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Soil-to-mushroom transfer of ^{137}Cs, ^{40}K, alkali–alkaline earth element and heavy metal in forest sites of Izmir, Turkey

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Abstract The present work is devoted to an investigation on the soil to mushroom transfer parameters for ^{137}Cs and ^{40}K radionuclides, as well as for some stable elements and heavy metals. The results of transfer factors for ^{137}Cs and ^{40}K were within the range of 0.06–3.15 and 0.67–5.68, respectively and the most efficiently transferred radionuclide was ^{40}K. The TF values for ^{137}Cs typically conformed to a lognormal distribution, while for ^{40}K showed normal distribution. Statistically significant correlations between ^{137}Cs soil to mushroom transfer factors and agrochemical soil properties have been revealed. Although the concentration ratios varied within the species, the most efficiently transferred elements seems to have been K, followed by Rb, Zn, Cu, Cd, S, Cs and Hg.

Keywords Soil to mushroom transfer · ^{137}Cs · ^{40}K · Alkali–alkaline earth elements · Heavy metals

Introduction

Soil–plant transfer is the first step by which radionuclides, stable elements and heavy metals enter the food chain. Compared to green plants, high accumulating ability of many essential and/or toxic trace elements, some radionuclides and heavy metals by mushrooms has been known and numerous works have been published since the 1970s [1–5 (and references therein)]. A number of authors have reported transfer factors of some radionuclides, especially for radiocesium, in different species of mushroom as presented in Table 1, while there still is little data available on the transfer of trace elements and heavy metals to mushrooms [15, 16]. Whereas reliable data on the transfer of these materials in mushrooms are needed for developing and testing models, predicting migrations of these elements and obtaining the associated parameter values appropriate for radioecological and environmental performance assessments [17].

The transfer of radionuclides and other elements of interest between different ecological compartments of an ecosystem is frequently quantified by many ratio types such as transfer factors, concentration ratios, transfer coefficients and concentration factors [2, 12, 18, 19]. These parameters have been recommended by many international agencies IAEA, IUR and ICRP because of their conceptual simplicity and common use in radioecology [20–25]. These coefficients are expressed as the ratio between the contamination of the receptor compartment, and that of the donor. The transfer values can be influenced by some factors such as soil characteristics, climatic conditions, type of plants, part of the plant concerned, physico-chemical form of the radionuclides and the effect of the competitive species [26 and references therein].

In this study, the uptake of ^{137}Cs, ^{40}K, stable elements and heavy metals in 25 mushroom samples, covering 12 biological species such as *Agaricus campestris*, *Lactarius semisanguifluus*, *Clitocybe bresadoliana*, *Tricholoma terreum*, *Lactarius* sp., *Sarcodon scabrosus*, *Lactarius deliciosus*, *Lepista nuda*, *Suillus bovinus*, *Tricholoma* sp., *Russula delica* and *Macrolepiota excoriate*, was evaluated by means of the estimation of the transfer factor.

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Table 1 Comparison of transfer factors of ^{137}Cs and ^{40}K in mushroom samples of different areas in the world

Region	TF		T_{agg} (10^{-3} m^2/kg)		Reference	Author
	^{137}Cs	^{40}K	^{137}Cs	^{40}K	Date	
Russia			1.5–1390		1996–1999	Kaduka et al. [6]
			0.6–41		1986–1994	Shutov et al. [7]
			12–176		1996–1998	Fesenko et al. [8]
Austria			200		1999	Stemmer et al. [9]
Spain	0.07–55	0.44–1.82				Baeza et al. [10]
Sweden			170–4080		1986–2007	Mascanzoni [3]
Poland	9–254	1.5–7.1			1996–1998	Malinowska et al. [11]
Turkey	0.19–3.15				2002	Karadeniz and Yaprak [12]
Taiwan	3.8–10.2	1.6–7.2			1994	Wang et al. [13]
Mexico	26–65		500–1200		1993–1997	Gaso et al. [14]

Materials and methods

Study area and sample collection

A radioecological study was carried out at seven forest sites in and around Izmir, in 2002 during September–December when mushrooms yield reached maximal values. Sampling locations and their coordinates are given in Table 2. At the investigated site, the soils were classified as *Dystric Xerorthent* (U.S. taxonomy) and characterized by the typical horizons of an undisturbed forest floor with high organic matter content. In this study, soil and mushroom samples were sampled simultaneously, taking each mushroom sample with its corresponding organic soil layers. The different fungi species was identified precisely at Muğla University, Ula Technical High School, Department of Mushroom. The taxonomical classification of the sampled mushrooms is presented in Table 3 according to Solak [27] and Solak et al. [28].

