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Soil–Plant Transfer of Radionuclides in Non-temperate Environments

Report of Working Group 4
Transfer Processes and Data
for Radiological Impact Assessment
Subgroup 3 on Non-temperate Data

IAEA Programme on Modelling and Data for Radiological Impact Assessments (MODARIA II)

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SOIL–PLANT TRANSFER OF RADIONUCLIDES IN NON-TEMPERATE ENVIRONMENTS

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IAEA-TECDOC-1979

SOIL–PLANT TRANSFER OF RADIONUCLIDES IN NON-TEMPERATE ENVIRONMENTS

REPORT OF WORKING GROUP 4 TRANSFER PROCESSES AND DATA FOR RADIOLOGICAL IMPACT ASSESSMENT SUBGROUP 3 ON NON-TEMPERATE DATA

IAEA PROGRAMME ON MODELLING AND DATA FOR RADIOLOGICAL IMPACT ASSESSMENTS (MODARIA II)

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FOREWORD

Activities such as the operation of nuclear installations, the production, transport and use of radioactive material, the management of radioactive waste, and the management of naturally occurring radioactive materials residues from uranium mining are subject to safety standards. Radiological environmental impact assessments for these types of nuclear facilities and activities are part of the authorization process and, when applicable, part of a governmental decision making process. The safe, sustainable planning and operation of facilities and activities are supported by relevant data used in these impact assessments.

In 1994, the IAEA published its first compilation of radioecological data in terrestrial ecosystems in the Handbook of Parameter Values for the Prediction of Radionuclide Transfers in Temperate Environments (Technical Reports Series No. 364), developed in cooperation with the International Union of Radioecology. A subsequent coordinated research project, carried out in 1993–1997, provided transfer parameter values in tropical environments. Under the IAEA's Environmental Modelling for Radiation Safety (EMRAS) programme, newly available data were incorporated into the existing datasets. The extended set of transfer parameter data was published in Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Terrestrial and Freshwater Environments (Technical Reports Series No. 472) and Quantification of Radionuclide Transfer in Terrestrial and Freshwater Environments for Radiological Assessments (IAEA-TECDOC-1616) and included mainly data for temperate regions and limited information for tropical and arctic environments.

The development of nuclear industries and uranium mining activities in both tropical and arid environments highlighted the need for appropriate and reliable default values for transfer parameters in radioecological models for these environments. The data from temperate environments and associated models may not be directly applicable to non-temperate environments and could influence both the reliability of associated radiological environmental impact assessments and the effectiveness of remedial actions. Therefore, further data were collated under the IAEA's Modelling and Data for Radiological Impact Assessments II (MODARIA II) programme, which focused on the soil to plant transfer for tropical and arid environments. The supplementary files available on-line provide descriptions and summaries of the activities undertaken within the framework of the coordinated research project carried out in 1993–1997 by each individual participating research group, including the agreed experimental protocol.

The IAEA officer responsible for this publication was A.R. Harbottle of the IAEA Environment Laboratories.

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1. INTRODUCTION

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Radiological environmental impact assessment (REIA) is required to evaluate the radiological risks associated with releases of radionuclides to the environment, both for supporting decision making during normal operation of nuclear facilities and for management and remediation of areas affected by enhanced levels of radioactivity. Following the release of radionuclides to the environment, radiation exposure of members of the public are assessed using models describing transfer of radionuclides through different ecosystems and compartments of the environment [1.1]. Such models serve as a key element of the regulatory control of nuclear facilities and activities in planned, existing and emergency exposure situations. The reliability of such models depends on a well-informed description of the environmental conditions and on high quality data that can be applied to represent radionuclide transfer through the environment.

For many years, the IAEA has supported the development of models for REIA for members of the public and has provided guidance on appropriate application of these models [1.1, 1.2]. The IAEA has coordinated the collation of appropriate datasets to quantify the transfer of radionuclides in the terrestrial and aquatic environment [1.3–1.6]. Extensive data collation has been carried out in the framework of the international model test and comparison programmes comprising: Biosphere Modelling and Assessment (BIOMASS) in 1996–2002, Environmental Modelling for Radiation Safety (EMRAS I and II) in 2003–2007 and 2009–2011 and Modelling and Data for Radiological Impact Assessments (MODARIA I and II) in 2012–2015 and 2016–2019. As one of the many outputs of these programmes, the "Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Terrestrial and Freshwater Environments" [1.4] was published which serves as a key document for many IAEA Members States when performing REIA for facilities and activities to ensure compliance with the IAEA Safety Standards [1.7, 1.8].

The IAEA programme MODARIA II addressed the following topics: (a) Assessment and decision making of existing exposure situations for NORM and nuclear legacy sites (Working Group 1); (b) Assessment of exposures and countermeasures in urban environments (Working Group 2); (c) Assessments and control of exposures to the public and biota for planned releases to the environment (Working Group 3); (d) Transfer processes and data for radiological impact assessment (Working Group 4); (e) Exposure and effects to biota (Working Group 5); (f) Biosphere modelling for long term safety assessments of high level waste disposal facilities (Working Group 6); (g) Assessment of fate and transport of radionuclides released in the marine environment (Working Group 7) [1.9].

Working Group 4 focused on transfer processes and data for radiological impact assessment and comprised the work of three subgroups, i.e. Subgroup 1, which continued the work under the MODARIA I programme on improving the K_d values in soils, freshwater and marine environments (technical document under preparation); Subgroup 2, which compiled radioecological data following the accident at the Fukushima Daiichi Nuclear Power Plant [1.9]; and Subgroup 3, which focused on improving the availability of reference transfer parameter datasets for non-temperate environments (arid and tropical). This publication summarises the work of Subgroup 3 on Transfer in non-temperate environments.

1.1. BACKGROUND

Transfer parameter data are essential inputs to models for REIA and are used to quantify the extent of movement of radionuclides from one environmental compartment to another. International data compilations have been frequently used by regulators and researchers when site-specific data were not available.

Significant work has been undertaken within IAEA programmes in compiling transfer parameter data for human food-chains [1.3–1.6] for use in REIA. A key source of such data is the "Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Terrestrial and Freshwater Environments" [1.4], published as Technical Reports Series No. 472 (TRS 472). The handbook compiles data for a variety of transfer parameters, including the root uptake of radionuclides by crops from soils which is reported in this document. Most of the root uptake data in TRS 472 [1.4] are for temperate environments. Only a small amount of data is available for tropical and subtropical environments and there are no data for arid environments. Although TRS 472 presents data according to different climate types, it does not follow a specific climate classification system.

The dependence of transfer parameter values on climatic factors with their specific environmental, agricultural and managerial features is well known. Key factors influencing the process of radionuclide transfer to humans from crops include the chemical and physical characteristics of soils, agricultural practices used, crop types and dietary habits. Such factors can vary with climatic region and it is therefore appropriate to collate adequate transfer data for non-temperate environments as well as temperate environments. Furthermore, there has been no previous international effort to collate such data for arid areas in different parts of the world or to develop site-specific assessment methodology for such environments.

Since the publication of TRS 472 [1.4] and IAEA-TECDOC-1616 [1.6], a significant number of new data on root uptake of radionuclides by crops in tropical environments have become available, and a revision of the existing tropical dataset was considered timely. Also, the need for such data in arid environments is emphasized by the current lack of any international compilation relevant to arid environments, the rise in global temperatures that has led to increasing arid and desert-like areas in many parts of the world [1.10] and the development of nuclear power in a number of arid countries [1.11].

The activities of the Non-temperate Subgroup focused on further developing the TRS 472 transfer parameter data for root uptake by crops in tropical environments and on providing the first international compilation of such data arid/semi-arid environments, classifying the data according to an international climate classification scheme [1.12]. This document describes the work of the Non-temperate Subgroup and presents the newly compiled datasets for tropical and arid environments. The dataset for arid/semi-arid environments was produced by the subgroup in coordination with the International Union of Radioecology (IUR) Task Group on radioecology in arid regions.

1.2. OBJECTIVE

The aim of this publication is to provide IAEA Member States with information on radionuclide transfer in tropical and arid environments to support the application of models and approaches for REIA. The information is intended to support national authorities meet the requirements of the International Basic Safety Standards [1.8] and associated guidance on REIA for facilities and activities [1.7].

The objectives are:

(1) To provide an enhanced (relative to TRS 472 [1.4]) dataset of transfer parameter values for root uptake of radionuclides by crops from soils in tropical environments;
(2) To compile the first international dataset of transfer parameter values for root uptake of radionuclides by crops from soils in arid environments;
(3) To compare the newly compiled data for tropical and arid environments to those presented in TRS 472 [1.4] for temperate environments to explore the possible effect of climate on root uptake.

1.3. SCOPE

This publication covers radionuclide transfer in tropical and arid environments with a focus on root uptake by crops from soils. The data collected and analysed are relevant for estimating the transfer of radionuclides through food chains to humans and for assessing radiation doses to the public due to intakes of radionuclides in plant products used as food. The data relate to equilibrium conditions between the radionuclide's dynamics into and out of the compartments of the environment and are appropriate for REIA in planned and existing exposure situations where such conditions have been established. Moreover, this publication classifies the data according to an international climate classification scheme [1.12] and compares the summary values derived for tropical and arid environments with those presented in TRS 472 [1.4] for temperate environments.

1.4. STRUCTURE

This publication consists of five Chapters, four Appendices and 16 Annexes[2]. General information and an overview on the approach for data compilation and analysis is given in Chapter 2, including criteria for data selection. Chapter 3 provides a comprehensive revision of TRS 472 root uptake data in tropical environments. The first international compilation of root uptake data for crops in arid environments is presented in Chapter 4. A comparison of transfer parameter data between non-temperate and temperate environments is presented in Chapter 5. Supplementary information on the plant types and references for data included in the tropical and arid datasets is provided in Appendices I–IV. Annex I presents the means used to ensure quality of the data collected. Annexes II–III describe the protocols respectively for soil–plant and freshwater–fish for transfer parameter data determination applied by participants of an IAEA Coordinated Research Project (CRP) on "Transfer of radionuclides from air, soil and fresh water in human food chains in tropical and subtropical environments" (1993–1997). In Annexes IV–XVI, a compilation of several related studies summarizing the results of the CRP participants is presented as online supplementary material to this document. Where appropriate, data from these studies have been included in the tropical dataset.

[2] Annexes I–XVI are published online (only) as a Supplementary File to accompany this publication.

REFERENCES TO CHAPTER 1

[1.1] INTERNATIONAL ATOMIC ENERGY AGENCY, Generic Models for Use in Assessing the Impact of Discharges of Radioactive Substances to the Environment, Safety Reports Series No. 19, IAEA, Vienna (2001).

[1.2] INTERNATIONAL ATOMIC ENERGY AGENCY, Generic Models and Parameters for Assessing the Environmental Transfer of Radionuclides from Routine Releases, Safety Series No. 57, IAEA, Vienna (1982).

[1.3] INTERNATIONAL ATOMIC ENERGY AGENCY, Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Temperate Environments, Technical Reports Series No. 364, IAEA, Vienna (1994).

[1.4] INTERNATIONAL ATOMIC ENERGY AGENCY, Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Terrestrial and Freshwater Environments, Technical Reports Series No. 472, IAEA, Vienna (2010).

[1.5] INTERNATIONAL ATOMIC ENERGY AGENCY, Sediment Distribution Coefficients and Concentration Factors for Biota in the Marine Environment, Technical Reports Series No. 422, IAEA, Vienna (2004).

[1.6] INTERNATIONAL ATOMIC ENERGY AGENCY, Quantification of Radionuclide Transfer in Terrestrial and Freshwater Environments for Radiological Assessments, IAEA-TECDOC-1616, IAEA, Vienna (2009).

[1.7] INTERNATIONAL ATOMIC ENERGY AGENCY, Prospective Radiological Environmental Impact Assessment for Facilities and Activities, IAEA Safety Standards Series GSG-10, IAEA, Vienna (2018).

[1.8] EUROPEAN COMMISSION, FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR ORGANIZATION, OECD NUCLEAR ENERGY AGENCY, PAN AMERICAN HEALTH ORGANIZATION, UNITED NATIONS ENVIRONMENT PROGRAMME, WORLD HEATH ORGANIZATION, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards, IAEA Safety Standards Series No. GSR Part 3, IAEA, Vienna (2014).

[1.9] INTERNATIONAL ATOMIC ENERGY AGENCY, Environmental Transfer of Radionuclides in Japan following the Accident at the Fukushima Daiichi Nuclear Power Plant, IAEA-TECDOC-1927, IAEA, Vienna (2020).

[1.10] ZHUGUO, M., CONGBIN, F., Global aridification in the second half of the 20th century and its relationship to large-scale climate background, Science in China Series D, Earth Sci. **50** 5 (2007) 776.

[1.11] INTERNATIONAL ATOMIC ENERGY AGENCY, Nuclear Power Reactors in the World, Reference Data Series 2, IAEA, Vienna (2020).

[1.12] BECK, H.E., ZIMMERMANN, N.E., MCVICAR, T.R., VERGOPOLAN, N., BERG, A., WOOD, E.F., Present and future Köppen-Geiger climate classification maps at 1-km resolution, Scientific Data **5** 180214 (2018).

2. CONCEPTS AND DATA ANALYSIS

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2.1. CONCEPTS

2.1.1. Concentration ratio

The term concentration ratio, CR (kg/kg or L/kg), quantifies the transfer of a radionuclide from an environmental donor compartment (e.g. soil, sediment or water) to an environmental receptor compartment (e.g. plant or animal products) in different contamination scenarios under steady state conditions [2.1, 2.2]. CR is a key transfer parameter in REIA models and is used to quantify root uptake of radionuclides and their stable analogues from soil to different compartments of terrestrial plants that are important components of the human food chain [2.3]. It has also been used to quantify radionuclide transfer to animal feed products [2.4, 2.5] and to wildlife [2.6].

The CR concept has been widely used to quantify root uptake of radionuclides by plants from soils ($CR_{\text{plant-soil}}$) and it is defined as the ratio of the radionuclide activity concentration in plants (C_{plant}, Bq/kg dry mass (DM)) to the activity concentration in soil (C_{soil}, Bq/kg DM) and is estimated as:

$$CR_{\text{plant-soil}} = \frac{C_{\text{plant}}}{C_{\text{soil}}} \quad (2.1)$$

This document presents summary values of $CR_{\text{plant-soil}}$ for crops growing in tropical and arid environments, classifying the data according to an international climate classification scheme [2.7].

Different symbols have been used in previous documents to describe the transfer of radionuclides from soil to plant. In a report of the International Commission on Radiation Units and Measurements (ICRU) the term C_r was used [2.1] whereas the symbol F_v was used in TRS 364 [2.8], TRS 472 [2.4] and IAEA-TECDOC-1616 [2.5]. The *CR* symbol is used in this publication because:

(1) The meaning of the *CR* symbol is clearer and more transparent to the reader than F_v, a symbol used in older documents;
(2) *CR* is also used for describing transfer to wildlife [2.6], thus providing consistency with other environmental pathways;
(3) *CR* is more adaptable to providing further specification and clarity regarding what is being compared (e.g, $CR_{\text{plant-soil}}$, $CR_{\text{fish-water}}$, $CR_{\text{animal product-feed}}$, etc);

(4) *CR* has become increasingly more commonly used in refereed publications and in recent IAEA publications (e.g. [2.2]).

CR values commonly used in REIA models are defined for steady state (or equilibrium) conditions. Thus, the concentrations of radionuclides or their stable analogues in environmental compartments are assumed to be constant, with no rapid changes in their concentrations in biological or physical compartments. The $CR_{\text{plant-soil}}$ datasets presented in this publication are only appropriate for equilibrium conditions. They are not applicable to non-equilibrium conditions that occur after short-term radionuclide releases to the environment, such as accidental releases or emergency exposure situations.

2.1.2. Köppen-Geiger climate classification

The Köppen-Geiger (K-G) climate classification [2.7] is one of the most widely used systems for climate classification worldwide. The K-G system classifies climate into five main classes: tropical (A), arid (B), temperate (C), cold (D) and polar (E). The classification is based on threshold values and seasonality of monthly air temperature and precipitation [2.7] and aims to map the biome distribution worldwide on the basis that different locations in a similar class share common vegetation characteristics.

Table 2.1 gives the K-G classification criteria for tropical (A) and arid (B) climates, which are the focus of this publication. An associated map of present-day (1980–2016) K-G climate classification at 1 km resolution is shown in Fig. 2.1. The criteria and map are presented according to the K-G system [2.7] and represent the latest climate classification information available when the work was undertaken.

TABLE 2.1. OVERVIEW OF TROPICAL AND ARID KÖPPEN-GEIGER CLIMATE CLASSES AND THEIR DEFINING CRITERIA (ADAPTED FROM REF. [2.7])

Symbols for climatic classes			Description	Criterion
1st	**2nd**	**3rd**		
A			TROPICAL	Not (B) and $T_{cold} \geq 18$
	f		Rainforest	$P_{dry} \geq 60$
	m		Monsoon	Not (A_f) and $P_{dry} \geq 100 - MAP/25$
	w		Savannah	Not (A_f) and $P_{dry} < 100 - MAP/25$
B			ARID	$MAP < 10 \times P_{threshold}$
	W		Desert	$MAP < 5 \times P_{threshold}$
	S		Steppe	$MAP \geq 5 \times P_{threshold}$
		h	Hot	$MAT \geq 18$
		k	Cold	$MAT < 18$

Note: MAT = mean annual air temperature (°C); T_{cold} = the air temperature of the coldest month (°C); MAP = mean annual precipitation (mm/y); P_{dry} = precipitation in the driest month (mm/month); $P_{threshold}$ =2×MAT if >70% of precipitation falls in winter, $P_{threshold}$ =2×MAT+28 if >70% of precipitation falls in summer, otherwise $P_{threshold}$ =2×MAT+14. Summer is the six-month period that is warmer) between April-September and October-March.

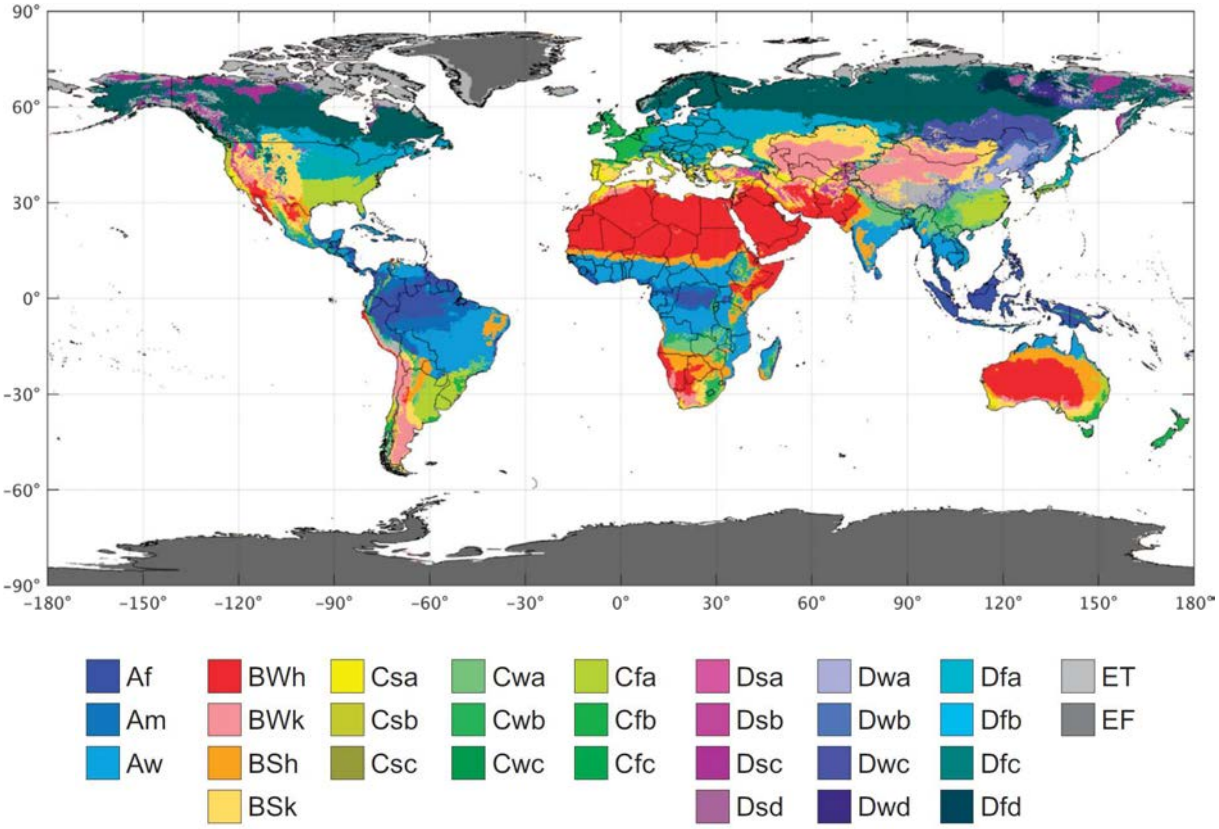

FIG. 2.1. Köppen-Geiger present-day (1980–2016) climate map after Beck et al. (2018) [2.7]).

Tropical (A) climates are divided into three subclasses: rainforest (Af), monsoon (Am) and savannah (Aw). The division is based on rainfall. Tropical rainforest (Af) has high rainfall in each month and no dry season, tropical monsoon (Am) has only a short or indistinct dry season and tropical savannah (Aw) has a pronounced dry season.

Arid (B) climates are divided into four subclasses: hot desert (BWh), cold desert (BWk), hot steppe (BSh) and cold steppe (BSk). The division between desert (arid) and steppe (semi-arid) is based on rainfall, with desert being drier than steppe. The division between hot and cold is based on air temperature.

The K-G climate classification scheme has been followed in this publication to define tropical and arid environments and to guide data selection. Only $CR_{\text{plant-soil}}$ data for locations meeting the K-G classification of tropical (A) or arid (B) climate have been included in the data compilations developed by the Non-temperate Subgroup.

2.1.3. Plant and soil classifications

Plant and soil classifications are used in TRS 472 [2.4] to distinguish between the $CR_{\text{plant-soil}}$ values for different types of crops and soils. The plant classification is based on crop type and the soil classification is based on mineral and organic matter content. This document follows the same general approach to classify plants and soils. However, some minor adjustments to the groupings have been made to account for specific features of the newly compiled data.

TABLE 2.2. PLANT GROUPS AND PLANT COMPARTMENTS USED IN THIS PUBLICATION

Plant group (and subgroups)	Plant compartment
Cereals	Grains, seeds and pods
	Stems and shoots
Maize	Grains, seeds and pods
	Stems and shoots
Rice	Grains, seeds and pods
	Stems and shoots
Leafy vegetables	Leaves
Non-leafy vegetables	Fruits, heads, berries and buds
Leguminous vegetables	Grains, seeds and pods
Root crops	Roots
Tubers	Tubers
Fruits (Woody trees, Non-woody trees, Shrubs, Herbaceous plants)	Fruits, heads, berries and buds
Grasses	Stems and shoots
Herbs	Grains, seeds and pods
	Leaves
	Rhizomes
	Roots
	Stems and shoots
	Whole plant
Medicinal plants (Woody trees, Non-woody trees, Shrubs)	Bark
	Leaves
Other crops	Cacao beans
	Coffee beans
	Peanuts

Table 2.2 lists the plant groups and plant compartments used in this publication. The species assigned to each group are listed in Appendix I for tropical environments and in Appendix II for arid environments. The group termed ‘medicinal plants’ (subdivided as shrubs, woody trees and non-woody trees) has been newly added to account for the medicinal use of certain compartments (e.g. bark and leaves) in the data collated for tropical environments (there were no medicinal plant data for arid environments). Although some species of herbs are also used for medicine, a herbs subgroup has not been included under medicinal plants since most herbs are generally also used for food or as a condiment. Instead, the primary group of ‘herbs’ is considered applicable to both the culinary and medicinal use of herbs. Within the ‘fruits’ group, a new subgroup termed non-woody trees has been added to classify crops such as banana, papaya and palm fruits. Only the subgroups of woody trees and palm trees were included under the fruits group for arid environments. A single group termed ‘grasses’ has been used to classify the data for all types of grass. This differs from TRS 472 [2.4], which classifies grasses into three separate groups: ‘grasses (cultivated species)’, ‘leguminous fodder (cultivated species)’ and ‘pasture (species mixture – natural or cultivated)’.

Table 2.3 lists the soil groups used in this publication. The primary means of classifying soils was based on the percentages of clay, sand and organic matter as specified in TRS 472 [2.4]. Soil texture information has also been considered where information on mineral and organic matter content was not available. A new soil group termed ‘coral sand’ has been added to the original soil classification scheme of TRS 472 [2.4] to account for the presence of highly calcareous soils in the data collated for tropical environments. The general characteristics of coral sand soils include high calcium carbonate concentrations, low organic matter

concentrations and a virtual absence of clay minerals which may uniquely influence radionuclide leachability and bioavailability. While in this publication, data for coral sand soils only relate to the Marshall Islands, it is anticipated that similar soils would be present on most coral atolls that fall within the within the K-G classification of tropical (A) climates. In TRS 472 [2.4], Marshall Islands soils were outside the soil classification scheme used and grouped as 'other'.

2.2. DATA ANALYSIS

2.2.1. Data collation

Separate data compilations were produced for tropical and arid environments. Both compilations followed the K-G climate classification scheme (see Section 2.1.2) to guide data selection. Only data for locations meeting the K-G classifications of Af, Am and Aw were included in the compilation for tropical environments and only data for locations meeting the K-G classifications of BWh, BWk, BSh and BSk were included in the compilation for arid environments. The compilations included data for anthropogenic and natural radionuclides and their stable analogues.

An Excel template was developed to facilitate the collation of $CR_{\text{plant-soil}}$ and associated data for tropical and arid environments. The template was distributed to all MODARIA II Working Group 4 members requesting that they populate their copy with their own data and return it to the Non-temperate Subgroup Leaders for consolidation with other sub-datasets received. As part of this process, most of the tropical data originally collated for TRS 472 [2.4] were obtained. A literature search for additional data to those received from Working Group 4 participants was also conducted by the Non-temperate Subgroup Leaders. The literature search considered published papers, book chapters, institutional reports and conference proceedings.

Table 2.4 lists the key data entry fields in the Excel template. Information against these fields was needed to identify and categorize the type of contamination, climate, soil and plant. It was also needed to calculate the $CR_{\text{plant-soil}}$. The information in each row was entered at the level of detail reported in the source references – either as individual measurement values or reported average values. Additional related information, if available, was also collated on the basis that it can help refine the data into more site-relevant subsets. This included information such as farming type and soil physicochemical characteristics.

TABLE 2.3. SOIL GROUPS USED IN THIS PUBLICATION

Soil group	Definition
Sand	Sand content ≥ 65% and clay content < 18%, or texture described as sandy
Clay	Clay content ≥ 35%, or texture described as clayey
Loam	Clay content between 18% and 35%, or texture described as loamy
Organic	Organic matter content ≥ 20%
Coral sand	Marshall Islands soils (predominance of calcium carbonate ($CaCO_3$), with some $MgCO_3$ and no silicate clay)
Unspecified	No characterization information

TABLE 2.4. KEY DATA ENTRY FIELDS IN THE EXCEL TEMPLATE USED FOR DATA COLLATION

Category	Field
General	Dataset record number
	Element
	Radionuclide
	Type of contamination (anthropogenic radionuclides, natural radionuclides, fallout radionuclides or stable isotopes)
	Köppen-Geiger climate classification
	Country
	Site name
	Experiment type (field, lysimeter or pot)
Soil	Sampling depth (cm)
	Texture
	Sand content (%)
	Silt content (%)
	Clay content (%)
	Organic matter content (%)
	Concentration value (Bq/kg or mg/kg DM)
	Concentration error (Bq/kg or mg/kg DM)
	Number of observations
Plant	Species common name
	Species Latin name
	Plant compartment
	Dry matter content (%)
	Washed or not washed
	Concentration value (Bq/kg or mg/kg DM)
	Concentration error (Bq/kg or mg/kg DM)
	Number of observations
CR	$CR_{\text{plant-soil}}$ value (DM plant and soil)
	$CR_{\text{plant-soil}}$ error (DM plant and soil)
	Number of observations
	Minimum value
	Maximum value
Quality	Measurement data quality control (proficiency tests, intercomparison exercises or reference materials)
	Sampling strategy described
	Sampling and measurement equipment described
Reference	Source reference (author, year, title, name of journal, DOI)

Source reference details were included with each row of information in the Excel template. Information relating to data quality and focusing on sampling and laboratory methodological approaches was also recorded. This included: (i) systematic sampling for plants and soils; (ii) descriptions of measurement techniques and equipment; and (iii) quality control procedures for the measurement results were applied such as participation in proficiency tests and use of reference materials for internal validation of results.

All data were evaluated by the Non-temperate Subgroup Leaders to ensure they met the K-G criteria for tropical (A) or arid (B) climates. Data not meeting the criteria were removed, including some of the tropical data originally collated for TRS 472 which fell under the K-G classification of humid subtropical (Cfa). The data compilations were also screened for duplicate entries and transcription errors.

2.2.2. Data treatment approaches

Soil sampling procedures varied between studies and did not always conform to the standard depth recommended in TRS 472 of 10 cm for grasses and 20 cm for all other crops [2.4]. Data for fallout radionuclides (e.g. ^{137}Cs and ^{90}Sr) not meeting these standard soil depths were excluded from the analysis due to possible migration and mixing of these radionuclides within the soil profile over time which may invalidate the resulting $CR_{\text{plant-soil}}$.

Some source references reported both a $CR_{\text{plant-soil}}$ and the associated plant and soil concentrations, so it was possible to confirm that the reported $CR_{\text{plant-soil}}$.was consistent with the data. If the $CR_{\text{plant-soil}}$ estimated from the plant and soil concentrations was more than a factor of 2 higher or lower than the reported $CR_{\text{plant-soil}}$, then a transcription error, rather than a rounding error, may have occurred within the source reference and the data were rejected from the analysis.

Values that were below detection limits were entered into the Excel template, but not used in the analyses. Use of below detection limit values could bias the $CR_{\text{plant-soil}}$.

Some source reference gave plant and soil concentrations but did not directly report $CR_{\text{plant-soil}}$ values. In such cases, the $CR_{\text{plant-soil}}$ was derived from the concentration data and the associated uncertainty ($\Delta CR_{\text{plant-soil}}$) was estimated as:

$$\Delta CR_{\text{plant-soil}} = CR_{\text{plant-soil}} \times \sqrt{\left(\frac{\Delta C_{\text{plant}}}{C_{\text{plant}}}\right)^2 + \left(\frac{\Delta C_{\text{soil}}}{C_{\text{soil}}}\right)^2} \quad (2.2)$$

where:

C_{plant} is the plant concentration of the radionuclide (Bq/kg DM) or stable isotope (mg/kg DM);
C_{soil} is the corresponding soil concentration of the radionuclide (Bq/kg DM) or stable isotope (mg/kg DM);
ΔC_{plant} is the uncertainty in the plant concentration (Bq/kg DM or mg/kg DM);
ΔC_{soil} is the uncertainty in the soil concentration (Bq/kg DM or mg/kg DM).

Plant data were entered into the Excel template on a DM basis. Conversion of plant data from fresh mass (FM) to DM was only necessary in a few cases and used site-specific information on DM content if available in the source reference. If DM content information was not given in the source reference, then default values from TRS 472 (specifically Tables 82 and 83) [2.4] were used to make the conversion.

Calculation of summary values used DM plant data for all plant groups except fruits, which used FM plant data, as consumption data for fruits are usually given as FM [2.4]. The conversion of fruit data from DM to FM used specific information on DM content if available in the source reference, otherwise a DM content of 20% has been assumed [2.4].

A small amount of data from pot and lysimeter experiments were included in the compilations. These data were only used in the calculation of summary values if corresponding data from field experiments were not available. The approach is consistent with that applied in TRS 472 [2.4]. Pot and lysimeter experiments tend to give higher $CR_{\text{plant-soil}}$ values than field data [2.9, 2.10].

Calculation of summary values used a weighted (with respect to sample numbers) mean approach that required information on the sample number (i.e. number of observations). The assumptions applied in TRS 479 for wildlife [2.5] were followed where sample number was not given in the source reference. These were:

(a) If information on replication was not given and no error term was available, a sample number of one was assumed.
(b) If a measure of error was available without a sample number, the sample number was assumed to be three.
(c) If a minimum and maximum were available with no details of sample replication, a sample number of two was assumed.

The data collated for tropical environments were a mixture of individual measurement values and average values due to the data being collated at the level of detail reported in the source references. This disparity was addressed by first calculating average values of $CR_{\text{plant-soil}}$ for each individual study and then using these averages to calculate the summary values of $CR_{\text{plant-soil}}$.

2.2.3. Calculation of $CR_{\text{plant-soil}}$ summary values

Summary values of $CR_{\text{plant-soil}}$ were calculated for each element by plant group, plant compartment and soil group. They were also calculated for all soil groups combined (termed 'All') and, for tropical environments, for all soil groups combined excluding coral sand (termed 'All*'). The reason for the latter exclusion was to permit more direct comparisons with $CR_{\text{plant-soil}}$ values for other environments (e.g. arid and temperate) that do not have coral sand soil data. The equations described below, previously used to derive summary *CR* values for wildlife in TRS 479 [2.5], were applied, as specific information on the analysis approach is not included in TRS 472.

The weighted arithmetic mean (AM) (i.e. the mean for an individual study is given weight according to the number of observations in that study) was calculated as [2.5]:

$$AM = \frac{\sum_i n_i CR_i}{N} \tag{2.3}$$

where:

n_i is the number of observations in study i;
CR_i is the mean $CR_{\text{plant-soil}}$ for study i;
N is the total number of observations in all studies.

The associated combined standard deviation (SD_{combined}) accounting for within, and between study variation, was estimated as [2.5]:

$$SD_{combined} = \sqrt{\frac{\sum_i \left((n_i - 1)SD_i^2 + n_i CR_i^2\right) - \frac{\left(\sum_i n_i CR_i\right)^2}{N}}{N-1}} \tag{2.4}$$

where SD_i is the standard deviation for study i.

An approximate estimate of the geometric mean (GM) was calculated as:

$$GM = exp\left(-0.5ln\left(\frac{SD^2+AM^2}{AM^4}\right)\right) \quad (2.5)$$

The associated geometric standard deviation (GSD) was calculated as:

$$GSD = exp\left(\sqrt{ln\left(\frac{SD^2+AM^2}{AM^2}\right)}\right) \quad (2.6)$$

REFERENCES TO CHAPTER 2

[2.1] INTERNATIONAL COMMISSION ON RADIATION UNITS AND MEASUREMENTS, Quantities, Units and Terms in Radioecology, ICRU Report 65, Journal of the ICRU (2001).

