Soil-to-Plant Transfer Factors and Distribution Coefficient of ^{137}Cs in Some Palestinian Agricultural Areas

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Abstract

^{137}Cs is one of a few radio contaminants. It stems from the radiation leakage that is left in measurable quantities in Palestine. The transfer factor (TF) from soil to plant, and the distribution coefficient (K_d) of fallout radionuclides ^{137}Cs in soil samples collected from agricultural areas in the southern part of the West Bank in Palestine are measured in this study. The TF of ^{137}Cs ranged from 0.02 to 0.46 with a total average value of 0.18. In the current study, the average values of TF of ^{137}Cs in plant parts were found to be closed to the IAEA range value of plants, which was ranged from 0.02 to 3.2. The K_d ranged from 138 to 143 $\text{mL}\cdot\text{g}^{-1}$ within a total average value of 140 $\text{mL}\cdot\text{g}^{-1}$. The average K_d value for ^{137}Cs in Hebron region is lower than the recommended level of 500 $\text{mL}\cdot\text{g}^{-1}$, which is assumed to be about 1/4th of the K_d recommended values. The methodology is applied to the other elements while physico-chemical forms of natural and non-natural isotopes should be also clarified. The obtained findings alongside some previous studies are discussed in this paper so as to evaluate the risk of the radio cesium endangerment.

Keywords

^{137}Cs , Soil-Plant Transfer, Distribution Coefficient, Agricultural Area, Palestine

Subject Areas: Environmental Sciences, Nuclear Physics

1. Introduction

Cesium-137 (^{137}Cs), as a major nuclear reactor fallout contaminant, is still persistent in the environment. It is being found in many agricultural products (e.g. fruits, vegetables, grass...), enhancing the naturally occurring radioactivity to which the global society is exposed every day [1].

The problem of contaminations due to artificial radionuclides, such as ^{137}Cs , has been a subject of many stu-

dies in the field. Radionuclides of long half-lives, such as ^{137}Cs , are of special importance for human health since these nuclides enter the human body via the food chain, and they increase the radiation burden for many years. Many studies have been done to understand the mechanisms that affect the radionuclide uptake by plants which grow under the field conditions. In addition, several researchers have focused on the transfer, while others focused on monitoring or eco-toxicological issues. In fact, exposure to radiocesium depends on some biogeochemical processes. These are transport and completing in the soil, uptake and accumulation in plants and animals, recirculation, bacterial and fungal immobilization, etc. [2].

In order to have the capability of controlling radiation contaminated food, the agriculture has been at the center of the attention. By studying radio nuclides transfer within arable ecosystems, methods to reduce the uptake by plants and animals have been developed and applied. Many studies examined the ^{137}Cs behavior in soil; current radionuclides enter the food chains mainly from the soil. Moreover, many strategies have to be followed so as to improve the methods, find out more about the radio nuclides and study their behavior and transport in the soil-plant system [3].

The transfer factor (TF) is a value used in evaluation studies that are concerned with the impact of routine or accidental releases of radionuclide in the environment. The soil-to-plant transfer factor (TF) is one of the most important parameters in environmental safety assessment needed for nuclear facilities. This parameter is necessary for the environmental transfer models which serve in the prediction of the radionuclide concentrations in agricultural crops, and in estimating dose intake by residents. The main factors which determine the variability of TFs are the type of radionuclide, the type of crop, the type of soil (soil characteristics), and the stable element concentration. Other minor factors could be the differences in crop varieties, the differences in agricultural management (fertilization), and the weather [3]. As the transfer factors differ from one area to another due to different climates, soil types, vegetation, and local transfer factors should be thoroughly observed [4].

The aim of this study is to study the uptake of ^{137}Cs from soil into different plant organs (roots, stems and leaves) through root system, and the distribution coefficient of ^{137}Cs in the soil samples. This paper includes a brief description of the past experience results [5]-[7] and the data collection of the differences of TFs to root and leaf plants. The previous studies show that the activity concentration of ^{137}Cs in both of the plant and its corresponding soils (from the same regions in this study) is determined by using gamma spectroscopy.