Sample treatments and gamma-spectrometric measurements

The soil samples were dried to a constant weight at 75 °C for 24 h in an electric oven, reweighed and passed through a 2 mm sieve for removing of stones and roots. The loss of weight on drying (d.w. loss) was calculated for each soil samples. Each dried sample (300–1,800 g) was placed in a 1,000 mL Marinelli beaker prior to analysis.

The fruitbodies were carefully cleaned with a plastic brush to eliminate extraneous soil particles and litter tissue, and then they were weighted ("wet" weight). Mushroom samples for each species were dried to a constant weight at 80 °C for 48 h in an electric oven up to the "airdry" weight and weighed again. The loss of weight on drying (d.w. loss) was calculated for each sample. Dried samples (40–90 g) were ground in a small mill and the ground material was transferred to plastic sample containers (45 mm in diameter) prior to analysis.

The measurements of ^{40}K and ^{137}Cs activity concentrations in the soil and mushroom samples were employed using a 184 cc *p*-type coaxial HPGe detector with a relative efficiency of 25% and a resolution of 1.85 keV at 1.332 MeV (with associated electronics procured from EG&G Ortec). The detector was sealed by 100 mm thick lead bricks internally lined with 1.5 mm copper foil. The spectrum was acquired and analyzed using a PC-based 8 K multichannel analyzer and the associated software. The detector efficiency calibration was performed using the IAEA quality assurance reference materials manufactured by IAEA. The standard materials and samples were put into the containers of the same size and type so that detection geometry should remain the same. The activity of ^{40}K was evaluated from the 1,460.75 keV photopeak while ^{137}Cs was determined by the 661.66 keV photopeak. Counting times were adjusted to achieve reasonable counting statistics.

For mushroom samples, the minimum detectable activity (MDA) based on Currie [29] for ^{40}K and ^{137}Cs of this spectrometer were estimated to be 49 and 0.25 Bq kg^{-1}, respectively for the counting time of 10,000 s and a sample weight of 100 g for ^{40}K and 70 g for ^{137}Cs. For soil samples, the minimum detectable activities (MDA) for ^{40}K and ^{137}Cs in this spectrometer were 4 and 0.01 Bq kg^{-1}, respectively for the counting time of 10,000 s and a sample weight of 1,650 g. The ^{40}K and ^{137}Cs activity concentrations of mushroom samples were expressed in Bq kg^{-1} on a dry weight basis. Because not all the soil layers are of equal thickness and densities, the ^{137}Cs and ^{40}K activities of soil samples were expressed in both Bq kg^{-1} and kBq m^{-2} on a dry weight basis. ^{137}Cs and ^{40}K activity deposition values (kBq m^{-2}) were calculated as the product of the activity per unit mass (Bq kg^{-1}) and the mass depth of each component (kg m^{-2}). The mass depth

Table 2 Sampling locations, annual precipitation (P), altitudes (A), species of mushroom, sample type, transfer factors (TF) and aggregated transfer factors (T_{agg}) for ^{137}Cs and ^{40}K

Site latitude and longitude	A (m) P (mm)	Species of mushroom	TF		T_{agg} (10^{-3} m^2/kg)	
			^{137}Cs	^{40}K	^{137}Cs	^{40}K
Aşağıbey	238	*L. semisanguifluus* (e)[a]	0.19	0.67	0.64	2.20
N 39°15′23.6″	669					
E 26°59′20.7″						
Çiçekli	210	*C. bresadoliana* (ne)	0.16	1.89	0.65	7.58
N 38°30′01.1″	618	*C. bresadoliana* (ne)	0.11	1.81	0.45	7.26
E 27°16′50.1″						
Yaka	308	Lactarius sp. (e)	0.20	2.52	0.84	10.5
N 38°32′01.8″	776	*T. terreum* (e)	0.08	1.82	0.33	7.56
E 27°19′19.1″						
Gölcük	1140	Lactarius sp. (e)	0.094	1.18	0.31	3.88
N 38°18′32.5″	600	Lactarius sp. (e)	0.057	1.33	0.19	4.37
E 28°00′54.7″		Lactarius sp. (e)	0.060	1.33	0.19	4.37
		Lactarius sp. (e)	0.081	0.99	0.29	3.62
Uruzlar	397	*T. terreum* (e)	0.14	4.54	0.52	16.9
N 39°16′11.7″	562	Lactarius sp. (e)	0.10	1.60	0.43	6.61
E 27°31′17.3″						
Çınardibi	1082	*S. scabrosus* (ne)	1.49	3.77	13.0	38.6
N 38°17′14.3″	938	*S. scabrosus* (ne)	2.71	3.79	23.5	38.8
E 27°31′12.8″		*S. scabrosus* (ne)	3.15	4.77	27.4	48.8
		S. scabrosus (ne)	0.84	4.22	7.33	43.2
		L. delicious (e)	0.31	4.20	2.68	43.0
		L. delicious (e)	0.19	3.90	1.70	40.0
		L. nuda (e)	0.93	5.68	8.07	58.2
		S. bovinus (e)	0.50	3.08	4.32	31.5
Kurudere	441	*S. bovinus* (e)	0.28	1.90	1.05	7.14
N 38°22′48.8″	739	*A. campestris* (e)	–	3.07	–	11.5
E 27°26′29.7″		*R. delica* (e)	0.068	2.40	0.26	9.04
		R. delica (e)	0.65	1.33	34.5	70.3
		M. excoriata (e)	0.30	3.11	3.60	25.2
		Tricholoma sp. (e)	0.34	2.07	3.28	18.4