[2.2] INTERNATIONAL ATOMIC ENERGY AGENCY, Environmental Transfer of Radionuclides in Japan following the Accident at the Fukushima Daiichi Nuclear Power Plant, IAEA-TECDOC-1927, IAEA, Vienna (2020).

[2.3] INTERNATIONAL ATOMIC ENERGY AGENCY, Generic Models for Use in Assessing the Impact of Discharges of Radioactive Substances to the Environment, Safety Reports Series No. 19, IAEA, Vienna (2001).

[2.4] INTERNATIONAL ATOMIC ENERGY AGENCY, Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Terrestrial and Freshwater Environments, Technical Reports Series No. 472, IAEA, Vienna (2010).

[2.5] INTERNATIONAL ATOMIC ENERGY AGENCY, Quantification of Radionuclide Transfer in Terrestrial and Freshwater Environments for Radiological Assessments, IAEA-TECDOC-1616, IAEA, Vienna (2009).

[2.6] INTERNATIONAL ATOMIC ENERGY AGENCY, Handbook of Parameter Values for the Prediction of Radionuclide Transfer to Wildlife, Technical Reports Series No. 479, IAEA, Vienna (2014).

[2.7] BECK, H.E., ZIMMERMANN, N.E., MCVICAR, T.R., VERGOPOLAN, N., BERG, A., WOOD, E.F., Present and future Köppen-Geiger climate classification maps at 1-km resolution, Scientific Data **5** 180214 (2018).

[2.8] INTERNATIONAL ATOMIC ENERGY AGENCY, Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Temperate Environments, Technical Reports Series No. 364, IAEA, Vienna (1994).

[2.9] SAVINKOV, A, SEMIOSHKINA, N., HOWARD, B.J., VOIGT, G., Radiostrontium uptake by plants from different soil types in Kazakhstan, Sci. Total Environ. **373** (2007) 324.

[2.10] POORTER, H., FIORANI, F., PIERUSCHKA, R., WOJCIECHOWSKI, T., VAN DER PUTTEN, W.H., et al., Pampered inside, pestered outside? Differences and similarities between plants growing in controlled conditions and in the field, New Phytol. **212** 4 (2016) 838.

3. CONCENTRATION RATIOS FOR PLANTS IN TROPICAL ENVIRONMENTS

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3.1. INTRODUCTION

TRS 472 [3.1] summarizes specific data for tropical environments published prior to 2006. However, at that time, the definition of what comprised 'tropical data' was unclear and there were no specifically defined criteria for inclusion. The data used to derive the $CR_{\text{plant-soil}}$ values published in TRS 472 for tropical environments included those obtained from regions as diverse as the Mediterranean and Middle East, southern and eastern Asia, northern Australia, Oceania and northern South America. A thorough review ensured that only those data in TRS 472 [3.1] that conformed with the K-G climate classifications for tropical climates were considered in MODARIA II (see Section 2.2.1 above). The amended reference base used in TRS 472 for tropical environments was supplemented with additional studies published in the period 2006–2019 that conformed with the K-G climate criteria. This chapter describes the outcome of the data collation for tropical environments undertaken in MODARIA II and presents the $CR_{\text{plant-soil}}$ summary values derived from the data.

3.1.1. Characteristic features of tropical climates

Tropical climates mostly occur between 20° north and south of the Equator. They are found in Central America and the Caribbean, northern South America, central and western Africa, southern and eastern Asia, northern Australia and many Pacific island countries. Tropical climates have high temperatures (monthly minimum ≥ 18°C) and a virtual absence of thermal seasons. Precipitation is generally abundant and may occur either year-round or seasonally. Environmental conditions tend to be humid. Plant and animal life is generally abundant and highly biodiverse.

3.1.2. Factors affecting concentration ratios in tropical environments

The main ecological factors likely to influence $CR_{\text{plant-soil}}$ values in tropical environments include soil type, plant type and physiological responses to higher temperatures, light intensity and rainfall periodicity. Agricultural practices are also adapted to mitigate the impact of the challenges of growing crops and raising animals in tropical conditions.

In tropical environments, higher temperatures and rainfall tend to develop deep, but nutrient depleted, soils. In some areas, the surface soils comprise hardened layers that are rich in iron and/or aluminum oxides, called laterites. The 2:1 clay mineral illite strongly binds caesium ions but may be absent in tropical environments because it is mainly formed at lower temperatures [3.2–3.3]. Kaolinite or secondary mineral clays such as goethite and gibbsite are more common in tropical environments and have lower cation binding abilities as they are 1:1 clay types. For

dissolved materials that are not leached out of these soils by high rainfall, there is a rapid recycling of both nutrients and contaminants into the vegetation, as most of the organic material that reaches the soil surface decomposes rapidly. Ammonium ions compete with caesium ions for absorption sites in some clay minerals, but microbiological oxidation of ammonium ions to nitrates occurs at a relatively fast rate in tropical environments thereby reducing potential competition.

Various relevant factors that have a significant effect on $CR_{\text{plant-soil}}$ values are discussed in more detail [3.2]. They include the effects of pH, redox potential, soil microbiology, soil organic matter, aluminium toxicity and regional farming management differences. Farming strategies vary widely in tropical environments and can substantially differ from those practiced in most temperate environments. They include collection of wild fruits and vegetables, machine-facilitated cropping, intermittent inundation of paddy fields and slash and burn cultivation, amongst other approaches. The FAO/World Bank identifies 72 farming systems grouped under eight major categories [3.4]. The largest single category based on agricultural population dependency comprises the inundation rice-based systems, that are predominantly used in southern and eastern parts of Asia and which supports more than 850 million people.

3.2. DATA FOR TROPICAL ENVIRONMENTS

3.2.1. Description of the data

The data for tropical environments were collated from 94 studies (see Appendix II below). Several of these studies were from the previously unpublished IAEA CRP on "Transfer of radionuclides from air, soil and fresh water to the food chain of man in tropical and subtropical environments" (1993–1997) which contributed tropical data to TRS 472 [3.1]. The individual CRP studies are described in Annexes IV–XVI[3].

The tropical data compilation produced under MODARIA II contains 7129 rows of information and includes data for:

(a) Thirty-six (36) elements (Al, Am, As, Ba, Ca, Cd, Co, Cr, Cs, Cu, Fe, Hg, K, La, Mg, Mn, Mo, Na, Ni, P, Pb, Po, Pu, Ra, Rb, S, Sb, Sc, Se, Sm, Sr, Th, U, V, Y and Zn);
(b) Twenty-one (21) countries (Australia, Bangladesh, Benin, Brazil, Cameroon, Cuba, Ecuador, French Polynesia, Ghana, Honduras, India, Indonesia, Malaysia, Marshall Islands, Nigeria, Peru, Philippines, Sri Lanka, Tanzania, Thailand and Vietnam) (see Fig 3.1);
(c) A range of environmental areas (contaminated sites and natural and semi-natural sites including coral atolls, rainforests and savannah) and land uses (agriculture, home gardens, urban areas and industrial zones); and
(d) More than 100 species of plants (many of the species are widely used as food crops in tropical environments, such as *Amaranthus, Brassica, Ficus, Manihot, Musa, Oryza, Solanum and Vigna*, while several permit direct comparisons with crops grown in temperate environments, including bean, cabbage, citrus, maize, potato, sorghum and wheat).

[3] Annexes I–XVI are published online (only) as a Supplementary File to accompany this publication.

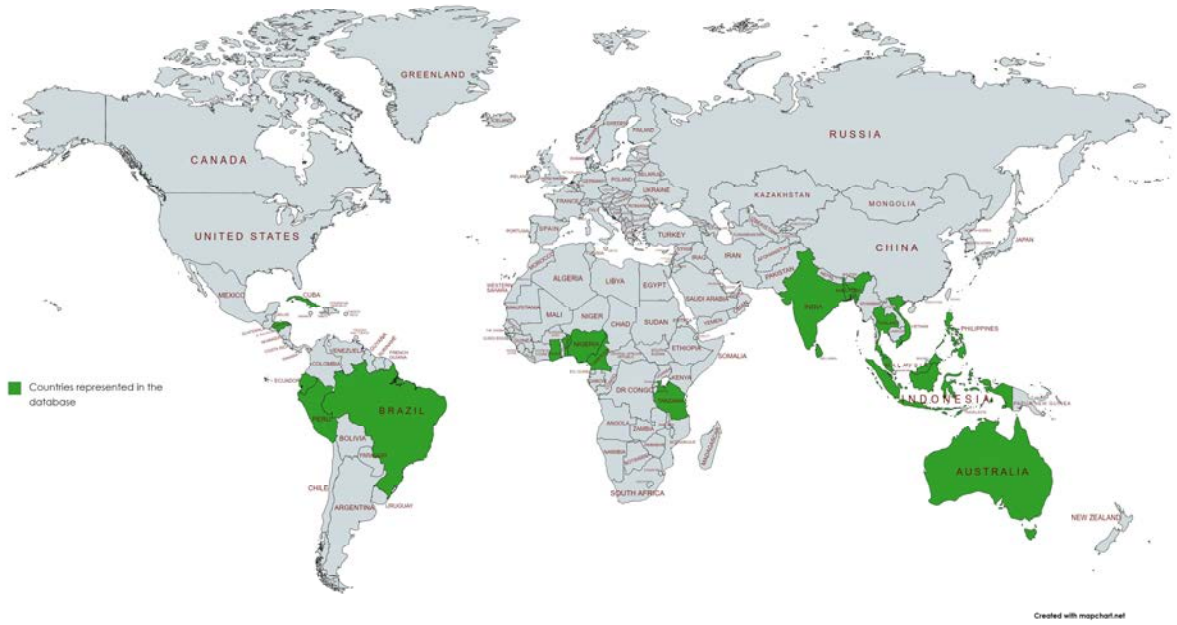

FIG. 3.1. Countries represented in the MODARIA II tropical dataset.

3.2.2. Tables of concentration ratios

Summary values of $CR_{\text{plant-soil}}$ are presented in Table 3.1 below. The GM and GSD are reported if the total number of observations is three or more. In a small number of cases with N ≥3 a GM and GSD have not been reported, as the underpinning data are from a single study where the source reference only reports an average value). Identification (ID) numbers for the source references are provided with each summary value. The publication index for these ID numbers is provided in Appendix II.

TABLE 3.1. CONCENTRATION RATIO ($CR_{plant-soil}$) VALUES FOR PLANTS IN TROPICAL ENVIRONMENTS

Plant group	Plant compartment	Soil group	N[a]	AM[b]	SD[b]	GM[c]	GSD[c]	Minimum	Maximum	ID number[d]
Al (aluminium)										
Rice	Stems and shoots	Loam	4	1.6E-3	9.6E-4	1.3E-3	1.8	5.9E-4	3.2E-3	3
Tubers	Tubers	Unspecified	23	8.9E-2	1.2E-1	5.4E-2	2.7	4.8E-4	4.6E-1	39
Fruits - all	Fruits, heads, berries and buds	Unspecified	93	3.0E-3	5.8E-3	1.4E-3	3.5	1.8E-5	2.6E-2	39, 78, 89
Fruits - herbaceous plants	Fruits, heads, berries and buds	Unspecified	12	3.8E-4	3.8E-4	2.7E-4	2.3	2.5E-5	1.1E-3	39
Fruits - shrubs	Fruits, heads, berries and buds	Unspecified	6	4.8E-3	9.5E-3	2.1E-3	3.6	1.8E-5	2.6E-2	39
Fruits - woody trees	Fruits, heads, berries and buds	Unspecified	72	3.4E-3	5.9E-3	1.7E-3	3.2	2.7E-5	2.4E-2	39, 78, 89
Fruits - non-woody trees	Fruits, heads, berries and buds	Unspecified	3	1.5E-3	8.2E-4	1.3E-3	1.7	8.2E-4	2.6E-3	39
Medicinal plants – woody trees	Leaves	Unspecified	4	4.3E-2	1.6E-3	4.3E-2	1.0	—[e]	—	78
Am (americium)										
Fruits - all	Fruits, heads, berries and buds	Coral sand	24	1.2E-5	1.5E-4	1.0E-6	9.3	8.8E-7	1.7E-4	30
Fruits - woody trees	Fruits, heads, berries and buds	Coral sand	4	1.2E-5	5.1E-5	2.5E-6	5.7	7.8E-6	1.2E-4	30
Fruits - non-woody trees	Fruits, heads, berries and buds	Coral sand	20	1.2E-5	1.4E-4	1.1E-6	9.0	8.8E-7	1.7E-4	30
As (arsenic)										
Cereals	Grains, seeds and pods	Unspecified	8	1.7E-2	—	—	—	—	—	71
Maize	Grains, seeds and pods	Unspecified	1	2.3E-3	n.a.[f]	n.a.	n.a.	n.a.	n.a.	64
Rice	Grains, seeds and pods	Unspecified	40	5.2E-2	1.1E-2	5.1E-2	1.2	7.7E-3	6.0E-2	64, 71
Leafy vegetables	Leaves	Unspecified	119	4.6E-2	2.8E-2	4.0E-2	1.7	3.7E-4	1.7E-1	48, 50, 62, 64, 71
Non-leafy vegetables	Fruits, heads, berries and buds	Unspecified	161	2.0E-2	1.3E-2	1.7E-2	1.8	1.9E-3	6.5E-2	50, 62, 64, 71
Leguminous vegetables	Grains, seeds and pods	Unspecified	66	1.5E-2	3.4E-3	1.5E-2	1.2	9.0E-3	2.4E-2	50, 62, 71
Root crops	Roots	Unspecified	28	5.2E-2	2.4E-2	4.7E-2	1.6	3.3E-2	1.0E-1	1, 50, 62, 71
Tubers	Tubers	Unspecified	47	7.6E-2	7.0E-2	5.6E-2	2.2	2.4E-3	5.4E-1	39, 50, 62, 64, 71
Fruits - all	Fruits, heads, berries and buds	Unspecified	73	6.9E-3	1.7E-2	2.6E-3	4.0	1.9E-4	1.3E-1	39, 50, 71
Fruits - herbaceous plants	Fruits, heads, berries and buds	Unspecified	1	1.9E-4	n.a.	n.a.	n.a.	n.a.	n.a.	39
Fruits - woody trees	Fruits, heads, berries and buds	Unspecified	45	7.1E-3	2.1E-2	2.3E-3	4.5	2.5E-4	1.3E-1	39, 71
Fruits - non-woody trees	Fruits, heads, berries and buds	Unspecified	27	6.7E-3	9.9E-4	6.6E-3	1.2	1.7E-3	6.9E-3	50, 71
Herbs	Leaves	All	26	5.3E-1	2.4E-1	4.9E-1	1.5	2.1E-3	1.4E+0	50, 62, 64, 94
Herbs	Leaves	Loam	21	6.5E-1	1.9E-2	6.5E-1	1.0	2.4E-1	1.4E+0	94
Herbs	Leaves	Unspecified	5	4.9E-2	7.5E-2	2.7E-2	3.0	2.1E-3	1.8E-1	50, 62, 64
Herbs	Rhizomes	Unspecified	14	4.0E-4	—	—	—	—	—	71

TABLE 3.1. (cont.)

Plant group	Plant compartment	Soil group	N[a]	AM[b]	SD[b]	GM[c]	GSD[c]	Minimum	Maximum	ID number[d]
Ba (barium)										
Root crops	Roots	Unspecified	3	1.1E+0	2.9E-1	1.1E+0	1.3	—	—	58
Tubers	Tubers	Unspecified	23	1.4E+1	2.5E+1	7.0E+0	3.3	9.2E-3	9.1E+1	39
Fruits - all	Fruits, heads, berries and buds	Unspecified	126	1.1E-1	2.2E-1	5.0E-2	3.6	2.0E-4	7.1E-1	39, 58
Fruits - herbaceous plants	Fruits, heads, berries and buds	Unspecified	24	3.9E-2	8.3E-2	1.6E-2	3.7	2.0E-4	3.4E-1	39, 58
Fruits - shrubs	Fruits, heads, berries and buds	Unspecified	6	8.0E-2	6.8E-2	6.1E-2	2.1	6.3E-3	1.8E-1	39
Fruits - woody trees	Fruits, heads, berries and buds	Unspecified	80	1.5E-1	1.9E-1	8.8E-2	2.7	2.5E-3	7.1E-1	39, 58
Fruits - non-woody trees	Fruits, heads, berries and buds	Unspecified	16	6.1E-2	1.7E-1	2.1E-2	4.3	9.1E-4	2.7E-1	39, 58
Other crops	Cacao beans	Unspecified	18	8.9E-1	3.4E-1	8.3E-1	1.4	5.5E-2	2.4E+0	58
Other crops	Coffee beans	Unspecified	3	3.8E-1	1.3E-2	3.8E-1	1.0	—	—	58
Ca (calcium)										
Non-leafy vegetables	Fruits, heads, berries and buds	Unspecified	20	1.5E+0						67
Tubers	Tubers	Unspecified	23	3.3E+1	4.3E+1	2.0E+1	2.7	2.7E-1	1.7E+2	39
Fruits - all	Fruits, heads, berries and buds	Unspecified	97	2.0E+0	2.5E+0	1.3E+0	2.6	1.8E-3	1.2E+1	39, 78, 89
Fruits - herbaceous plants	Fruits, heads, berries and buds	Unspecified	15	8.1E-1	1.6E+0	3.7E-1	3.5	9.1E-2	6.4E+0	39
Fruits - shrubs	Fruits, heads, berries and buds	Unspecified	6	1.4E+0	1.2E+0	1.0E+0	2.1	8.5E-2	2.9E+0	39
Fruits - woody trees	Fruits, heads, berries and buds	Unspecified	72	2.4E+0	2.6E+0	1.7E+0	2.4	1.8E-3	1.2E+1	39, 78, 89
Fruits - non-woody trees	Fruits, heads, berries and buds	Unspecified	4	3.2E-1	1.8E-1	2.8E-1	1.7	9.2E-2	5.8E-1	39
Medicinal plants – woody trees	Leaves	Unspecified	4	3.3E+0	1.1E-1	3.3E+0	1.0	—	—	78
Cd (cadmium)										
Maize	Grains, seeds and pods	Unspecified	3	2.7E-1	2.1E-1	2.1E-1	2.0	3.8E-2	4.9E-1	60, 64
Maize	Stems and shoots	Unspecified	2	3.4E-1	n.a.	n.a.	n.a.	1.8E-1	5.0E-1	60
Rice	Grains, seeds and pods	Unspecified	28	1.9E-1	1.0E-1	1.7E-1	1.7	5.2E-2	2.7E-1	52, 64, 81, 87
Rice	Stems and shoots	Unspecified	22	8.6E-1	1.4E+0	4.5E-1	3.2	2.2E-1	2.3E+0	52, 81
Leafy vegetables	Leaves	Unspecified	81	6.4E-1	1.0E+0	3.4E-1	3.1	7.8E-3	4.1E+0	48, 50, 53, 64, 70, 72, 75, 91
Non-leafy vegetables	Fruits, heads, berries and buds	All	40	5.4E-1	7.1E-1	3.3E-1	2.7	2.9E-3	1.1E+0	50, 64, 66, 67, 72, 93
Non-leafy vegetables	Fruits, heads, berries and buds	Sand	10	8.8E-1	1.4E+0	4.8E-1	3.0	—	—	66
Non-leafy vegetables	Fruits, heads, berries and buds	Unspecified	30	4.3E-1	2.1E-1	3.9E-1	1.6	2.9E-3	1.1E+0	50, 64, 67, 72, 93
Leguminous vegetables	Grains, seeds and pods	Unspecified	15	2.4E-1	1.8E-1	1.9E-1	1.9	2.0E-1	8.5E-1	50, 52
Root crops	Roots	Unspecified	5	7.6E-1	7.8E-1	5.4E-1	2.3	2.6E-1	2.0E+0	50, 58, 72
Tubers	Tubers	Unspecified	15	2.8E-1	2.6E-1	2.1E-1	2.2	1.3E-2	9.0E-1	1, 39, 50, 64, 93
Fruits - all	Fruits, heads, berries and buds	All	87	9.6E-2	2.0E-1	4.2E-2	3.6	2.4E-5	8.5E-1	39, 50, 58, 66, 69, 72, 89

TABLE 3.1. (cont.)

Plant group	Plant compartment	Soil group	N[a]	AM[b]	SD[b]	GM[c]	GSD[c]	Minimum	Maximum	ID number[d]
Fruits - all	Fruits, heads, berries and buds	Loam	14	1.2E-1	2.0E-1	6.1E-2	3.2	1.2E-1	1.2E-1	69
Fruits - all	Fruits, heads, berries and buds	Sand	10	4.2E-2	2.5E-1	6.8E-3	6.7	—	—	66
Fruits - all	Fruits, heads, berries and buds	Unspecified	63	1.0E-1	1.9E-1	4.7E-2	3.4	2.4E-5	8.5E-1	39, 50, 58, 72, 89
Fruits - herbaceous plants	Fruits, heads, berries and buds	All	24	5.5E-2	2.0E-1	1.5E-2	5.1	3.0E-3	6.2E-1	39, 58, 66
Fruits - herbaceous plants	Fruits, heads, berries and buds	Sand	10	4.2E-2	2.5E-1	6.8E-3	6.7	—	—	66
Fruits - herbaceous plants	Fruits, heads, berries and buds	Unspecified	14	6.4E-2	1.5E-1	2.5E-2	4.0	3.0E-3	6.2E-1	39, 58
Fruits - shrubs	Fruits, heads, berries and buds	Unspecified	2	4.5E-1	n.a.	n.a.	n.a.	5.2E-2	8.5E-1	39
Fruits - woody trees	Fruits, heads, berries and buds	Unspecified	36	1.1E-1	1.6E-1	6.6E-2	2.8	2.4E-5	6.2E-1	39, 58, 89
Fruits - non-woody trees	Fruits, heads, berries and buds	All	25	8.2E-2	1.6E-1	3.8E-2	3.4	2.4E-3	1.6E-1	50, 58, 69, 72
Fruits - non-woody trees	Fruits, heads, berries and buds	Loam	14	1.2E-1	2.0E-1	6.1E-2	3.2	1.2E-1	1.2E-1	69
Fruits - non-woody trees	Fruits, heads, berries and buds	Unspecified	11	3.6E-2	6.0E-2	1.9E-2	3.2	2.4E-3	1.6E-1	50, 58, 72
Grasses	Stems and shoots	Sand	3	2.3E-1	2.8E-1	1.5E-1	2.6	—	—	66
Herbs	Leaves	All	49	4.4E-1	5.8E-1	2.7E-1	2.7	3.0E-2	4.0E+0	1, 50, 64, 91, 94
Herbs	Leaves	Loam	30	4.8E-1	7.1E-2	4.7E-1	1.2	2.0E-1	1.1E+0	94
Herbs	Leaves	Unspecified	19	3.9E-1	9.4E-1	1.5E-1	4.0	3.0E-2	4.0E+0	1, 50, 64, 91
Herbs	Roots	Unspecified	12	1.6E-1	5.2E-2	1.5E-1	1.4	6.7E-2	1.9E-1	91
Herbs	Stems and shoots	Unspecified	12	3.2E-2	6.7E-3	3.1E-2	1.2	3.1E-2	3.3E-2	91
Medicinal plants – shrubs	Leaves	Unspecified	12	2.4E-1	4.2E-2	2.3E-1	1.2	1.0E-1	2.8E-1	91
Medicinal plants – non-woody trees	Leaves	All	18	4.9E-1	2.7E-1	4.3E-1	1.7	1.6E-2	6.3E-1	69, 70
Medicinal plants – non-woody trees	Leaves	Loam	14	6.1E-1	1.6E-1	5.9E-1	1.3	6.0E-1	6.3E-1	69
Medicinal plants – non-woody trees	Leaves	Unspecified	4	7.8E-2	7.7E-2	5.5E-2	2.3	1.6E-2	2.1E-1	70
Other crops	Cacao beans	All	268	2.8E+0	3.2E+0	1.8E+0	2.5	1.8E-2	4.6E+1	46, 51, 58, 61, 65
Other crops	Cacao beans	Clay	3	2.9E-1	5.6E-2	2.9E-1	1.2	—	—	51
Other crops	Cacao beans	Loam	151	3.1E+0	3.5E+0	2.1E+0	2.5	1.8E-2	4.6E+1	46, 51, 65
Other crops	Cacao beans	Sand	9	1.2E+0	1.0E+0	8.9E-1	2.1	2.6E-1	2.0E+0	51
Other crops	Cacao beans	Unspecified	105	2.5E+0	2.8E+0	1.7E+0	2.5	2.6E-1	1.0E+1	58, 61
Other crops	Coffee beans	Unspecified	3	3.7E-2	5.0E-3	3.6E-2	1.1	—	—	58
Co (cobalt)										
Maize	Grains, seeds and pods	Unspecified	1	2.3E-1	n.a.	n.a.	n.a.	n.a.	n.a.	64
Rice	Grains, seeds and pods	All	11	5.7E-2	3.7E-2	4.8E-2	1.8	4.0E-2	9.8E-2	36, 64, 81
Rice	Grains, seeds and pods	Loam	3	8.7E-2	7.9E-3	8.7E-2	1.1	8.0E-2	9.8E-2	36

TABLE 3.1. (cont.)

Plant group	Plant compartment	Soil group	N[a]	AM[b]	SD[b]	GM[c]	GSD[c]	Minimum	Maximum	ID number[d]
Rice	Grains, seeds and pods	Unspecified	8	4.6E-2	3.8E-2	3.6E-2	2.0	4.0E-2	4.7E-2	64, 81
Rice	Stems and shoots	All	11	1.7E-1	2.1E-1	1.0E-1	2.6	1.9E-3	2.6E-1	3, 81
Rice	Stems and shoots	Loam	4	3.0E-3	1.2E-3	2.8E-3	1.5	1.9E-3	5.0E-3	3
Rice	Stems and shoots	Unspecified	7	2.6E-1	2.1E-1	2.0E-1	2.0	—	—	81
Leafy vegetables	Leaves	All	33	4.0E-1	4.3E-1	2.7E-1	2.4	1.9E-2	1.2E+0	36, 50, 53, 64
Leafy vegetables	Leaves	Loam	6	6.6E-1	3.9E-1	5.6E-1	1.7	2.0E-1	1.2E+0	36
Leafy vegetables	Leaves	Unspecified	27	3.4E-1	4.2E-1	2.1E-1	2.6	1.9E-2	8.2E-1	50, 53, 64
Non-leafy vegetables	Fruits, heads, berries and buds	All	19	1.7E-1	3.0E-1	8.4E-2	3.3	4.2E-3	8.8E-1	36, 50, 64, 66
Non-leafy vegetables	Fruits, heads, berries and buds	Loam	3	7.9E-1	6.5E-2	7.9E-1	1.1	7.3E-1	8.8E-1	36
Non-leafy vegetables	Fruits, heads, berries and buds	Sand	10	7.0E-2	1.5E-1	3.0E-2	3.7	—	—	66
Non-leafy vegetables	Fruits, heads, berries and buds	Unspecified	6	2.4E-2	1.8E-2	1.9E-2	2.0	4.2E-3	6.0E-2	50, 64
Leguminous vegetables	Grains, seeds and pods	All	4	1.1E-1	8.3E-2	9.2E-2	1.9	5.3E-3	2.2E-1	36, 50
Leguminous vegetables	Grains, seeds and pods	Loam	3	1.5E-1	5.1E-2	1.4E-1	1.4	1.0E-1	2.2E-1	36
Leguminous vegetables	Grains, seeds and pods	Unspecified	1	5.3E-3	n.a.	n.a.	n.a.	n.a.	n.a.	50
Root crops	Roots	Unspecified	4	4.2E-3	3.8E-3	3.1E-3	2.2	2.4E-3	9.7E-3	1, 50
Tubers	Tubers	Unspecified	22	3.4E-1	4.5E-1	2.0E-1	2.8	2.2E-3	1.4E+0	1, 39, 50, 64
Fruits - all	Fruits, heads, berries and buds	All	43	3.4E-2	6.4E-2	1.6E-2	3.4	2.7E-4	2.9E-1	36, 39, 50, 58, 89
Fruits - all	Fruits, heads, berries and buds	Loam	3	1.3E-1	1.6E-2	1.3E-1	1.1	1.2E-1	1.6E-1	36
Fruits - all	Fruits, heads, berries and buds	Unspecified	40	2.7E-2	6.0E-2	1.1E-2	3.8	2.7E-4	2.9E-1	39, 50, 58, 89
Fruits - herbaceous plants	Fruits, heads, berries and buds	All	6	7.0E-2	7.1E-2	4.9E-2	2.3	1.2E-3	1.6E-1	36, 39
Fruits - herbaceous plants	Fruits, heads, berries and buds	Loam	3	1.3E-1	1.6E-2	1.3E-1	1.1	1.2E-1	1.6E-1	36
Fruits - herbaceous plants	Fruits, heads, berries and buds	Unspecified	3	6.2E-3	3.5E-3	5.4E-3	1.7	1.2E-3	9.2E-3	39
Fruits - shrubs	Fruits, heads, berries and buds	Unspecified	5	1.1E-1	1.3E-1	7.1E-2	2.6	6.2E-4	2.9E-1	39
Fruits - woody trees	Fruits, heads, berries and buds	Unspecified	31	1.6E-2	2.4E-2	9.2E-3	2.9	2.7E-4	1.2E-1	39, 58, 89
Fruits - non-woody trees	Fruits, heads, berries and buds	Unspecified	1	1.3E-3	n.a.	n.a.	n.a.	n.a.	n.a.	50
Grasses	Stems and shoots	All	6	1.7E-1	1.8E-1	1.1E-1	2.4	3.3E-3	4.3E-1	36, 66
Grasses	Stems and shoots	Loam	3	3.3E-1	7.3E-2	3.2E-1	1.2	2.7E-1	4.3E-1	36
Grasses	Stems and shoots	Sand	3	3.3E-3	4.3E-3	2.0E-3	2.7	—	—	66
Herbs	Leaves	Unspecified	7	3.6E-2	1.8E-2	3.2E-2	1.6	2.2E-2	6.0E-2	1, 50, 64
Other crops	Cacao beans	Unspecified	18	1.6E-1	1.2E-1	1.3E-1	1.9	2.7E-2	5.5E-1	58
Other crops	Peanuts	Loam	3	1.2E-1	4.3E-2	1.1E-1	1.4	8.0E-2	1.8E-1	36
Cr (chromium)										
Maize	Grains, seeds and pods	Unspecified	1	7.0E-2	n.a.	n.a.	n.a.	n.a.	n.a.	64

TABLE 3.1. (cont.)

Plant group	Plant compartment	Soil group	N[a]	AM[b]	SD[b]	GM[c]	GSD[c]	Minimum	Maximum	ID number[d]
Rice	Grains, seeds and pods	All	48	2.7E-1	4.4E-1	1.4E-1	3.1	8.6E-3	1.1E+0	52, 64, 81, 85, 86, 87
Rice	Grains, seeds and pods	Clay	5	1.1E-1	6.0E-2	1.0E-1	1.6	4.0E-2	2.1E-1	85
Rice	Grains, seeds and pods	Unspecified	43	2.9E-1	4.6E-1	1.5E-1	3.1	8.6E-3	1.1E+0	52, 64, 81, 86, 87
Rice	Stems and shoots	All	61	2.6E-1	5.3E-1	1.1E-1	3.6	1.8E-3	1.3E+0	3, 52, 81, 85, 86
Rice	Stems and shoots	Clay	5	3.5E-1	2.1E-1	3.0E-1	1.7	2.1E-1	7.6E-1	85
Rice	Stems and shoots	Loam	4	3.9E-3	2.7E-3	3.2E-3	1.9	1.8E-3	8.6E-3	3
Rice	Stems and shoots	Unspecified	52	2.7E-1	5.7E-1	1.1E-1	3.7	4.4E-2	1.3E+0	52, 81, 86
Leafy vegetables	Leaves	Unspecified	246	9.2E-1	1.1E+1	7.7E-2	9.2	1.1E-2	1.9E+2	50, 53, 64, 75, 83
Non-leafy vegetables	Fruits, heads, berries and buds	Unspecified	28	1.3E-1	1.1E-1	9.9E-2	2.1	1.6E-3	5.0E-1	50, 64, 67, 93
Leguminous vegetables	Grains, seeds and pods	Unspecified	15	1.3E-1	1.0E-1	1.0E-1	2.0	1.0E-1	4.9E-1	50, 52
Root crops	Roots	Unspecified	4	1.4E-1	2.3E-1	7.4E-2	3.1	2.7E-2	4.8E-1	1, 50
Tubers	Tubers	Unspecified	25	1.5E-1	2.3E-1	8.4E-2	3.0	2.5E-3	9.7E-1	1, 39, 50, 64, 93
Fruits - all	Fruits, heads, berries and buds	Unspecified	55	1.5E-2	3.8E-2	5.8E-3	4.1	1.5E-4	2.4E-1	39, 50, 89
Fruits - herbaceous plants	Fruits, heads, berries and buds	Unspecified	3	1.1E-3	6.0E-4	9.9E-4	1.6	4.8E-4	1.9E-3	39
Fruits - shrubs	Fruits, heads, berries and buds	Unspecified	4	4.0E-3	2.9E-3	3.3E-3	1.9	6.5E-4	7.3E-3	39
Fruits - woody trees	Fruits, heads, berries and buds	Unspecified	46	1.6E-2	4.0E-2	5.9E-3	4.1	1.5E-4	2.4E-1	39, 89
Fruits - non-woody trees	Fruits, heads, berries and buds	Unspecified	2	4.9E-2	n.a.	n.a.	n.a.	2.8E-3	9.6E-2	39, 50
Herbs	Leaves	Unspecified	6	1.1E-1	1.7E-1	6.4E-2	3.0	2.6E-2	4.6E-1	1, 50, 64
Medicinal plants – shrubs	Leaves	Unspecified	3	3.4E-1	4.4E-1	2.1E-1	2.7	—	—	53
Cs (caesium)										
Cereals	Grains, seeds and pods	All	21	9.4E+0	9.1E+0	6.7E+0	2.3	1.3E-1	3.1E+1	25, 30
Cereals	Grains, seeds and pods	All*	6	2.3E-1	1.2E-1	2.1E-1	1.6	1.3E-1	3.3E-1	25
Cereals	Grains, seeds and pods	Coral sand	15	1.3E+1	8.2E+0	1.1E+1	1.8	9.4E-1	3.1E+1	30
Cereals	Grains, seeds and pods	Loam	3	3.3E-1	5.2E-2	3.3E-1	1.2	—	—	25
Cereals	Grains, seeds and pods	Sand	3	1.3E-1	3.5E-2	1.3E-1	1.3	—	—	25
Maize	Grains, seeds and pods	Coral sand	41	1.4E+0	1.4E+0	9.9E-1	2.3	2.0E-1	7.8E+0	30
Maize	Stems and shoots	Coral sand	27	2.5E+0	1.8E+0	2.0E+0	1.9	4.9E-1	9.0E+0	30
Rice	Grains, seeds and pods	All	33	2.6E-1	3.2E-1	1.7E-1	2.6	3.4E-2	3.7E-1	24, 28, 44, 90
Rice	Grains, seeds and pods	Clay	1	3.4E-2	n.a.	n.a.	n.a.	n.a.	n.a.	90
Rice	Grains, seeds and pods	Loam	15	2.1E-1	8.2E-2	2.0E-1	1.4	6.6E-2	3.4E-1	24
Rice	Grains, seeds and pods	Sand	14	3.7E-1	4.7E-1	2.3E-1	2.7	—	—	44
Rice	Grains, seeds and pods	Unspecified	3	9.4E-2	9.0E-3	9.4E-2	1.1	8.3E-2	1.0E-1	28
Rice	Stems and shoots	Loam	11	2.1E-1	1.7E-1	1.6E-1	2.0	5.3E-2	4.9E-1	24

TABLE 3.1. (cont.)