2. Materials and Methods

Soil and plant leaves samples were collected from some Palestinian agricultural areas in the Southern part of the West Bank in Palestine (Figure 1). Soil samples were taken from the vertical profile 0 - 5 cm. The samples were grounded and crushed to a fine grain of about 1 mm mesh screen, sieved and mixed for homogenization. Large pieces were removed. The samples were then dried at 110°C for 24 h to ensure that the moisture is completely removed. The plant samples were dried for 10 - 15 h at 100°C in an electric oven to obtain a constant dry weight. The samples were powdered and cared for homogenization. All soil and plant samples were packed in 1 l Marenilli beaker and sealed for 4 weeks to reach secular equilibrium between ^{226}Ra (daughter of ^{238}U) and ^{232}Th with their daughter nuclei. This was done in order to allow radon and its short-lived progenies to reach secular radioactive equilibrium before gamma spectroscopy [5]-[7].

^{137}Cs is measured by using n-type coaxial lead shielded intrinsic Ortec high-purity germanium (HPGe) detector. The detector has an efficiency of about 15%, energy resolution of 1.85 keV, full width to the half maximum (FWHM) for the 1332.5 KeV gamma line of ^{60}Co and MCA with 8000 channels. The 662 keV gamma ray transitions were used to determine the concentrations of ^{137}Cs in the soil and plant samples. An empty Marenilli beaker was used for the same period of time to assess the background concentrations of the γ -rays. To protect the γ -rays background from building and cosmic rays, a cylindrical lead shield of 100 mm thickness was used to shield the detector from the surroundings environment. The detection limit for both plant and soil samples are $0.01 \text{ Bq}\cdot\text{kg}^{-1}$ dry weights.

3. Results and Discussion

3.1. The Transfer Factor

The transfer factor (TF) is a mathematical tool used to compare the transfer of nuclides from soil to plant at different times or at different sites. TF depends only on the environmental conditions; therefore, differences in deposition level between sites can be ignored.

Figure 1. West Bank geographical map contain the studied region.

In this study the transfer factor was calculated from the concentration activity of the dry plant matter divided by the activity in the top layer of the soil and as following [8]:

$$TF = \frac{A_p}{A_s} \quad (1)$$

where A_p is the activity of ^{137}Cs radionuclides in plant ($\text{Bq}\cdot\text{kg}^{-1}$ dry weight), A_s is the activity of ^{137}Cs radionuclides in soil ($\text{Bq}\cdot\text{kg}^{-1}$ dry weight). The dry weight was preferred because the amount of radioactivity per kilogram dry weight is much less variable than the amount per unit of fresh weight.

In recent studies [5]–[7], the concentration of natural radioactivity and the associated effective dose levels for ^{137}Cs radioisotopes and other radionuclides were measured in soil and plant samples collected from the southern part of West Bank in Palestine.

Soil-to-plant TF of ^{137}Cs for different plant species was calculated by using the average of concentration activity of ^{137}Cs in plant samples, and the average activity value of ^{137}Cs in soil. As shown in **Table 1**, the average maximum TF was 0.46 in Yatta region, and the minimum was 0.02 in Dura region, giving a ratio of maximum TF to minimum TF of 23. The total average value of TF is 0.18. These results show that TF values observed at these sampling sites were almost the same.

Generally speaking, a TF factor for ^{137}Cs is found to be less than that of all other radionuclides in all plant species. This indicates that ^{137}Cs is less efficiently transported from soil to plants than other radionuclides such as: ^{226}Ra , ^{238}U , ^{232}Th and ^{40}K . It was reported that soil-to-plant TF depends on soil properties such as nutrient standard, exchangeable K content, pH and moisture content [8]. In order to analyze the obtained data concerning the transfer of ^{137}Cs from the soil to the green parts of plants, it should be noted that all samples reveal the transportation of this isotope. The high availability of ^{137}Cs in some samples is probably due to its sandy texture which also contains little clay to fix ^{137}Cs in the soil [8]. Furthermore, the higher concentration of fallout radionuclides in some plant samples and soil particles is because of the accumulation of atmospheric fallout over a long period of time through dry weight deposition and due to strong adsorption of these nuclides to soil particles. The deposition fallout radionuclides on the upper layer of the earth's crust may get washed out by heavy rain. This causes the motion of the nuclides fallout along with surface soil, whereas root dust keeps on accumulating without moving [9].

Fallout ^{137}Cs was more mobile and more easily adsorbed by plants than the stable Cs in the soil. There is a high probability that some of the stable Cs is found in soil structures where ^{137}Cs cannot easily be in, so this isotope

Table 1. The average of concentration activity of ^{137}Cs radionuclides (in $\text{Bq}\cdot\text{kg}^{-1}$) and their average transfer factors (TF) from soil to plant samples.