[a] *e* Edible, *ne* not edible

Table 3 Taxonomical classification of the sampled mushrooms in and around Izmir

Classis	Order	Family	Genus	Species	N[a]
Basidiomycetes	Agaricales	Agaricaceae	Agaricus	*A. campestris*	s
		Boletaceae	Suillus	*S. bovinus*	m
		Lepiotaceae	Macrolepiota	*M. excoriata*	s
		Russulaceae	Lactarius	*L. semisanguifluus*	m
			Lactarius	*L. delicious*	m
			Russula	*R. delica*	m
		Tricholomataceae	Clitocybe	*C. bresadoliana*	s
			Tricholoma	*T. terreum*	m
			Lepista	*L. nuda*	s
	Aphyllophorales	Telephorales	Sarcodon	*S. scabrosus*	m

[a] Type of nutrition (N): (m) mycorrhizal fungi, (s) saprophytic fungi

(kg m^{-2}) for each of the soil layers was estimated such that the soil density (kg m^{-3}) is multiplied by the depth, from the surface down to midpoint of each layer. The bulk density (kg m^{-3}) of all soil samples was determined as the ratio of weight after drying to fresh soil volume as described by McGee et al. [30, 31]. All measured soil and

mushroom activities were corrected for radioactive decay to the sampling date for ^{137}Cs.

Agrochemical analyses of the soil samples were conducted according to standard methods as described by Schlichting et al. [32]; Jackson [33] and Black [34] adopted in the Ege University, Faculty of Agriculture, Department of Soil Science. For each sample, nine relevant soil parameter values were determined, i.e., content of organic matter (%), clay content (%), K (%), sand (%), $CaCO_3$ (%), soil acidity (pH), N, silt, salt, texture.

Alkali–alkaline earth element and heavy metal determinations

To determine trace elements in environmental samples, several analytical methods are available. For example, neutron activation analysis (NAA), atomic absorption spectrometry (AAS), X-ray fluorescence (XRF) and inductively coupled plasma-atomic emission spectrometry (ICP-AES) turned out to be a useful tool for the detection of many trace elements in plant and soil samples [35–38]. Recently, inductively coupled plasma mass spectrometry (ICP-MS) has been used for precise determination of trace elements in environmental samples. Due to its low detection limits, analytical speed, relative lack of chemical interferences, and multi-element capability, the method has been applied to more than 50 elements in environmental samples [39]. In the present study, major and trace elements in mushroom samples were measured by ICP-MS technique in ACME laboratory in Canada.

For ICP-MS analysis, mushroom and soil samples were dried at 60 °C. Soil samples were sieved to −80 mesh and mushroom samples were pulverized. Mushroom samples of 1 g were weighed into centrifuge vials, and soil samples of 0.5 g were weighed into test tubes. Mushroom samples were first cold leached with concentrated nitric acid for 1 h then digested in a hot water both for an additional hour. After cooling a modified Aqua Regia Solution of equal parts concentrated ACS grade HCl and HNO_3 and demineralized H_2O was added to each sample (6 mL g^{-1}) to leach in a hot-water bath (~95 °C) for 2 h (for mushroom sample) or for 1 h (for soil sample). After cooling the solution was made up to a final volume with 5% HCl than filtered. Sample weight to solution volume ratio were 1 g per 20 mL for mushroom and 0.5 g per 10 mL for soil. Solutions aspirated into a Perkin Elmer Elan 6000 ICP mass spectrometer were analyzed for the Full package comprising 51 elements. Duplicate sample preparation and measurement were done for each sample. Two standard reference materials were used to validate the analytical procedure and certified against CANMET Reference Materials for analyzed elements. A mixture of soil and rock material (STD DS5) was used for soil as Standard Reference Material. For mushroom analyses STD V6, made from jack pine (*Pinus banksiana*), mostly twig tissue with a minor component of needles was used.