Plant group	Plant compartment	Soil group	N[a]	AM[b]	SD[b]	GM[c]	GSD[c]	Minimum	Maximum	ID number[d]
Leafy vegetables	Leaves	All	117	2.3E+1	3.9E+1	1.2E+1	3.2	3.4E-1	2.5E+2	28, 30, 43, 44, 63, 90
Leafy vegetables	Leaves	All*	66	1.8E+0	1.6E+0	1.3E+0	2.2	3.4E-1	2.9E+0	28, 44, 63, 90
Leafy vegetables	Leaves	Clay	2	4.5E-1	n.a.	n.a.	n.a.	3.4E-1	5.5E-1	90
Leafy vegetables	Leaves	Coral sand	51	5.1E+1	4.6E+1	3.8E+1	2.1	2.9E+0	2.5E+2	30, 43
Leafy vegetables	Leaves	Loam	5	6.8E-1	9.5E-1	4.0E-1	2.8	—	—	63
Leafy vegetables	Leaves	Sand	20	2.8E+0	2.5E+0	2.1E+0	2.2	—	—	44
Leafy vegetables	Leaves	Unspecified	39	1.4E+0	6.5E-1	1.3E+0	1.5	3.6E-1	2.9E+0	28
Non-leafy vegetables	Fruits, heads, berries and buds	All	66	1.0E+0	1.6E+0	5.5E-1	3.0	2.8E-3	9.7E+0	28, 30, 45, 56
Non-leafy vegetables	Fruits, heads, berries and buds	All*	55	5.2E-1	5.5E-1	3.6E-1	2.4	2.8E-3	2.3E+0	28, 45, 56
Non-leafy vegetables	Fruits, heads, berries and buds	Clay	1	7.4E-3	n.a.	n.a.	n.a.	n.a.	n.a.	45
Non-leafy vegetables	Fruits, heads, berries and buds	Coral sand	11	3.4E+0	2.6E+0	2.8E+0	2.0	7.3E-1	9.7E+0	30
Non-leafy vegetables	Fruits, heads, berries and buds	Loam	4	7.0E-3	2.6E-3	6.5E-3	1.4	2.8E-3	9.6E-3	45
Non-leafy vegetables	Fruits, heads, berries and buds	Sand	24	5.7E-2	1.9E-2	5.4E-2	1.4	4.6E-2	7.2E-2	56
Non-leafy vegetables	Fruits, heads, berries and buds	Unspecified	26	1.1E+0	3.2E-1	1.0E+0	1.3	3.6E-1	2.3E+0	28
Leguminous vegetables	Grains, seeds and pods	All	8	6.6E-1	1.3E+0	2.9E-1	3.6	8.4E-3	3.9E+0	25, 30, 45
Leguminous vegetables	Grains, seeds and pods	All*	7	1.9E-1	1.0E-1	1.7E-1	1.6	8.4E-3	2.6E-1	25, 45
Leguminous vegetables	Grains, seeds and pods	Coral sand	1	3.9E+0	n.a.	n.a.	n.a.	n.a.	n.a.	30
Leguminous vegetables	Grains, seeds and pods	Loam	3	1.9E-1	1.7E-2	1.9E-1	1.1	—	—	25
Leguminous vegetables	Grains, seeds and pods	Sand	3	2.6E-1	8.7E-2	2.5E-1	1.4	—	—	25
Leguminous vegetables	Grains, seeds and pods	Unspecified	1	8.4E-3	n.a.	n.a.	n.a.	n.a.	n.a.	45
Root crops	Roots	All	18	2.9E-1	3.3E-1	1.9E-1	2.5	7.1E-2	8.1E-1	28, 32, 63, 90
Root crops	Roots	Clay	2	3.1E-1	n.a.	n.a.	n.a.	7.4E-2	5.5E-1	32, 90
Root crops	Roots	Loam	10	8.6E-2	2.5E-1	2.8E-2	4.4	7.1E-2	1.0E-1	63
Root crops	Roots	Unspecified	6	6.2E-1	1.8E-1	6.0E-1	1.3	4.5E-1	8.1E-1	28
Tubers	Tubers	All	7	1.6E+0	1.5E+0	1.2E+0	2.2	1.6E-1	3.8E+0	28, 30, 90
Tubers	Tubers	All*	4	5.7E-1	3.4E-1	4.9E-1	1.7	1.6E-1	1.0E+0	28, 90
Tubers	Tubers	Clay	1	1.6E-1	n.a.	n.a.	n.a.	n.a.	n.a.	90
Tubers	Tubers	Coral sand	3	3.0E+0	1.1E+0	2.8E+0	1.4	1.7E+0	3.8E+0	30
Tubers	Tubers	Unspecified	3	7.1E-1	2.5E-1	6.7E-1	1.4	5.6E-1	1.0E+0	28
Fruits - all	Fruits, heads, berries and buds	All	718	2.5E+0	2.6E+1	2.5E-1	8.6	4.5E-3	4.1E+1	11, 30, 31, 56
Fruits - all	Fruits, heads, berries and buds	All*	14	6.4E-2	6.7E-2	4.4E-2	2.4	4.5E-3	2.3E-1	11, 31, 56
Fruits - all	Fruits, heads, berries and buds	Coral sand	704	2.6E+0	2.6E+1	2.5E-1	8.6	1.0E-1	4.1E+1	30
Fruits - all	Fruits, heads, berries and buds	Loam	6	4.5E-3	4.0E-3	3.4E-3	2.1	—	—	11

TABLE 3.1. (cont.)

Plant group	Plant compartment	Soil group	N[a]	AM[b]	SD[b]	GM[c]	GSD[c]	Minimum	Maximum	ID number[d]
Fruits - all	Fruits, heads, berries and buds	Sand	5	7.3E-2	—	—	—	—	—	56
Fruits - all	Fruits, heads, berries and buds	Unspecified	3	1.7E-1	4.4E-2	1.6E-1	1.3	1.3E-1	2.3E-1	31
Fruits - herbaceous plants	Fruits, heads, berries and buds	Loam	3	7.2E-2	4.3E-2	6.2E-2	1.7	3.8E-2	1.3E-1	29
Fruits - shrubs	Fruits, heads, berries and buds	Sand	5	7.3E-2	—	—	—	—	—	56
Fruits - woody trees	Fruits, heads, berries and buds	All	42	3.2E-1	1.1E+0	8.7E-2	5.0	4.5E-3	3.7E+0	11, 30, 31
Fruits - woody trees	Fruits, heads, berries and buds	All*	7	2.4E-2	5.1E-2	1.0E-2	3.7	4.5E-3	1.4E-1	11, 31
Fruits - woody trees	Fruits, heads, berries and buds	Coral sand	35	3.7E-1	1.2E+0	1.1E-1	4.7	2.2E-1	3.7E+0	30
Fruits - woody trees	Fruits, heads, berries and buds	Loam	6	4.5E-3	4.0E-3	3.4E-3	2.1	—	—	11
Fruits - woody trees	Fruits, heads, berries and buds	Unspecified	1	1.4E-1	n.a.	n.a.	n.a.	n.a.	n.a.	31
Fruits - non-woody trees	Fruits, heads, berries and buds	All	671	2.7E+0	2.6E+1	2.8E-1	8.4	1.0E-1	4.1E+1	30, 31
Fruits - non-woody trees	Fruits, heads, berries and buds	Coral sand	669	2.7E+0	2.6E+1	2.8E-1	8.4	1.0E-1	4.1E+1	30
Fruits - non-woody trees	Fruits, heads, berries and buds	Unspecified	2	1.8E-1	n.a.	n.a.	n.a.	1.3E-1	2.3E-1	31
Grasses	Stems and shoots	All	16	1.3E-1	7.7E-2	1.1E-1	1.8	4.0E-2	3.4E-1	40, 45, 90
Grasses	Stems and shoots	Clay	1	5.5E-2	n.a.	n.a.	n.a.	n.a.	n.a.	90
Grasses	Stems and shoots	Loam	11	1.5E-1	8.1E-2	1.3E-1	1.6	4.0E-2	3.4E-1	45
Grasses	Stems and shoots	Sand	4	7.2E-2	5.7E-3	7.2E-2	1.1	6.3E-2	8.0E-2	40, 45
Herbs	Leaves	All	48	5.1E+0	1.1E+1	2.1E+0	3.8	4.0E-2	5.7E+1	23, 40, 43
Herbs	Leaves	All*	40	6.3E-1	1.7E-1	6.1E-1	1.3	4.0E-2	3.0E+0	23, 40
Herbs	Leaves	Coral sand	8	2.7E+1	1.3E+1	2.5E+1	1.6	1.6E+1	5.7E+1	43
Herbs	Leaves	Sand	3	6.2E-2	1.5E-2	6.0E-2	1.3	4.0E-2	7.5E-2	40
Herbs	Leaves	Unspecified	37	6.8E-1	5.1E-2	6.8E-1	1.1	2.0E-1	3.0E+0	23
Herbs	Rhizomes	Clay	2	6.8E-2	n.a.	n.a.	n.a.	4.7E-2	8.9E-2	90
Herbs	Stems and shoots	Sand	3	6.5E-2	8.2E-3	6.4E-2	1.1	5.5E-2	7.5E-2	40
Herbs	Whole plant	Sand	2	4.1E-2	n.a.	n.a.	n.a.	3.4E-2	4.7E-2	40
Medicinal plants – woody trees	Leaves	Unspecified	55	3.4E-1	1.7E-1	3.0E-1	1.6	5.0E-2	1.5E+0	23
Medicinal plants – non-woody trees	Leaves	Unspecified	12	6.3E-1	—	—	—	2.3E-1	1.3E+0	23
Other crops	Peanuts	Loam	3	7.8E-1	8.4E-2	7.7E-1	1.1	6.9E-1	8.9E-1	29
Cu (copper)										
Maize	Grains, seeds and pods	All	13	5.7E-1	5.7E-1	4.0E-1	2.3	3.4E-2	7.1E-1	60, 64, 66
Maize	Grains, seeds and pods	Sand	10	7.1E-1	5.8E-1	5.5E-1	2.1	—	—	66
Maize	Grains, seeds and pods	Unspecified	3	1.1E-1	1.0E-1	7.6E-2	2.2	3.4E-2	2.2E-1	60, 64
Maize	Stems and shoots	Unspecified	2	5.7E-2	n.a.	n.a.	n.a.	4.6E-2	6.8E-2	60

TABLE 3.1. (cont.)

Plant group	Plant compartment	Soil group	N[a]	AM[b]	SD[b]	GM[c]	GSD[c]	Minimum	Maximum	ID number[d]
Rice	Grains, seeds and pods	All	33	2.8E-1	1.9E-1	2.3E-1	1.9	4.2E-2	5.0E-1	52, 64, 81, 85, 87
Rice	Grains, seeds and pods	Clay	5	3.2E-1	9.6E-2	3.1E-1	1.3	2.3E-1	5.0E-1	85
Rice	Grains, seeds and pods	Unspecified	28	2.7E-1	2.0E-1	2.2E-1	1.9	4.2E-2	4.5E-1	52, 64, 81, 87
Rice	Stems and shoots	All	31	3.8E-1	5.9E-1	2.1E-1	3.0	3.1E-3	7.2E-1	3, 52, 81, 85
Rice	Stems and shoots	Clay	5	4.0E-1	1.9E-1	3.6E-1	1.6	2.1E-1	7.2E-1	85
Rice	Stems and shoots	Loam	4	1.1E-2	1.1E-2	7.8E-3	2.3	3.1E-3	2.9E-2	3
Rice	Stems and shoots	Unspecified	22	4.5E-1	6.8E-1	2.4E-1	3.0	4.2E-1	5.0E-1	52, 81
Leafy vegetables	Leaves	All	68	5.1E-1	5.2E-1	3.6E-1	2.3	4.0E-2	1.9E+0	48, 50, 64, 70, 72, 75, 91, 92
Leafy vegetables	Leaves	Clay	2	5.6E-1	n.a.	n.a.	n.a.	4.5E-1	6.7E-1	92
Leafy vegetables	Leaves	Loam	3	2.3E-1	1.1E-1	2.1E-1	1.6	8.0E-2	3.3E-1	92
Leafy vegetables	Leaves	Unspecified	63	5.2E-1	5.4E-1	3.7E-1	2.3	4.0E-2	1.9E+0	48, 50, 64, 70, 72, 75, 91
Non-leafy vegetables	Fruits, heads, berries and buds	All	20	3.5E-1	2.7E-1	2.8E-1	2.0	3.0E-4	7.5E-1	50, 64, 66, 72, 92, 93
Non-leafy vegetables	Fruits, heads, berries and buds	Clay	1	3.5E-1	n.a.	n.a.	n.a.	n.a.	n.a.	92
Non-leafy vegetables	Fruits, heads, berries and buds	Sand	10	3.8E-1	3.1E-1	2.9E-1	2.0	—	—	66
Non-leafy vegetables	Fruits, heads, berries and buds	Unspecified	9	3.2E-1	2.6E-1	2.5E-1	2.0	3.0E-4	7.5E-1	50, 64, 72, 93
Leguminous vegetables	Grains, seeds and pods	All	16	3.8E-1	2.7E-1	3.1E-1	1.9	3.0E-1	1.3E+0	50, 52, 92
Leguminous vegetables	Grains, seeds and pods	Clay	1	6.0E-1	n.a.	n.a.	n.a.	n.a.	n.a.	92
Leguminous vegetables	Grains, seeds and pods	Unspecified	15	3.7E-1	2.7E-1	2.9E-1	1.9	3.0E-1	1.3E+0	50, 52
Root crops	Roots	All	28	7.9E-1	7.8E-1	5.7E-1	2.3	1.3E-1	1.0E+0	1, 50, 58, 66, 72
Root crops	Roots	Sand	20	1.0E+0	8.2E-1	7.8E-1	2.0	—	—	66
Root crops	Roots	Unspecified	8	2.5E-1	1.1E-1	2.3E-1	1.5	1.3E-1	3.6E-1	1, 50, 58, 72
Tubers	Tubers	Unspecified	33	1.3E+0	1.6E+0	8.2E-1	2.6	4.0E-4	6.1E+0	1, 39, 50, 64, 93
Fruits - all	Fruits, heads, berries and buds	All	188	2.3E-1	7.3E-1	7.0E-2	4.7	2.9E-3	3.5E+0	39, 50, 58, 69, 72, 74, 89
Fruits - all	Fruits, heads, berries and buds	Loam	14	1.3E-1	2.8E-1	5.3E-2	3.8	1.1E-1	1.5E-1	69
Fruits - all	Fruits, heads, berries and buds	Unspecified	174	2.4E-1	7.5E-1	7.3E-2	4.7	2.9E-3	3.5E+0	39, 50, 58, 72, 74, 89
Fruits - herbaceous plants	Fruits, heads, berries and buds	Unspecified	23	9.2E-2	1.3E-1	5.3E-2	2.8	2.9E-3	5.8E-1	39, 58
Fruits - shrubs	Fruits, heads, berries and buds	Unspecified	6	1.5E-1	1.2E-1	1.1E-1	2.0	3.3E-2	3.2E-1	39
Fruits - woody trees	Fruits, heads, berries and buds	Unspecified	107	2.9E-1	5.9E-1	1.3E-1	3.6	1.3E-2	3.5E+0	39, 58, 74, 89
Fruits - non-woody trees	Fruits, heads, berries and buds	All	52	1.9E-1	6.7E-1	5.2E-2	5.0	2.1E-2	5.0E-1	39, 50, 58, 69, 72, 74
Fruits - non-woody trees	Fruits, heads, berries and buds	Loam	14	1.3E-1	2.8E-1	5.3E-2	3.8	1.1E-1	1.5E-1	69
Fruits - non-woody trees	Fruits, heads, berries and buds	Unspecified	38	2.1E-1	7.7E-1	5.7E-2	5.1	2.1E-2	5.0E-1	39, 50, 58, 72, 74
Grasses	Stems and shoots	Sand	3	6.0E-1	4.9E-1	4.6E-1	2.0	—	—	66
Herbs	Leaves	Unspecified	16	1.6E+0	7.6E-1	1.4E+0	1.6	9.0E-2	2.5E+0	50, 64, 91

TABLE 3.1. (cont.)

Plant group	Plant compartment	Soil group	N[a]	AM[b]	SD[b]	GM[c]	GSD[c]	Minimum	Maximum	ID number[d]
Herbs	Roots	Unspecified	12	1.9E+0	1.7E-1	1.8E+0	1.1	5.9E-1	2.3E+0	91
Herbs	Stems and shoots	Unspecified	12	1.1E+0	1.8E-1	1.1E+0	1.2	5.0E-1	1.3E+0	91
Medicinal plants – shrubs	Leaves	Unspecified	12	2.3E+0	3.4E-1	2.3E+0	1.2	8.0E-1	2.8E+0	91
Medicinal plants – non-woody trees	Leaves	All	18	5.7E-1	3.0E-1	5.1E-1	1.6	1.8E-1	6.8E-1	69, 70
Medicinal plants – non-woody trees	Leaves	Loam	14	6.7E-1	2.7E-1	6.2E-1	1.5	6.5E-1	6.8E-1	69
Medicinal plants – non-woody trees	Leaves	Unspecified	4	2.6E-1	5.3E-2	2.5E-1	1.2	1.8E-1	3.2E-1	70
Other crops	Cacao beans	All	25	1.4E+0	9.1E-1	1.1E+0	1.8	7.3E-1	2.6E+0	58, 65
Other crops	Cacao beans	Loam	7	1.7E+0	1.1E+0	1.4E+0	1.8	8.8E-1	2.6E+0	65
Other crops	Cacao beans	Unspecified	18	1.2E+0	8.3E-1	1.0E+0	1.8	7.3E-1	1.8E+0	58
Other crops	Coffee beans	Unspecified	3	8.1E-1	5.6E-2	8.1E-1	1.1	—	—	58
Fe (iron)										
Maize	Grains, seeds and pods	Unspecified	1	9.0E-2	n.a.	n.a.	n.a.	n.a.	n.a.	64
Rice	Grains, seeds and pods	All	27	4.6E-2	2.7E-2	4.0E-2	1.7	1.0E-2	6.8E-2	52, 81, 85
Rice	Grains, seeds and pods	Clay	5	1.8E-2	1.2E-2	1.5E-2	1.8	1.0E-2	4.0E-2	85
Rice	Grains, seeds and pods	Unspecified	22	5.3E-2	2.5E-2	4.8E-2	1.6	2.0E-2	6.8E-2	52, 81
Rice	Stems and shoots	All	31	4.1E-1	3.0E-1	3.3E-1	1.9	1.0E-3	6.0E-1	3, 52, 81, 85
Rice	Stems and shoots	Clay	5	5.8E-2	7.1E-2	3.7E-2	2.6	2.0E-2	2.0E-1	85
Rice	Stems and shoots	Loam	4	2.2E-3	1.5E-3	1.8E-3	1.9	1.0E-3	4.7E-3	3
Rice	Stems and shoots	Unspecified	22	5.6E-1	1.9E-1	5.3E-1	1.4	5.5E-1	6.0E-1	52, 81
Leafy vegetables	Leaves	Unspecified	53	1.0E+0	6.0E-1	9.0E-1	1.7	3.0E-3	2.9E+0	53, 64, 70, 72, 91
Non-leafy vegetables	Fruits, heads, berries and buds	Unspecified	9	5.6E-2	8.3E-2	3.1E-2	2.9	5.6E-4	2.3E-1	64, 72, 93
Leguminous vegetables	Grains, seeds and pods	Unspecified	14	1.8E-1	1.4E-2	1.8E-1	1.1	—	—	52
Root crops	Roots	Unspecified	1	6.4E-2	n.a.	n.a.	n.a.	n.a.	n.a.	72
Tubers	Tubers	Unspecified	25	6.6E-2	8.3E-2	4.1E-2	2.6	3.5E-4	2.6E-1	39, 64, 93
Fruits - all	Fruits, heads, berries and buds	Unspecified	94	1.3E-3	2.4E-3	5.9E-4	3.5	2.9E-5	1.4E-2	39, 72, 89
Fruits - herbaceous plants	Fruits, heads, berries and buds	Unspecified	13	8.9E-4	1.3E-3	4.9E-4	3.0	8.3E-5	5.0E-3	39
Fruits - shrubs	Fruits, heads, berries and buds	Unspecified	6	8.7E-4	6.9E-4	6.8E-4	2.0	6.3E-5	2.1E-3	39
Fruits - woody trees	Fruits, heads, berries and buds	Unspecified	70	1.2E-3	2.3E-3	5.8E-4	3.4	2.9E-5	1.4E-2	39, 89
Fruits - non-woody trees	Fruits, heads, berries and buds	Unspecified	5	3.4E-3	5.9E-3	1.7E-3	3.2	4.9E-4	1.4E-2	39, 72
Herbs	Leaves	Unspecified	15	1.8E+0	9.3E-1	1.6E+0	1.6	1.0E-2	2.7E+0	64, 91
Herbs	Roots	Unspecified	12	1.2E+0	1.1E-1	1.2E+0	1.1	4.2E-1	1.5E+0	91

TABLE 3.1. (cont.)

Plant group	Plant compartment	Soil group	N[a]	AM[b]	SD[b]	GM[c]	GSD[c]	Minimum	Maximum	ID number[d]
Herbs	Stems and shoots	Unspecified	12	1.7E+0	8.3E-2	1.7E+0	1.0	5.6E-1	2.1E+0	91
Medicinal plants – shrubs	Leaves	Unspecified	15	2.1E+0	9.5E-1	1.9E+0	1.5	2.5E-1	3.1E+0	53, 91
Medicinal plants – woody trees	Leaves	Unspecified	4	2.0E+0	9.2E-3	2.0E+0	1.0	—	—	78
Medicinal plants – non-woody trees	Leaves	Unspecified	4	1.7E-1	3.6E-2	1.6E-1	1.2	1.1E-1	2.0E-1	70
Other crops	Cacao beans	Loam	7	2.3E-3	1.2E-3	2.1E-3	1.6	1.7E-3	3.2E-3	65
Hg (mercury)										
Fruits - all	Fruits, heads, berries and buds	Loam	14	1.4E-1	3.0E-1	5.6E-2	3.8	1.1E-1	1.6E-1	69
Fruits - non-woody trees	Fruits, heads, berries and buds	Loam	14	1.4E-1	3.0E-1	5.6E-2	3.8	1.1E-1	1.6E-1	69
Medicinal plants – non-woody trees	Leaves	Loam	14	7.4E-1	3.1E-1	6.9E-1	1.5	6.5E-1	8.3E-1	69
K (potassium)										
Cereals	Grains, seeds and pods	Loam	6	3.0E+0	5.8E-1	2.9E+0	1.2	—	—	59
Maize	Grains, seeds and pods	All	6	2.6E-1	2.9E-1	1.7E-1	2.5	5.7E-2	9.4E-1	41, 54, 80, 82
Maize	Grains, seeds and pods	Sand	1	2.6E-1	n.a.	n.a.	n.a.	n.a.	n.a.	54
Maize	Grains, seeds and pods	Unspecified	5	2.6E-1	3.3E-1	1.6E-1	2.7	5.7E-2	9.4E-1	41, 80, 82
Maize	Stems and shoots	Unspecified	1	7.8E-2	n.a.	n.a.	n.a.	n.a.	n.a.	80
Rice	Grains, seeds and pods	All	86	6.4E-1	7.0E-1	4.3E-1	2.4	5.9E-2	4.1E+0	4, 6, 12, 16, 17, 24, 33, 34, 84, 88
Rice	Grains, seeds and pods	Clay	11	7.4E-1	1.3E-1	7.3E-1	1.2	4.7E-1	1.2E+0	4
Rice	Grains, seeds and pods	Loam	26	1.0E+0	7.9E-1	7.8E-1	2.0	1.1E-1	2.9E+0	6, 24
Rice	Grains, seeds and pods	Organic	4	1.0E+0	4.2E-1	9.3E-1	1.5	4.0E-1	1.3E+0	4, 6
Rice	Grains, seeds and pods	Sand	12	1.8E-1	1.1E-1	1.6E-1	1.8	7.4E-2	4.6E-1	6
Rice	Grains, seeds and pods	Unspecified	33	4.5E-1	7.4E-1	2.4E-1	3.1	5.9E-2	4.1E+0	12, 16, 17, 33, 34, 84, 88
Rice	Stems and shoots	All	59	4.1E+0	4.6E+0	2.7E+0	2.5	4.0E-2	2.1E+1	6, 16, 24, 88
Rice	Stems and shoots	Loam	26	3.7E+0	2.5E+0	3.1E+0	1.8	1.1E+0	1.0E+1	6, 24
Rice	Stems and shoots	Organic	1	2.2E+0	n.a.	n.a.	n.a.	n.a.	n.a.	6
Rice	Stems and shoots	Sand	12	1.8E+0	7.7E-1	1.6E+0	1.5	1.1E+0	3.8E+0	6
Rice	Stems and shoots	Unspecified	20	6.1E+0	7.0E+0	4.1E+0	2.5	4.0E-2	2.1E+1	16, 88
Leafy vegetables	Leaves	All	69	9.8E+0	1.9E+1	4.5E+0	3.5	1.8E-1	1.1E+2	7, 14, 18, 21, 34, 45, 54, 68, 73, 77, 80, 82
Leafy vegetables	Leaves	Clay	4	1.5E+1	2.1E+1	8.4E+0	2.9	7.4E-1	5.2E+1	18, 68
Leafy vegetables	Leaves	Loam	15	2.5E+1	3.4E+1	1.5E+1	2.8	4.4E-1	1.1E+2	18, 45, 68
Leafy vegetables	Leaves	Sand	10	2.5E+0	3.8E+0	1.4E+0	3.0	1.8E-1	1.2E+1	54, 68

TABLE 3.1. (cont.)

Plant group	Plant compartment	Soil group	N[a]	AM[b]	SD[b]	GM[c]	GSD[c]	Minimum	Maximum	ID number[d]
Leafy vegetables	Leaves	Unspecified	40	5.5E+0	6.4E+0	3.6E+0	2.5	2.0E-1	3.8E+1	7, 14, 21, 34, 73, 77, 80, 82
Non-leafy vegetables	Fruits, heads, berries and buds	All	99	4.5E+0	6.2E+0	2.6E+0	2.8	3.2E-2	2.1E+1	7, 10, 14, 16, 18, 21, 33, 34, 45, 67, 73, 82, 84
Non-leafy vegetables	Fruits, heads, berries and buds	Clay	3	1.3E+0	8.0E-1	1.1E+0	1.8	3.7E-1	1.9E+0	18, 45
Non-leafy vegetables	Fruits, heads, berries and buds	Loam	17	5.7E-1	4.5E-1	4.5E-1	2.0	2.2E-1	1.8E+0	18, 45
Non-leafy vegetables	Fruits, heads, berries and buds	Sand	1	2.2E-1	n.a.	n.a.	n.a.	n.a.	n.a.	45
Non-leafy vegetables	Fruits, heads, berries and buds	Unspecified	78	5.5E+0	6.6E+0	3.6E+0	2.6	3.2E-2	2.1E+1	7, 10, 14, 16, 21, 33, 34, 67, 73, 82, 84
Leguminous vegetables	Grains, seeds and pods	All	12	5.7E+0	4.6E+0	4.4E+0	2.0	3.1E-1	1.5E+1	21, 45, 84
Leguminous vegetables	Grains, seeds and pods	Loam	1	3.1E-1	n.a.	n.a.	n.a.	n.a.	n.a.	45
Leguminous vegetables	Grains, seeds and pods	Unspecified	11	6.2E+0	4.5E+0	5.0E+0	1.9	5.3E-1	1.5E+1	21, 45, 84
Root crops	Roots	All	86	3.4E+0	7.1E+0	1.5E+0	3.6	4.0E-2	2.4E+1	2, 5, 7, 14, 16, 21, 27, 41, 42, 47, 54, 55, 73, 79
Root crops	Roots	All*	78	1.3E+0	2.7E+0	5.7E-1	3.6	4.0E-2	2.2E+1	2, 5, 7, 14, 16, 21, 41, 42, 47, 54, 55, 73, 79
Root crops	Roots	Coral sand	8	2.4E+1	—	—	—	—	—	27
Root crops	Roots	Loam	24	1.0E+0	3.5E-1	9.5E-1	1.4	1.0E-1	1.8E+0	5, 55, 79
Root crops	Roots	Organic	5	2.0E+0	2.3E-1	2.0E+0	1.1	1.7E+0	2.2E+0	5
Root crops	Roots	Sand	5	8.6E-1	6.4E-1	6.9E-1	1.9	2.4E-1	2.1E+0	54, 79
Root crops	Roots	Unspecified	44	1.4E+0	3.6E+0	5.4E-1	4.1	4.0E-2	2.2E+1	2, 7, 14, 16, 21, 41, 42, 47, 73
Tubers	Tubers	All	56	3.7E+1	9.8E+1	1.3E+1	4.2	1.3E-1	4.6E+2	5, 18, 21, 39, 41, 47, 49, 55, 73
Tubers	Tubers	Loam	13	1.9E+0	1.3E+0	1.6E+0	1.8	7.5E-1	3.7E+0	5, 18, 55
Tubers	Tubers	Organic	5	6.9E-1	5.5E-2	6.9E-1	1.1	6.1E-1	7.5E-1	5
Tubers	Tubers	Unspecified	38	5.4E+1	1.2E+2	2.3E+1	3.7	1.3E-1	4.6E+2	21, 39, 41, 47, 49, 73
Fruits - all	Fruits, heads, berries and buds	All	412	9.6E+0	4.7E+1	1.9E+0	6.0	1.6E-3	1.1E+2	9, 11, 16, 27, 39, 41, 64, 73, 84, 89
Fruits - all	Fruits, heads, berries and buds	All*	179	4.1E+0	9.7E+0	1.6E+0	3.9	1.6E-3	1.1E+2	9, 11, 16, 39, 41, 64, 73, 84, 89
Fruits - all	Fruits, heads, berries and buds	Coral sand	233	1.4E+1	6.2E+1	3.0E+0	5.7	1.2E+1	1.9E+1	27
Fruits - all	Fruits, heads, berries and buds	Loam	10	1.1E-1	6.3E-2	9.4E-2	1.7	—	—	11
Fruits - all	Fruits, heads, berries and buds	Sand	10	2.9E+0	9.9E-1	2.7E+0	1.4	1.4E+0	4.5E+0	64
Fruits - all	Fruits, heads, berries and buds	Unspecified	159	4.5E+0	1.0E+1	1.8E+0	3.9	1.6E-3	1.1E+2	9, 16, 39, 41, 73, 84, 89
Fruits - herbaceous plants	Fruits, heads, berries and buds	Unspecified	13	8.9E-1	8.4E-1	6.5E-1	2.2	2.4E-2	3.0E+0	39, 41, 84
Fruits - shrubs	Fruits, heads, berries and buds	Unspecified	14	2.7E+0	4.4E+0	1.4E+0	3.1	3.1E-3	1.4E+1	16, 39
Fruits - woody trees	Fruits, heads, berries and buds	All	158	7.8E+0	1.0E+1	4.7E+0	2.7	2.9E-3	1.1E+2	9, 11, 16, 27, 39, 41, 84, 89
Fruits - woody trees	Fruits, heads, berries and buds	All*	108	5.7E+0	1.2E+1	2.4E+0	3.7	2.9E-3	1.1E+2	9, 11, 16, 39, 41, 84, 89

TABLE 3.1. (cont.)

