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Analysis of radionuclide transfer factors from soil to plant in tropical and subtropical environments

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ABSTRACT

In this study, the factors that influence the variability of soil to plant radionuclide transfer factors (TF) in tropical and subtropical environments were statistically analyzed. More than 2700 TF values were obtained from the literature, and from this four broad soil groups and 13 plant groups were investigated. Additionally, different plant compartments were distinguished. The wide variability and uncertainty observed in TF is considerably reduced when data are independently grouped into groups of plant/plant part/soil type combinations. In most plant groups Zn and Sr have the highest transfer values. TFs are lower for Cs and the lowest TFs were found for Ra, U and Pb.

1. Introduction

The tropical zone is the area of the Earth centered on the equator and is limited in latitude by the Tropic of Cancer (northern hemisphere) and the Tropic of Capricorn (southern hemisphere). In this region, ecosystems typically consist of rainforests, dry deciduous forests, spiny forests, or deserts. The subtropical region is within the zones of the Earth immediately north and south of tropic zone (latitudes between 23.5° and approximately 40°). These areas typically have hot summers and temperate conditions for the rest of the year (with air temperatures that usually do not go below 0 °C). Subtropical areas do not usually have markedly wet or dry seasons and the rain distribution is fairly regular throughout the year.

In the past, investigations regarding radionuclide transfer have mainly been limited to temperate regions. However, in the last two decades, new data on tropical and subtropical environments have become available. Although it has been shown in many studies that there are no systematic differences between soil-to-plant transfer factors (TF) between climatic zones, some extreme values have been reported in special tropical and subtropical environments (Segalen, 1971; Wasserman, 1998). Probable reasons for these differences are:

(a) In tropical environments, almost all organic material that reaches the soil surface decomposes rapidly, and the surface accumulation of soil organic matter is therefore minimal. Consequently, there is rapid recycling of nutrients and contaminants into the vegetation. In temperate zones the decomposition of organic debris is slower, and the accumulation of soil organic matter is usually greater than the rate of decomposition, resulting in highly organic surface soil.
(b) In the tropics, due to the relatively aged soils and high mineral weathering rates, clays of low exchange activity, such as kaolinite, are more common than in temperate zones. This leads to soils that, despite having high clay content, have a low exchange capacity.

In this study, more than 2700 TF values from tropical and subtropical environments have been analysed, with the intent of exploring the variability and dependence of TFs on different soil/crop type combinations. Data were obtained from the draft version of the revised 'Handbook of Parameter Value for Predicting Radionuclide Transfer in Temperate Environments' (IAEA, 1994), from the reports of Working Group of the International Union of Radioecologists (IUR) on soil-to-plant TFs (Frissel, 1992), from published papers, books, reports, and the proceedings of conferences. Data were grouped taking into account the possible combinations of plants, plant compartments, and soil types, and then a descriptive statistical analysis was carried out.

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2. Materials and methods

The definition of TF proposed by the IUR (Frissel, 1992) has been used:

$$\mathrm{TF} = \frac{\text{Concentration of radionuclide in plant}\,(\mathrm{Bq\,kg^{-1}}\,\text{dry crop mass})}{\text{Concetration of radionuclide in soil}\,(\mathrm{Bq\,kg^{-1}}\,\text{dry soil mass in the upper 20 cm})} \qquad (1)$$

For grass, the soil depth considered is 10 cm.

In total, 2708 TF values were considered (1353 from tropical environments and 1355 from subtropical environments). Soil types were differentiated by texture. Table 1 shows the criteria adopted for defining soil type. The following plant groups were separately considered: cereals, fruits, grasses, herbs, leguminous, leafy and non-leafy vegetables, pasture, rice, root crops, tubers and maize.

2.1. Statistical analysis

For each plant group/plant parts/soil type combination, a descriptive statistical analysis was developed using Origin software (OriginLab, 2002). This includes the calculation of mean values (arithmetic (AM) and geometric (GM)), standard deviation (SD), geometric standard deviation (GSD), minimum (Min), maximum (Max) and coefficient of variation (CV = SD/AM).

The Shapiro–Wilk Normality test (Devore, 1998; OriginLab, 2002) was performed to explore the probability distribution of the data in each group. In particular, the normality distribution of the logarithm of TF was tested, using a significance level of 0.05.