Calculation of transfer parameters

The soil-mushroom transfer factors or concentration ratios for a radionuclide are frequently defined as the ratio between the activity of this radionuclide in the fruitbodies and that in the soil. The transfer of a radionuclide from soil to fungal fruitbodies of selected species has been estimated by calculating both the transfer ratio "TF" (the traditional transfer factor) and the aggregated transfer parameter "T_{agg}", where;

$$\mathrm{TF} = \frac{\text{Radionuclide concentration in fruitbodies Bq kg}^{-1}\text{ (dry wt.)}}{\text{Radionuclide concentration in soil Bq kg}^{-1}\text{ (dry wt.)}} \quad (1)$$

$$T_{agg}\ (\mathrm{m^2\ kg^{-1}}) = \frac{\text{Radionuclide concentration in fruitbodies Bq kg}^{-1}\text{ (dry wt.)}}{\text{Total radionuclide deposition in soil Bq m}^{-2}\text{ (dry wt.)}} \quad (2)$$

For agricultural soils, which are characterized by a more or less homogeneous distribution in soil of the investigated radionuclide, the transfer factor, where the specific activities of the mushroom and the soil are both expressed in Bq kg^{-1} air dry soil, is frequently used. The situation, however, is different in the case of semi-natural environments, such as forests, meadows or peatlands, where soil is characterized by layers or so-called horizons with different fallout radionuclide activity levels. Here, because the multi-layered character of forest soils in which bulk density, chemical properties and the distribution of root systems (including mycelia) are highly heterogeneous, the vertical distribution of a radionuclide in the root zone is, even many years after its deposition, usually quite inhomogeneous and the dry weight density of these soils can vary greatly, especially if organic soils are considered [40, 41 and references therein]. For these ecosystems the aggregated transfer factor T_{agg}, defined as the ratio of the radionuclide activity concentration in a mushroom sample (Bq kg^{-1}, air-dry weight) to the radionuclide soil deposition at the forest site where mushrooms were collected (in Bq m^{-2}), is usually proposed. T_{agg} value defines the fraction of radionuclide activity deposited on a square meter transferred to 1 kg of mushroom fruit body dry matter [6].

According to what is taken to be the activity of the soil, such as the activity deposited on the surface layer, the total specific activity, or the activity of a particular layer (depth-specific measurements), a major dispersion of the reported transfer factors can be found in the literature (Table 1) and

this situation makes it difficult to compare the transfer parameters among different studies. Therefore, although it is more valid to express the T_{agg} values in the studies on forest ecosystem, the traditional transfer factors were also presented in this study.

Statistical analysis

All statistical evaluations were carried out with SPSS 8.0 version. Statistical analyses for possible significant correlations between the parameters were performed with non-parametric Spearman rank correlation analysis. The frequency distribution of data sets was tested against a normal or lognormal distribution by the Kolmogorov–Smirnov test (significance level $p > 0.05$).

Results and discussion

Soil-to-mushroom relationship of ^{137}Cs and ^{40}K

Because of quantification of the radionuclide uptake of a plant from the soil by transfer factors is only meaningful if a linear relation between the radionuclide concentration in the soil and the plant exists [40] and previous studies show that ^{137}Cs and ^{40}K activity concentration in soil can be an influencing factor on ^{137}Cs levels in plants [19], the relationship between the ^{137}Cs and ^{40}K activities in soil and in mushrooms was examined. In order to investigate the presence of a possible correlation, the Spearman rank correlation coefficients (r_{sp}) were calculated for both activity concentration and deposition in soil. The four correlation analyses performed and the results are given below as follows: (1) ^{137}Cs activity of mushrooms versus ^{137}Cs activity concentration of soil; (2) ^{137}Cs activity of mushroom versus ^{137}Cs activity deposition of soil; (3) ^{40}K activity of mushrooms versus ^{40}K activity concentration of soil; (4) ^{40}K activity of mushrooms versus ^{40}K activity deposition of soil. Using the complete data set, significant relationship was found ($r_{sp} = 0.756$, $p < 0.01$) between the ^{137}Cs activity of mushrooms and ^{137}Cs activity concentration of soil. There is not a statistically significant relationship between the ^{137}Cs activity of mushroom and ^{137}Cs activity deposition of soil; between the ^{40}K activity of mushrooms and ^{40}K activity concentration of soil; between the ^{40}K activity of mushroom and ^{40}K activity deposition of soil at the 90% or higher confidence level. Nevertheless it must be pointed out that failure to detect a significant correlation between two quantities does not necessarily imply that such a correlation does not exist as mentioned recent publications [19 and references therein].