Plant group	Plant compartment	Soil group	N[a]	AM[b]	SD[b]	GM[c]	GSD[c]	Minimum	Maximum	ID number[d]
Fruits - woody trees	Fruits, heads, berries and buds	Coral sand	50	1.2E+1	—	—	—	—	—	27
Fruits - woody trees	Fruits, heads, berries and buds	Loam	10	1.1E-1	6.3E-2	9.4E-2	1.7	—	—	11
Fruits - woody trees	Fruits, heads, berries and buds	Unspecified	98	6.2E+0	1.2E+1	2.8E+0	3.6	2.9E-3	1.1E+2	9, 16, 39, 41, 84, 89
Fruits - non-woody trees	Fruits, heads, berries and buds	All	227	1.2E+1	5.7E+1	2.3E+0	6.0	1.6E-3	1.9E+1	16, 27, 39, 41, 64, 73, 84
Fruits - non-woody trees	Fruits, heads, berries and buds	All*	44	1.8E+0	2.7E+0	9.5E-1	3.0	1.6E-3	1.1E+1	16, 39, 41, 64, 73, 84
Fruits - non-woody trees	Fruits, heads, berries and buds	Coral sand	183	1.4E+1	6.3E+1	3.1E+0	5.7	1.4E+1	1.9E+1	27
Fruits - non-woody trees	Fruits, heads, berries and buds	Sand	10	2.9E+0	9.9E-1	2.7E+0	1.4	1.4E+0	4.5E+0	64
Fruits - non-woody trees	Fruits, heads, berries and buds	Unspecified	34	1.4E+0	3.0E+0	6.2E-1	3.6	1.6E-3	1.1E+1	16, 39, 41, 73, 84
Grasses	Stems and shoots	All	32	1.7E+0	1.2E+0	1.4E+0	1.9	1.0E-1	3.7E+0	26, 40, 41, 45, 80
Grasses	Stems and shoots	Clay	2	3.6E+0	n.a.	n.a.	n.a.	3.6E+0	3.7E+0	45
Grasses	Stems and shoots	Loam	18	2.2E+0	8.5E-1	2.1E+0	1.5	5.9E-1	3.5E+0	26, 45
Grasses	Stems and shoots	Sand	6	8.7E-1	9.5E-1	5.9E-1	2.4	2.4E-1	2.2E+0	40, 45
Grasses	Stems and shoots	Unspecified	6	2.6E-1	1.7E-1	2.1E-1	1.8	1.0E-1	5.1E-1	41, 80
Herbs	Leaves	All	150	2.7E+1	2.3E+1	2.0E+1	2.1	2.4E-2	5.6E+1	9, 13, 16, 19, 22, 23, 26, 27, 40, 49, 84
Herbs	Leaves	All*	77	4.6E+0	6.2E+0	2.8E+0	2.7	2.4E-2	3.1E+1	9, 13, 16, 19, 22, 23, 26, 40, 49, 84
Herbs	Leaves	Coral sand	73	5.0E+1	5.5E+0	5.0E+1	1.1	4.5E+1	5.6E+1	27
Herbs	Leaves	Loam	2	3.5E+0	n.a.	n.a.	n.a.	1.3E+0	5.6E+0	26
Herbs	Leaves	Sand	4	2.6E-1	2.0E-2	2.6E-1	1.1	2.3E-1	2.8E-1	40
Herbs	Leaves	Unspecified	71	4.9E+0	6.3E+0	3.0E+0	2.7	2.4E-2	3.1E+1	9, 13, 16, 19, 22, 23, 49, 84
Herbs	Rhizomes	Unspecified	15	2.1E+0	1.7E+0	1.6E+0	2.1	3.1E-1	6.2E+0	13, 22
Herbs	Roots	Unspecified	1	1.5E+0	n.a.	n.a.	n.a.	n.a.	n.a.	49
Herbs	Stems and shoots	All	19	1.6E+0	1.8E+0	1.1E+0	2.5	2.3E-2	7.9E+0	13, 16, 22, 26, 40, 49
Herbs	Stems and shoots	Loam	2	1.8E+0	n.a.	n.a.	n.a.	1.4E+0	2.3E+0	26
Herbs	Stems and shoots	Sand	4	2.6E-1	1.9E-2	2.6E-1	1.1	2.4E-1	2.9E-1	40
Herbs	Stems and shoots	Unspecified	13	2.0E+0	2.0E+0	1.4E+0	2.3	2.3E-2	7.9E+0	13, 16, 22, 49
Herbs	Whole plant	All	6	8.9E-1	1.1E+0	5.6E-1	2.6	2.1E-1	2.9E+0	9, 19, 26, 40
Herbs	Whole plant	Loam	1	2.1E-1	n.a.	n.a.	n.a.	n.a.	n.a.	26
Herbs	Whole plant	Sand	3	2.8E-1	2.6E-2	2.8E-1	1.1	2.6E-1	3.2E-1	40
Herbs	Whole plant	Unspecified	2	2.1E+0	n.a.	n.a.	n.a.	1.3E+0	2.9E+0	9, 19
Medicinal plants – shrubs	Bark	Unspecified	1	1.3E+1	n.a.	n.a.	n.a.	n.a.	n.a.	9
Medicinal plants – shrubs	Leaves	All	109	4.8E+1	1.4E+1	4.6E+1	1.3	3.3E-2	5.6E+1	9, 16, 19, 26, 27, 84
Medicinal plants – shrubs	Leaves	All*	10	5.4E+0	7.9E+0	3.1E+0	2.9	3.3E-2	2.4E+1	9, 16, 19, 26, 84
Medicinal plants – shrubs	Leaves	Coral sand	99	5.2E+1	4.0E+0	5.2E+1	1.1	4.8E+1	5.6E+1	27

TABLE 3.1. (cont.)

Plant group	Plant compartment	Soil group	N[a]	AM[b]	SD[b]	GM[c]	GSD[c]	Minimum	Maximum	ID number[d]
Medicinal plants – shrubs	Leaves	Loam	1	1.5E+0	n.a.	n.a.	n.a.	n.a.	n.a.	26
Medicinal plants – shrubs	Leaves	Unspecified	9	5.9E+0	8.3E+0	3.4E+0	2.8	3.3E-2	2.4E+1	9, 16, 19, 84
Medicinal plants – woody trees	Bark	All	28	1.6E+0	5.0E-1	1.6E+0	1.3	1.7E-1	2.4E+0	9, 26
Medicinal plants – woody trees	Bark	Loam	25	1.8E+0	3.3E-1	1.7E+0	1.2	7.9E-1	2.4E+0	26
Medicinal plants – woody trees	Bark	Unspecified	3	5.9E-1	4.2E-1	4.9E-1	1.9	1.7E-1	1.2E+0	9
Medicinal plants – woody trees	Leaves	All	132	1.6E+1	1.9E+1	1.1E+1	2.5	3.5E-2	4.0E+1	16, 19, 23, 26, 27, 84
Medicinal plants – woody trees	Leaves	All*	82	1.7E+0	2.2E+0	1.0E+0	2.7	3.5E-2	1.3E+1	16, 19, 23, 26, 84
Medicinal plants – woody trees	Leaves	Coral sand	50	4.0E+1	—	—	—	—	—	27
Medicinal plants – woody trees	Leaves	Loam	31	1.2E+0	1.0E+0	8.9E-1	2.1	3.5E-1	3.7E+0	26
Medicinal plants – woody trees	Leaves	Unspecified	51	2.0E+0	2.7E+0	1.2E+0	2.8	3.5E-2	1.3E+1	16, 19, 23, 84
Medicinal plants – non-woody trees	Leaves	Unspecified	20	1.6E+0	1.6E+0	1.2E+0	2.2	3.8E-2	5.3E+0	16, 23
La (lanthanum)										
Medicinal plants – woody trees	Leaves	Unspecified	4	1.3E+0	2.2E-1	1.3E+0	1.2	—	—	78
Mg (magnesium)										
Non-leafy vegetables	Fruits, heads, berries and buds	Unspecified	20	2.1E+0	—	—	—	—	—	67
Tubers	Tubers	Unspecified	23	3.3E+1	5.9E+1	1.6E+1	3.3	3.7E-2	2.2E+2	39
Fruits - all	Fruits, heads, berries and buds	Unspecified	137	1.3E+0	2.4E+0	6.2E-1	3.4	6.3E-3	1.4E+1	39, 74, 89
Fruits - herbaceous plants	Fruits, heads, berries and buds	Unspecified	15	3.3E-1	4.1E-1	2.0E-1	2.7	6.3E-3	1.6E+0	39
Fruits - shrubs	Fruits, heads, berries and buds	Unspecified	6	7.3E-1	8.2E-1	4.8E-1	2.5	6.8E-2	1.9E+0	39
Fruits - woody trees	Fruits, heads, berries and buds	Unspecified	92	1.8E+0	2.7E+0	9.5E-1	3.0	2.6E-2	1.4E+1	39, 74, 89
Fruits - non-woody trees	Fruits, heads, berries and buds	Unspecified	24	3.0E-1	7.6E-1	1.1E-1	4.1	7.2E-2	1.0E+0	39, 74
Mn (manganese)										
Maize	Grains, seeds and pods	Unspecified	1	1.6E-1	n.a.	n.a.	n.a.	n.a.	n.a.	64
Rice	Grains, seeds and pods	All	33	7.9E-1	7.7E-1	5.7E-1	2.3	3.0E-2	1.6E+0	64, 81, 85, 86, 87
Rice	Grains, seeds and pods	Clay	5	7.6E-2	4.2E-2	6.7E-2	1.7	3.0E-2	1.5E-1	85

TABLE 3.1. (cont.)

Plant group	Plant compartment	Soil group	N[a]	AM[b]	SD[b]	GM[c]	GSD[c]	Minimum	Maximum	ID number[d]
Rice	Grains, seeds and pods	Unspecified	28	9.2E-1	7.7E-1	7.1E-1	2.1	8.2E-2	1.6E+0	64, 81, 86, 87
Rice	Stems and shoots	All	46	6.9E+0	5.8E+0	5.3E+0	2.1	9.1E-3	1.3E+1	3, 81, 85, 86
Rice	Stems and shoots	Clay	5	9.9E-1	3.6E-1	9.3E-1	1.4	5.8E-1	1.7E+0	85
Rice	Stems and shoots	Loam	4	1.3E-2	3.0E-3	1.3E-2	1.3	9.1E-3	1.6E-2	3
Rice	Stems and shoots	Unspecified	37	8.4E+0	5.4E+0	7.1E+0	1.8	6.1E-1	1.3E+1	81, 86
Leafy vegetables	Leaves	Unspecified	13	2.6E-1	2.1E-1	2.0E-1	2.0	3.0E-2	7.0E-1	50, 64, 72
Non-leafy vegetables	Fruits, heads, berries and buds	Unspecified	11	2.4E-1	2.8E-1	1.6E-1	2.5	4.5E-4	7.2E-1	50, 64, 72, 93
Leguminous vegetables	Grains, seeds and pods	Unspecified	1	1.1E-1	n.a.	n.a.	n.a.	n.a.	n.a.	50
Root crops	Roots	Unspecified	8	1.7E-1	1.7E-1	1.2E-1	2.3	8.8E-3	3.6E-1	1, 50, 58, 72
Tubers	Tubers	Unspecified	36	2.1E+0	4.4E+0	8.9E-1	3.7	1.2E-3	2.1E+1	1, 39, 50, 64, 93
Fruits - all	Fruits, heads, berries and buds	Unspecified	176	1.5E-1	5.5E-1	3.8E-2	5.2	9.8E-4	3.3E+0	39, 50, 58, 72, 74, 78, 89
Fruits - herbaceous plants	Fruits, heads, berries and buds	Unspecified	24	5.9E-2	8.3E-2	3.4E-2	2.9	2.6E-3	2.3E-1	39, 58
Fruits - shrubs	Fruits, heads, berries and buds	Unspecified	6	8.6E-1	1.2E+0	4.9E-1	2.9	2.7E-3	3.3E+0	39
Fruits - woody trees	Fruits, heads, berries and buds	Unspecified	108	1.2E-1	3.4E-1	4.1E-2	4.4	9.8E-4	1.2E+0	39, 58, 74, 78, 89
Fruits - non-woody trees	Fruits, heads, berries and buds	Unspecified	38	1.6E-1	4.8E-1	5.4E-2	4.5	2.9E-3	5.8E-1	39, 50, 58, 72, 74
Herbs	Leaves	Unspecified	7	5.1E-1	4.3E-1	3.9E-1	2.1	1.6E-1	1.5E+0	1, 50, 64
Medicinal plants – woody trees	Leaves	Unspecified	4	1.4E-1	1.6E-2	1.4E-1	1.1	—	—	78
Other crops	Cacao beans	All	25	6.2E-1	4.0E-1	5.2E-1	1.8	2.2E-2	2.5E+0	58, 65
Other crops	Cacao beans	Loam	7	3.8E-2	2.0E-2	3.4E-2	1.6	2.2E-2	5.6E-2	65
Other crops	Cacao beans	Unspecified	18	8.4E-1	1.8E-1	8.3E-1	1.2	4.8E-2	2.5E+0	58
Other crops	Coffee beans	Unspecified	3	2.2E-1	1.8E-2	2.2E-1	1.1	—	—	58
Mo (molybdenum)										
Root crops	Roots	Unspecified	3	6.4E-2	5.6E-2	4.8E-2	2.1	—	—	1
Tubers	Tubers	Unspecified	9	4.4E-1	6.9E-1	2.3E-1	3.1	6.7E-2	1.1E+0	1
Fruits - all	Fruits, heads, berries and buds	Unspecified	9	7.2E-2	7.1E-2	5.1E-2	2.3	1.2E-2	1.4E-1	58
Fruits - woody trees	Fruits, heads, berries and buds	Unspecified	3	1.4E-1	8.6E-2	1.1E-1	1.8	—	—	58
Fruits - non-woody trees	Fruits, heads, berries and buds	Unspecified	6	4.0E-2	3.0E-2	3.2E-2	2.0	1.2E-2	6.8E-2	58
Herbs	Leaves	Unspecified	3	2.5E-1	2.9E-1	1.6E-1	2.5	—	—	1
Other crops	Cacao beans	Unspecified	12	2.7E-1	1.4E-1	2.4E-1	1.6	5.1E-2	8.3E-1	58
Na (sodium)										
Non-leafy vegetables	Fruits, heads, berries and buds	Unspecified	20	6.0E+0	—	—	—	—	—	67
Fruits - all	Fruits, heads, berries and buds	Unspecified	16	6.6E+0	1.6E+1	2.5E+0	4.0	7.7E-2	6.9E+1	39, 78, 89

TABLE 3.1. (cont.)

Plant group	Plant compartment	Soil group	N[a]	AM[b]	SD[b]	GM[c]	GSD[c]	Minimum	Maximum	ID number[d]
Fruits - woody trees	Fruits, heads, berries and buds	Unspecified	16	6.6E+0	1.6E+1	2.5E+0	4.0	7.7E-2	6.9E+1	39, 78, 89
Medicinal plants – woody trees	Leaves	Unspecified	4	3.5E-1	1.3E-2	3.5E-1	1.0	—	—	78
Ni (nickel)										
Maize	Grains, seeds and pods	Sand	10	7.7E-1	7.0E-1	5.7E-1	2.2	—	—	66
Rice	Grains, seeds and pods	All	43	2.8E-1	4.0E-1	1.6E-1	2.9	7.2E-3	8.8E-1	52, 64, 81, 85, 86
Rice	Grains, seeds and pods	Clay	5	1.9E-1	6.7E-2	1.7E-1	1.4	1.0E-1	2.9E-1	85
Rice	Grains, seeds and pods	Unspecified	38	2.9E-1	4.2E-1	1.7E-1	2.9	7.2E-3	8.8E-1	52, 64, 81, 86
Rice	Stems and shoots	All	61	6.7E-1	9.3E-1	3.9E-1	2.8	1.0E-3	2.5E+0	3, 52, 81, 85, 86
Rice	Stems and shoots	Clay	5	6.5E-1	2.7E-1	6.0E-1	1.5	3.9E-1	1.1E+0	85
Rice	Stems and shoots	Loam	4	1.7E-3	8.1E-4	1.5E-3	1.6	1.0E-3	3.0E-3	3
Rice	Stems and shoots	Unspecified	52	7.2E-1	9.9E-1	4.2E-1	2.8	2.2E-1	2.5E+0	52, 81, 86
Leafy vegetables	Leaves	Unspecified	38	4.9E-1	2.0E+0	1.1E-1	5.5	2.0E-3	9.0E-1	50, 53, 64, 70
Non-leafy vegetables	Fruits, heads, berries and buds	All	35	4.8E+1	4.2E+1	3.6E+1	2.1	1.0E-2	8.4E+1	50, 64, 66, 67
Non-leafy vegetables	Fruits, heads, berries and buds	Sand	10	1.1E-1	1.5E-1	6.5E-2	2.8	—	—	66
Non-leafy vegetables	Fruits, heads, berries and buds	Unspecified	25	6.7E+1	3.4E+1	6.0E+1	1.6	1.0E-2	8.4E+1	50, 64, 67
Leguminous vegetables	Grains, seeds and pods	Unspecified	15	1.8E-1	3.4E-2	1.7E-1	1.2	1.8E-1	2.0E-1	50, 52
Root crops	Roots	All	24	1.9E+0	2.2E+0	1.2E+0	2.5	2.5E-2	2.2E+0	1, 50, 66
Root crops	Roots	Sand	20	2.2E+0	2.2E+0	1.6E+0	2.3	—	—	66
Root crops	Roots	Unspecified	4	7.0E-2	9.1E-2	4.3E-2	2.7	2.5E-2	2.1E-1	1, 50
Tubers	Tubers	Unspecified	11	7.0E-2	1.1E-1	3.8E-2	3.0	4.9E-3	3.5E-1	1, 50, 64
Fruits - all	Fruits, heads, berries and buds	All	18	2.0E-1	9.8E-1	4.0E-2	6.0	3.3E-4	3.9E-1	50, 66, 89
Fruits - all	Fruits, heads, berries and buds	Sand	10	2.9E-1	1.3E+0	6.1E-2	5.8	—	—	66
Fruits - all	Fruits, heads, berries and buds	Unspecified	8	9.0E-2	1.4E-1	4.8E-2	3.1	3.3E-4	3.9E-1	50, 89
Fruits - herbaceous plants	Fruits, heads, berries and buds	Sand	10	2.9E-1	1.3E+0	6.1E-2	5.8	—	—	66
Fruits - woody trees	Fruits, heads, berries and buds	Unspecified	7	9.7E-2	1.5E-1	5.2E-2	3.1	3.3E-4	3.9E-1	89
Fruits - non-woody trees	Fruits, heads, berries and buds	Unspecified	1	4.1E-2	n.a.	n.a.	n.a.	n.a.	n.a.	50
Grasses	Stems and shoots	Sand	3	8.4E-1	7.0E-1	6.4E-1	2.1	—	—	66
Herbs	Leaves	Unspecified	6	1.7E-1	1.5E-1	1.3E-1	2.1	4.9E-2	4.0E-1	1, 50, 64
Medicinal plants – shrubs	Leaves	Unspecified	3	1.8E-1	2.4E-1	1.1E-1	2.7	—	—	53
Medicinal plants – non-woody trees	Leaves	Unspecified	4	1.1E-1	1.2E-1	7.9E-2	2.3	7.8E-3	3.1E-1	70
Other crops	Cacao beans	All	10	3.5E-1	2.9E-1	2.7E-1	2.0	1.8E-1	5.6E-1	58, 65
Other crops	Cacao beans	Loam	7	4.3E-1	3.2E-1	3.4E-1	1.9	3.0E-1	5.6E-1	65

TABLE 3.1. (cont.)

Plant group	Plant compartment	Soil group	N[a]	AM[b]	SD[b]	GM[c]	GSD[c]	Minimum	Maximum	ID number[d]
Other crops	Cacao beans	Unspecified	3	1.8E-1	1.7E-2	1.8E-1	1.1	—	—	58
P (phosphorus)										
Tubers	Tubers	Unspecified	8	1.3E+1	6.6E+0	1.1E+1	1.6	4.3E+0	2.3E+1	39
Fruits - all	Fruits, heads, berries and buds	Unspecified	41	2.9E+0	2.3E+0	2.2E+0	2.0	1.5E-1	1.3E+1	39
Fruits - shrubs	Fruits, heads, berries and buds	Unspecified	4	1.6E+0	3.5E-1	1.5E+0	1.2	1.2E+0	2.0E+0	39
Fruits - woody trees	Fruits, heads, berries and buds	Unspecified	33	3.0E+0	2.6E+0	2.3E+0	2.1	1.5E-1	1.3E+1	39
Fruits - non-woody trees	Fruits, heads, berries and buds	Unspecified	4	3.0E+0	2.5E-1	3.0E+0	1.1	2.8E+0	3.4E+0	39
Pb (lead)										
Maize	Grains, seeds and pods	All	12	3.4E-2	2.4E-2	2.8E-2	1.9	3.0E-2	6.3E-2	60, 66
Maize	Grains, seeds and pods	Sand	10	3.0E-2	2.5E-2	2.3E-2	2.1	—	—	66
Maize	Grains, seeds and pods	Unspecified	2	5.4E-2	n.a.	n.a.	n.a.	4.4E-2	6.3E-2	60
Maize	Stems and shoots	Unspecified	2	5.3E-2	n.a.	n.a.	n.a.	3.6E-2	6.9E-2	60
Rice	Grains, seeds and pods	All	71	1.8E-1	1.9E-1	1.3E-1	2.3	3.8E-3	8.1E-1	24, 33, 34, 52, 64, 81, 85, 86, 87
Rice	Grains, seeds and pods	Clay	5	4.6E-1	2.0E-1	4.3E-1	1.5	2.5E-1	7.5E-1	85
Rice	Grains, seeds and pods	Loam	13	1.8E-1	2.0E-1	1.2E-1	2.5	2.3E-2	8.1E-1	24
Rice	Grains, seeds and pods	Unspecified	53	1.6E-1	1.6E-1	1.1E-1	2.3	3.8E-3	3.9E-1	33, 34, 52, 64, 81, 86, 87
Rice	Stems and shoots	All	73	2.0E-1	1.5E-1	1.6E-1	1.9	8.0E-3	7.2E-1	24, 52, 81, 85, 86
Rice	Stems and shoots	Clay	5	4.2E-1	1.7E-1	3.9E-1	1.5	2.8E-1	7.2E-1	85
Rice	Stems and shoots	Loam	16	5.7E-2	7.7E-2	3.4E-2	2.8	8.0E-3	3.5E-1	24
Rice	Stems and shoots	Unspecified	52	2.3E-1	1.2E-1	2.0E-1	1.7	9.8E-2	3.0E-1	52, 81, 86
Leafy vegetables	Leaves	All	282	6.6E-1	1.8E+0	2.3E-1	4.2	1.2E-2	9.0E+0	48, 50, 53, 70, 72, 75, 83, 91, 92
Leafy vegetables	Leaves	Clay	2	4.7E+0	n.a.	n.a.	n.a.	4.1E+0	5.2E+0	92
Leafy vegetables	Leaves	Loam	3	6.3E+0	1.2E+0	6.2E+0	1.2	4.7E+0	7.5E+0	92
Leafy vegetables	Leaves	Unspecified	277	5.7E-1	1.6E+0	1.9E-1	4.4	1.2E-2	9.0E+0	48, 50, 53, 70, 72, 75, 83, 91
Non-leafy vegetables	Fruits, heads, berries and buds	All	48	4.5E-1	8.2E-1	2.2E-1	3.3	1.3E-4	5.5E+0	33, 50, 66, 67, 72, 92, 93
Non-leafy vegetables	Fruits, heads, berries and buds	Clay	1	5.5E+0	n.a.	n.a.	n.a.	n.a.	n.a.	92
Non-leafy vegetables	Fruits, heads, berries and buds	Sand	10	1.0E-2	7.2E-3	8.1E-3	1.9	—	—	66
Non-leafy vegetables	Fruits, heads, berries and buds	Unspecified	37	4.4E-1	3.3E-1	3.5E-1	2.0	1.3E-4	1.1E+0	33, 50, 67, 72, 93
Leguminous vegetables	Grains, seeds and pods	All	16	8.2E-1	1.0E+0	5.2E-1	2.6	5.6E-1	4.6E+0	50, 52, 92
Leguminous vegetables	Grains, seeds and pods	Clay	1	4.6E+0	n.a.	n.a.	n.a.	n.a.	n.a.	92
Leguminous vegetables	Grains, seeds and pods	Unspecified	15	5.7E-1	7.2E-2	5.7E-1	1.1	5.6E-1	7.6E-1	50, 52
Root crops	Roots	Unspecified	5	5.6E-1	3.2E-1	4.9E-1	1.7	3.4E-1	9.9E-1	50, 58, 72
Tubers	Tubers	Unspecified	36	2.8E-1	3.4E-1	1.8E-1	2.6	1.3E-3	1.2E+0	39, 50, 93

TABLE 3.1. (cont.)

Plant group	Plant compartment	Soil group	N[a]	AM[b]	SD[b]	GM[c]	GSD[c]	Minimum	Maximum	ID number[d]
Fruits - all	Fruits, heads, berries and buds	All	175	5.4E-2	4.7E-1	6.2E-3	8.0	7.6E-5	2.6E-1	39, 50, 69, 72, 74, 89
Fruits - all	Fruits, heads, berries and buds	Loam	14	1.2E-1	4.2E-1	3.6E-2	4.9	1.1E-1	1.4E-1	69
Fruits - all	Fruits, heads, berries and buds	Unspecified	161	4.8E-2	4.7E-1	4.8E-3	8.5	7.6E-5	2.6E-1	39, 50, 72, 74, 89
Fruits - herbaceous plants	Fruits, heads, berries and buds	Unspecified	14	6.3E-3	9.5E-3	3.4E-3	3.0	8.0E-5	3.0E-2	39
Fruits - shrubs	Fruits, heads, berries and buds	Unspecified	9	9.5E-3	1.5E-2	5.1E-3	3.0	6.0E-4	5.0E-2	39
Fruits - woody trees	Fruits, heads, berries and buds	Unspecified	114	4.1E-2	2.5E-1	6.7E-3	6.7	7.6E-5	2.6E-1	39, 74, 89
Fruits - non-woody trees	Fruits, heads, berries and buds	All	38	1.2E-1	5.5E-1	2.5E-2	5.8	1.1E-3	1.6E-1	39, 50, 69, 72, 74
Fruits - non-woody trees	Fruits, heads, berries and buds	Loam	14	1.2E-1	4.2E-1	3.6E-2	4.9	1.1E-1	1.4E-1	69
Fruits - non-woody trees	Fruits, heads, berries and buds	Unspecified	24	1.2E-1	6.3E-1	2.1E-2	6.3	1.1E-3	1.6E-1	39, 50, 72, 74
Grasses	Stems and shoots	All	28	3.0E-1	2.5E-1	2.3E-1	2.0	1.6E-2	1.0E+0	38, 66
Grasses	Stems and shoots	Sand	3	1.6E-2	1.4E-2	1.2E-2	2.1	—	—	66
Grasses	Stems and shoots	Unspecified	25	3.3E-1	2.4E-1	2.7E-1	1.9	5.9E-2	1.0E+0	38
Herbs	Leaves	All	45	5.8E-1	1.4E+0	2.3E-1	4.0	8.0E-4	7.0E+0	8, 9, 19, 50, 64, 91, 94
Herbs	Leaves	Loam	24	3.9E-2	2.9E-3	3.9E-2	1.1	8.0E-4	1.3E-1	94
Herbs	Leaves	Unspecified	21	1.2E+0	1.9E+0	6.5E-1	3.0	7.2E-2	7.0E+0	8, 9, 19, 50, 64, 91
Herbs	Rhizomes	Unspecified	1	1.0E-1	n.a.	n.a.	n.a.	n.a.	n.a.	8
Herbs	Roots	Unspecified	15	5.5E-1	1.3E-1	5.3E-1	1.3	3.9E-1	6.2E-1	20, 91
Herbs	Stems and shoots	Unspecified	12	2.0E-1	4.7E-2	1.9E-1	1.3	1.5E-1	3.4E-1	91
Herbs	Whole plant	Unspecified	6	8.2E-1	5.2E-1	7.0E-1	1.8	3.1E-1	1.5E+0	8, 9, 19, 20
Medicinal plants – shrubs	Bark	Unspecified	1	6.8E-1	n.a.	n.a.	n.a.	n.a.	n.a.	9
Medicinal plants – shrubs	Leaves	Unspecified	18	4.9E-1	2.5E-1	4.4E-1	1.6	2.4E-3	7.3E-1	8, 9, 19, 53, 91
Medicinal plants – woody trees	Bark	Unspecified	5	4.7E-1	4.0E-1	3.6E-1	2.1	8.0E-2	1.1E+0	8, 9
Medicinal plants – woody trees	Leaves	Unspecified	3	1.8E+0	1.1E+0	1.5E+0	1.8	1.2E-1	2.6E+0	8, 19
Medicinal plants – non-woody trees	Leaves	All	18	5.9E-1	4.8E-1	4.6E-1	2.0	1.6E-1	8.0E-1	69, 70
Medicinal plants – non-woody trees	Leaves	Loam	14	7.0E-1	4.9E-1	5.7E-1	1.9	5.9E-1	8.0E-1	69
Medicinal plants – non-woody trees	Leaves	Unspecified	4	2.3E-1	6.5E-2	2.2E-1	1.3	1.6E-1	3.4E-1	70
Other crops	Cacao beans	Loam	7	2.0E-1	9.6E-2	1.8E-1	1.6	1.6E-1	2.4E-1	65
Po (polonium)										
Rice	Grains, seeds and pods	Unspecified	11	1.3E-2	3.9E-3	1.2E-2	1.3	9.4E-3	1.7E-2	33, 34

TABLE 3.1. (cont.)

Plant group	Plant compartment	Soil group	N[a]	AM[b]	SD[b]	GM[c]	GSD[c]	Minimum	Maximum	ID number[d]
Non-leafy vegetables	Fruits, heads, berries and buds	Unspecified	12	3.3E-3	—	—	—	—	—	33
Tubers	Tubers	Unspecified	4	1.9E-1	2.3E-1	1.2E-1	2.6	2.6E-2	5.9E-1	39
Fruits - all	Fruits, heads, berries and buds	Unspecified	22	1.7E-2	2.8E-2	8.5E-3	3.2	5.2E-5	1.2E-1	39
Fruits - herbaceous plants	Fruits, heads, berries and buds	Unspecified	2	6.7E-4	n.a.	n.a.	n.a.	6.4E-4	6.9E-4	39
Fruits - shrubs	Fruits, heads, berries and buds	Unspecified	2	3.4E-2	n.a.	n.a.	n.a.	1.8E-3	6.7E-2	39
Fruits - woody trees	Fruits, heads, berries and buds	Unspecified	18	1.6E-2	2.8E-2	8.4E-3	3.2	5.2E-5	1.2E-1	39
Herbs	Leaves	Unspecified	5	2.3E+0	9.1E-1	2.1E+0	1.5	1.2E+0	3.7E+0	8
Herbs	Rhizomes	Unspecified	1	1.0E-1	n.a.	n.a.	n.a.	n.a.	n.a.	8
Herbs	Whole plant	Unspecified	1	3.2E+0	n.a.	n.a.	n.a.	n.a.	n.a.	8
Medicinal plants – shrubs	Leaves	Unspecified	1	9.0E-1	n.a.	n.a.	n.a.	n.a.	n.a.	8
Medicinal plants – woody trees	Bark	Unspecified	3	6.7E-1	1.7E-1	6.5E-1	1.3	5.0E-1	9.0E-1	8
Medicinal plants – woody trees	Leaves	Unspecified	1	2.5E+0	n.a.	n.a.	n.a.	n.a.	n.a.	8
Pu (plutonium)										
Fruits - all	Fruits, heads, berries and buds	Coral sand	40	8.5E-6	1.8E-4	4.0E-7	11.8	2.2E-7	9.5E-5	30
Fruits - woody trees	Fruits, heads, berries and buds	Coral sand	6	7.0E-6	2.0E-5	2.3E-6	4.4	5.2E-6	5.6E-5	30
Fruits - non-woody trees	Fruits, heads, berries and buds	Coral sand	34	8.7E-6	1.8E-4	4.2E-7	11.8	2.2E-7	9.5E-5	30
Ra (radium)										
Maize	Grains, seeds and pods	Unspecified	1	8.5E-3	n.a.	n.a.	n.a.	n.a.	n.a.	80
Maize	Stems and shoots	Unspecified	1	9.1E-3	n.a.	n.a.	n.a.	n.a.	n.a.	80
Rice	Grains, seeds and pods	All	78	1.3E-1	2.2E-1	7.0E-2	3.1	2.2E-3	9.8E-1	4, 6, 12, 16, 33, 34, 84
Rice	Grains, seeds and pods	Clay	11	2.4E-1	1.2E-1	2.1E-1	1.6	1.0E-1	4.3E-1	4
Rice	Grains, seeds and pods	Loam	10	1.7E-2	8.7E-3	1.5E-2	1.6	6.0E-3	3.6E-2	6
Rice	Grains, seeds and pods	Organic	4	2.5E-1	1.7E-1	2.1E-1	1.9	3.5E-2	3.7E-1	4, 6
Rice	Grains, seeds and pods	Sand	12	1.8E-2	5.3E-3	1.7E-2	1.3	8.0E-3	2.6E-2	6
Rice	Grains, seeds and pods	Unspecified	41	1.6E-1	2.7E-1	7.8E-2	3.3	2.2E-3	9.8E-1	12, 16, 33, 34, 84
Rice	Stems and shoots	All	33	6.9E-2	2.6E-2	6.4E-2	1.4	3.1E-2	9.7E-2	6, 16
Rice	Stems and shoots	Loam	10	5.8E-2	1.6E-2	5.6E-2	1.3	3.1E-2	8.7E-2	6
Rice	Stems and shoots	Organic	1	5.3E-2	n.a.	n.a.	n.a.	n.a.	n.a.	6
Rice	Stems and shoots	Sand	12	7.2E-2	1.7E-2	7.0E-2	1.3	4.7E-2	9.7E-2	6
Rice	Stems and shoots	Unspecified	10	7.7E-2	3.9E-2	6.9E-2	1.6	7.4E-2	8.0E-2	16
Leafy vegetables	Leaves	All	69	3.3E-1	3.5E-1	2.2E-1	2.4	1.0E-2	2.0E+0	7, 14, 18, 21, 68, 73, 77, 80

TABLE 3.1. (cont.)