Table 1
Soil groups

Soil groups	Hydrolitic acidity (pH)	% Humus	Cation exchange capacity	Clay content
Sand	3.5–6.5	0.5–3.0	3.0–15.0	<20%
Loam	4.0–6.0	2.0–6.5	5.0–25.0	20–40%
Clay	5.0–8.0	3.5–10.0	20.0–70.0	>40%
Organic	3.0–5.0	5.0–30.0	20.0–200.0	

Table 2
Principal radionuclides in tropical and subtropical database: statistical values

Rad.	Tropical					Subtropical				
	N	AM	GM	CV	DIF[a]	N	AM	GM	CV	DIF[a]
Cs	299	1.52E+00	1.97E−01	2.6	5	495	3.29E−01	5.28E−02	3.1	4
Sr	149	3.17E+00	8.43E−01	2.0	4	299	5.48E−01	1.80E−01	1.6	4
Co	104	3.34E−01	1.78E−01	1.6	2	83	2.36E−01	4.33E−02	1.4	4
Zn	133	2.22E+00	1.21E+00	1.8	2	64	1.14E+00	4.70E−01	1.7	2
Ra	282	2.46E+00	5.96E−02	4.0	5	–	–	–	–	–
U	148	2.28E−01	5.70E−02	1.3	3	–	–	–	–	–
Pb	70	1.37E−01	1.26E−02	1.6	4	–	–	–	–	–
I	–	–	–	–	–	63	3.62E−01	1.20E−02	3.8	4

[a] Differences in the order of magnitude.

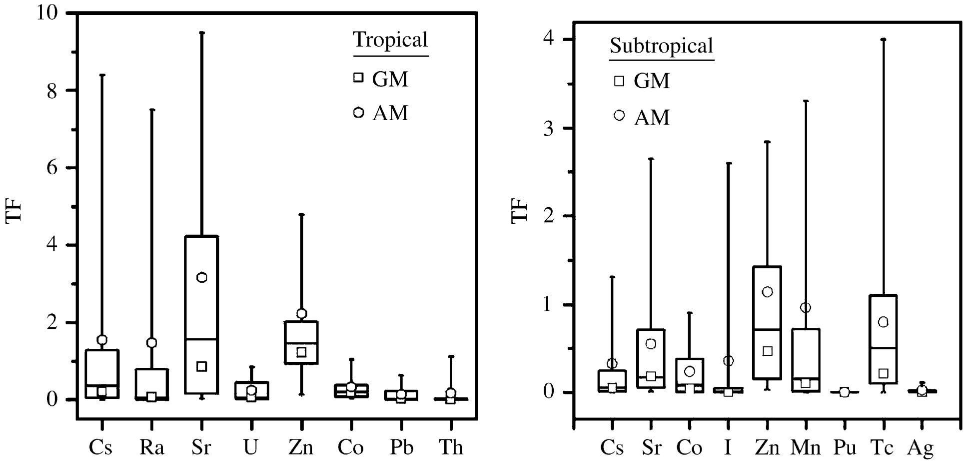

Fig. 1. Box chart representation of TF distribution in plants from tropical and subtropical environments. GM and AM indicate geometric and arithmetic mean values, respectively.

3. Results and discussion

3.1. Radionuclide dependence

Table 2 shows the TF AM and GM values for the principal radionuclides without differentiating between plant and soil types. Coefficients of variation (CV) and the differences in order of magnitude (DIF) are given. The TF values show a very wide variability. Differences in the order of a factor of 2 were found for Co and Zn, but as high as a factor of 5 for Cs and Ra. CVs are always greater than 1 and the maximum dispersion of the data was found to be for Cs (CV = 2.6) and Ra (CV = 4.0). For GM values, the following sequence was found: $TF_{Zn} > TF_{Sr} > TF_{Cs} \cong TF_{Co} > TF_{Ra} \cong TF_{U} > TF_{Pb} \cong TF_{I}$.

Fig. 1 shows, as a box chart, the TF distribution for the principal radionuclides for tropical and subtropical environments. In this figure, boxes show the 25th and 75th percentiles. The whiskers are determined by the 5th and 95th percentiles, with a coefficient of 1.5 (OriginLab, 2002). GM and AM values are also reported. In most cases, TF data are asymmetrically distributed, and, consequently, the GMs and AMs are, for the most part, different. The Shapiro–Wilk Normality test (Devore, 1998; OriginLab, 2002) was performed to explore the probability distribution of TF values for each radionuclide. In particular, the normality distribution of the logarithm of TF was tested using a significance level of 0.05. It was found that TF is log-normally distributed. Additionally, considering separately the TF values for tropical and subtropical environments, the test indicates statistically significant differences for Cs, Sr, Zn and Co.