In addition, the relationships between the ^{137}Cs activity of mushrooms versus ^{40}K activity concentration of soil and ^{137}Cs activity of mushrooms versus ^{40}K activity deposition of soil were also investigated. Although there is not a correlation between ^{40}K and ^{137}Cs activity in mushroom species, statistically significant negative correlations were found both ^{137}Cs activity of mushrooms versus ^{40}K activity concentration of soil ($r_{sp} = -0.767$) at the $p = 0.01$ level, and ^{137}Cs activity of mushrooms versus ^{40}K activity deposition of soil ($r_{sp} = -0.854$) at the $p = 0.01$ level.

Transfer factors (TF) and aggregated transfer factors (T_{agg}) for ^{137}Cs and ^{40}K

Based on the evidence that mushrooms take up radiocesium and stable cesium from organic layers of forest soil [42, 43] and on the results of our studies which showed that most of radiocesium in Turkish forest soil is located in organic layers [44], transfer factors for ^{137}Cs and ^{40}K were calculated according to Eqs. 1 and 2 for the investigated species, according to the total organic layer.

Transfer factors (TF) and aggregated transfer factors (T_{agg}) for ^{137}Cs and ^{40}K, both the mass concentration averaged over the soil column (Bq kg^{-1} d.w.) and the area concentration (or deposition density, Bq m^{-2}) for some mushroom species, collected in areas with different soil properties are presented in Table 2. The results given in Table 2 shows significant difference in the transfer factors (TF) and aggregated transfer factors (T_{agg}) for ^{137}Cs and ^{40}K not only for mushrooms with different nutritional status, but also for mushrooms, belonging to different genera and families. The results for ^{137}Cs and ^{40}K were within the range of variation reported in previous studies (Table 1) and the most efficiently transferred radionuclide was ^{40}K. While the species of mushroom that presented the highest TF for ^{137}Cs was *S. scabrosus*, for ^{40}K was *L. nuda*. Because all the fungus species have TF and T_{agg} for ^{40}K greater than unity, it seems to indicate that potassium is essential for fungi.

Table 4 lists the statistical data (median, mean value, standard error of mean, standard deviation, range, skewness and kurtosis) and the type of frequency distributions of transfer factors (TF) and aggregated transfer factors (T_{agg}) for ^{137}Cs and ^{40}K. Figure 1 shows the fits made to the empirical frequency distributions, taking into account the values obtained for skewness and kurtosis coefficient. Given the approximate null value of the skewness coefficient obtained for transfer factors (TF) and aggregated transfer factors (T_{agg}) of ^{40}K, this distribution is practically symmetrical as can be seen in Fig. 1b–d, while the positive values obtained in the statistics of the transfer factors (TF) and aggregated transfer factors (T_{agg}) for ^{137}Cs indicate that the distribution is asymmetric with the right tail being longer than the left, as can be seen in Fig. 1a–c. The fact that the kurtosis coefficient values of transfer factors (TF)

Table 4 Summary statistics for the transfer factors (TF) and aggregated transfer factors (T_{agg}) for ^{137}Cs and ^{40}K

	TF (^{137}Cs)	TF (^{40}K)	T_{agg} (10^{-3} m^2/kg) (^{137}Cs)	T_{agg} (10^{-3} m^2/kg) (^{40}K)
Median	0.19	2.26	1.51	16.9
Arithmetic mean ± SEM	0.56 ± 0.17	2.66 ± 0.27	5.87 ± 1.92	23.26 ± 3.90
SD	0.81	1.37	9.42	19.51
Geometric mean	0.28	2.32	1.86	15.19
CV (%)	145	51	160	84
GCV (%)	289	59	506	128
Range	0.06–3.15	0.67–5.68	0.19–34.5	2.20–70.30
Skewness	2.415	0.513	2.119	0.805
Kurtosis	5.443	−0.782	3.720	−0.312
Frequency distribution	Log-normal	Normal	Log-normal	Normal

Median, arithmetic mean, standard error of arithmetic mean (SEM), standard deviation (SD), geometric mean (GM), coefficient of variation (CV), geometric coefficient of variation (GCV), range and skewness, kurtosis of the frequency distributions for the transfer factors (TF) and aggregated transfer factors (T_{agg}) for ^{137}Cs and ^{40}K