Plant group	Plant compartment	Soil group	N[a]	AM[b]	SD[b]	GM[c]	GSD[c]	Minimum	Maximum	ID number[d]
Leafy vegetables	Leaves	Clay	6	5.2E-1	1.7E-1	4.9E-1	1.4	3.2E-1	8.1E-1	18, 68
Leafy vegetables	Leaves	Loam	15	6.7E-1	4.9E-1	5.4E-1	1.9	1.9E-1	2.0E+0	18, 68
Leafy vegetables	Leaves	Sand	3	4.2E-1	3.4E-1	3.3E-1	2.0	1.2E-1	9.0E-1	68
Leafy vegetables	Leaves	Unspecified	45	1.8E-1	1.8E-1	1.3E-1	2.3	1.0E-2	9.6E-1	7, 14, 21, 73, 77, 80
Non-leafy vegetables	Fruits, heads, berries and buds	All	85	1.4E-1	2.5E-1	6.6E-2	3.4	1.2E-3	7.6E-1	7, 10, 14, 16, 18, 21, 33, 73, 84
Non-leafy vegetables	Fruits, heads, berries and buds	Clay	4	1.8E-1	1.4E-1	1.4E-1	2.0	6.1E-2	4.2E-1	18
Non-leafy vegetables	Fruits, heads, berries and buds	Loam	4	2.3E-1	1.2E-1	2.1E-1	1.6	8.2E-2	4.0E-1	18
Non-leafy vegetables	Fruits, heads, berries and buds	Unspecified	77	1.3E-1	2.6E-1	5.8E-2	3.5	1.2E-3	7.6E-1	7, 10, 14, 16, 21, 33, 73, 84
Leguminous vegetables	Grains, seeds and pods	Unspecified	15	1.3E-1	1.3E-1	9.7E-2	2.2	6.3E-3	4.2E-1	21, 84
Root crops	Roots	All	52	7.9E-1	7.8E-1	5.6E-1	2.3	4.0E-2	5.0E+0	5, 7, 14, 16, 21, 42, 73, 79
Root crops	Roots	Loam	16	1.0E+0	4.0E-1	9.5E-1	1.5	4.6E-1	2.2E+0	5, 79
Root crops	Roots	Organic	5	1.1E+0	3.0E-1	1.0E+0	1.3	7.5E-1	1.4E+0	5
Root crops	Roots	Sand	3	2.5E+0	1.9E+0	2.0E+0	2.0	4.0E-1	5.0E+0	79
Root crops	Roots	Unspecified	28	4.2E-1	5.2E-1	2.7E-1	2.6	4.0E-2	2.0E+0	7, 14, 16, 21, 42, 73
Tubers	Tubers	All	45	6.2E-1	9.0E-1	3.5E-1	2.9	3.9E-3	4.1E+0	5, 18, 21, 39, 73
Tubers	Tubers	Loam	6	6.0E-1	1.6E-1	5.8E-1	1.3	3.5E-1	9.3E-1	5, 18
Tubers	Tubers	Organic	5	8.4E-1	1.8E-1	8.2E-1	1.2	6.1E-1	1.1E+0	5
Tubers	Tubers	Unspecified	34	5.9E-1	1.0E+0	3.0E-1	3.3	3.9E-3	4.1E+0	21, 39, 73
Fruits - all	Fruits, heads, berries and buds	All	177	2.8E-2	5.6E-2	1.2E-2	3.6	2.4E-4	4.6E-1	9, 16, 39, 64, 73, 84
Fruits - all	Fruits, heads, berries and buds	Sand	10	1.9E-1	1.3E-1	1.6E-1	1.8	5.8E-2	4.6E-1	64
Fruits - all	Fruits, heads, berries and buds	Unspecified	167	1.8E-2	2.9E-2	9.4E-3	3.1	2.4E-4	1.0E-1	9, 16, 39, 73, 84
Fruits - herbaceous plants	Fruits, heads, berries and buds	Unspecified	21	1.6E-2	2.4E-2	8.8E-3	3.0	2.5E-4	9.5E-2	39, 84
Fruits - shrubs	Fruits, heads, berries and buds	Unspecified	11	2.0E-2	2.9E-2	1.2E-2	2.9	1.1E-3	9.1E-2	16, 39
Fruits - woody trees	Fruits, heads, berries and buds	Unspecified	105	2.0E-2	2.6E-2	1.2E-2	2.7	2.4E-4	1.0E-1	9, 16, 39, 84
Fruits - non-woody trees	Fruits, heads, berries and buds	All	40	5.5E-2	1.0E-1	2.7E-2	3.4	3.8E-4	4.6E-1	16, 39, 64, 73, 84
Fruits - non-woody trees	Fruits, heads, berries and buds	Sand	10	1.9E-1	1.3E-1	1.6E-1	1.8	5.8E-2	4.6E-1	64
Fruits - non-woody trees	Fruits, heads, berries and buds	Unspecified	30	1.0E-2	1.9E-2	5.0E-3	3.4	3.8E-4	6.9E-2	16, 39, 73, 84
Grasses	Stems and shoots	All	35	5.9E+0	7.4E+0	3.7E+0	2.6	4.0E-3	3.0E+1	26, 38, 40, 80
Grasses	Stems and shoots	Loam	1	1.9E-1	n.a.	n.a.	n.a.	n.a.	n.a.	26
Grasses	Stems and shoots	Sand	4	5.8E-2	1.8E-2	5.6E-2	1.4	3.8E-2	7.8E-2	40
Grasses	Stems and shoots	Unspecified	30	6.9E+0	7.6E+0	4.6E+0	2.4	4.0E-3	3.0E+1	38, 80
Herbs	Leaves	All	90	2.1E-1	2.7E-1	1.3E-1	2.7	6.3E-3	2.0E+0	9, 13, 16, 19, 22, 23, 26, 40, 84
Herbs	Leaves	Loam	2	1.7E-1	n.a.	n.a.	n.a.	1.3E-1	2.1E-1	26

TABLE 3.1. (cont.)

Plant group	Plant compartment	Soil group	N[a]	AM[b]	SD[b]	GM[c]	GSD[c]	Minimum	Maximum	ID number[d]
Herbs	Leaves	Sand	4	5.3E-2	3.1E-3	5.3E-2	1.1	4.8E-2	5.6E-2	40
Herbs	Leaves	Unspecified	84	2.2E-1	2.8E-1	1.4E-1	2.6	6.3E-3	2.0E+0	9, 13, 16, 19, 22, 23, 84
Herbs	Rhizomes	Unspecified	8	1.1E-1	2.7E-1	4.1E-2	4.1	2.0E-3	1.7E-1	13, 22
Herbs	Roots	Unspecified	6	4.2E-1	5.7E-2	4.2E-1	1.1	2.2E-1	6.3E-1	20
Herbs	Stems and shoots	All	13	7.0E-2	7.4E-2	4.8E-2	2.4	1.1E-2	1.7E-1	13, 16, 22, 26, 40
Herbs	Stems and shoots	Loam	2	1.4E-1	n.a.	n.a.	n.a.	1.0E-1	1.7E-1	26
Herbs	Stems and shoots	Sand	4	6.1E-2	1.0E-2	6.0E-2	1.2	4.5E-2	7.4E-2	40
Herbs	Stems and shoots	Unspecified	7	5.7E-2	9.5E-2	2.9E-2	3.2	1.1E-2	8.7E-2	13, 16, 22
Herbs	Whole plant	All	12	1.0E-1	5.2E-2	9.4E-2	1.6	1.0E-2	2.3E-1	9, 19, 20, 26, 40
Herbs	Whole plant	Loam	1	8.0E-2	n.a.	n.a.	n.a.	n.a.	n.a.	26
Herbs	Whole plant	Sand	3	6.0E-2	6.6E-3	5.9E-2	1.1	5.4E-2	6.9E-2	40
Herbs	Whole plant	Unspecified	8	1.2E-1	5.4E-2	1.1E-1	1.5	1.0E-2	2.3E-1	9, 19, 20
Medicinal plants – shrubs	Bark	Unspecified	1	7.0E-2	n.a.	n.a.	n.a.	n.a.	n.a.	9
Medicinal plants – shrubs	Leaves	All	11	1.2E-1	8.8E-2	9.2E-2	2.0	3.7E-2	3.3E-1	9, 16, 19, 26, 40, 84
Medicinal plants – shrubs	Leaves	Loam	1	1.0E-1	n.a.	n.a.	n.a.	n.a.	n.a.	26
Medicinal plants – shrubs	Leaves	Sand	1	6.1E-2	n.a.	n.a.	n.a.	n.a.	n.a.	40
Medicinal plants – shrubs	Leaves	Unspecified	9	1.2E-1	9.6E-2	9.8E-2	2.0	3.7E-2	3.3E-1	9, 16, 19, 84
Medicinal plants – woody trees	Bark	All	28	1.4E-1	7.1E-2	1.2E-1	1.6	7.0E-2	2.7E-1	9, 26
Medicinal plants – woody trees	Bark	Loam	25	1.4E-1	7.5E-2	1.2E-1	1.7	7.0E-2	2.7E-1	26
Medicinal plants – woody trees	Bark	Unspecified	3	1.3E-1	3.3E-2	1.3E-1	1.3	9.0E-2	1.7E-1	9
Medicinal plants – woody trees	Leaves	All	83	1.1E-1	1.0E-1	8.1E-2	2.2	1.5E-2	6.5E-1	16, 19, 23, 26, 84
Medicinal plants – woody trees	Leaves	Loam	30	1.2E-1	1.3E-1	8.2E-2	2.4	6.0E-2	3.7E-1	26
Medicinal plants – woody trees	Leaves	Unspecified	53	1.1E-1	8.5E-2	8.2E-2	2.0	1.5E-2	6.5E-1	16, 19, 23, 84
Medicinal plants – non-woody trees	Leaves	Unspecified	20	8.6E-2	7.6E-2	6.4E-2	2.1	9.7E-3	3.8E-1	16, 23
Rb (rubidium)										
Tubers	Tubers	Unspecified	8	1.5E+1	8.1E+0	1.3E+1	1.7	2.1E+0	2.9E+1	39
Fruits - all	Fruits, heads, berries and buds	Unspecified	41	4.3E+0	3.3E+0	3.4E+0	2.0	3.9E-1	1.3E+1	39

TABLE 3.1. (cont.)

Plant group	Plant compartment	Soil group	N[a]	AM[b]	SD[b]	GM[c]	GSD[c]	Minimum	Maximum	ID number[d]
Fruits - shrubs	Fruits, heads, berries and buds	Unspecified	4	1.7E+0	1.0E+0	1.4E+0	1.7	4.1E-1	2.9E+0	39
Fruits - woody trees	Fruits, heads, berries and buds	Unspecified	33	5.0E+0	3.4E+0	4.1E+0	1.9	3.9E-1	1.3E+1	39
Fruits - non-woody trees	Fruits, heads, berries and buds	Unspecified	4	1.6E+0	1.4E-1	1.6E+0	1.1	1.5E+0	1.8E+0	39
S (sulphur)										
Tubers	Tubers	Unspecified	17	2.7E+1	2.8E+1	1.9E+1	2.4	1.3E-1	9.5E+1	39
Fruits - all	Fruits, heads, berries and buds	Unspecified	67	2.6E+0	1.9E+0	2.1E+0	1.9	5.4E-2	7.7E+0	39
Fruits - herbaceous plants	Fruits, heads, berries and buds	Unspecified	6	3.0E+0	1.9E+0	2.5E+0	1.8	7.4E-1	6.0E+0	39
Fruits - shrubs	Fruits, heads, berries and buds	Unspecified	4	2.6E+0	1.8E+0	2.2E+0	1.9	7.7E-1	5.6E+0	39
Fruits - woody trees	Fruits, heads, berries and buds	Unspecified	53	2.5E+0	1.9E+0	2.0E+0	2.0	5.4E-2	7.7E+0	39
Fruits - non-woody trees	Fruits, heads, berries and buds	Unspecified	4	4.4E+0	7.9E-1	4.3E+0	1.2	3.5E+0	5.7E+0	39
Sb (antimony)										
Leafy vegetables	Leaves	Unspecified	25	1.5E+0	1.1E+0	1.2E+0	1.9	8.9E-1	1.8E+0	48
Tubers	Tubers	Unspecified	1	5.8E-2	n.a.	n.a.	n.a.	n.a.	n.a.	39
Sc (scandium)										
Medicinal plants – woody trees	Leaves	Unspecified	4	1.3E+1	1.2E+0	1.3E+1	1.1	—	—	78
Se (selenium)										
Tubers	Tubers	Unspecified	3	2.5E-2	8.1E-3	2.4E-2	1.4	1.8E-2	3.7E-2	39
Fruits - all	Fruits, heads, berries and buds	Unspecified	13	3.0E-1	2.4E-1	2.4E-1	2.0	3.7E-3	7.8E-1	39
Fruits - herbaceous plants	Fruits, heads, berries and buds	Unspecified	1	6.0E-2	n.a.	n.a.	n.a.	n.a.	n.a.	39
Fruits - woody trees	Fruits, heads, berries and buds	Unspecified	12	3.2E-1	2.4E-1	2.6E-1	1.9	3.7E-3	7.8E-1	39
Herbs	Leaves	Loam	6	9.1E-1	8.8E-3	9.1E-1	1.0	7.8E-1	1.0E+0	94
Sm (samarium)										
Medicinal plants – woody trees	Leaves	Unspecified	4	2.3E+1	3.8E+0	2.2E+1	1.2	—	—	78
Sr (strontium)										
Cereals	Grains, seeds and pods	All	6	6.0E-1	2.0E-1	5.7E-1	1.4	4.4E-1	7.6E-1	25
Cereals	Grains, seeds and pods	Loam	3	7.6E-1	8.7E-2	7.6E-1	1.1	—	—	25
Cereals	Grains, seeds and pods	Sand	3	4.4E-1	1.0E-1	4.3E-1	1.3	—	—	25
Rice	Grains, seeds and pods	All	28	3.5E-1	3.4E-1	2.6E-1	2.2	1.2E-1	8.9E-1	29, 44, 64
Rice	Grains, seeds and pods	Loam	18	3.2E-1	3.2E-1	2.3E-1	2.3	2.0E-1	8.9E-1	29, 44
Rice	Grains, seeds and pods	Sand	9	4.4E-1	3.8E-1	3.3E-1	2.1	—	—	44
Rice	Grains, seeds and pods	Unspecified	1	1.2E-1	n.a.	n.a.	n.a.	n.a.	n.a.	64

TABLE 3.1. (cont.)

Plant group	Plant compartment	Soil group	N[a]	AM[b]	SD[b]	GM[c]	GSD[c]	Minimum	Maximum	ID number[d]
Leafy vegetables	Leaves	All	35	8.1E+0	8.0E+0	5.8E+0	2.3	1.6E-1	1.8E+1	29, 44, 64
Leafy vegetables	Leaves	Loam	24	5.8E+0	4.2E+0	4.7E+0	1.9	6.6E-1	9.2E+0	29, 44
Leafy vegetables	Leaves	Sand	8	1.8E+1	1.0E+1	1.6E+1	1.7	—	—	44
Leafy vegetables	Leaves	Unspecified	3	3.4E-1	1.4E-1	3.2E-1	1.5	1.6E-1	4.9E-1	64
Non-leafy vegetables	Fruits, heads, berries and buds	All	4	6.2E-1	5.9E-2	6.1E-1	1.1	5.5E-1	6.9E-1	29, 64
Non-leafy vegetables	Fruits, heads, berries and buds	Loam	3	5.9E-1	4.2E-2	5.9E-1	1.1	5.5E-1	6.5E-1	29
Non-leafy vegetables	Fruits, heads, berries and buds	Unspecified	1	6.9E-1	n.a.	n.a.	n.a.	n.a.	n.a.	64
Leguminous vegetables	Grains, seeds and pods	All	17	3.4E+0	1.4E+0	3.2E+0	1.5	5.8E-1	5.9E+0	25, 28
Leguminous vegetables	Grains, seeds and pods	Loam	3	2.7E+0	3.5E-1	2.7E+0	1.1	—	—	25
Leguminous vegetables	Grains, seeds and pods	Sand	3	1.8E+0	2.8E-1	1.8E+0	1.2	—	—	25
Leguminous vegetables	Grains, seeds and pods	Unspecified	11	4.1E+0	1.3E+0	3.9E+0	1.4	5.8E-1	5.9E+0	28
Root crops	Roots	Unspecified	6	2.0E+0	2.2E-1	2.0E+0	1.1	1.1E+0	3.0E+0	28
Tubers	Tubers	Unspecified	23	3.8E+1	6.2E+1	2.0E+1	3.1	7.0E-2	2.2E+2	39
Fruits - all	Fruits, heads, berries and buds	All	191	4.4E-1	1.1E+0	1.6E-1	4.1	6.0E-4	7.4E+0	29, 30, 39
Fruits - all	Fruits, heads, berries and buds	All*	93	9.0E-1	1.5E+0	4.6E-1	3.2	1.9E-3	7.4E+0	29, 39
Fruits - all	Fruits, heads, berries and buds	Coral sand	98	1.3E-2	1.2E-1	1.4E-3	8.2	6.0E-4	8.3E-1	30
Fruits - all	Fruits, heads, berries and buds	Loam	3	1.6E-1	8.4E-3	1.6E-1	1.1	1.6E-1	1.8E-1	29
Fruits - all	Fruits, heads, berries and buds	Unspecified	90	9.2E-1	1.5E+0	4.8E-1	3.1	1.9E-3	7.4E+0	39
Fruits - herbaceous plants	Fruits, heads, berries and buds	All	18	2.1E-1	5.5E-1	7.8E-2	4.1	1.9E-3	2.5E+0	29, 39
Fruits - herbaceous plants	Fruits, heads, berries and buds	Loam	3	1.6E-1	8.4E-3	1.6E-1	1.1	1.6E-1	1.8E-1	29
Fruits - herbaceous plants	Fruits, heads, berries and buds	Unspecified	15	2.2E-1	6.0E-1	7.8E-2	4.3	1.9E-3	2.5E+0	39
Fruits - shrubs	Fruits, heads, berries and buds	Unspecified	6	5.5E-1	5.0E-1	4.1E-1	2.2	4.8E-2	1.4E+0	39
Fruits - woody trees	Fruits, heads, berries and buds	All	76	1.0E+0	1.6E+0	5.4E-1	3.1	1.4E-2	7.4E+0	30, 39
Fruits - woody trees	Fruits, heads, berries and buds	Coral sand	11	3.4E-2	1.1E-1	9.9E-3	4.8	1.8E-2	2.9E-1	30
Fruits - woody trees	Fruits, heads, berries and buds	Unspecified	65	1.2E+0	1.7E+0	6.7E-1	2.9	1.4E-2	7.4E+0	39
Fruits - non-woody trees	Fruits, heads, berries and buds	All	91	1.2E-2	8.9E-2	1.6E-3	7.5	6.0E-4	8.3E-1	30, 39
Fruits - non-woody trees	Fruits, heads, berries and buds	Coral sand	87	1.1E-2	9.1E-2	1.2E-3	8.0	6.0E-4	8.3E-1	30
Fruits - non-woody trees	Fruits, heads, berries and buds	Unspecified	4	3.8E-2	8.2E-3	3.8E-2	1.2	2.5E-2	4.7E-2	39
Grasses	Stems and shoots	Loam	3	8.4E-1	5.0E-2	8.4E-1	1.1	7.9E-1	9.1E-1	29
Herbs	Leaves	Unspecified	8	1.0E+0	7.6E-1	8.3E-1	1.9	9.0E-2	2.8E+0	23, 64
Medicinal plants – woody trees	Leaves	Unspecified	15	1.2E+0	7.1E-1	1.1E+0	1.7	1.8E-1	2.7E+0	23, 78
Other crops	Peanuts	Loam	3	2.1E-1	2.5E-2	2.1E-1	1.1	1.8E-1	2.4E-1	29

TABLE 3.1. (cont.)

Plant group	Plant compartment	Soil group	N[a]	AM[b]	SD[b]	GM[c]	GSD[c]	Minimum	Maximum	ID number[d]
Th (thorium)										
Cereals	Grains, seeds and pods	Loam	6	9.0E-3	1.1E-3	8.9E-3	1.1	—	—	59
Maize	Grains, seeds and pods	All	5	3.2E-1	1.7E-1	2.8E-1	1.7	9.7E-3	4.4E-1	41, 54, 80
Maize	Grains, seeds and pods	Sand	2	3.9E-1	n.a.	n.a.	n.a.	3.3E-1	4.4E-1	54
Maize	Grains, seeds and pods	Unspecified	3	2.7E-1	2.3E-1	2.1E-1	2.1	9.7E-3	4.1E-1	41, 80
Maize	Stems and shoots	Unspecified	1	1.0E-2	n.a.	n.a.	n.a.	n.a.	n.a.	80
Rice	Grains, seeds and pods	All	62	2.2E-1	2.9E-1	1.3E-1	2.7	4.0E-3	1.0E+0	4, 6, 12, 16, 17
Rice	Grains, seeds and pods	Clay	11	3.1E-1	1.8E-1	2.7E-1	1.7	8.0E-2	5.9E-1	4
Rice	Grains, seeds and pods	Loam	10	7.9E-3	2.4E-3	7.6E-3	1.4	4.0E-3	1.3E-2	6
Rice	Grains, seeds and pods	Organic	4	3.6E-1	2.5E-1	3.0E-1	1.9	1.3E-2	5.5E-1	4, 6
Rice	Grains, seeds and pods	Sand	12	1.0E-2	2.7E-3	9.9E-3	1.3	6.0E-3	1.4E-2	6
Rice	Grains, seeds and pods	Unspecified	25	3.5E-1	3.6E-1	2.4E-1	2.3	2.0E-2	1.0E+0	12, 16, 17
Rice	Stems and shoots	All	33	5.7E-2	6.1E-2	3.9E-2	2.4	1.5E-2	1.3E-1	6, 16
Rice	Stems and shoots	Loam	10	2.8E-2	4.5E-3	2.8E-2	1.2	1.8E-2	3.4E-2	6
Rice	Stems and shoots	Organic	1	2.8E-2	n.a.	n.a.	n.a.	n.a.	n.a.	6
Rice	Stems and shoots	Sand	12	2.7E-2	6.1E-3	2.6E-2	1.3	1.5E-2	4.2E-2	6
Rice	Stems and shoots	Unspecified	10	1.2E-1	7.5E-2	1.1E-1	1.7	1.2E-1	1.3E-1	16
Leafy vegetables	Leaves	All	45	2.8E-1	2.6E-1	2.1E-1	2.2	2.5E-3	1.4E+0	7, 15, 21, 41, 54, 68, 77, 80
Leafy vegetables	Leaves	Clay	1	5.5E-1	n.a.	n.a.	n.a.	n.a.	n.a.	68
Leafy vegetables	Leaves	Loam	12	3.9E-1	3.8E-1	2.7E-1	2.3	4.0E-2	1.4E+0	68
Leafy vegetables	Leaves	Sand	9	4.3E-1	1.5E-1	4.1E-1	1.4	1.7E-1	6.8E-1	54, 68
Leafy vegetables	Leaves	Unspecified	23	1.6E-1	1.5E-1	1.2E-1	2.2	2.5E-3	5.0E-1	7, 15, 21, 41, 77, 80
Non-leafy vegetables	Fruits, heads, berries and buds	Unspecified	59	2.0E-1	4.0E-1	9.3E-2	3.5	7.0E-4	1.4E+0	7, 10, 15, 16, 21
Leguminous vegetables	Grains, seeds and pods	Unspecified	3	2.8E-3	1.9E-3	2.3E-3	1.8	—	—	21
Root crops	Roots	All	75	7.9E-1	1.0E+0	4.8E-1	2.7	1.0E-2	5.8E+0	2, 5, 7, 16, 41, 42, 47, 54, 55, 76, 79
Root crops	Roots	Loam	24	9.0E-1	6.6E-1	7.2E-1	1.9	1.5E-1	2.7E+0	5, 55, 79
Root crops	Roots	Organic	5	3.3E-1	3.0E-1	2.5E-1	2.2	1.4E-1	7.3E-1	5
Root crops	Roots	Sand	4	2.2E+0	1.6E+0	1.8E+0	1.9	8.3E-1	4.8E+0	54, 79
Root crops	Roots	Unspecified	42	6.5E-1	1.1E+0	3.3E-1	3.2	1.0E-2	5.8E+0	2, 7, 16, 41, 42, 47, 76
Tubers	Tubers	All	52	2.3E-1	2.9E-1	1.5E-1	2.6	1.9E-3	1.4E+0	5, 39, 41, 47, 55, 76
Tubers	Tubers	Loam	12	6.1E-1	3.3E-1	5.4E-1	1.7	2.3E-1	1.4E+0	5, 55
Tubers	Tubers	Organic	5	3.3E-1	1.4E-1	3.1E-1	1.5	2.2E-1	5.0E-1	5
Tubers	Tubers	Unspecified	35	9.0E-2	1.0E-1	6.0E-2	2.5	1.9E-3	5.2E-1	39, 41, 47, 76

TABLE 3.1. (cont.)

Plant group	Plant compartment	Soil group	N[a]	AM[b]	SD[b]	GM[c]	GSD[c]	Minimum	Maximum	ID number[d]
Fruits - all	Fruits, heads, berries and buds	All	120	2.0E-2	7.0E-2	5.5E-3	5.0	1.2E-5	6.2E-1	9, 16, 39, 41, 64, 76
Fruits - all	Fruits, heads, berries and buds	Sand	9	1.6E-1	1.7E-1	1.1E-1	2.4	5.1E-2	6.2E-1	64
Fruits - all	Fruits, heads, berries and buds	Unspecified	111	8.3E-3	3.5E-2	1.9E-3	5.6	1.2E-5	2.7E-1	9, 16, 39, 41, 76
Fruits - herbaceous plants	Fruits, heads, berries and buds	Unspecified	8	1.1E-3	7.1E-4	8.8E-4	1.8	1.6E-4	2.1E-3	39, 41
Fruits - shrubs	Fruits, heads, berries and buds	Unspecified	11	3.2E-3	1.3E-2	7.7E-4	5.4	1.6E-3	7.8E-3	16, 39
Fruits - woody trees	Fruits, heads, berries and buds	Unspecified	65	1.2E-2	3.7E-2	3.5E-3	4.7	1.2E-5	2.7E-1	9, 16, 39, 41
Fruits - non-woody trees	Fruits, heads, berries and buds	All	36	4.4E-2	1.1E-1	1.7E-2	4.1	4.0E-5	6.2E-1	16, 39, 64, 76
Fruits - non-woody trees	Fruits, heads, berries and buds	Sand	9	1.6E-1	1.7E-1	1.1E-1	2.4	5.1E-2	6.2E-1	64
Fruits - non-woody trees	Fruits, heads, berries and buds	Unspecified	27	4.5E-3	1.5E-2	1.3E-3	4.8	4.0E-5	4.6E-2	16, 39, 76
Grasses	Stems and shoots	All	14	1.0E-1	5.5E-2	9.1E-2	1.6	3.7E-2	2.8E-1	40, 41, 80
Grasses	Stems and shoots	Sand	8	1.1E-1	2.8E-2	1.0E-1	1.3	6.7E-2	1.4E-1	40
Grasses	Stems and shoots	Unspecified	6	9.7E-2	8.1E-2	7.5E-2	2.1	3.7E-2	2.8E-1	41, 80
Herbs	Leaves	All	19	5.9E-2	4.7E-2	4.6E-2	2.0	8.0E-3	1.5E-1	9, 16, 19, 22, 40
Herbs	Leaves	Sand	8	1.1E-1	2.6E-2	1.0E-1	1.3	6.4E-2	1.5E-1	40
Herbs	Leaves	Unspecified	11	2.4E-2	2.1E-2	1.8E-2	2.1	8.0E-3	6.0E-2	9, 16, 19, 22
Herbs	Rhizomes	Unspecified	9	8.8E-3	1.0E-2	5.8E-3	2.5	2.0E-3	3.6E-2	22
Herbs	Roots	Unspecified	6	1.2E-1	1.6E-2	1.2E-1	1.1	5.7E-2	1.9E-1	20
Herbs	Stems and shoots	All	16	6.7E-2	5.5E-2	5.2E-2	2.0	4.0E-3	1.7E-1	16, 22, 40
Herbs	Stems and shoots	Sand	8	1.2E-1	2.9E-2	1.1E-1	1.3	8.5E-2	1.7E-1	40
Herbs	Stems and shoots	Unspecified	8	2.0E-2	1.7E-2	1.5E-2	2.1	4.0E-3	6.1E-2	16, 22
Herbs	Whole plant	All	13	7.0E-2	4.2E-2	5.9E-2	1.7	1.4E-2	1.5E-1	9, 20, 40
Herbs	Whole plant	Sand	6	1.1E-1	2.5E-2	1.1E-1	1.2	7.9E-2	1.5E-1	40
Herbs	Whole plant	Unspecified	7	3.5E-2	9.0E-3	3.4E-2	1.3	1.4E-2	5.5E-2	9, 20
Medicinal plants – shrubs	Bark	Unspecified	1	4.0E-2	n.a.	n.a.	n.a.	n.a.	n.a.	9
Medicinal plants – shrubs	Leaves	All	8	5.7E-2	3.9E-2	4.7E-2	1.9	3.1E-2	1.3E-1	9, 16, 40
Medicinal plants – shrubs	Leaves	Sand	2	1.2E-1	n.a.	n.a.	n.a.	1.0E-1	1.3E-1	40
Medicinal plants – shrubs	Leaves	Unspecified	6	3.8E-2	1.6E-2	3.5E-2	1.5	3.1E-2	7.0E-2	9, 16
Medicinal plants – woody trees	Bark	Unspecified	3	9.7E-2	2.9E-2	9.3E-2	1.3	6.0E-2	1.3E-1	9
Medicinal plants – woody trees	Leaves	Unspecified	11	2.3E-2	1.8E-2	1.7E-2	2.1	1.5E-2	6.0E-2	16, 19
Medicinal plants – non-woody trees	Leaves	Unspecified	10	5.4E-3	2.3E-3	4.9E-3	1.5	1.3E-3	9.4E-3	16
Other crops	Peanuts	Unspecified	3	5.5E-2	7.4E-2	3.3E-2	2.8	2.0E-3	1.6E-1	76

TABLE 3.1. (cont.)

Plant group	Plant compartment	Soil group	N[a]	AM[b]	SD[b]	GM[c]	GSD[c]	Minimum	Maximum	ID number[d]
U (uranium)										
Cereals	Grains, seeds and pods	Loam	6	2.0E-3	5.4E-4	1.9E-3	1.3	—	—	59
Maize	Grains, seeds and pods	All	4	6.4E-1	1.4E-1	6.2E-1	1.2	4.7E-1	8.0E-1	41, 54
Maize	Grains, seeds and pods	Sand	2	7.6E-1	n.a.	n.a.	n.a.	7.2E-1	8.0E-1	54
Maize	Grains, seeds and pods	Unspecified	2	5.2E-1	n.a.	n.a.	n.a.	4.7E-1	5.7E-1	41
Rice	Grains, seeds and pods	Unspecified	15	9.2E-2	5.1E-2	8.1E-2	1.7	4.0E-2	2.0E-1	16, 17
Rice	Stems and shoots	Unspecified	10	4.3E-2	2.4E-2	3.7E-2	1.7	4.0E-2	4.5E-2	16
Leafy vegetables	Leaves	All	9	4.9E-1	4.1E-1	3.8E-1	2.1	2.1E-2	1.3E+0	15, 41, 54
Leafy vegetables	Leaves	Sand	5	7.6E-1	2.9E-1	7.1E-1	1.4	4.0E-1	1.3E+0	54
Leafy vegetables	Leaves	Unspecified	4	1.6E-1	2.7E-1	7.8E-2	3.2	2.1E-2	5.6E-1	15, 41
Non-leafy vegetables	Fruits, heads, berries and buds	Unspecified	33	1.2E-2	2.3E-2	5.9E-3	3.4	6.0E-4	3.1E-2	15, 16
Root crops	Roots	All	34	4.8E-1	5.6E-1	3.1E-1	2.5	1.9E-2	2.7E+0	2, 16, 41, 47, 54, 55, 76
Root crops	Roots	Loam	8	1.0E+0	2.6E-1	1.0E+0	1.3	6.1E-1	1.3E+0	55
Root crops	Roots	Sand	3	8.1E-1	3.6E-2	8.1E-1	1.0	7.8E-1	8.6E-1	54
Root crops	Roots	Unspecified	23	2.4E-1	5.1E-1	1.0E-1	3.7	1.9E-2	2.7E+0	2, 16, 41, 47, 76
Tubers	Tubers	All	49	1.8E-1	2.6E-1	1.0E-1	2.9	1.6E-3	1.5E+0	39, 41, 47, 55, 76
Tubers	Tubers	Loam	8	3.5E-1	1.0E-1	3.4E-1	1.3	2.4E-1	5.9E-1	55
Tubers	Tubers	Unspecified	41	1.5E-1	2.7E-1	7.1E-2	3.4	1.6E-3	1.5E+0	39, 41, 47, 76
Fruits - all	Fruits, heads, berries and buds	All	134	1.3E-2	4.6E-2	3.7E-3	5.0	1.2E-5	3.5E-1	16, 39, 41, 64, 76
Fruits - all	Fruits, heads, berries and buds	Sand	9	1.6E-1	8.9E-2	1.4E-1	1.7	7.2E-2	3.5E-1	64
Fruits - all	Fruits, heads, berries and buds	Unspecified	125	2.5E-3	5.7E-3	1.0E-3	3.9	1.2E-5	5.0E-2	16, 39, 41, 76
Fruits - herbaceous plants	Fruits, heads, berries and buds	Unspecified	15	2.1E-3	3.3E-3	1.2E-3	3.0	1.2E-5	1.0E-2	39, 41
Fruits - shrubs	Fruits, heads, berries and buds	Unspecified	12	2.1E-3	3.8E-3	1.0E-3	3.3	1.4E-4	1.3E-2	16, 39
Fruits - woody trees	Fruits, heads, berries and buds	Unspecified	84	2.2E-3	3.7E-3	1.1E-3	3.2	3.7E-5	2.2E-2	16, 39, 41
Fruits - non-woody trees	Fruits, heads, berries and buds	All	23	6.7E-2	9.6E-2	3.9E-2	2.9	1.4E-4	3.5E-1	16, 39, 41, 64, 76
Fruits - non-woody trees	Fruits, heads, berries and buds	Sand	9	1.6E-1	8.9E-2	1.4E-1	1.7	7.2E-2	3.5E-1	64
Fruits - non-woody trees	Fruits, heads, berries and buds	Unspecified	14	5.0E-3	1.2E-2	2.0E-3	3.9	1.4E-4	5.0E-2	16, 39, 41, 76
Grasses	Stems and shoots	Unspecified	2	3.1E-1	n.a.	n.a.	n.a.	2.6E-1	3.5E-1	41
Herbs	Leaves	Unspecified	2	2.7E-3	n.a.	n.a.	n.a.	n.a.	n.a.	16
Herbs	Roots	Unspecified	3	2.0E-1	2.6E-2	2.0E-1	1.1	—	—	20
Herbs	Stems and shoots	Unspecified	2	5.0E-3	n.a.	n.a.	n.a.	n.a.	n.a.	16
Herbs	Whole plant	Unspecified	3	1.1E-1	1.7E-2	1.1E-1	1.2	—	—	20
Medicinal plants – shrubs	Leaves	Unspecified	5	5.7E-3	2.3E-3	5.3E-3	1.5	—	—	16

TABLE 3.1. (cont.)