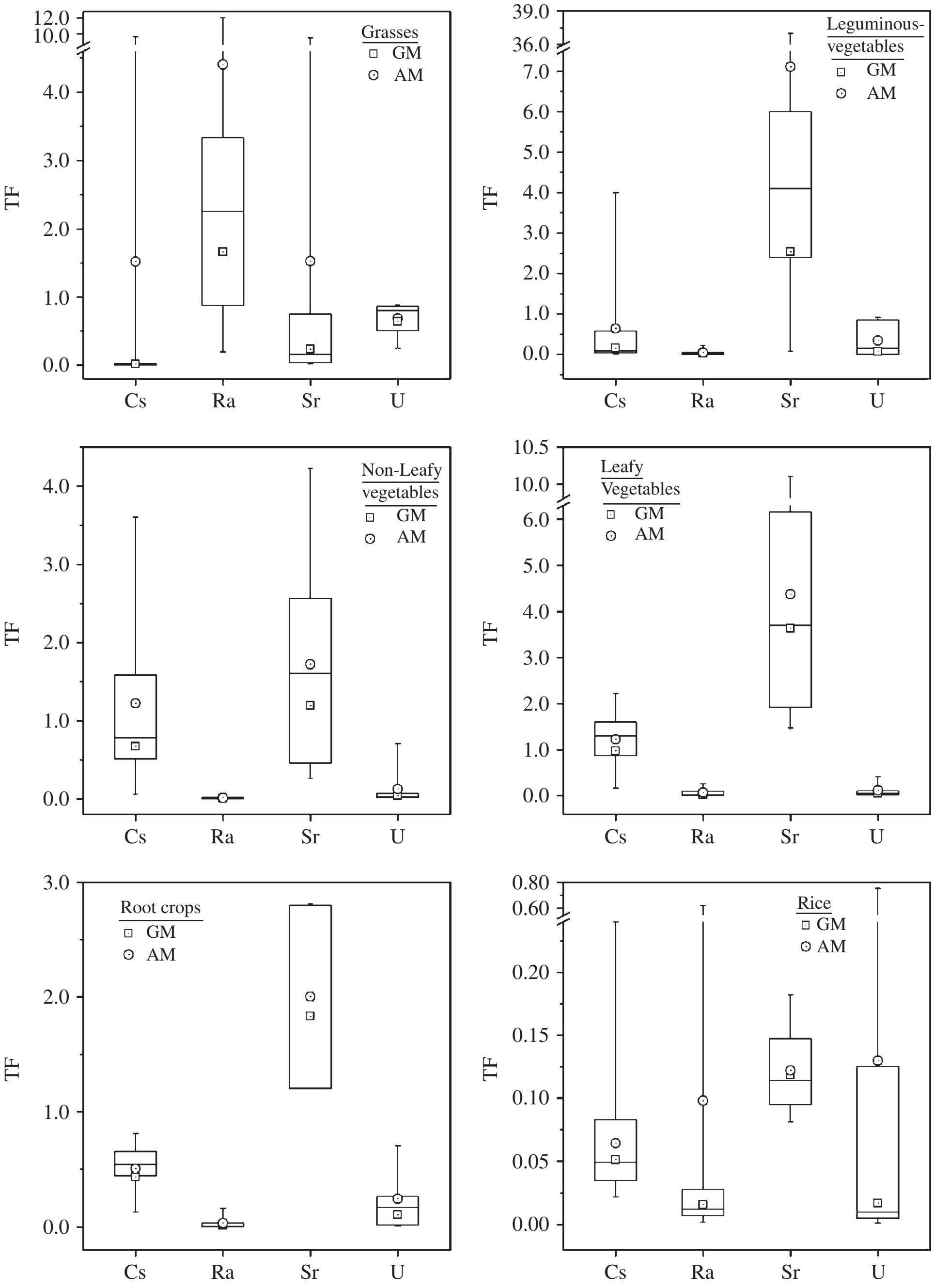

Fig. 2. Box chart representation of TF values for different plant groups. Geometric (GM) and arithmetic (AM) mean values are also presented.

3.2. *Influence of plant group*

The distribution of TF for some plant groups was examined. Fig. 2 shows, by means of box charts, TF distributions of the main radionuclides for six plant groups. Fig. 3 shows, by means of box charts, TFs for radiocaesium for all the plant groups considered. When the plant groups were separately analyzed, the variability in TF was markedly lower, with most combinations demonstrating