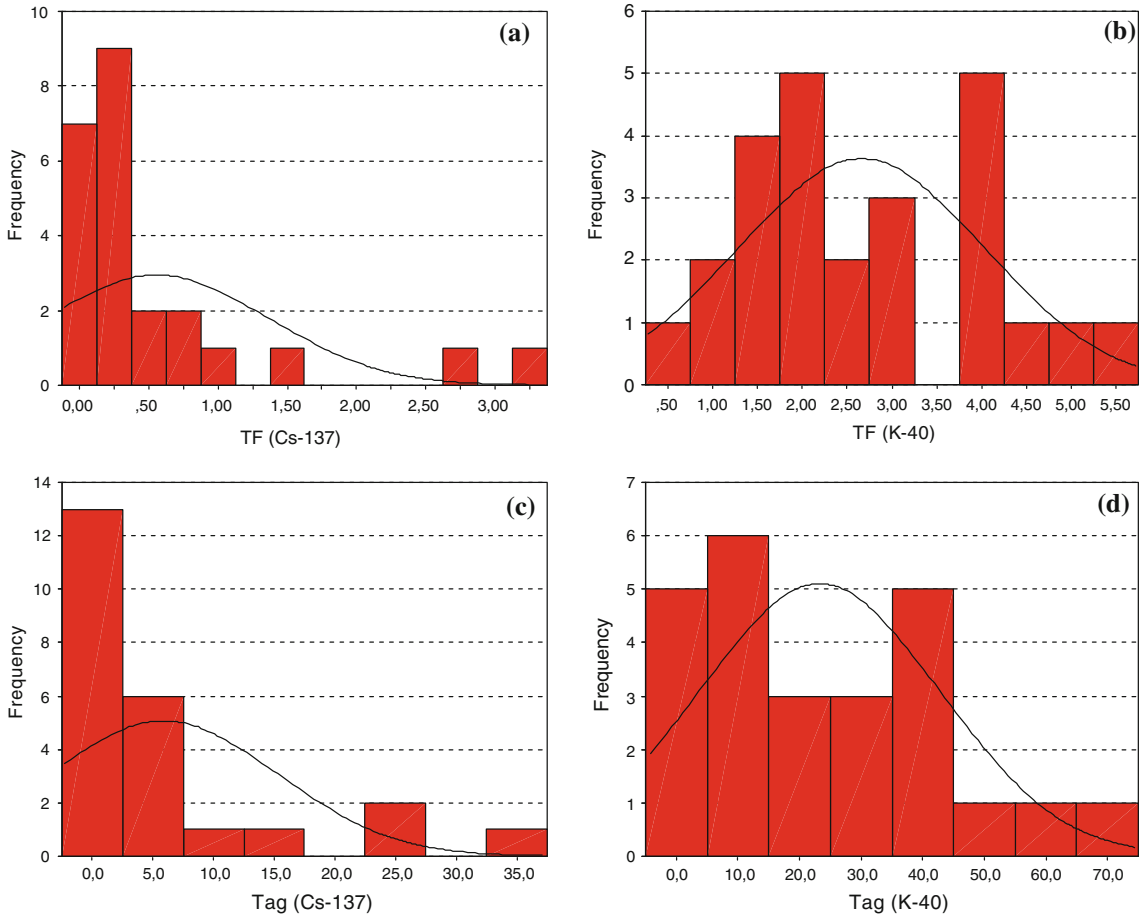

Fig. 1 Frequency distributions of **a** TF (^{137}Cs), **b** TF (^{40}K), **c** T_{agg} (10^{-3} m^2/kg) (^{137}Cs) and **d** T_{agg} (10^{-3} m^2/kg) (^{40}K) for different species of mushrooms analyzed. Also shown are fits of transfer factors (TF) and aggregated transfer factors (T_{agg}) for ^{137}Cs and ^{40}K to a log-normal distribution or a normal distribution

and aggregated transfer factors (T_{agg}) for ^{137}Cs is positive indicates that the distribution is higher and narrower than normal.

Effect of soil characteristics on the transfer factors

It has been suggested that various factors influence the transfer of radiocaesium to fungal fruitbodies, including: mycelium depth; habitat and or sampling strategy; soil clay content; and soil moisture and or microclimate [45 and references therein]. Table 5 presents the following agrochemical soil characteristics of the investigated areas: organic matter (%), clay (%), K (%), pH, sand (%), $CaCO_3$ (%), silt (%) and salt (%). The statistical significance of the association between T_{agg}, TF values of ^{137}Cs and eight soil agrochemical characteristics was explored for mushroom samples and presented in Table 6. Relationships between ^{137}Cs transfer factors of mushrooms and most soil parameters are negative as indicated by previous studies [6]. The significant correlations are observed with silt (%) and K (%) in soil.