Plant group	Plant compartment	Soil group	N[a]	AM[b]	SD[b]	GM[c]	GSD[c]	Minimum	Maximum	ID number[d]
Medicinal plants – woody trees	Leaves	Unspecified	10	9.6E-3	3.5E-3	9.0E-3	1.4	5.5E-3	1.4E-2	16
Medicinal plants – non-woody trees	Leaves	Unspecified	10	3.0E-3	8.2E-4	2.8E-3	1.3	1.4E-3	4.5E-3	16
Other crops	Peanuts	Unspecified	3	5.1E-1	7.0E-1	3.0E-1	2.8	1.0E-2	1.5E+0	76
V (vanadium)										
Rice	Grains, seeds and pods	Unspecified	1	2.5E-3	n.a.	n.a.	n.a.	n.a.	n.a.	64
Leafy vegetables	Leaves	Unspecified	4	2.9E-3	1.7E-3	2.5E-3	1.7	1.8E-3	5.8E-3	64
Non-leafy vegetables	Fruits, heads, berries and buds	Unspecified	2	7.0E-4	n.a.	n.a.	n.a.	4.0E-4	1.0E-3	64
Root crops	Roots	Unspecified	3	2.5E-3	1.9E-3	2.0E-3	2.0	—	—	58
Tubers	Tubers	Unspecified	7	9.9E-2	1.4E-1	5.6E-2	2.9	1.5E-3	4.1E-1	39, 64
Fruits - all	Fruits, heads, berries and buds	Unspecified	14	5.6E-4	1.4E-2	2.3E-5	12.6	1.5E-4	1.7E-3	39, 58
Fruits - shrubs	Fruits, heads, berries and buds	Unspecified	1	3.5E-4	n.a.	n.a.	n.a.	n.a.	n.a.	39
Fruits - woody trees	Fruits, heads, berries and buds	Unspecified	10	5.6E-4	4.5E-3	6.8E-5	7.7	1.5E-4	1.7E-3	39, 58
Fruits - non-woody trees	Fruits, heads, berries and buds	Unspecified	3	6.4E-4	1.3E-2	3.2E-5	11.6	—	—	58
Herbs	Leaves	Unspecified	2	3.0E-3	n.a.	n.a.	n.a.	2.7E-3	3.4E-3	64
Y (yttrium)										
Root crops	Roots	Loam	7	4.1E-1	4.3E-1	2.8E-1	2.4	1.6E-1	9.5E-1	5
Zn (zinc)										
Cereals	Grains, seeds and pods	All	6	2.2E+1	5.0E+0	2.1E+1	1.3	1.8E+1	2.6E+1	25
Cereals	Grains, seeds and pods	Loam	3	2.6E+1	1.7E+0	2.6E+1	1.1	—	—	25
Cereals	Grains, seeds and pods	Sand	3	1.8E+1	3.5E+0	1.8E+1	1.2	—	—	25
Maize	Grains, seeds and pods	All	13	1.9E+0	1.7E+0	1.4E+0	2.2	6.2E-2	4.5E+0	60, 64, 66
Maize	Grains, seeds and pods	Sand	10	2.0E+0	1.6E+0	1.5E+0	2.1	—	—	66
Maize	Grains, seeds and pods	Unspecified	3	1.7E+0	2.4E+0	9.6E-1	2.9	6.2E-2	4.5E+0	60, 64
Maize	Stems and shoots	Unspecified	2	3.3E-1	n.a.	n.a.	n.a.	7.1E-2	6.0E-1	60
Rice	Grains, seeds and pods	All	35	5.0E-1	6.6E-1	3.1E-1	2.7	1.5E-1	2.6E+0	36, 52, 64, 81, 85, 87
Rice	Grains, seeds and pods	Clay	4	4.4E-1	1.5E-1	4.2E-1	1.4	2.9E-1	6.7E-1	85
Rice	Grains, seeds and pods	Loam	3	2.4E+0	7.9E-2	2.4E+0	1.0	2.4E+0	2.6E+0	36
Rice	Grains, seeds and pods	Unspecified	28	3.0E-1	3.0E-1	2.2E-1	2.3	1.5E-1	1.7E+0	52, 64, 81, 87
Rice	Stems and shoots	All	31	3.2E-1	4.8E-1	1.8E-1	3.0	6.8E-2	1.1E+0	3, 52, 81, 85
Rice	Stems and shoots	Clay	5	6.7E-1	2.5E-1	6.2E-1	1.4	3.8E-1	1.1E+0	85
Rice	Stems and shoots	Loam	4	8.3E-2	1.2E-2	8.2E-2	1.2	6.8E-2	1.0E-1	3

TABLE 3.1. (cont.)

Plant group	Plant compartment	Soil group	N[a]	AM[b]	SD[b]	GM[c]	GSD[c]	Minimum	Maximum	ID number[d]
Rice	Stems and shoots	Unspecified	22	2.9E-1	5.3E-1	1.4E-1	3.4	1.7E-1	5.4E-1	52, 81
Leafy vegetables	Leaves	All	83	5.7E-1	1.2E+0	2.5E-1	3.6	1.6E-2	7.1E+0	48, 50, 53, 64, 70, 72, 75, 92
Leafy vegetables	Leaves	Clay	2	4.8E+0	n.a.	n.a.	n.a.	2.5E+0	7.1E+0	92
Leafy vegetables	Leaves	Loam	3	4.9E+0	9.6E-1	4.8E+0	1.2	3.6E+0	5.8E+0	92
Leafy vegetables	Leaves	Unspecified	78	3.0E-1	1.9E-1	2.5E-1	1.8	1.6E-2	1.0E+0	48, 50, 53, 64, 70, 72, 75
Non-leafy vegetables	Fruits, heads, berries and buds	All	45	1.6E+0	1.2E+0	1.2E+0	2.0	1.7E-3	4.8E+0	36, 50, 64, 66, 67, 72, 92, 93
Non-leafy vegetables	Fruits, heads, berries and buds	Clay	1	4.8E+0	n.a.	n.a.	n.a.	n.a.	n.a.	92
Non-leafy vegetables	Fruits, heads, berries and buds	Loam	3	1.3E+0	1.3E-1	1.3E+0	1.1	1.2E+0	1.5E+0	36
Non-leafy vegetables	Fruits, heads, berries and buds	Sand	10	5.7E-1	5.4E-1	4.1E-1	2.2	—	—	66
Non-leafy vegetables	Fruits, heads, berries and buds	Unspecified	31	1.8E+0	1.1E+0	1.5E+0	1.8	1.7E-3	2.6E+0	50, 64, 67, 72, 93
Leguminous vegetables	Grains, seeds and pods	All	22	5.4E+0	7.9E+0	3.0E+0	2.9	3.6E-1	2.0E+1	25, 50, 52, 92
Leguminous vegetables	Grains, seeds and pods	Clay	1	7.5E+0	n.a.	n.a.	n.a.	n.a.	n.a.	92
Leguminous vegetables	Grains, seeds and pods	Loam	3	2.0E+1	1.4E+0	2.0E+1	1.1	—	—	25
Leguminous vegetables	Grains, seeds and pods	Sand	3	1.5E+1	2.3E+0	1.5E+1	1.2	—	—	25
Leguminous vegetables	Grains, seeds and pods	Unspecified	15	3.8E-1	5.8E-2	3.8E-1	1.2	3.6E-1	5.9E-1	50, 52
Root crops	Roots	All	25	5.1E-1	4.2E-1	3.9E-1	2.0	2.2E-1	7.4E-1	50, 58, 66, 72
Root crops	Roots	Sand	20	5.4E-1	4.5E-1	4.2E-1	2.1	—	—	66
Root crops	Roots	Unspecified	5	3.8E-1	2.4E-1	3.2E-1	1.8	2.2E-1	7.4E-1	50, 58, 72
Tubers	Tubers	Unspecified	25	5.8E+0	9.1E+0	3.2E+0	3.0	4.0E-3	3.5E+1	1, 39, 50, 64, 93
Fruits - all	Fruits, heads, berries and buds	All	191	3.5E-1	6.7E-1	1.7E-1	3.4	9.6E-3	3.6E+0	39, 50, 58, 66, 69, 72, 74, 89
Fruits - all	Fruits, heads, berries and buds	Loam	14	1.2E-1	2.2E-1	6.1E-2	3.3	1.1E-1	1.4E-1	69
Fruits - all	Fruits, heads, berries and buds	Sand	10	1.0E-1	4.4E-1	2.3E-2	5.6	—	—	66
Fruits - all	Fruits, heads, berries and buds	Unspecified	167	3.9E-1	7.0E-1	1.9E-1	3.3	9.6E-3	3.6E+0	39, 50, 58, 72, 74, 89
Fruits - herbaceous plants	Fruits, heads, berries and buds	All	36	2.4E-1	4.3E-1	1.2E-1	3.3	1.0E-2	1.8E+0	36, 39, 58, 66
Fruits - herbaceous plants	Fruits, heads, berries and buds	Loam	3	2.2E-1	2.3E-2	2.2E-1	1.1	2.0E-1	2.5E-1	36
Fruits - herbaceous plants	Fruits, heads, berries and buds	Sand	10	1.0E-1	4.4E-1	2.3E-2	5.6	—	—	66
Fruits - herbaceous plants	Fruits, heads, berries and buds	Unspecified	23	3.1E-1	4.4E-1	1.7E-1	2.9	1.0E-2	1.8E+0	39, 58
Fruits - shrubs	Fruits, heads, berries and buds	Unspecified	6	8.6E-1	1.0E+0	5.5E-1	2.6	4.6E-2	2.7E+0	39
Fruits - woody trees	Fruits, heads, berries and buds	Unspecified	100	4.1E-1	6.4E-1	2.2E-1	3.0	9.6E-3	3.5E+0	39, 58, 74, 89
Fruits - non-woody trees	Fruits, heads, berries and buds	All	52	2.6E-1	5.9E-1	1.1E-1	3.8	2.0E-2	3.6E+0	39, 50, 58, 69, 72, 74
Fruits - non-woody trees	Fruits, heads, berries and buds	Loam	14	1.2E-1	2.2E-1	6.1E-2	3.3	1.1E-1	1.4E-1	69
Fruits - non-woody trees	Fruits, heads, berries and buds	Unspecified	38	3.1E-1	6.7E-1	1.3E-1	3.7	2.0E-2	3.6E+0	39, 50, 58, 72, 74
Grasses	Stems and shoots	All	6	1.2E+0	7.2E-1	1.0E+0	1.8	5.9E-1	1.9E+0	36, 66

TABLE 3.1. (cont.)

Plant group	Plant compartment	Soil group	N[a]	AM[b]	SD[b]	GM[c]	GSD[c]	Minimum	Maximum	ID number[d]
Grasses	Stems and shoots	Loam	3	1.8E+0	9.6E-2	1.8E+0	1.1	1.7E+0	1.9E+0	36
Grasses	Stems and shoots	Sand	3	5.9E-1	4.8E-1	4.6E-1	2.1	—	—	66
Herbs	Leaves	Unspecified	7	9.6E-1	7.1E-1	7.7E-1	1.9	4.2E-1	2.4E+0	1, 50, 64
Medicinal plants – shrubs	Leaves	Unspecified	3	1.1E-1	2.4E-2	1.1E-1	1.2	—	—	53
Medicinal plants – woody trees	Leaves	Unspecified	4	1.3E+2	1.4E+1	1.3E+2	1.1	—	—	78
Medicinal plants – non-woody trees	Leaves	All	18	4.8E-1	2.3E-1	4.3E-1	1.6	1.7E-1	6.9E-1	69, 70
Medicinal plants – non-woody trees	Leaves	Loam	14	5.5E-1	2.2E-1	5.1E-1	1.5	4.1E-1	6.9E-1	69
Medicinal plants – non-woody trees	Leaves	Unspecified	4	2.3E-1	4.7E-2	2.2E-1	1.2	1.7E-1	2.9E-1	70
Other crops	Cacao beans	All	25	8.8E-1	3.2E-1	8.3E-1	1.4	6.4E-1	1.2E+0	58, 65
Other crops	Cacao beans	Loam	7	8.8E-1	4.7E-1	7.8E-1	1.7	6.4E-1	1.2E+0	65
Other crops	Cacao beans	Unspecified	18	8.8E-1	2.5E-1	8.4E-1	1.3	7.2E-1	1.2E+0	58
Other crops	Coffee beans	Unspecified	3	8.1E-2	8.7E-3	8.1E-2	1.1	—	—	58
Other crops	Peanuts	Loam	3	8.9E-1	9.4E-2	8.9E-1	1.1	8.0E-1	1.0E+0	36

[a] N: the number of data points used for analysis.
[b] AM: Arithmetic mean; SD: Standard Deviation.
[c] GM: Geometric mean; GSD: Geometric Standard Deviation.
[d] ID number: Identification number for the source reference presented in Appendix II.
[e] —: data not available.
[f] n.a: not applicable.

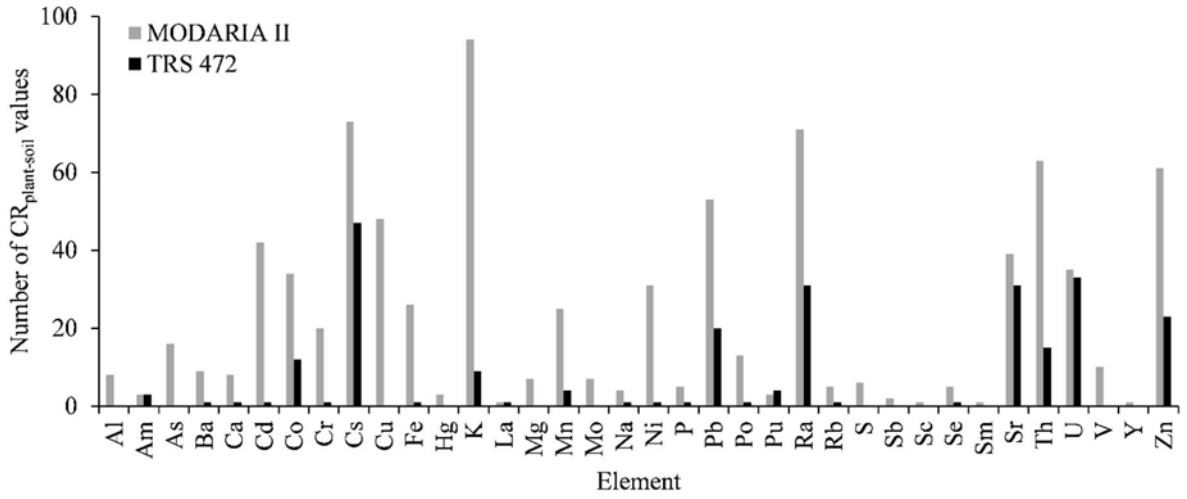

FIG. 3.2. Comparison of the number of $CR_{plant-soil}$ values by element in the MODARIA II and TRS 472 [3.1] tropical datasets.

3.3. SUMMARY

The MODARIA II tropical dataset (given in Table 3.1 above) substantially improves the number of $CR_{plant-soil}$ values available for tropical environments compared with TRS 472 [3.1]. It also benefits from being based on data for locations that conform to a specific, international definition of tropical climate under the K-G classification system.

The total number of summary values of $CR_{plant-soil}$ for tropical environments calculated in MODARIA II is 824 and the total number of observations on which they are based is 10 721. This is about three times more $CR_{plant-soil}$ values and about ten times more observations than in TRS 472 [3.1]. The MODARIA II tropical dataset also includes 25 additional elements that are not given in TRS 472 [3.1] and enhances the number of $CR_{plant-soil}$ values available for elements already reported in the TRS 472 tropical dataset (i.e. Am, Co, Cs, K, Pb, Pu, Ra, Sr, Th, U and Zn) (see Fig. 3.2 above).

The plant groups in the MODARIA II tropical dataset (see Table 3.1) with the most extensive information are fruits, herbs, leafy vegetables, non-leafy vegetables and rice. Tubers and root crops are also well represented by the data. Information is more limited for cereals, maize, grasses and leguminous vegetables.

Most of the $CR_{plant-soil}$ values in the MODARIA II tropical dataset (see Table 3.1) are for unspecified soil types due to a general lack of soil characterization information (including mineral and organic matter content and soil texture information) in the source references. Values with a specific soil group are mostly for loam and sand.

The $CR_{plant-soil}$ values for the newly introduced coral sand soil group are limited to K and four anthropogenic radionuclides, Am, Cs, Pu and Sr, in nuclear weapons fallout. Compared with all other soils (i.e. 'All*'), the $CR_{plant-soil}$ of Cs for coral sand soils is up to an order of magnitude higher in cereals, fruits, leafy vegetables, non-leafy vegetables, leguminous vegetables and tubers ($p<0.05$). In contrast, the $CR_{plant-soil}$ of Sr in fruits (herbaceous plants and woody trees subgroups) for coral sand soils is about two orders of magnitude lower than for other soils ($p<0.05$). The marked difference for Sr may be due to strong competition from its chemical analogue, Ca (both group II elements) and is a major component of the coral sand soil matrix.

The $CR_{plant\text{-}soil}$ values for K are similar between coral sand soils and other soil groups. No comparative values are available for Am and Pu. In Annex X[4] on transfer factors for food in the Marshall Islands, the data were collected to a depth of 40 cm to include the rooting zone of the trees (although it is acknowledged that IUR protocol for concentration ratios states a soil depth of 20 cm). CRs calculated based on 20 cm depth are likely to be roughly half those based on 40 cm depth.

Figure 3.3 compares the number of $CR_{plant\text{-}soil}$ values for plant groups in the MODARIA II tropical dataset with that in TRS 472 (specifically Table 20) [3.1], to which rice is also added as an important staple food in tropical environments. Most of the rice data published in TRS 472 originated from temperate/mesothermal climates, sub-type subtropical (Cfa), with about 20% from continental climates (Dfa) and tropical savannah climates (Aw).

There is a substantial enhancement in the number of $CR_{plant\text{-}soil}$ values in the MODARIA II tropical dataset for maize, leafy and non-leafy vegetables, root crops, tubers, fruits and herbs compared to the TRS 472 tropical dataset (see Fig. 3.3 below). All these plant groups, in addition to rice, represent a significant proportion of the food basket in tropical environments.

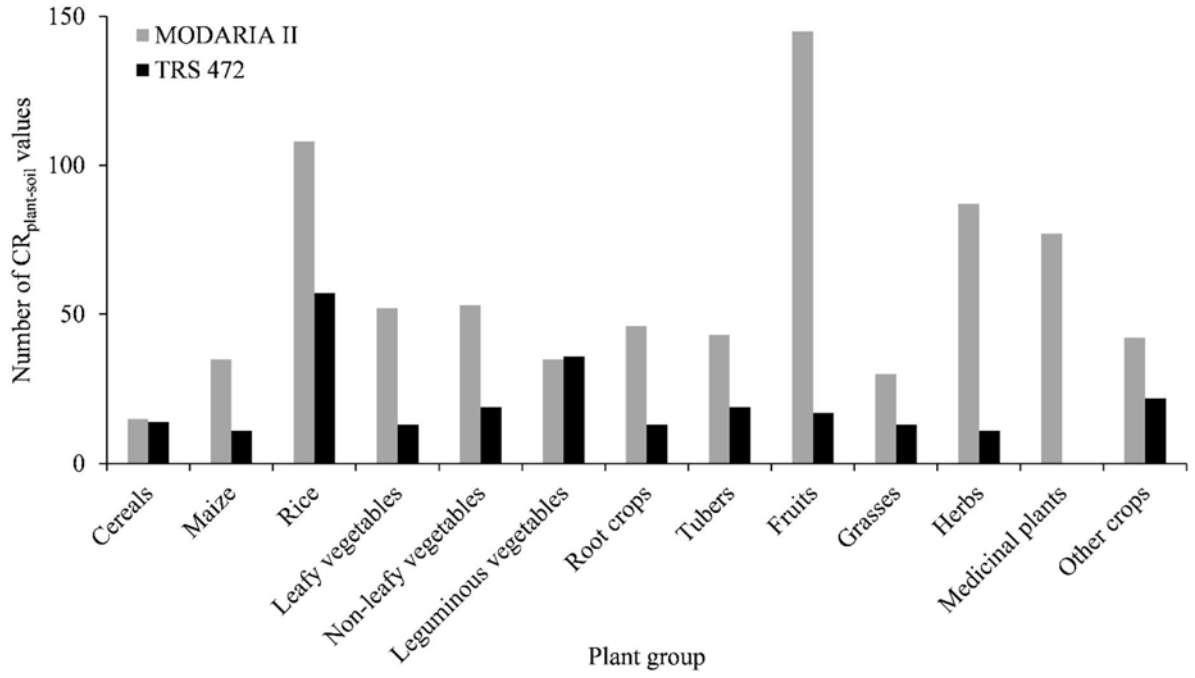

FIG. 3.3. Comparison of the number of $CR_{plant\text{-}soil}$ summary values by plant group in the MODARIA II and TRS 472 tropical datasets (the Fruits group and Medicinal Plants group includes all subgroups (see Table 2.2 above)).

[4] Annexes I–XVI are published online (only) as a Supplementary File to accompany this publication.

REFERENCES TO CHAPTER 3

[3.1] INTERNATIONAL ATOMIC ENERGY AGENCY, Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Terrestrial and Freshwater Environments, Technical Reports Series No. 472, IAEA, Vienna (2010).

[3.2] TAGAMI, K., TWINING, J., WASSERMAN, M.A., "Terrestrial Radioecology in Tropical Systems", Tropical Radioecology (TWINING, J., Ed.), Radioactivity in the Environment **18**, Elsevier (2012).

[3.3] VELDE B., MEUNIER, A., Clays and Climate – Clay Assemblages Formed under Extreme Humidity Conditions. In: The Origin of Clay Minerals in Soils and Weathered Rocks. Springer, Berlin, Heidelberg (2008). https://doi.org/10.1007/978-3-540-75634-7_6

[3.4] DIXON, J., GULLIVER, A., GIBBON, D., "Global challenges, potentials and priorities", Farming Systems and Poverty: Improving Farmers' Livelihoods in a Changing World (Hall, M., Ed.), Food And Agriculture Organization and World Bank, Rome and Washington D.C. (2001).

4. CONCENTRATION RATIOS FOR PLANT CROPS IN ARID ENVIRONMENTS

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4.1. INTRODUCTION

Previous IAEA publications on transfer parameter data compilations, i.e. TRS 472 [4.1] and TECDOC-1616 [4.2], included radioecological parameter values from temperate environments with limited data from arctic, alpine and tropical systems.

Recently, development of nuclear energy facilities is being considered in a number of countries that have arid and/or semi-arid climates. The paucity of data from arid/semi-arid areas, was addressed under the MODARIA II programme, Working Group 4, Subgroup 3 in collaboration with the International Union of Radioecology (IUR) Arid Environments Task Group.

This chapter presents the first dataset of soil-to-plant $CR_{\text{plant-soil}}$ for arid environments classified according to the Köppen-Geiger classifications for arid climates (see Chapter 2).

4.1.1. Characteristic features of arid environments

The climate of arid areas typically includes excessive heat, low and highly variable precipitation and correspondingly high evapotranspiration [4.3]. Arid environments commonly have long-term water deficits, termed aridity, that arises from the presence of dry, descending air usually during anticyclonic conditions. Aridity is quantified using the climatic aridity index (AI) as adopted by UNEP in the World Aridity Atlas [4.4]:

$$AI = \frac{P}{ETP} \tag{4.1}$$

where:

P is the precipitation;
ETP is the potential evapotranspiration, affected by atmospheric humidity, solar radiation, and wind [4.4].

Widespread droughts and desertification mean that the availability of water for agriculture in arid environments is a key constraint [4.5]. Three arid zones have been defined by the *AI*: extreme arid ($AI \leq 0.03$), arid (*AI* in the range 0.03 and 0.20) and semi-arid (*AI* in the range 0.20 and 0.50). Of the total global land area, the extreme arid zone covers 4.2%, the arid zone 14.6%, and the semiarid zone 12.2%. About one-third of the total area of the world has arid features [4.6]. The limited amount of annual precipitation in arid environments influences the life history characteristics, physiology, and species composition of both plants and animals [4.7]).

The extreme arid zone comprises dryland areas largely without vegetation. Annual rainfall is low and rarely exceeds 100 mm. Precipitation is infrequent and irregular, sometimes with no rain for several years. Only nomadic pastoralism occurs in these areas.

In the arid zone, native vegetation is sparse, consisting of annual and perennial grasses, shrubs and small trees. There is a high rainfall variability ranging from 100 to 300 mm/y. Nomadic pastoral activities occurs and farming is possible when irrigation is applied.

In the semi-arid zone, there is a wider range of native vegetation including grasses and grass-like plants, forbs and half-shrubs[5], shrubs and trees. Annual precipitation varies from 300 to 800 mm during summer, and from 200 to 500 mm during winter. Rain-supported sustained agricultural production is possible, including limited livestock production.

4.1.2. Factors influencing the radionuclide behavior in arid environments

4.1.2.1. Precipitation

Unlike in temperate environments, the rainfall distribution in arid environments varies strongly between summer and winter and between years. Winter rains can penetrate the soil and accumulate underground, but summer rains fall on hot soil surfaces and are lost to evaporation. Rainfall intensity affects water retention as the soil may not be able to absorb all the water which is lost by runoff.

4.1.2.2. Temperature

The climatic pattern in arid environments is frequently characterized by three seasons: 'cool' dry, 'hot' dry, and a 'moderate' rainy season, with significant diurnal temperature fluctuations within these seasons [4.8]. Extremely high or low temperatures, and long periods of occasional low temperatures, restrict plant growth and damage plants. Plants can survive high temperatures if they have compensatory mechanisms that affect rates of transpiration, but growth rates are then reduced.

4.1.2.3. Air moisture

Air moisture is important for water balance in soil. Water evaporates when there is a higher moisture content in soil than in the air. Conversely, water will condense into the soil when there is more moisture in the air. Humidity is generally low in arid environments (an average of about 30% whereas that for tropical rain forest reaches 80–100%). Arid environments are typically windy, due to the low density of vegetation, which removes the moist air around plants and soil and thereby increases evaporation and transpiration.

4.1.2.4. Soil properties

Soil formation in an arid climate is controlled by parent material, topography and climate [4.9]. Significant diurnal changes in temperature cause mechanical or physical disintegration of rocks, while aeolian activity score and abrade exposed rock surfaces [4.9]. In addition to chemical weathering and solution-precipitation processes physical weathering is prominent in hyper-arid (cold-desert conditions) and arid environments.

The role of the vegetation in soil formation is low in arid environments because of the sparse canopy cover and the limited development of above-ground plant parts. Nevertheless, the plants often have extensive root systems which enhance the soil water-holding capacity and the supply of nutrients to plants. The soil water-holding capacity depends mainly on its texture (i.e. clay, sand, and silt), structure (influenced by the amount of organic matter) and soil depth [4.10]. The chemical properties of soils control the availability of nutrients and radionuclides. Nutrient leaching and intensive weathering of minerals are characteristic processes for arid soils.

[5] A perennial plant in which the stems are more or less woody especially at the base.

Organic matter content of the topsoil, and therefore the natural fertility is often low in arid soils. Arid or desert soils have limited water available to mesophytic[6] plants for long periods of time.

As there is little deposition and accumulation of organic litter in arid environments the organic matter content of soil is low and is quickly lost when these soils are cultivated. Soil erosion is enhanced in arid conditions, especially when there is dry or fine topsoil, smooth ground surfaces, sparse vegetative cover, and strong winds to initiate soil movement. Soil erosion by wind preferentially removes silt, clay, and organic matter from the surface soil that then becomes sandy and infertile. The effect of these erosive processes may influence the transfer of radionuclides from soil to plants due to the redistribution of contaminated soil and soil particles specifically in agricultural land [4.11].

4.1.2.5. Vegetation

The vegetation of arid environments is usually characterized in terms of rainfall amount and its pattern of occurrence [4.12] with four categories namely desert land, semidesert, low rainfall woodland savanna and evergreen scrub.

Plants that survive in an arid climate have adapted to cope with the scarce rainfall. Adaptive mechanisms include: (i) remaining dormant until water is available; (ii) reducing transpiration; (iii) storing water; (iv) having a fast life cycle; or (v) having extensive penetrating roots. The natural vegetation cover in arid environments is scarce and comprises three major plant groups: the dominant non-succulent perennials which includes hardy plants, including grasses, woody herbs, shrubs, and trees, ephemeral annuals which only grow after rainfall and succulent perennials that can store water [4.13].

4.1.2.6. Land use

Due to the significant environmental constraints in arid environments discussed above, a large proportion of food in these regions is imported. The types of land use that can be implemented in arid environments is highly dependent upon seasons and precipitation.

Locally produced vegetables and fruits are mainly cultivated under irrigation in greenhouses or shelters to protect the soil and plants from evaporation and heat exposures. Such facilities are used to grow vegetables such as tomato, cucumber, squash and beans. The cultivation of date palms and production of olive oil occurs mainly in areas with available surface water such as oases or under irrigation systems. Animals can graze pasture grass in some areas during rainy seasons so milk and meat from camels, sheep and goats is locally available for part of the year. Cow milk production is less common.

4.1.2.7. Consumption patterns and food baskets in arid areas

Contamination of agricultural products leads to internal exposure through ingestion. Agricultural practices and consumption habits of the local population are important parameters when estimating radiation exposure. The ‘food basket’ for the general population living in arid areas of the Arabic peninsula and northern Africa, includes cereals, sweeteners and vegetable

[6] Mesophytes are terrestrial plants which are neither adapted to particularly dry nor particularly wet environments.

oils among the major food groups, followed by fruits and vegetables, milk and eggs, and pulses and nuts[7].

The nutrition of the population in arid environments is characterized by the prevailing climate and social conditions [4.14]. The dietary habits of people in these areas are determined by: socio-cultural factors (i.e. income, urban/rural characteristics of living, religious beliefs, food preferences, gender discrimination, education and women's employment), food subsidy policies (which encourage the intake of fat, sugar, rice, wheat flour and meat), mass media and migration movements.

4.2. SPECIFIC DATA COLLATION DATA COLLECTION, TREATMENT AND ANALYSIS FOR ARID ENVIRONMENTS

4.2.1. Data collection approaches for arid environments

The compilation of $CR_{\text{plant-soil}}$ data for arid environments was limited by the paucity of published data in the open literature. There were no identified data for semi-arid environments. Many of the studies identified could not be included in the $CR_{\text{plant-soil}}$ arid dataset because of a lack of information on variables such as sampling strategies, plant and/or soil activity concentrations, and statistical data. In some publications, the available information for a radionuclide was inconsistent in that different $CR_{\text{plant-soil}}$ were presented for the same soil type and same coordinates. There was also some data (10 data in Syria) from experimental field investigations.

The $CR_{\text{plant-soil}}$ dataset includes values from 10 countries: Libya, Egypt, Israel, Jordan, Syria, Iraq, Iran, Saudi Arabia, and Kazakhstan (see Figure 4.1 below), and 11 elements. Most of the data were for natural radionuclides (Be, K, Pb, Po, Pu, Ra, Th, U) with only three anthropogenic radionuclides (Am, Sr, and Cs) (Figure 4.2).

FIG. 4.1. Countries represented in the MODARIA II arid dataset.

[7] https://www.radenv.net/files/Report%20Consumption_NS.pdf

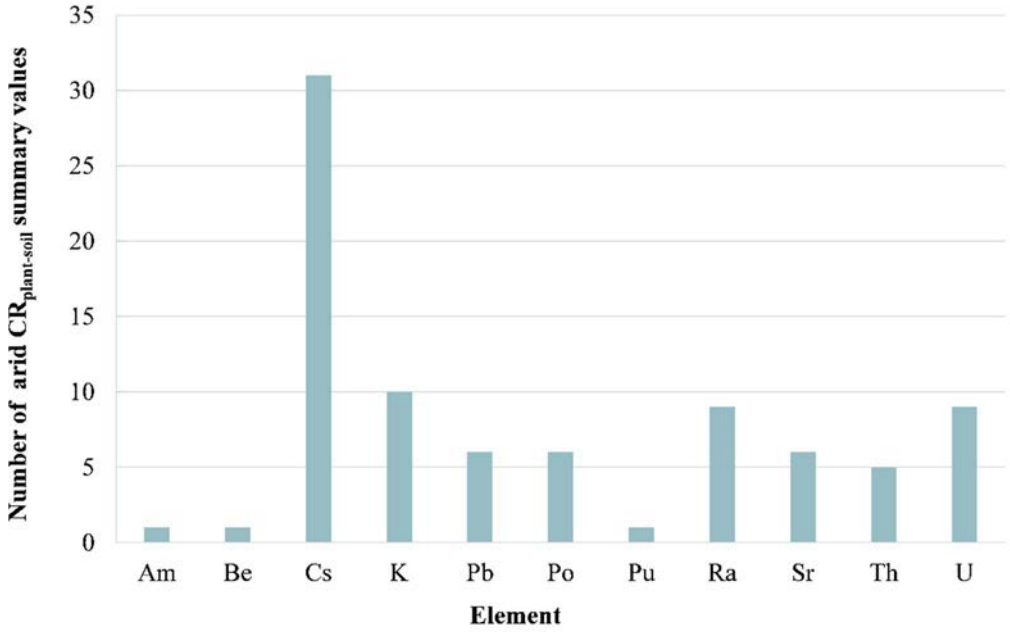

FIG. 4.2. The number of $CR_{plant\text{-}soil}$ summary values by element in the MODARIA II arid.

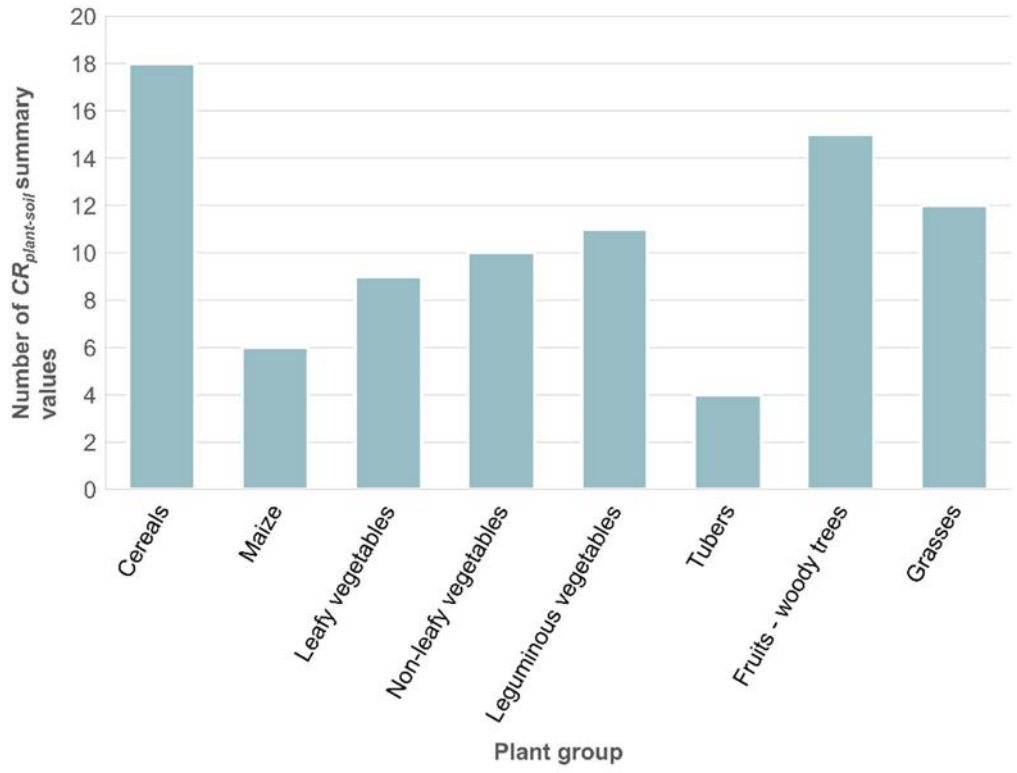

FIG. 4.3. The number of $CR_{plant\text{-}soil}$ summary values by plant group in the MODARIA II arid dataset, as classified in TRS 472 [4.1].