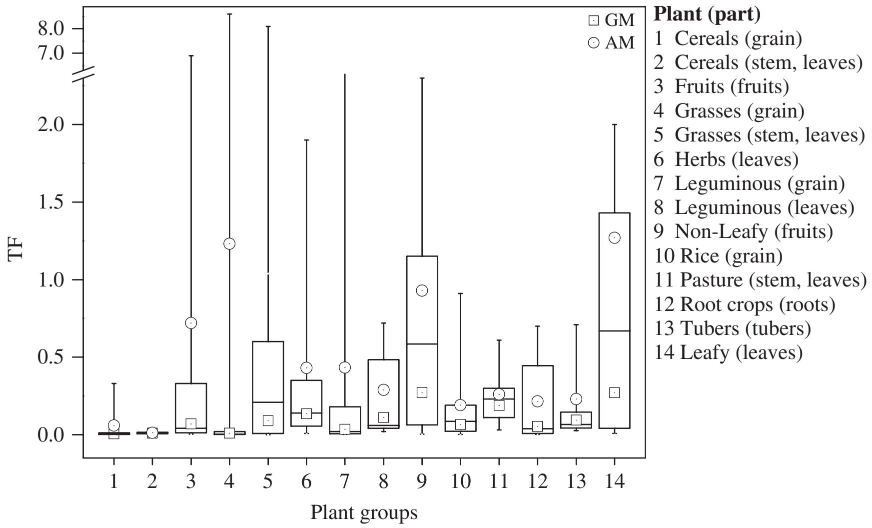

Fig. 3. Box chart representation of TF for Cs for the different plant groups. GM and AM indicate geometric and arithmetic mean values, respectively.

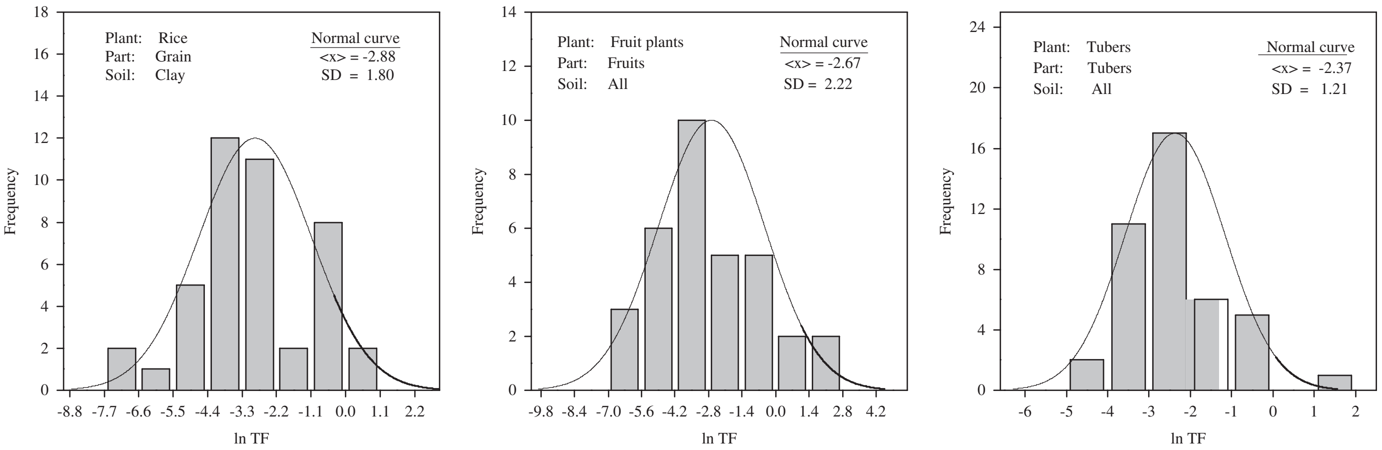

Fig. 4. Histograms of the logarithm of radiocaesium TF for the different plant/plant part/soil combinations. The curves represent the normal distribution probability with the indicated parameter values.

