agricultural crops that irrigated from the groundwater of the confined part of the Saq sandstone aquifer through many drilled wells (MAW, 1984). The topsoil of the farms is mainly silty sand of light brown to brownish color. The mean annual rainfall in this area is about 20 mm with higher evaporation rate of 40 mm/a and mean annual air temperature varies between −2 °C and 47 °C (MAW, 1984). Fig. 1 shows a map of Saudi Arabia and the investigated farms.

2.2. Sampling and pretreatment

Soil and crop samples were randomly collected from eight farms within the study area, which is a large and important food producing region for the population of Saudi Arabia. Soil samples were collected from the topsoil layer (10–30 cm) of the root zones of the plants in selected locations of the farms using a sharp aluminum plate. At each sampling site, three soil samples (about 1 kg each) were collected and mixed to obtain a representative sample. The same spots were chosen for crops sampling. The principal crops produced in these farms are: Cereals (wheat), bulbs (onion), legumes (beans), tubers or root vegetables (potatoes), and leafy vegetables (tomato, cucumber, pepper, capsicum, organic pepper, chili pepper, eggplant, organic eggplant, zucchini). These are the crops considered in this study. The crops were collected by gathering a material equivalent to about 1 kg dry weight from each sampling spot. Each crop sample was thoroughly washed, free of adhering soil particles, peeled when necessary, and packed in polyethylene bags to minimize decomposition of organic matter. Samples' roots were gently washed with milliQ-water to remove fine soil particles that may still adhere. The crop plants were then divided into three compartments; the edible parts (fruits), the green part (stem and leaves) and the roots. Each compartment was treated hereafter as individual sample. In total, 102 soil and crop samples were analyzed. The detailed numbers of these samples are listed in Table 1.

2.3. Radioactivity determination

The activity concentrations in soil and plant samples were carried out by alpha spectrometry after applying the same radiochemical separation procedure on both soil and plant samples. The method of separation was based on ion exchange and micro co-precipitation techniques. Details of the chemical separation procedure can be found in Alkhomashi et al. (2016). In brief, all samples were oven dried separately at 105 °C to constant weight, ground, sieved through a mesh of pore size of 2 mm, and homogenized. A 1 g of each dried sample was then placed in silica dishes and ashed in a muffle furnace at 550 °C for 16 h in order to remove hydrocarbon materials to avoid interference during analysis. The ash obtained from each sample was then transferred to a 250-mL Teflon beaker for U and Ra determination. A ^{232}U radiotracer was used for U determination and ^{133}Ba radiotracer was used for Ra determination. In both cases, a spike of 0.2 mL of the tracer was added to 15 mL of conc. HF to the sample ash and the beaker was then closed with Teflon cover and completely digested under temperature (240–300 °C) and pressure (120 bar) in a microwave reaction system (Multiwave Pro, Anton Paar Company, Austria). Digestion of silica (for soil samples) and inorganic materials (for vegetations) was continued for 8 h until a colorless solution is obtained. The colorless solution was then transferred to a glass cup and 3 mL of conc. HCl and HNO_3 were added and the sample was evaporated to dryness in three successive times to insure complete digestion. For U separation procedure, HCl was then added until a final solution of 20 mL of 10 M HCl was obtained. For Ra separation procedure, few drops of conc. HCl were then added to adjust the pH to 1.5 and the solution was diluted with distilled water until the sample reaches about 40 mL.

The separation processes of U and Ra were then continued as described elsewhere (Alkhomashi et al., 2016). The measurement method adopted for determining the activity concentrations of ^{226}Ra, ^{234}U and ^{238}U has also been reported by Alkhomashi et al. (2016). Each sample was mounted on a stainless steel disc for counting by an ORTEC octet α-spectrometer of high-resolution. The efficiency of the detectors ranged from 25.1 to 27.9%. It is worth