Most of the data entries were for grasses, cereals, non-leafy vegetables and fruits, as classified in TRS 472 [4.1]. No distinction was made between different fruit subgroups (i.e. woody trees, herbaceous, shrubs, non-woody trees). The majority of fruit data were for woody fruit trees (see Appendix III). There were several plant groups for which no data could be identified, such as: root crops, herbs, leguminous fodder, or other crops (see Fig. 4.3).

Most data (65%) were for clay soils, with only 10% of entries for loamy soils, 13% of entries for sandy soils, and 12% of entries for unspecified soils. Other soil parameters important for the behaviour of elements/radionuclides in the environment, such as organic matter (OM), exchangeable cation concentrations or capacity (CEC), pH and soil bulk density, were not documented in the publications.

All data have been scrutinized according to quality control requirements defined by the sampling procedures and quality of laboratory measurements (see Chapter 2).

4.2.2. Mean $CR_{plant\text{-}soil}$ values for arid environments

The $CR_{plant\text{-}soil}$ data given in Table 4.1 below for different plant groups and soil types were compiled from mean values published in the open literature. Palm tree dates and olives/oil are presented separately, as they are important staple food products for arid environments (see Tables 4.2–4.3). The number of entries given in Tables 4.1–4.3 represent the number of mean values reported in publications for a specific plant groups and soil type.

The set of references used to compile the arid datasets below are presented in Appendix IV.

The box plots given below (see Figs 4.4–4.6) compare distributions sets for two types of soil and various plant groups and nuclides, allowing the visualization in the degree of scatter (variance) and skewness of the data and to identify outliers. The box diagrams show that standard deviations exceed mean values allowing no statistical conclusions.

Figure 4.4 shows a comparison of CR values for non-leafy vegetation growing in sand and clay soil. Here, the distribution of data is close to log-normal. The data analysis shows that the difference in median values between the two groups is large with a statistically significant difference ($P = <0.001$). The box plots in Figs 4.5 and 4.6 are for illustration purposes only. They show that the distribution of the data is far from normal or log-normal (except for Ra CR for grass, with only 5 entries).

TABLE 4.1. CONCENTRATION RATIO ($CR_{plant-soil}$) VALUES FOR FOOD PLANT GROUPS IN ARID ENVIRONMENTS

Plant group	Plant compartment	Soil group	N[a]	AM[b]	SD[b]	GM[c]	GSD[c]	Minimum	Maximum	ID number[d]
Am (americium)										
Grasses	Stems and shoots	Clay	23	2.5E-02	8.6E-02	6.0E-03	4.2	1.0E-03	4.2E-01	1
Be (beryllium)										
Fruits, woody-tree	Fruits, heads, berries and buds	All	5	5.8E-01	2.2E-01	5.4E-01	1.5	3.5E-01	8.9E-01	2
Cs (caesium)										
Cereals	Grains, seeds and pods	All	15	1.6E-02	4.2E-02	3.6E-03	4.0	1.0E-03	1.7E-01	3; 14
Cereals	Grains, seeds and pods	Sand	2	1.1E-01	9.1E-02	n.a.[e]	n.a.	4.1E-02	1.7E-01	3; 14
Cereals	Grains, seeds and pods	Loam	8	2.0E-03	1.0E-03	3.0E-03	2.7	1.4E-03	4.6E-03	3; 14
Cereals	Grains, seeds and pods	Clay	5	4.0E-03	6.0E-03	2.0E-03	2.8	1.0E-03	1.4E-02	3; 14
Cereals	Stems and shoots	All	15	3.6E-01	9.6E-01	2.2E-02	12	2.3E-03	4.3E+00	3; 14
Cereals	Stems and shoots	Sand	2	2.6E+00	2.3E+00	n.a.	n.a.	9.9E-01	4.3E+00	3; 14
Cereals	Stems and shoots	Loam	8	1.4E-01	3.4E-01	1.5E-02	7.2	2.7E-03	1.1E+00	3; 14
Cereals	Stems and shoots	Clay	5	9.2E-02	2.0E-01	1.1E-02	8.4	2.3E-03	5.5E-01	3; 14
Fruits, woody-tree	Fruits, heads, berries and buds	Clay	7	1.3E-02	9.0E-03	1.0E-02	2.3	8.0E-03	2.5E-02	2; 15
Grasses	Stems and shoots	Clay	5	4.4E-02	4.9E-02	1.8E-02	2.9	2.3E-04	3.0E-01	1
Leafy vegetables	Leaves	All	2	1.4E-02	3.0E-03	—	—	—	—	3; 4
Leafy vegetables	Leaves	Loam	1	1.6E-02	—	—	—	—	—	3; 4
Leafy vegetables	Leaves	Clay	1	1.1E-02	—	—	—	—	—	3; 4
Leguminous vegetables	Grains, seeds and pods	All	2	6.0E-03	1.0E-03	n.a.	n.a.	5.0E-03	7.0E-03	3; 4
Leguminous vegetables	Grains, seeds and pods	Loam	1	7.0E-03	n.a.	n.a.	n.a.	n.a.	n.a.	3; 4
Leguminous vegetables	Grains, seeds and pods	Clay	1	5.0E-03	n.a.	n.a.	n.a.	n.a.	n.a.	3; 4
Leguminous vegetables	Stems and shoots	All	2	1.8E-02	1.0E-02	n.a.	n.a.	1.0E-03	2.5E-02	3; 4
Leguminous vegetables	Stems and shoots	Loam	1	2.5E-02	n.a.	n.a.	n.a.	n.a.	n.a.	3; 4
Leguminous vegetables	Stems and shoots	Clay	1	1.1E-03	n.a.	n.a.	n.a.	n.a.	n.a.	3; 4
Maize	Grains, seeds and pods	All	2	1.3E-03	1.0E-03	n.a.	n.a.	8.0E-04	1.7E-03	3
Maize	Grains, seeds and pods	Loam	1	1.7E-03	n.a.	n.a.	n.a.	n.a.	n.a.	3
Maize	Grains, seeds and pods	Clay	1	8.0E-04	n.a.	n.a.	n.a.	n.a.	n.a.	3
Maize	Stems and shoots	All	2	6.4E-03	4.0E-03	n.a.	n.a.	3.8E-03	9.0E-03	3
Maize	Stems and shoots	Loam	1	9.0E-03	n.a.	n.a.	n.a.	n.a.	n.a.	3
Maize	Stems and shoots	Clay	1	3.8E-03	n.a.	n.a.	n.a.	n.a.	n.a.	3
Non-leafy vegetables	Fruits, heads, berries and buds	All	2	4.2E-02	4.5E-02	n.a.	n.a.	1.0E-02	7.4E-02	3; 4
Non-leafy vegetables	Fruits, heads, berries and buds	Loam	1	1.0E-02	n.a.	n.a.	n.a.	n.a.	n.a.	3; 4

TABLE 4.1 (cont.)

Plant group	Plant compartment	Soil group	N[a]	AM[b]	SD[b]	GM[c]	GSD[c]	Minimum	Maximum	ID number[d]
Non-leafy vegetables	Fruits, heads, berries and buds	Clay	1	7.4E-02	n.a.	n.a.	n.a.	n.a.	n.a.	3; 4
Tubers	Tubers	All	3	3.7E-02	3.2E-02	2.8E-02	2.6E+00	2.7E-02	7.3E-02	3
Tubers	Tubers	Loam	1	2.7E-02	n.a.	n.a.	n.a.	n.a.	n.a.	3
Tubers	Tubers	Clay	2	4.2E-02	4.4E-02	n.a.	n.a.	1.1E-01	7.3E-02	3
K (potassium)										
Cereals	Stems and shoots	Clay	4	1.6E+00	4.4E-01	1.5E+00	1.3	1.2E+00	2.0E+00	5
Fruits, woody-tree	Fruits, heads, berries and buds	Clay	10	1.8E+00	1.3E+00	1.2E+00	1.6	7.0E-01	3.5E+00	5; 2; 6
Fruits, woody-tree	Leaves	Clay	3	9.7E-01	3.2E-01	9.3E-01	1.4	6.0E-01	1.2E+00	5; 2; 6
Grasses	Stems and shoots	Clay	2	3.0E+00	1.1E+00	5.8E-02	1.1	—	3.1E-01	7
Grasses	Stems and shoots	Sand	7	2.4E+00	1.5E+00	2.1E+00	1.8	9.4E-01	5.2E+00	8; 9
Leafy vegetables	Leaves	Clay	9	1.8E-02	1.0E-02	1.4E-02	1.0	4.0E-03	3.5E-02	10
Leguminous vegetables	Seeds and Pods	Clay	7	9.5E-01	5.1E-01	8.6E-01	1.6	5.8E-01	2.0E+00	5; 6
Non-leafy vegetables	Fruits, heads, berries and buds	Clay	25	1.7E+00	2.1E+00	9.8E-01	2.6	3.2E-01	7.8E+00	5; 6
Tubers	Tubers	Clay	2	2.0E+00	1.6E+00	n.a.	n.a.	8.5E-01	3.1E+00	2
Pb (lead)										
Cereals	Grains, seeds and pods	Clay	4	8.8E-02	4.6E-02	7.5E-02	2.0	3.0E-02	1.4E-01	5
Cereals	Stems and shoots	Clay	4	3.9E-01	7.5E-02	3.8E-01	1.2	3.1E-01	4.7E-01	5
Fruits - woody trees	Fruits, heads, berries and buds	Clay	6	2.1E-01	2.5E-01	1.1E-01	4.0	1.0E-02	7.0E-01	5
Leafy vegetables	Leaves	Clay	3	4.3E-01	3.3E-01	2.7E-01	4.3	5.0E-02	6.3E-01	5
Leguminous vegetables	Seeds and Pods	Clay	4	1.1E-01	9.6E-02	6.8E-02	3.4	1.0E-02	2.3E-01	5
Non-leafy vegetables	Fruits, heads, berries, buds	Clay	7	1.5E-01	2.0E-01	9.0E-02	2.8	2.0E-02	5.9E-01	5
Po (polonium)										
Cereals	Grains, seeds and pods	Clay	2	1.0E+00	1.4E+00	n.a.	n.a.	9.0E-02	2.0E+00	5
Cereals	Stems and shoots	Clay	4	3.6E-01	3.5E-02	2.9E-01	1.3	3.3E-01	3.8E-01	5
Fruits, woody-tree	Fruits, heads, berries and buds	Clay	5	1.8E-01	2.7E-01	9.8E-02	3.0	4.0E-02	6.6E-01	5
Leafy vegetables	Leaves	Clay	3	4.8E-01	7.5E-02	4.7E-01	1.1	4.0E-01	5.5E-01	5
Leguminous vegetables	Seeds and Pods	Clay	5	7.0E-02	4.2E-02	6.0E-02	1.8	3.0E-02	1.2E-01	5
Non-leafy vegetables	Fruits, heads, berries and buds	Clay	7	1.0E-01	6.9E-02	8.1E-02	2.1	3.0E-02	2.1E-01	5
Pu (plutonium)										
Grasses	Stems and shoots	Clay	6	2.6E-03	1.5E+00	2.3E-02	1.9	6.0E-03	4.2E-02	1
Ra (radium)										
Cereals	Grains, seeds and pods	Sand	5	1.2E-01	3.2E-02	1.2E-01	1.3	9.0E-02	1.6E-01	12
Grasses	Stems and shoots	Sand	5	1.4E-01	3.6E-02	1.4E-01	1.3	9.0E-02	1.9E-01	7; 9

TABLE 4.1 (cont.)

Plant group	Plant compartment	Soil group	N[a]	AM[b]	SD[b]	GM[c]	GSD[c]	Minimum	Maximum	ID number[d]
Grasses	Stems and shoots	Clay	3	7.9E-01	7.3E-01	6.1E-01	2.4	3.2E-01	1.6E+00	7; 9
Leafy vegetables	Leaves	Clay	9	3.3E-02	1.6E-02	1.9E-02	1.0	0.0E+00	5.0E-02	10
Leguminous vegetables	Seeds and Pods	Clay	3	6.8E-01	1.6E-01	6.7E-01	1.3	5.3E-01	8.5E-01	6
Non-leafy vegetables	Fruits, heads, berries and buds	Clay	18	1.0E+00	4.1E-01	4.5E-01	1.5	2.0E-01	9.4E-01	6; 13
Non-leafy vegetables	Fruits, heads, berries and buds	Sand	9	4.1E-02	2.6E-02	3.3E-02	2.1	1.0E-02	9.0E-02	6; 13
Sr (strontium)										
Cereals	Grains, seeds and pods	All	3	2.1E-02	3.2E-02	6.0E-03	7.8	1.0E-03	5.7E-02	14
Cereals	Stems and shoots	All	2	2.8E-01	1.9E-01	n.a.	n.a.	1.4E-01	4.1E-01	14
Fruits, woody-tree	Fruits, heads, berries and buds	Clay	2	1.1E-01	3.5E-02	n.a.	n.a.	0.0E+00	1.4E-01	15
Grasses	Stems and shoots	Clay	5	7.2E-01	9.4E-01	1.6E-01	6.6	2.3E-02	1.7E+00	1
Th (thorium)										
Grasses	Stems and shoots	Sand	10	4.7E-01	5.4E-01	2.5E-01	3.0	1.0E-01	1.3E+00	9
Grasses	Stems and shoots	Clay	10	2.3E+00	5.0E-01	2.2E+00	n.a.	1.6E+00	3.0E+00	7
Non-leafy vegetables	Fruits, heads, berries and buds	Clay	10	5.4E-01	2.2E-01	4.9E-01	1.7	1.5E-01	8.3E-01	6
Leafy vegetables	Leaves	Clay	1	4.0E-03	2.0E-03	3.6E-03.	1.0.	2.0E-02	7.7E-02	10
U (uranium)										
Cereals	Grains, seeds and pods	Clay	4	≤5.0E-02	—		—	—	—	5
Cereals	Stems and shoots	Clay	4	1.1E-02	3.0E-03	1.1E-02	1.3	8.0E-03	1.5E-02	5
Fruits, woody-tree	Fruits, heads, berries and buds	Clay	6	2.2E-02	2.2E-02	1.3E-02	3.4	4.0E+00	1.7E-02	5
Fruits, woody-tree	Leaves	Clay	3	3.7E-02	1.7E-02	3.4E-02	1.0	1.8E-02	4.8E-02	5
Grasses	Stems and shoots	Clay	10	1.6E+00	5.8E-01	n.a.[b]	n.a.	6.2E-01	2.6E+00	8; 9
Grasses	Stems and shoots	Sand	10	5.1E-02	9.5E-02	5.0E-03	12	1.9E-04	2.4E-01	8; 9
Leafy vegetables	Leaves	Clay	9	6.0E-03	2.0E-03	6.3E-03	—	4.0E-03	1.1E-01	10
Leguminous vegetables	Seeds and Pods	Clay	5	2.8E-02	2.7E-02	1.6E-02	3.9	3.0E-03	6.4E-02	5
Non-leafy vegetables	Fruits, heads, berries and buds	Clay	7	2.8E-02	2.3E-02	1.9E-02	3.0	4.0E-03	5.7E-02	5

[a] N: the number of data points used for analysis.
[b] AM: Arithmetic mean; SD: Standard Deviation.
[c] GM: Geometric mean; GSD: Geometric Standard Deviation.
[d] ID number: Identification number for the source reference presented in Appendix IV.
[e] —: data not available.
[f] n.a: not applicable.

TABLE 4.2. CONCENTRATION RATIO ($CR_{plant-soil}$) VALUES FOR PALM (NON-WOODY) TREES IN ARID ENVIRONMENTS

Element	Plant compartment	Soil group	N[a]	AM[b]	SD[b]	GM[c]	GSD[c]	Minimum	Maximum	ID number[d]
K	Pits	Sand	9	6.1E-01	3.0E-01	5.1E-01	2.0E+00	1.2E-01	1.0E+00	11
Ra	Pits	Sand	9	4.1E-01	2.3E-01	3.4E+02	2.1E+00	1.1E-01	6.6E-01	11
Ra	Dates	Sand	5	3.8E-01	6.3E-01	1.6E-01	3.6E+00	6.0E-02	1.5E+00	12
Th	Pits	Sand	9	2.7E-01	2.2E-01	2.3E-01	1.8E+00	1.3E-01	8.3E-01	11

[a] N: the number of data points used for analysis.
[b] AM: Arithmetic mean; SD: Standard Deviation.
[c] GM: Geometric mean; GSD: Geometric Standard Deviation.
[d] ID number: Identification number for the source reference presented in Appendix IV.
[e] —: data not available.
[f] n.a: not applicable.

TABLE 4.3. CONCENTRATION RATIO ($CR_{plant-soil}$) VALUES FOR OLIVE (WOODY) TREES IN ARID ENVIRONMENTS

Element	Plant compartment	Soil group	N[a]	AM[b]	SD[b]	GM[c]	GSD[c]	Minimum	Maximum	ID number[d]
Sr	Fruit	All	3[a]	—	—	9.3E-02	2.0E+00	8.0E-02	1.0E-01	15
Sr	Oil	All	3	—	—	5.0E-03	1.1E+00	5.0E-03	6.0E-03	15

[a] N: the number of data points used for analysis.
[b] AM: Arithmetic mean; SD: Standard Deviation.
[c] GM: Geometric mean; GSD: Geometric Standard Deviation.
[d] ID number: Identification number for the source reference presented in Appendix IV.
[e] —: data not available.
[f] n.a: not applicable.

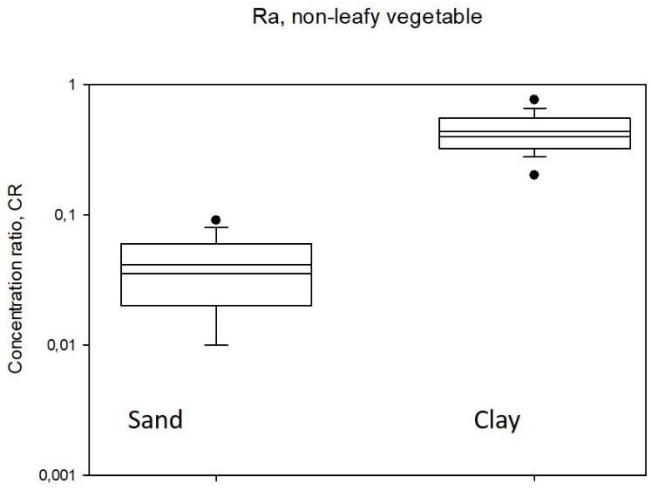

FIG. 4.4. Distribution of $CR_{plant\text{-}soil}$ values of radium (LOG scale) for non-leafy vegetable for sand and clay soils (median, mean, lower and upper quartiles, minimum and maximum values and outliers are represented).

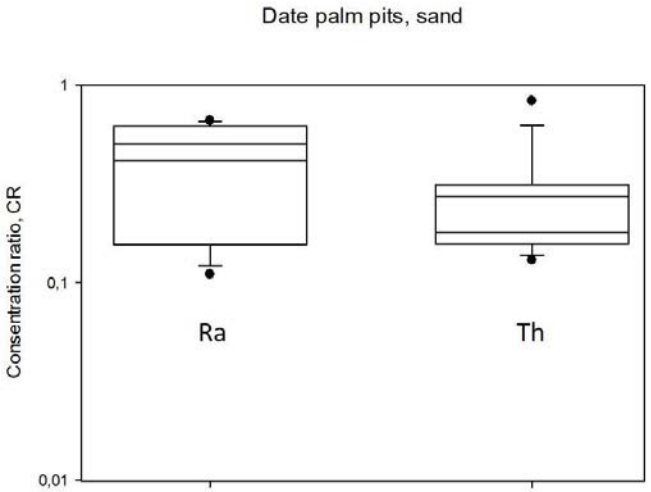

FIG. 4.5. Distribution of $CR_{plant\text{-}soil}$ values for date palm pits (in LOG scale) grown in sandy soil for radium and thorium (median, mean, lower and upper quartiles, minimum and maximum values and outliers are represented).

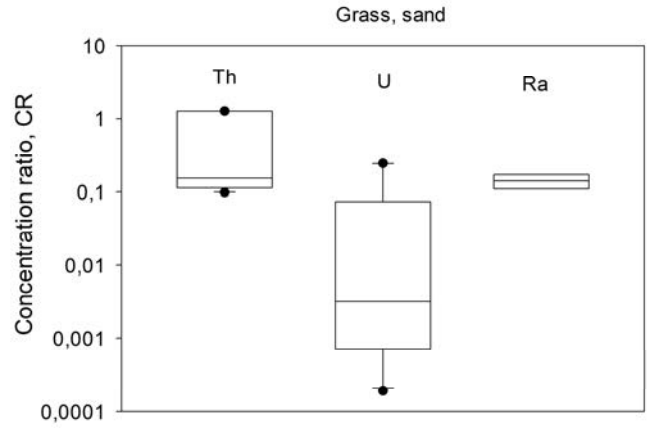

FIG. 4.6. Distribution of $CR_{plant\text{-}soil}$ values for grass (in LOG scale) grown on sandy soil for thorium; uranium and radium (median, mean, lower and upper quartiles, minimum and maximum values and outliers are represented).

4.3. SUMMARY

Specific climatic characteristics of arid environments such as excessive heat and highly variable precipitation pattern, scarce precipitation and low humidity, (see Fig. 4.1 above) define the type of soils and vegetation typically found in arid areas and the contaminant transfer pattern from soil to plants. Currently, there is no international comprehensive dataset on the uptake of elements by plants from soils in arid/semi-arid environments in the published IAEA reports (TRS 472 [4.1] and IAEA-TECDOC-1616 [4.2]). These documents only incorporate transfer data from temperate, arctic and tropical/subtropical areas. In collaboration with the International Union of Radioecology, the MODARIA II compilation of arid $CR_{plant\text{-}soil}$ data represents the first attempt to summarize available published data in international literature based on defined screening criteria.

The arid $CR_{\text{plant-soil}}$ data are important to improve the confidence of environmental impact assessments in arid environments associated with the increased demand and expansion of nuclear energy in these areas. The compiled data improves the scientific understanding of the specific transfer of elements and three radionuclides under the prevailing conditions of excessive heat and low precipitation.

Currently, the MODARIA II arid $CR_{plant\text{-}soil}$ dataset:

(a) Includes only a limited number of $CR_{\text{plant-soil}}$ values due to: (i) the scarcity of published literature data for the arid/semi-arid environments compared with temperate environments. From 120 identified literature sources only 15 (for 11 elements) could be used in the dataset (407 entries) due to (i) noncompliance of data where the sampling strategy and protocols described did not correspond to the generally accepted methods; (ii) Unrealistic conditions in that irrigation and/or the use of greenhouses (common agriculture practice in arid areas) for transfer experiments did not reflect the local climatic and growing conditions;
(b) Not all crops and all elements are covered (in general, artificial radionuclides are less represented);
(c) Local food stuff (e.g. palm dates), important for human food chain in arid areas are less documented;
(d) Mean arid $CR_{\text{plant-soil}}$ values presented have poor underlaying statistics due to the limited number of data available for each element–plant group–plant compartment–soil type combination, with a multitude of mean $CR_{\text{plant-soil}}$ results given based on <3 individual entries. - Where more data are available for one element and plant group/compartment, the range of values (minimum–maximum) is extend over more than 1–2 orders of magnitude;
(e) Soil classification or other soil chemical parameters (e.g. pH, cation exchange capacity, LOI (%), exchangeable Ca, Mg, K) were not hardly available.

More information may be available from non-English language internal institute reports, unpublished in the international scientific literature, or could be generated by structured experimental research in the countries of interest. Further experimental data are needed to cover the gaps in data for specific radionuclides important in environmental assessments and for plant groups according to the specific dietary habits in arid areas, experiments that are strictly designed according to a standard protocol and conditions.

REFERENCES TO CHAPTER 4

[4.1] INTERNATIONAL ATOMIC ENERGY AGENCY, Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Terrestrial and Freshwater Environments, Technical Reports Series No. 472, IAEA, Vienna (2010).

[4.2] INTERNATIONAL ATOMIC ENERGY AGENCY, Quantification of Radionuclide Transfer in Terrestrial and Freshwater Environments for Radiological Assessments, IAEA-TECDOC-1616, IAEA, Vienna (2009).

[4.3] DREGNE, H., KASSAS, M., ROZANOV, B., A new assessment of the world status of desertification, Desertification Control Bulletin **20** (1991) 6.

[4.4] UNITED NATIONS ENVIRONMENT PROGRAMME, World Atlas of Desertification, (MIDDLETON, N., THOMAS EDWARD ARNOLD, D.S.G., Eds), UNEP, London (1992).

[4.5] UNITED NATIONS CONVENTION TO COMBAT DESERTIFICATION, Elaboration of an International Convention to Combat Desertification in Countries Experiencing Serious Drought and/or Desertification, Particularly in Africa, UNCCD, New York (1997).

[4.6] INGLEZAKIS, J., POULOPOULOS, S.G., ARKHANGELSKY, E., ZORPAS, A.A., MENEGAKI, A.N., "Chapter 3. Aquatic Environment", Environment and Development, Basic Principles, Human Activities, and Environmental Implications (POULOPOULOS, S.G., INGLEZAKIS, V.J., Eds), Elsevier (2016).

[4.7] CHESSON, P., et al., Resource pulses, species interactions, and diversity maintenance in arid and semi-arid environments, Oecologia **141** (2004) 236.

[4.8] ABU-HAMDEH, N.H., "The effect of tillage treatments on soil water holding capacity and on soil physical properties", paper No.669 presented at ISCO 2004 - 13th International Soil Conservation Organisation Conference. Conserving Soil and Water for Society: Sharing Solutions, Brisbane (2004).

[4.9] KHRESAT, S.A., RAWAJFIH, Z., BUCK, B., MONGER, H.C., Geomorphic features and soil formation of arid lands in northeastern Jordan, Archives of Agronomy and Soil Science **50** (2004) 607.

[4.10] PICKUP, G., CHEWINGS, V.H., NELSON, D.J., Estimating changes in vegetation cover over time in arid rangelands using landsat MSS data, Remote Sens. Environ. **43**(3) (1993) 243.

[4.11] MABIT, L., BLAKE, W., Assessing recent soil erosion rates through the use of Beryllium 7 (Be-7), Springer (2019).

[4.12] MUSAIGER, A.O., Socio-Cultural and Economic Factors Affecting Food Consumption Patterns in the Arab Countries, J. Roy. Soc. Health **113** 2 (1993) 68.

[4.13] UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION, Map of the world distribution of arid regions, Explanatory note, UNESCO, Paris (1977).

[4.14] KHALDI, N., Evolving food gaps in the Middle East/North Africa: prospects policy implications, Washington D.C. (1984).

5. COMPARISON OF NON-TEMPERATE AND TEMPERATE $CR_{PLANT\text{-}SOIL}$ VALUES

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The amount of $CR_{plant\text{-}soil}$ summary data collated in the MODARIA II tropical environment dataset is considerably enhanced for several different crops (such as fruits, herbs, leafy and non-leafy vegetables), compared with the tropical dataset published in TRS 472 [5.1] (see Fig. 3.3). However, fewer data are available compared with the temperate $CR_{plant\text{-}soil}$ dataset from TRS 472 [5.1], especially for plant groups that are important components of the human food chain, such as cereals or leguminous vegetables (see Fig. 5.1). The newly collated $CR_{plant\text{-}soil}$ dataset for arid environments consists of considerably fewer values then that for tropical or temperate datasets for all plant groups, and there are no data for root crops, herbs or other crops. Comparisons of the tropical and arid datasets with the values in TRS 472 [5.1] are given in associated papers for both climatic areas [5.2, 5.3].

The $CR_{plant\text{-}soil}$ values in the revised tropical dataset are significantly higher than each equivalent row of data in the TRS 472 tables [5.1] for temperate environments and subtropical environments but not tropical environments. However, for tropical environments, the ratio of new to old $CR_{plant\text{-}soil}$ tended towards higher values in many cases.

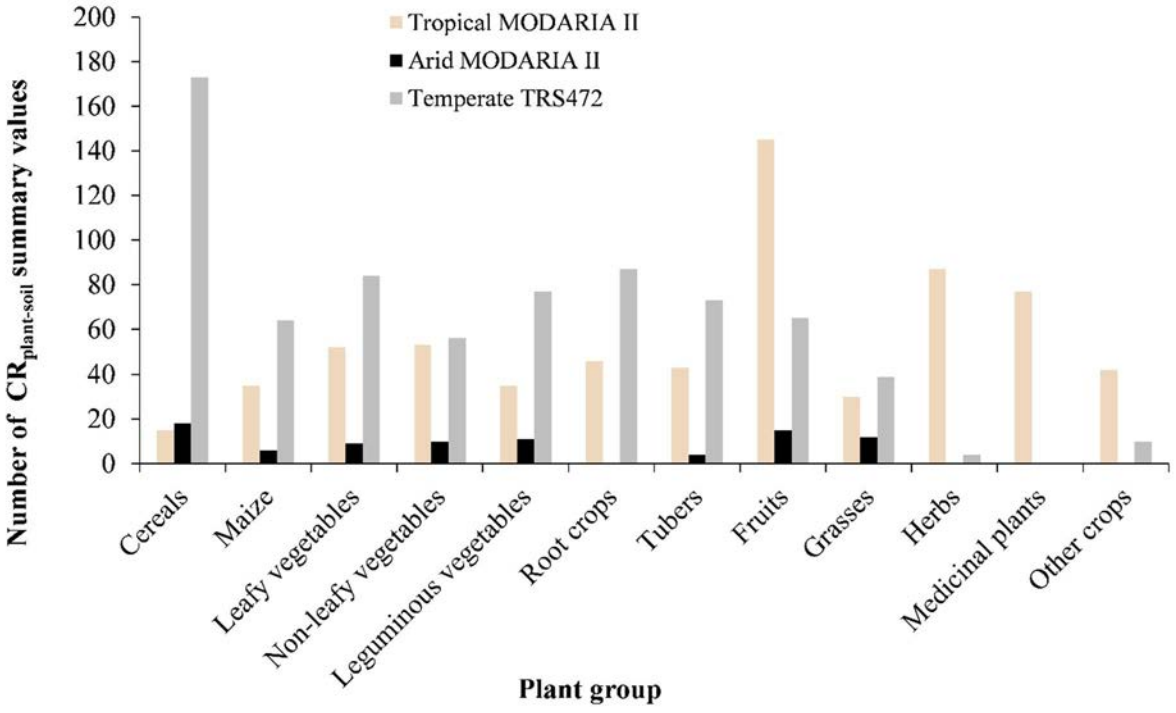

FIG. 5.1. Comparison of the number of $CR_{plant\text{-}soil}$ summary values for different crops collated within MODARIA II for tropical and arid environments and in TRS 472 [5.1] for temperate environment.

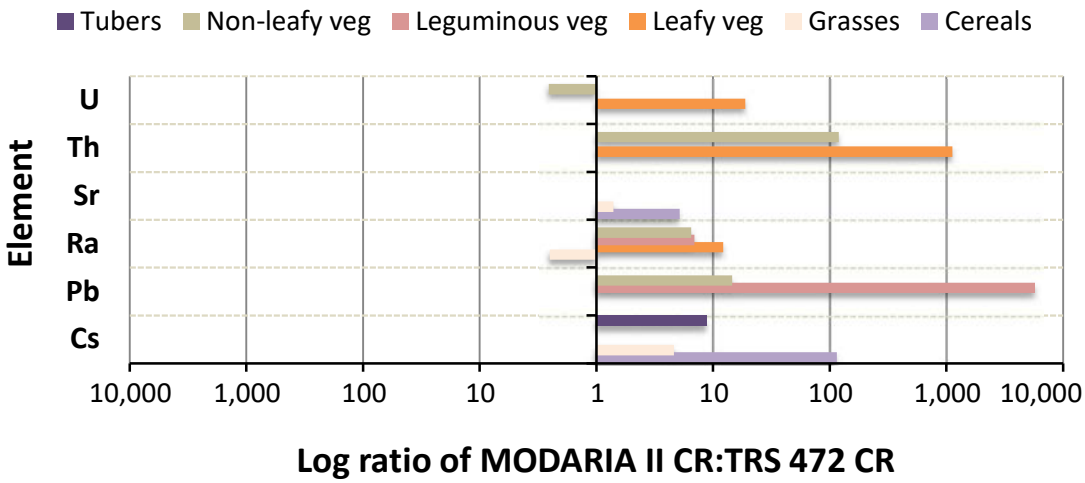

FIG. 5.2. Ratio of $CR_{plant\text{-}soil}$ values for six elements and crops grown in tropical environments (MODARIA II) and temperate environments (TRS 472 [5.1]).

Natural environmental factors raised in the journal paper [5.2] as potential reasons for the higher values in tropical environments include: the predominance of 1:1 type clays in the soil profile giving rise to reduced cationic exchange capacity and hence greater availability of dissolved elements for plant uptake; nutrient limitation which reduces inhibition of uptake by competitive analog elements; the presence of more prolific soil fungal communities, due to increased soil moisture content, leading to enhanced effective root area as well as reduced organic matter loads (less opportunity for complexation of dissolved radionuclides). Relevant information was generally not available in the source references for hypothesis testing or exploring relationships with these environmental factors. Similarly, other factors such as the impact of methodology used, or source and chemical characteristics of the radionuclide have also not been considered.

There are much less data available for arid environments, which have a wide range of values. Furthermore, the publications about element transfer to plants in arid environments often lack information on fertilizing, soil type and number of samples taken which constrains the usefulness of making statistical comparison of the data with temperate or tropical data.

In Figs 5.2 and 5.3, the ratio of the $CR_{plant\text{-}soil}$ values (geometric means) for selected elements and crops in the tropical and arid datasets with that in TRS 472 [5.1] for temperate environments is shown for cases where the comparison could be made for $CR_{plant\text{-}soil}$ in all three datasets.

The vertical axis showing unity (1) in Figs 5.2 and 5.3 indicates no difference between the new $CR_{plant\text{-}soil}$ values derived during MODARIA II and the standard published $CR_{plant\text{-}soil}$ values from TRS 472 [5.1]. The values to the left of unity show that the TRS 472 $CR_{plant\text{-}soil}$ value is higher, whilst those to the right show that the MODARIA II $CR_{plant\text{-}soil}$ value is larger. Values of less than 10 either side of unity probably indicate reasonable agreement.

Figure 5.4 compares the MODARIA II tropical and arid $CR_{plant\text{-}soil}$ values. Tropical is the numerator, so values above one (i.e. to the right of the axis) show that the tropical $CR_{plant\text{-}soil}$ is higher than the arid. Only $CR_{plant\text{-}soil}$ values for non-leafy vegetables are mostly higher in arid systems, whereas the $CR_{plant\text{-}soil}$ values are consistently higher for leafy vegetables. The highest $CR_{plant\text{-}soil}$ ratio is for cereals where the $CR_{plant\text{-}soil}$ value for tropical is considerably higher than that for arid.