Transfer factors for alkali–alkaline earth elements and heavy metals

If the averaged mushroom and soil concentrations for each element are compared (Fig. 2), it is seen that the linear relationship required for the TF approach is valid. In order to estimate the accumulation of each element by mushrooms, transfer factors (TFs) from soil to mushrooms were calculated by using the element concentrations in the surface soil (total organic layer) collected in the Çinardibi and Kurudere forest sites. The calculated TFs for 8 alkali–alkaline earth elements and 11 heavy metals are summarized in Tables 7 and 8. The results are within the range of variation reported in previous studies except for Zn [15, 16, 39]. According to the concentration ratios that higher than 1, the most efficiently transferred elements seems to have

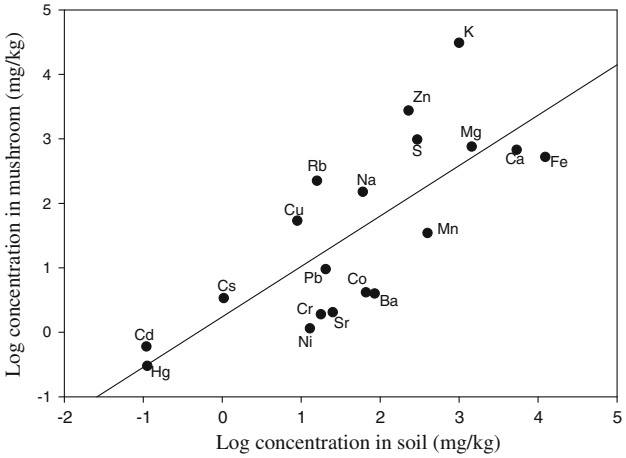

Fig. 2 Relationship of mean mushroom concentration to mean soil concentration for studied elements in Çinardibi forest site. Also shown is best-fit line ($r = 0.760$, significance level: $p < 0.01$)

Table 5 Agrochemical soil properties of the investigated sites, mushrooms were sampled

Site	OM (%)	Clay (%)	K (%)	pH	Sand (%)	$CaCO_3$ (%)	Silt	Salt	Soil texture
Bergama Aşağıbey	5.01	4.16	2.82	5.82	85.8	0.71	10	0.03	Loamy sand
Bornova Çiçekli	10.3	29.8	1.29	7.40	50.2	17.9	20	0.09	Sandy clay loam
Bornova Yaka	11.0	19.8	1.39	7.10	52.2	14.7	28	0.09	Sandy loam
Gölcük	8.77	1.84	2.19	5.74	82.2	0.49	16	0.03	Loamy sand
	7.33	1.84	2.48	5.90	82.2	0.57	16	0.03	Sandy clay loam
Soma Uruzlar	10.5	29.8	1.64	7.26	52.2	5.70	18	0.14	Sandy clay loam
	8.36	27.8	1.32	7.51	52.2	14	24	0.12	Sandy loam
Çınardibi	10.1	1.84	0.90	5.06	64.2	0.57	34	0.03	Sandy loam
Kemalpaşa Kurudere	9.24	7.84	2.02	6.10	70.2	0.65	22	0.04	Sandy clay loam
	10.5	11.8	1.27	6.20	64.2	0.98	24	0.03	Sandy loam

Table 6 Pair correlation coefficients between the transfer parameters (TF, T_{agg}) and agrochemical soil properties for ^{137}Cs

	OM (%)	Clay (%)	K (%)	pH	Sand (%)	$CaCO_3$ (%)	Salt (%)	Silt (%)
TF	0.251	−0.283	−0.742**	−0.495*	−0.175	−0.088	−0.343	0.740**
T_{agg}	0.286	−0.222	−0.732**	−0.440*	−0.202	−0.038	−0.282	0.737**

* $p < 0.05$; ** $p < 0.01$)

Table 7 Transfer factor (TF) values of alkali–alkaline earth elements for different mushroom species at sampling areas

	Species	Na	K	Rb	Cs	Mg	Ca	Sr	Ba
Çınardibi	*S. scabrosus*	1.32	28.091	15.2	2.98	0.42	0.056	0.040	0.027
	S. scabrosus	3.62	28.252	25.20	6.16	0.43	0.056	0.052	0.028
	L. deliciosus	2.63	31.327	6.44	0.87	0.69	0.22	0.13	0.068
	L. deliciosus	2.96	29.094	6.00	0.67	0.83	0.28	0.16	0.079
	S. scabrosus	1.81	35.566	31.89	10.59	0.63	0.11	0.084	0.055
	S. scabrosus	1.48	31.489	15.5	2.31	0.37	0.037	0.028	0.014
	L. nuda	2.47	42.362	7.00	1.64	0.40	0.11	0.068	0.043
	S. bovinus	3.78	22.945	4.38	1.059	0.42	0.13	0.092	0.058
Kurudere	*R. delica*	1.8	18.5	8.17	1.05	0.15	0.051	0.05	0.05
	R. delica	5.81	56.2	13.7	1.12	0.84	0.64	0.22	0.26
	S. bovinus	5.33	44.40	9.47	1.37	0.34	0.41	0.22	0.20
	Tricholoma sp.	3.15	51.49	2.25	0.27	0.29	0.48	0.18	0.30
	M. excoriata	1.23	31.46	0.47	0.20	0.07	0.049	0.065	0.037