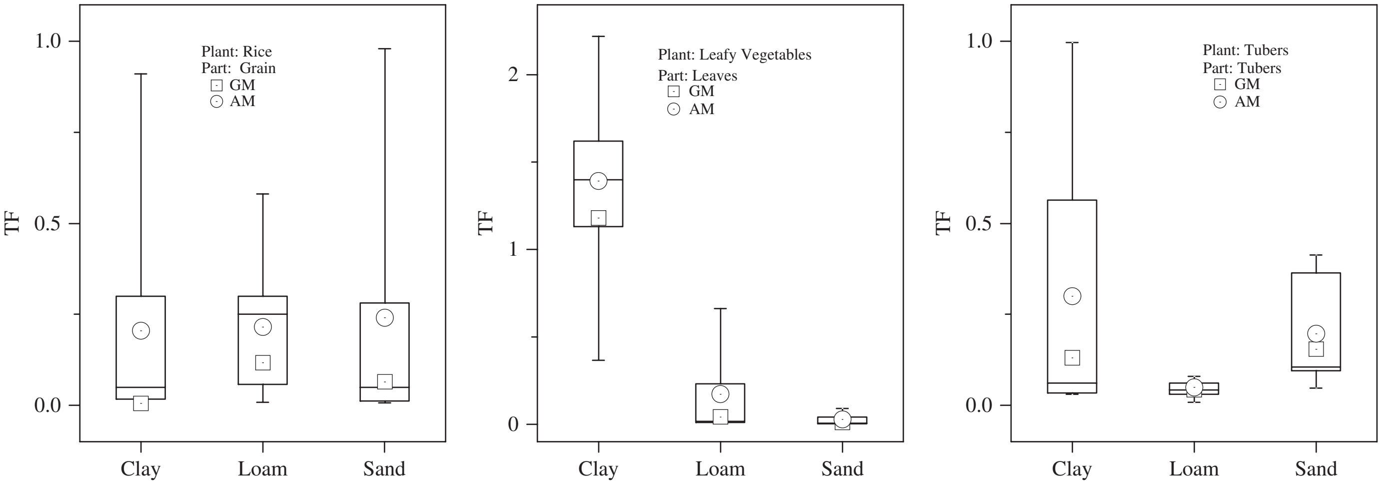

Fig. 5. Box chart representation of radiocaesium TF values for three plant groups. Different soil types are separately considered. Geometric (GM) and arithmetic (AM) mean values are represented.

a CV value of less than 1. For most plant groups, Zn and Sr have the highest TF, values with Ra and U having the lowest TF values. Leguminous and leafy vegetables have the largest TF values. For grains, particularly rice, the TF values are noticeably less. For radiocaesium it was found that non-leafy and leafy vegetables, pasture and leguminous plants and herbs have the highest TF values (order of magnitude from 0 to -1). Grasses, fruits and tubers have intermediate TF values (order of magnitude from -1 to -2), while grains (cereals, rice and leguminous vegetables) have minimum TF values (order of magnitude from -2 to -3).

The probability distribution of TF values was examined. In many cases, for different plant/plant part/soil combinations, it was found that a lognormal distribution fitted the point distribution. The Shapiro–Wilk Normality test (Devore, 1998; OriginLab, 2002) was performed to explore the probability distribution of the data in each group. The normality distribution of the logarithm of TF was tested using a significance level of 0.05. The results of the test are shown in the right column of Table 2. (In this table, *yes* indicates that the logarithm of TF is normal; in other words, TF is log-normally distributed.)

As an example, Fig. 4 shows, for radiocaesium, the ln(TF) frequency histogram for rice, fruits, and tubers. Normal curves are shown using mean and standard deviation values calculated from the logarithm of the data.

In Fig. 5, the values of TF obtained for three plant/plant part groups are shown, distinguishing the data obtained for different soil types. For rice, in spite of the TF GM being lower in clay soil, no significant differences in TF distribution were observed for the different soil types. Leafy vegetable TF values from clay soil demonstrate a larger transfer factor than loam and sand soils. In the case of tubers, in spite of TF GM values having the same order of magnitude, the variability is markedly different: clay soil presents the greatest variability ($CV = 1.2$), followed by sand soil ($CV = 0.7$)), and finally loam soil ($CV = 0.5$).

4. Conclusions

More than 2700 TF values from tropical and subtropical environments have been statistically analyzed with the purpose of exploring the influence of crop types and soil properties on radionuclide uptake by plants. Various radionuclides were examined; however, most information was found for the radioisotopes of Ra, Cs, Sr, U and Co.

The main results obtained are as follows:

- A wide TF value variability was found for all radionuclides when plant and soil groups were not distinguished. CV values ranged from 1.6 (Pb and Co) to 4.0 (Ra). The difference in the order of magnitude of TF value ranged from 2 (Co and Zn) to 5 (Cs and Ra).
- When different plant group/plant part combinations are considered, TF value variability is markedly lower. For most combinations, CV is less than 1.
- It was found that, for many combinations, TF values are reasonably fitted by a log-normal probability distribution.
- In most plant groups Zn and Sr have the highest TF values. Ra and U have low TF values, and the TF is lowest for Th. A relatively high TF was found for Ra in grasses. TFs for Cs have intermediate values.
- Leguminous and leafy vegetables have the highest TF values, while for grains, particularly rice, transfer factors are lower.
- Soil type seems not to have a decisive influence on TF values. Only the Cs TF value in tubers grown in sand soil has a noticeably higher value than TF values obtained in clay and loam.

Acknowledgments

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