Zone	Soil Samples	Plant Samples	TF
Beit Umar	7.5	1.0	0.13
Halhul	8.8	1.3	0.15
Al-Fawar	5.5	1.5	0.27
Yatta	14.0	6.5	0.46
Al-Dahria	7.0	2.1	0.30
Twaneh	11.0	1.1	0.10
Tarqumia	6.3	1.3	0.21
Kharas	6.0	1.0	0.17
Suba	4.3	1.3	0.30
Beit Elroush	30.2	1.1	0.04
Ramadien	12.5	2.5	0.20
Wadi Alkhaleel	24.0	4.5	0.19
Esamou	15.3	3.8	0.25
Jabal Abu Ashrah	24.2	1.0	0.04
Dura	12.4	0.2	0.02
Bani Naim	9.1	1.1	0.12
Hebron	7.9	0.4	0.05
Total Average			0.18

cannot reach an equilibrium condition. However, because the TF values for radioactive and stable isotopes are almost the same, the TF-stable Cs could be used for long-term transfer of ^{137}Cs in the environment [2].

In this study, the average values of TF of ^{137}Cs in plant parts were found to be very closed to the IAEA range value of plants which was in the range of 0.02 - 3.2 [10].

It is important to understand the effects of soil properties and other variables influencing the ^{137}Cs availability in soil, and the transfer to plants to predict the impact of possible future fallout. Field studies are very helpful to evaluate the importance of each characteristic as well as the relationship between them.

3.2. The Distribution Coefficient, K_d

The distribution coefficient (K_d) is the ratio of the concentration of radionuclides in solid phase, A_s , to the concentration of radionuclides in liquid phase, A_L . The distribution coefficient represents the partition of the solute in the soil matrix and soil water, assuming that equilibrium conditions exist between the soil and solution phases. A linear Freundlich isotherm, which assumes complete reversibility of ion adsorption, has been extensively used to correlate the relationship between A_s and A_L , that is [11]:

$$K_d \left(\text{ml} \cdot \text{g}^{-1} \right) = \frac{A_s \left(\text{Bq} \cdot \text{g}^{-1} \right)}{A_L \left(\text{Bq} \cdot \text{ml}^{-1} \right)} \quad (2)$$

where K_d is the distribution coefficient, A_s is the concentration of ^{137}Cs on the solid sample and A_L is the equilibrium concentration in the aqueous solution. The transfer of radionuclides from the liquid to the solid phase or vice versa may be controlled by mechanisms such as adsorption and precipitation, depending on the radionuclides.

The two most common experimental techniques to measure the K_d are the static (batch) and dynamic (column) methods. Usually, the batch method is used to measure the distribution coefficient K_d under saturated equilibrium conditions. The column method is used to approach a more “natural” soil condition.

Measurement of the distribution coefficient can be performed quickly by the batch method with any radionuclide on any soil sample like, independent of the porosity, brittleness, or other properties of the soil. In most instances, the soil material is continually agitated to facilitate mixing and contact. At specific times and so as to approach equilibrium conditions, the solid and solution is separated and the resultant distribution of the nuclide is determined. In the batch system, radionuclides desorption and adsorptions are affected by some factors: agitation effects; solid-liquid separation techniques; and limitation of analytical determination, that is, multiple species of soil cannot be differentiated if present.

The distribution coefficients measured values are not constant when used with soils. The K_d values are dependent on the soil's physical and chemical characteristics, which in themselves do not necessarily remain constant over the long-term because soils are dynamic systems. Soil properties affecting the distribution coefficient include the texture of soils (sand, loam, clay, or organic soils), the soil solution ratio [12], the organic matter content of the soils, pH values, the solution or pore water concentration [12], and the presence of competing captions and complexing agents [13]. Because it depends on many soil properties, the value of the distribution coefficient for a specific radionuclide in soils may range over several orders of magnitude under different conditions.

The batch experiment consists of mixing a series of working solutions containing aqueous contaminant solution with an accurately weighed dose of the site soils that were collected in the area under investigation. The amount of soil used on a wet scale basis will yield a soil to solution ratio of about 1:8 (*i.e.*, 75 g of soil to 600 ml of water). The vials containing the soil/water mixture will be kept headspace free. All batch tests will be performed using a leak tight closure on the sampling container which will prevent the solutions from being exposed to the atmosphere [14]. The beaker is sealed and mixed until sorption is complete, typically takes 3 to 16 hrs. When possible, the person conducting the study should ascertain the actual time required to reach sorption equilibrium. The solutions are filtered, and the concentration activity of the material (A_L in Bq·ml⁻¹) in the supernatant is measured [15].