Table 8 Transfer factor (TF) values of heavy metals for different mushroom species at sampling areas

	Species	Mn	Fe	S	Hg	Cr	Co	Ni	Cu	Zn	Cd	Pb
Çınardibi	*S. scabrosus*	0.056	0.027	1.03	3.54	0.07	0.065	0.055	4.89	18.54	4.54	0.15
	S. scabrosus	0.065	0.034	1.71	2.65	0.084	0.084	0.086	6.11	9.00	8.18	0.87
	L. deliciosus	0.12	0.053	6.50	1.77	0.17	0.12	0.13	6.33	13.90	3.64	0.21
	L. deliciosus	0.13	0.055	5.47	1.77	0.16	0.021	0.14	7.33	5.71	4.54	0.25
	S. scabrosus	0.10	0.066	4.45	5.31	0.14	0.10	0.14	13.2	9.87	13.6	1.066
	S. scabrosus	0.035	0.018	0.68	2.65	0.067	0.038	0.031	3.11	6.48	2.73	0.73
	L. nuda	0.083	0.035	3.76	2.65	0.062	0.036	0.0625	4.33	18.96	5.45	0.15
	S. bovinus	0.11	0.049	3.08	0.88	0.10	0.039	0.062	2.11	15.16	0.91	0.23
Kurudere	*R. delica*	0.03	0.01	2.67	5.06	0.07	0.09	0.01	0.25	3.77	3.33	0.03
	R. delica	0.15	0.15	16.53	2.06	1.11	0.32	0.63	1.86	10.6	82.5	0.09
	S. bovinus	0.096	0.111	15.75	0.51	0.24	0.16	0.18	1.29	3.87	5	0.16
	Tricholoma sp.	0.12	0.073	16.53	10.31	0.33	0.13	0.21	5.34	29.9	17.5	0.47
	M. excoriata	0.031	0.024	4.02	18.6	0.034	0.025	0.029	2.14	5.05	0.010	1.60

been K, followed by Rb, Zn, Cu, Cd, S, Cs and Hg. While the values for these elements are above the best-fit line in Fig. 2, the ratios for the others were lie below the line. It is obvious that K is an essential element that must be taken up for plants to complete their life cycles and mushrooms can be characterized as Rb, Zn, Cu, Cd and Cs accumulators as mentioned previous studies [5, 39].

Unlike other publications, the transfer factor of ^{137}Cs was lower than that of stable Cs in this study [35, 46]. Although TF for stable Cs had the higher variability depending on the mushroom species (range 0.2–10.6), the high TFs for stable Cs indicate that mushrooms are important Cs accumulators also. In addition, a good correlation between the transfer factors for ^{137}Cs and stable Cs was shown in our previous study [12]. This finding shows that about 16 years after the accident bioavailability of ^{137}Cs from Chernobyl and stable Cs is similar, at least for species taking up radiocesium from the organic layers.

Conclusion

The present study was initiated aiming at evaluating the soil to mushroom transfer parameters of ^{137}Cs, ^{40}K, some stable elements and heavy metals in 25 mushroom samples, covering 12 biological species. The following conclusions can be derived;

- Significant positive relationship was found between the ^{137}Cs activity of mushrooms and ^{137}Cs activity concentration of soil, while negative correlations were found both ^{137}Cs activity of mushrooms versus ^{40}K

activity concentration of soil and ^{137}Cs activity of mushrooms versus ^{40}K activity deposition of soil.

- Transfer factors for ^{137}Cs and ^{40}K were within the range of variation reported in previous studies and the most efficiently transferred radionuclide was ^{40}K.
- Statistics of the transfer parameters (TF and T_{agg}) indicate that the distribution is asymmetric for ^{137}Cs and symmetrical for ^{40}K.
- The influence of agrochemical properties of forest soils on ^{137}Cs transfer factors were revealed, so that the significant correlations are observed between silt and K in soil and ^{137}Cs transfer factors.
- The most efficiently transferred elements seems to have been K, followed by Rb, Zn, Cu, Cd, S, Cs and Hg.

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