According to the static study for K_d , the equilibrium condition between soil and liquid phase was attained after about 8 hours. At equilibrium, the K_d ranged from 138 to 143 ml·g⁻¹ with an average value of 140 ml·g⁻¹ (Table 2). The K_d values decrease as the concentration of cesium in the solution increases. Figure 2 shows the relation between A_S and A_L and explained the magnitude of K_d .

Results' analysis shows that the distribution coefficient values in the loess layers are smaller than those for clay layers for Cs-137 with an order of magnitude. By analyzing experimental results, we find a good behavior of clay formation in the sorption process of radionuclides; consequently the clay can play the role of natural barrier for the radionuclide migration.

The K_d value of ¹³⁷Cs derived from our experiments is lower than many reported experimental values in previous studies [16] [17]. The average K_d values for ¹³⁷Cs in Hebron region are given as 140 ml·g⁻¹, which is lower than the recommended level 500 ml·g⁻¹ [17]. The K_d value of soil samples is assumed to be about 1/4th of the K_d recommended values. This situation depends partially on the particle size, since the size of the soil particles collected from the study area is relatively large [18].

4. Conclusions

¹³⁷Cs, as a major nuclear reactors fallout contaminant, is still persistent in the environment. It is being found in many agricultural products (e.g. fruits, vegetables, grass...) enhancing the naturally occurring radioactivity to which the global society is exposed every day.

The Transfer Factors (TF) and distribution coefficients (K_d) of ¹³⁷Cs radionuclide in soil samples collected from different locations in some Palestinian agricultural area were studied in the Pollution Lab of Hebron University.

Cesium is taken up by the apical zone of the root and transported toward the acropetal direction, and in parallel, is assimilated by the leaves and transported basically into the root. For this reason, we calculated TFs in terms of activity concentration in a plant relative to the activity concentration in soil. The TF of ¹³⁷Cs varied and ranged from 0.02 to 0.46 with a total average value of 0.18. In the present study, the average values of TF of ¹³⁷Cs

Table 2. The average activity concentrations (A_S and A_L) of ^{137}Cs radionuclides and their average distribution coefficient (K_d) for soil samples.

Zone	$A_S (\times 10^{-3}) (\text{Bq}\cdot\text{g}^{-1})$	$A_L (\times 10^{-5}) (\text{Bq}\cdot\text{mL}^{-1})$	$K_d (\text{mL}\cdot\text{g}^{-1})$
Beit Umar	7.5	5.4	139
Halhul	8.8	6.4	138
Al-Fawar	5.5	4.0	138
Yatta	14.0	10	140
Al-Dahria	7.0	5.0	140
Twaneh	11.0	8.0	138
Tarqumia	6.3	4.5	140
Kharas	6.0	4.3	140
Suba	4.3	3.0	143
Beit Elroush	30.2	21	142
Ramadien	12.5	9.0	139
Wadi Alkhaleel	24.0	17	141
Esamou	15.3	11	139
Jabal Abu Ashrah	24.2	17	142
Dura	12.4	9.0	138
Bani Naim	9.1	6.6	138
Hebron	7.9	5.7	139
Total Average Value			140

Figure 2. The relation between concentrations of radionuclides in solid phase, A_S , to the concentration of radionuclides in liquid phase, A_L .

in plant parts were found to be closer to the IAEA range value of plants which was in the range of 0.02 - 3.2.

The K_d ranged from 138 to 143 $\text{mL}\cdot\text{g}^{-1}$ within the average value of 140 $\text{mL}\cdot\text{g}^{-1}$. The K_d value decreases as the concentration of cesium in the solution increases. The K_d value of ^{137}Cs derived from our experiments is lower than many reported experimental values in literature. The average K_d value for ^{137}Cs in the Hebron region is lower than the recommended level of 500 $\text{mL}\cdot\text{g}^{-1}$, which is assumed to be about 1/4th of the K_d recommended

value.

Thus, the collected data from this study will help to develop a reference database on this important issue, meaning that any change in this respect in the future due to radiation leakage can be ascertained and accordingly, radiation safety measurements will be taken into account.

Authors Contribution

Author was involved in the conception, designing, drafting, and approved the final version of the manuscript.

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