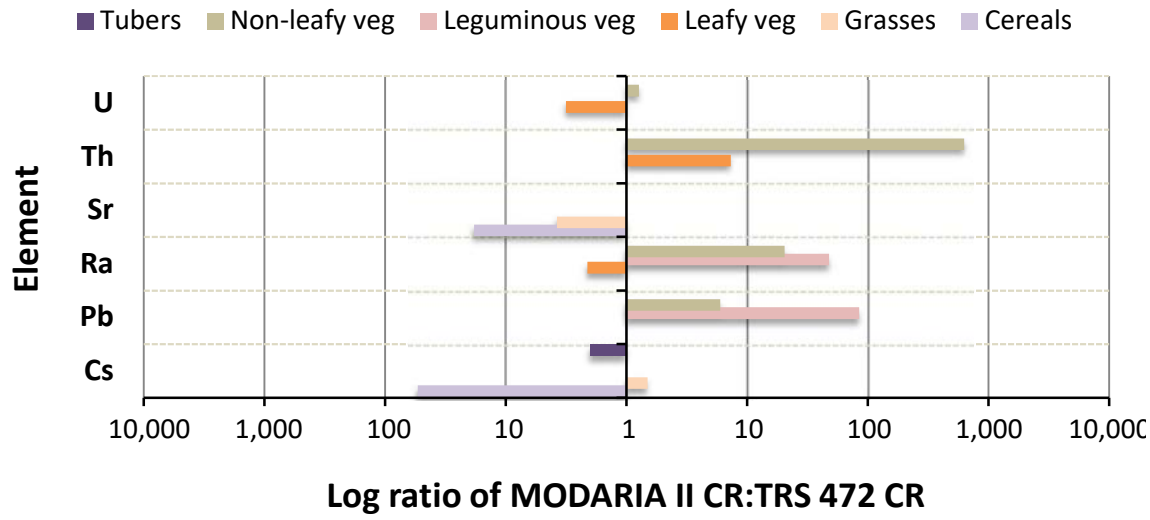

FIG. 5.3. Ratio of $CR_{plant\text{-}soil}$ values for six elements and crops grown in arid environments (MODARIA II) and temperate environments (TRS 472 [5.1]).

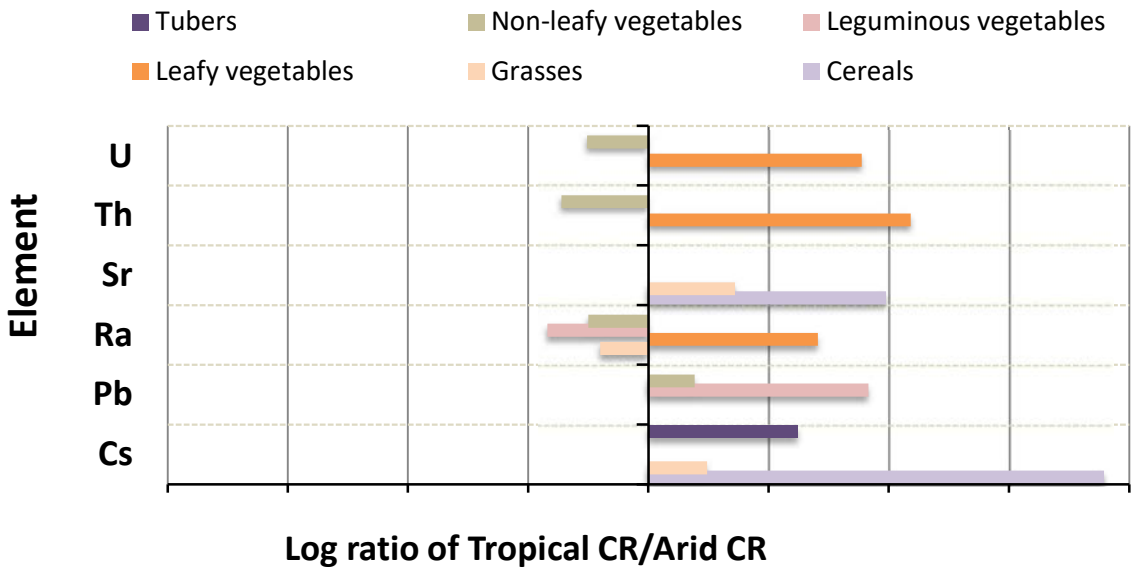

FIG. 5.4. Log ratio of MODARIA II $CR_{plant\text{-}soil}$ values for six elements and crops grown in tropical environments and arid environments (TRS 472 [5.1]).

Statistical analysis comparing the data has not been carried out due to the low number of data for the different plant and soil groups in the arid dataset. A comparison of the currently available data suggests that:

(1) Crops grown in tropical environments have generally higher $CR_{\text{plant-soil}}$ values than those grown in both temperate and arid environments;
(2) Crops grown in arid environments do not show an overall preference for higher or lower $CR_{\text{plant-soil}}$ values than crops grown in temperate environments, but $CR_{\text{plant-soil}}$ values for non-leafy vegetables are consistently higher in arid environments;
(3) Radium has comparable data in more plant groups than other elements but has only three instances of ratios exceeding an order of magnitude across both tropical and arid environments compared with temperate environments;
(4) The $CR_{\text{plant-soil}}$ values for Th in tropical leafy vegetables, Pb in tropical leguminous vegetables and Th in arid non-leafy vegetables are all more than 100 times higher than the corresponding temperate environment $CR_{\text{plant-soil}}$;
(5) Relative to temperate environments, $CR_{\text{plant-soil}}$ values for Cs can be considerably higher in tropical environments and considerably lower in arid environments for certain plant groups.

REFERENCES TO CHAPTER 5

[5.1] INTERNATIONAL ATOMIC ENERGY AGENCY, Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Terrestrial and Freshwater Environments, Technical Reports Series No. 472, IAEA, Vienna (2010).

[5.2] DOERING, C., TWINING, J., ROUT, S., IURIAN, A., HOWARD, B.J., A revised IAEA data compilation for estimating the soil to plant transfer of radionuclides in tropical environments, J. Environ. Radioact. **232** (2021) 106570.

[5.3] SEMIOSHKINA, N., VOIGT, G., Soil-Plant Transfer of Radionuclides in Arid Environments, J. Environ. Radioact. (2021) (in press).

APPENDIX I. SUPPLEMENTARY DATA FOR CHAPTER 3

TABLE I.1. PLANT SPECIES INCLUDED IN THE TROPICAL DATASET

Plant group	Common name	Latin name
Cereals	Sorghum	*Sorghum bicolor*
	Wheat	*Triticum* sp.
Maize	Maize, corn	*Zea mays*
Rice	Rice	*Oryza sativa*
Leafy vegetables	Amaranth	*Amaranthus* spp.
	Bitter leaf	*Vernonia amygdalina*
	Cabbage	*Brassica oleracea capitata*
	Cauliflower	*Brassica oleracea botrytis*
	Chinese cabbage, bok choy	*Brassica chinensis*
	Chinese cabbage, won bok	*Brassica pekinensis*
	Jute	*Corchorus capsularis*
	Kale	*Brassica alboglabra*
	Kohila	*Lasia spinosa*
	Kohlrabi	*Brassica oleracea gongylodes*
	Leek	*Allium ampeloprasum*
	Lettuce	*Lactuca sativa*
	Malabar spinach	*Basella alba*
	Mizuna	*Brassica campestris*
	Mukunuwenna, sessile joyweed	*Alternanthera sessilis*
	Mustard	*Brassica* sp.
	Purslane	*Portulaca oleracea*
	Spinach	*Spinacia oleracea*
	Swiss chard	*Beta vulgaris*
	Vegetable fern	*Athyrium esculentum*
	Water spinach	*Ipomoea aquatica*
	Watercress	*Nasturtium officinale*
	Waterleaf	*Talinum triangulare*
	White mustard	*Brassica rapa*
Non-leafy vegetables	Bitter gourd	*Momordica charantia*
	Bottle gourd	*Lagenaria siceraria*
	Chili, pepper	*Capsicum annuum, Capsicum frutescens*
	Cucumber	*Cucumis sativus*
	Eggplant, brinjal	*Solanum melongena*
	Garlic	*Allium sativum*
	Gboma	*Solanum macrocarpon*
	Ivy gourd	*Coccinia grandis*
	Jilo	*Solanum gilo*
	Ladies' fingers, okra	*Abelmoschus esculentus*
	Onion	*Allium cepa*
	Pointed gourd	*Trichosanthes dioica*
	Pumpkin, squash, sweet gourd	*Cucurbita maxima, Cucurbita pepo*
	Shirala	*Luffa acutangula*
	Snake gourd	*Trichosanthes anguina*
	Sponge gourd	*Luffa aegyptiaca*
	Tomato	*Lycopersicon esculentum, Solanum lycopersicum*
	Wax gourd	*Benincasa hispida*

TABLE I.1. (cont.)

Plant group	Common name	Latin name
Leguminous vegetables	Bean	*Phaseolus vulgaris*
	Country bean	*Lablab niger*
	Cowpea	*Vigna unguiculata*
	Gavar	*Cyamopsis tetragonoloba*
	Lentil	*Lens esculenta*
	Long bean	*Vigna sinensis*
	Mung	*Vigna radiata*
	Pea	*Pisum sativum*
	Soybean	*Glycine max*
	Stink bean	*Parkia speciosa*
	Yard long bean	*Vigna unguiculata sesquipedalis*
Root crops	Arrowroot	*Tacca leontopetaloides*
	Carrot	*Daucus carota*
	Cassava, manioc, tapioca, yucca	*Manihot esculenta, Manihot utilissima*
	Radish	*Raphanus raphanistrum, Raphanus sativus*
Tubers	Arum	*Arum* sp.
	Bengal arum	*Typhonium trilobatum*
	Bush carrot	*Eriosema chinense*
	Bush potato	*Brachystelma glabriflorum*
	Cocoyam	*Caladium bicolor, Xanthosoma sagittifolium*
	Long yam	*Dioscorea transversa*
	Pencil yam	*Vigna lanceolata*
	Potato	*Solanum tuberosum*
	Round yam	*Dioscorea bulbifera*
	Sweet potato	*Ipomoea batatas*
	Taro, cocoyam, elephant ears	*Colocasia esculenta*
	White yam	*Dioscorea rotundata*
	Yam	*Cartonema parviflorum*
	Yam	*Unidentified*
Fruits - herbaceous plants	Gooseberry	*Physalis minima*
	Passionfruit	*Passiflora* spp.
	Pineapple	*Ananas comosus, Ananas sativa*
Fruits - shrubs	Black currant	*Antidesma parvifolium*
	Indian caper	*Capparis sepiaria*
	Milky plum	*Persoonia falcata*
	Pomegranate	*Punica granatum*
	Roselle	*Hibiscus sabdariffa*
	White currant	*Flueggia virosa*
Fruits - woody trees	Abiu	*Pouteria caimito*
	Breadfruit	*Artocarpus altilis*
	Bush apple	*Syzygium* spp.
	Bush fig	*Ficus adenosperma, Ficus congesta*
	Bush plum (black)	*Vitex acuminata, Vitex glabrata*
	Bush plum (green)	*Buchanania obovata*
	Cluster fig	*Ficus racemosa*
	Cocky apple	*Planchonia careya*
	Cupuacu	*Theobroma grandiflorum*
	Drumstick	*Moringa pterygosperma*
	Gardenia	*Gardenia megasperma*
	Grapefruit (red)	*Citrus paradisi*
	Guava	*Psidium guajava*
	Jackfruit	*Artocarpus integra*

TABLE I.1. (cont.)

Plant group	Common name	Latin name
	Kakadu plum	*Terminalia ferdinandiana*
	Lemon	*Citrus limon*
	Lime	*Citrus aurantifolia*
	Mandarin	*Citrus reticulata*
	Mango	*Mangifera indica*
	Mangosteen	*Garcinia mangostana*
	Noni, Indian mulberry	*Morinda citrifolia*
	Orange	*Citrus aurantium, Citrus sinensis*
	Rambutan	*Nephelium lappaceum*
	Rock fig	*Ficus platypoda*
	Soursop	*Annona muricata*
Fruits - non-woody trees	Banana, plantain	*Musa* spp.
	Buriti	*Mauritia vinifera*
	Coconut	*Cocos nucifera*
	Pandanus	*Pandanus* spp.
	Papaya, pawpaw	*Carica papaya*
	Peach palm	*Bactris gasipaes*
	Salak	*Salacca zalacca*
	Sand palm	*Livistona humilis*
Grasses	Bamboo	*Bambusa arundinacea*
	Bermuda grass	*Cynodon dactylon*
	Cockspur grass	*Echinochloa crus-galli*
	Grass	*Cyrtococcum oxyphyllum*
	Grass	*Unidentified*
	Guinea grass	*Panicum maximum*
	Horse grass	*Andropogon tectorum*
	Indian goosegrass	*Eleusine indica*
	Kangaroo grass, red grass	*Themeda triandra*
	Nut grass	*Cyperus rotundus*
	Para grass	*Brachiaria mutica*
	Sedge grass	*Carex* sp.
	Sugarcane	*Saccharum officinarum*
Herbs	Aloe-leafed cymbidium	*Cymbidium aloifolium*
	Asian pigeonwings, butterfly pea	*Clitoria ternatea*
	Black nightshade	*Solanum nigrum*
	Burbark	*Triumfetta procumbens*
	Cassumunar ginger	*Zingiber montanum*
	Chinese ginger, Chinese keys, fingerroot	*Boesenbergia rotunda*
	Chinese mustard, leaf mustard	*Brassica juncea*
	Coriander	*Coriandrum sativum*
	Devil weed	*Chromolaena odorata*
	Dill, dukat	*Anethum graveolens*
	Doveweed	*Murdannia nudiflora*
	Ginger	*Zingiber officinale*
	Greater galangal	*Alpinia galangal*
	Green chiretta	*Andrographis paniculata*
	Helencha	*Enhydra fluctuans*
	Hill glory bower	*Clerodendrum viscosum*
	Holy basil, tulsi	*Ocimum sanctum*
	Indian acalypha	*Acalypha indica*
	Indian mint	*Plectranthus amboinicus*
	Indian pennywort	*Centella asiatica*
	Lemongrass	*Cymbopogon citratus*

TABLE I.1. (cont.)

Plant group	Common name	Latin name
	Milkweed, crown plant	*Calotropis gigantea*
	Monarch fern	*Polypodium scolopendria*
	Nodeweed	*Synedrella nodiflora*
	Pepper	*Piper nigrum*
	Pepper elder	*Peperomia pellucida*
	Sensitive plant	*Mimosa pudica*
	Sickle senna	*Cassia tora*
	Tea	*Camellia sinensis*
	Turmeric	*Curcuma longa*
	Ukshi	*Calycopteris floribunda*
	Water hyssop	*Bacopa monnieri*
	White goosefoot	*Chenopodium album*
	Yanang	*Tiliacora triandra*
Shrubs	Beach naupaka	*Scaevola taccada*
	Climbing wattle	*Senegalia pennata*
	Dwarf white bauhinia	*Bauhinia acuminata*
	Indian caper	*Capparis sepiaria*
	Lantana	*Lantana camara*
	Malabar nut	*Justicia adhatoda*
	Microcos	*Microcos paniculata*
	Roselle	*Hibiscus sabdariffa*
	Velvetleaf soldierbush	*Tournefortia argentea*
Woody trees	Blackboard tree	*Alstonia scholaris*
	Cashew	*Anacardium occidentale*
	Ceylon ironwood	*Mesua ferrea*
	Champak	*Michelia champaca*
	Cluster fig	*Ficus racemosa*
	Drumstick	*Moringa pterygosperma*
	Gaub tree	*Diospyros malabarica*
	Indian almond	*Terminalia catappa*
	Indian mulberry	*Morinda citrifolia*
	Karmal	*Dillenia pentagyna*
	Kindal tree	*Terminalia paniculata*
	Malabar plum	*Syzygium cumini*
	Mandarin	*Citrus reticulata*
	Mango	*Mangifera indica*
	Melinjo	*Gnetum gnemon*
	Neem	*Azadirachta indica*
	Sacred fig	*Ficus religiosa*
	Tamarind	*Tamarindus indica*
	Teak	*Tectona grandis*
	Wild guava, ceylon oak	*Careya arborea*
	Ylang-Ylang	*Cananga odorata*
	Zunna berry	*Ziziphus rugosa*
Non-woody trees	Banana, plantain	*Musa* spp.
	Papaya, pawpaw	*Carica papaya*
Other crops	Cacao, cocoa	*Theobroma cacao*
	Coffee	*Coffea* sp.
	Groundnut, peanut	*Arachis hypogaea*

APPENDIX II. PUBLICATIONS USED TO BUILD THE TROPICAL DATASET

The publications listed below relate to the identification (ID) numbers in the table presenting summary values of $CR_{\text{plant-soil}}$ for tropical environments (see Table 3.1 of this publication). Letters added after certain ID numbers indicate that the data were compiled from multiple source references relating to the same study.

Publication	ID number
OBIORA, S.C., CHUKWU, A., DAVIES, T.C., Heavy metals and health risk assessment of arable soils and food crops around Pb-Zn mining localities in Enyigba, southeastern Nigeria, Journal of African Earth Sciences **116** (2016) 182.	1
DOYI, I.N.Y., ESSUMANG, D.K., AGYAPONG, A.K., ASUMADU-SARKODIE, S., Soil-to-cassava transfer of naturally occurring radionuclides from communities along Ghana's oil and gas rich Tano Basin, Journal of Environmental Radioactivity **182** (2018) 138.	2
AZIZ, R.A., RAHIM, S.A., SAHID, I., IDRIS, W.M.R., Speciation and availability of heavy metals on serpentinized paddy soil and paddy tissue, Procedia Social and Behavioral Sciences **195** (2015) 1658.	3
ASADUZZAMAN, Kh., KHANDAKER, M.U., AMIN, Y.M., MAHAT, R., Uptake and distribution of natural radioactivity in rice from soil in north and west part of peninsular malaysia for the estimation of ingestion dose to man, Annals of Nuclear Energy **76** (2015) 8.	4
ASADUZZAMAN, Kh. et al., Soil-to-root vegetable transfer factors for ^{226}Ra, ^{232}Th, ^{40}K, and ^{88}Y in Malaysia, Journal of Environmental Radioactivity **135** (2014) 120.	5
ALSAFFAR, M.S., JAAFAR, M.S. KABIR, N.A., AHMAD, N., Distribution of ^{226}Ra, ^{232}Th, and ^{40}K in rice plant components and physico-chemical effects of soil on their transportation to grains, Journal of Radiation Research and Applied Sciences **8** (2016) 300.	6
KHANDAKER, M.U. et al., Evaluation of radionuclides transfer from soil-to-edible flora and estimation of radiological dose to the Malaysian populace, Chemosphere **154** (2016) 528.	7
CHANDRASHEKARA, K., SOMASHEKARAPPA, H.M., ^{210}Po and ^{210}Pb in medicinal plants in the region of Karnataka, Southern India, Journal of Environmental Radioactivity **160** (2016) 87.	8
CHANDRASHEKARA, K., SOMASHEKARAPPA, H.M., Estimation of radionuclides concentration and average annual committed effective dose due to ingestion for some selected medicinal plants of South India, Journal of Radiation Research and Applied Sciences **9** (2016) 68.	9
OKEJI, M.C., AGWU, K.K., IDIGO, F.U., Natural radioactivity in cultivated land in the vicinity of a phosphate fertilizer plant in Nigeria, Radiation Physics and Chemistry **81** (2012) 1823.	10
VELASCO, H. et al., Variability of ^{137}Cs and ^{40}K soil-to-fruit transfer factor in tropical lemon trees during the fruit development period, Journal of Environmental Radioactivity **104** (2012) 64.	11
OKEME, I.C., SULE, I.V., JIBIRI, N.N., SHITTU, H.O., Radioactivity concentrations in soil and transfer factors of radionuclides (^{40}K, ^{226}Ra and ^{232}Th) from soil to rice in Kogi state, Nigeria, Archives of Applied Science Research **8** (2016) 34.	12
SAENBOONRUANG, K., PHONCHANTHUEK, E., PRASANDEE, K., Soil-to-plant transfer factors of natural radionuclides (^{226}Ra and ^{40}K) in selected Thai medicinal plants, Journal of Environmental Radioactivity 1**84-185** (2018) 1.	13
ADJIRACKOR, T., DARKO, E.O., SAM, F., Naturally occurring radionuclide transfer from soil to vegetables in some farmlands in Ghana and statistical analysis, Radiation Protection and Environment **40** (2017) 34.	14
ASWOOD, M.Sh., JAAFAR, M.S., BAUK, S., Assessment of radionuclide transfer from soil to vegetables in farms from Cameron Highlands and Penang, (Malaysia) using neutron activation analysis, Applied Physics Research **5** (2013) 85.	15

Publication	ID number
SHANTHI, G., KUMARAN, J.T.T., RAJ, G.A.G., MANIYAN, C.G., Transfer factor of the radionuclides in food crops from high-background radiation area of South West India, Radiation Protection Dosimetry **149** (2012) 327.	16
SAEED, M.A. et al., Soil to rice transfer factor of the natural radionuclides in Malaysia, Romanian Journal of Physics **57** (2011) 1417.	17
GAFFAR, S., FERDOUS, M.J., BEGUM, A., ULLAH, S.M., Transfer of natural radionuclides from soil to plants in North Western parts of Dhaka, Malaysian Journal of Soil Science **18** (2014) 61.	18
CHANDRASHEKARA, K., KARUNAKARA, N., SOMASHEKARAPPA, H.M., Activity distribution and uptake of radionuclides in medicinal plants of coastal Karnataka, India, Research Journal of Recent Sciences **4** (2015) 101.	19
SUSSA, F.V., DAMATTO, S.R., ALENCAR, M.M., MAZZILLI, B.P., SILVA, P.S.C., Natural radioactivity determination in samples of Peperomia pellucida commonly used as a medicinal herb, Journal of Environmental Radioactivity **116** (2013) 148.	20
SOLEHAH, A.R., YASIR, M.S., SAMAT, S.B., Activity concentration, transfer factors and resultant radiological risk of ^{226}Ra, ^{232}Th, and ^{40}K in soil and some vegetables consumed in Selangor, Malaysia, AIP Conference Proceedings **1784** (2016) 040016.	21
KRITSANANUWAT, R., CHANYOTHA, S., KRANROD, C., PENGVANICH, P., Transfer factor of 226Ra, ^{232}Th and ^{40}K from soil to Alpinia galangal plant grown in northern Thailand, Journal of Physics: Conference Series **860** (2017) 012008.	22
JAMES, J.P. et al., Soil to leaf transfer factor for the radionuclides 226Ra, 40K, 137Cs and 90Sr at Kaiga region, India, Journal of Environmental Radioactivity **102** (2011) 1070.	23
KARUNAKARA, N. et al., Soil to rice transfer factors for ^{226}Ra, ^{228}Ra, ^{210}Pb, ^{40}K and ^{137}Cs: a study on rice grown in India, Journal of Environmental Radioactivity **118** (2013) 80.	24
TWINING, J.R., PAYNE, T.E., ITAKURA, T., Soil-water distribution coefficients and plant transfer factors for ^{134}Cs, ^{85}Sr and ^{65}Zn under field conditions in tropical Australia, Journal of Environmental Radioactivity **71** (2004) 71.	25a
TWINING, J. et al., "Transfer of radioactive caesium, strontium and zinc from soil to sorghum and mung beans under field conditions in tropical northern Australia", Classification of Soil Systems on the Basis of Transfer Factors from Soil to Reference Plants, IAEA-TECDOC-1497, IAEA, Vienna (2006).	25b
KARUNAKARA, N. et al., ^{226}Ra, ^{40}K and 7Be activity concentrations in plants in the environment of Kaiga, India, Journal of Environmental Radioactivity **65** (2003) 255.	26
SIMON, S.L., GRAHAM, J.C., TERP, S.D., Uptake of ^{40}K and ^{137}Cs in native plants of the Marshall Islands, Journal of Environmental Radioactivity **59** (2002) 223.	27
BINH, N.T. et al., "The transfer of radionuclides in the terrestrial environments - recent research results in monsoon tropical condition of Vietnam", Proceedings of the International Symposium: Transfer of Radionuclides in Biosphere - Prediction and Assessment (AMANO, H., UCHIDA, S., Eds), Japan Atomic Energy Research Institute (2003).	28a
NGUYEN, T.B. et al., "Radionuclide transfer factors from air, soil and freshwater to the food chain of man in monsoon tropical condition of Vietnam", IAEA CRP Transfer of Radionuclides from Air, Soil and Fresh Water to the Foodchain of Man in Tropical and Subtropical Environments, Annex VIII to this publication[8].	28b
MOLLAH, A.S., BEGUM, A., ULLAH, S.M., Determination of soil-to-plant transfer factors of ^{137}Cs and ^{90}Sr in the tropical environment of Bangladesh, Radiation and Environmental Biophysics **37** (1998) 125.	29a

[8] Annexes I–XVI are published online (only) as a Supplementary File to accompany this publication.

Publication	ID number
MOLLAH, A.S., BEGUM, A., ULLAH, S.M., KHAN, Z.H., "Studies on radionuclide transfer from soil and freshwater to the foodchain of man in tropical environment of Bangladesh", IAEA CRP Transfer of Radionuclides from Air, Soil and Fresh Water to the Foodchain of Man in Tropical and Subtropical Environments, Annex VII to this publication[9].	29b
ROBISON, W.L., CONRADO, C.L., "Concentration ratios for foods grown on Bikini Island at Bikini atoll", IAEA CRP Transfer of Radionuclides from Air, Soil and Fresh Water to the Foodchain of Man in Tropical and Subtropical Environments, Annex X to this publication[9].	30
TWINING, J.R., FERRIS, J.M., MARKICH, S.J., "Measurements of transfer factors for radionuclides, including ^{137}Cs and ^{85}Sr, in freshwater fish and plant crops from tropical and sub-tropical Australia: research summary", IAEA CRP Transfer of Radionuclides from Air, Soil and Fresh Water to the Foodchain of Man in Tropical and Subtropical Environments, Annex XIV to this publication[9].	31
WASSERMAN, M.A., "Soil-to-plant transfer of ^{137}Cs in tropical areas", IAEA CRP Transfer of Radionuclides from Air, Soil and Fresh Water to the Foodchain of Man in Tropical and Subtropical Environments, Annex XVI to this publication[9].	32
NARAYANA, Y. et al., Distribution of some natural and artificial radionuclides in the environment of coastal Karnataka of south India, Journal of Environmental Radioactivity **28** (1995) 113.	33
RADHAKRISHNA, A.P., SOMASHEKARAPPA, H.M., NARAYANA, Y., SIDDAPPA, K., Distribution of some natural and artificial radionuclides in Mangalore environment of south India, Journal of Environmental Radioactivity **30** (1996) 31.	34
VELASCO, H., "Individual entries for the transfer parameter dataset in IAEA TRS 472 Chapter 5.3. TROPICAL AND SUBTROPICAL ENVIRONMENTS (Excel file)"	35
MOLLAH, A.S., BEGUM, A., A study on transfer factors of ^{60}Co and ^{65}Zn from soil to plants in the tropical environment of Bangladesh, Environmental Monitoring and Assessment **68** (2001) 91.	36
RAHMAN, M.M., RAHMAN, M.M., KODDUS, A., AHMAD, G.U., VOIGT, G., Soil-to-plant transfer of radiocaesium for selected tropical plant species in Bangladesh, Journal of Environmental Radioactivity **83** (2005) 199.	37
DAVY, D.R. (Ed), Rum Jungle environmental studies, AAEC/E365, Australian Atomic Energy Commission (1975).	38
DOERING, C., BOLLHÖFER, A., A database of radionuclide activity and metal concentrations for the Alligator Rivers Region uranium province, Journal of Environmental Radioactivity **162-163** (2016) 154.	39
CHAKRABORTY, S.R., AZIM, R., REZAUR RAHMAN, A.K.M., SARKER, R., Radioactivity concentrations in soil and transfer factors of radionuclides from soil to grass and plants in the Chittagong City of Bangladesh, Journal of Physical Science **24** (2013) 95.	40
TCHOKOSSA, P., OLOMO, J.B., BALOGUN, F.A., ADESANMI, C.A., Assessment of radioactivity contents of food in the oil and gas producing areas in Delta State, Nigeria, International Journal of Science and Technology **3** (2013) 315.	41
ONONUGBO, C.P., AZIKIWE, O., AVWIRI, G.O., Uptake and distribution of natural radionuclides in cassava crops from Nigerian Government farms, Journal of Scientific Research and Reports **23** (2019) 1.	42
ROBISON, W.L., HAMILTON, T.F., CONRADO, C.L., KEHL, S., "Uptake of Caesium-137 by leafy vegetables and grains from calcareous soils", Classification of Soil Systems on the Basis of Transfer Factors from Soil to Reference Plants, IAEA-TECDOC-1497, IAEA, Vienna (2006).	43
NGUYEN, H.Q., "The classification of soil systems on the basis of transfer factors from soil to reference plants", Classification of Soil Systems on the Basis of Transfer Factors from Soil to Reference Plants, IAEA-TECDOC-1497, IAEA, Vienna (2006).	44

[9] Annexes I–XVI are published online (only) as a Supplementary File to accompany this publication.

Publication	ID number
PANCHAL, R.H., RAO, D.D., MEHTA, B.H., Transfer of ^{137}Cs and ^{40}K from agricultural soils to food products in terrestrial environment of Tarapur, India, Water, Air, & Soil Pollution **219** (2011) 429-442.	45
GRAMLICH, A. et al., Soil cadmium uptake by cocoa in Honduras, Science of the Total Environment **612** (2018) 370.	46
DARKO, G. et al., Distribution of natural and artificial radioactivity in soils, water and tuber crops, Environmental Monitoring and Assessment **187** (2015) 339.	47
UZU, G. et al., Urban market gardening in Africa: foliar uptake of metal(loid)s and their bioaccessibility in vegetables; implications in terms of health risks, Water, Air, & Soil Pollution **225** (2014) 2185.	48
JOSHI, R.M., RAVI, P.M., GURG, R.P., Baseline radioactivity levels in Kaiga site soil and its migration to biosphere, Journal of Radioanalytical and Nuclear Chemistry **247** (2001) 571.	49
RAHMAN, M.M., ASADUZZAMAN, Md., NAIDU, R., Consumption of arsenic and other elements from vegetables and drinking water from an arsenic-contaminated area of Bangladesh, Journal of Hazardous Materials **262** (2013) 1056.	50
CHAVEZ, E. et al., Concentration of cadmium in cacao beans and its relationship with soil cadmium in southern Ecuador, Science of the Total Environment **533** (2015) 205.	51
GONI, M.A., AHMAD, J.U., HALIM, M.A., MOTTALIB, M.A., CHOWDHURY, D.A., Uptake and translocation of metals in different parts of crop plants irrigated with contaminated water from DEPZ area of Bangladesh, Bulletin of Environmental Contamination and Toxicology **92** (2014) 726.	52
ACKAH, M. et al., Uptake of heavy metals by some edible vegetables irrigated using wastewater: a preliminary study in Accra, Ghana, Environmental Monitoring and Assessment **186** (2014) 621.	53
OLUYIDE, S.O., TCHOKOSSA, P., AKINYOSE, F.C., OROSUN, M.M., Assessment of radioactivity levels and transfer factor of natural radionuclides around iron and steel smelting company located in Fashina village, Ile-Ife, Osun State, Nigeria, Facta Universitatis Working and Living Environmental Protection **15** (2018) 241.	54
GREGORY, A.O., AGBALAGBA, E.O., Assessment of natural radioactivity, associated radiological health hazards indices and soil-to-crop transfer factors in cultivated area around a fertilizer factory in Onne, Nigeria, Environmental Earth Sciences **71** (2013) 1541.	55
CARVALHO, C., ANJOS, R.M., MOSQUERA, B., MACARIO, K., VEIGA, R., Radiocesium contamination behavior and its effect on potassium absorption in tropical or subtropical plants, Journal of Environmental Radioactivity **86** (2006) 241.	56
HANDL, J. et al., Accumulation of ^{137}Cs in Brazilian soils and its transfer to plants under different climatic conditions, Journal of Environmental Radioactivity **99** (2008) 271.	57
BARRAZA, F. et al., Distribution, contents and health risk assessment of metal(loid)s in small-scale farms in the Ecuadorian Amazon: An insight into impacts of oil activities, Science of the Total Environment **622-623** (2018) 106.	58
PULHANI, V.A., DAFAUTI, S., HEGDE, A.G., SHARMA, R.M., MISHRA, U.C., Uptake and distribution of natural radioactivity in wheat plants from soil, Journal of Environmental Radioactivity **79** (2005) 331.	59
CORTEZ, L.A.S., CHING, J.A., Heavy Metal Concentration of Dumpsite Soil and Accumulation in Zea mays (corn) Growing in a Closed Dumpsite in Manila, Philippines, International Journal of Environmental Science and Development **5** (2014) 77.	60
BARRAZA, F. et al., Cadmium bioaccumulation and gastric bioaccessibility in cacao: A field study in areas impacted by oil activities in Ecuador, Environmental Pollution **229** (2017) 950.	61
RASHID, M.H., SEN, R., SHIL, N.C., NASER, H.M., AKTER, S., Study on arsenic contamination in soil and crops of arsenic prone areas in Bangladesh, International Journal of Biological Research **15** (2013) 1.	62
LAURIA, D.C., SACHETT, I.A., PEREIRA, J.C., ZENARO, R., Determination of caesium-137 soil-to-plant concentration ratios for vegetables in Goiania City, Brazil, Journal of Radioanalytical and Nuclear Chemistry, Articles **182** (1994) 91.	63

Publication	ID number
SULTANA, M.S. et al., "Transfer of heavy metals and radionuclides from soil to vegetables and plants in Bangladesh", Soil Remediation and Plants, Elsevier (2015).	64
ARÉVALO-GARDINI, E., ARÉVALO-HERNÁNDEZ, C.O., BALIGAR, V.C., HE, Z.L., Heavy metal accumulation in leaves and beans of cacao (Theobroma cacao L.) in major cacao growing regions in Peru, Science of the Total Environment **605-606** (2017) 792.	65a
ARÉVALO-GARDINI, E. et al., Metales pesados en suelos de plantaciones de cacao (Thobroma cacao L.) en tres regiones del Perú, Ecologia Aplicada **15** (2016) 81 (in Spanish).	65b
EMUROTU, J.E., ONIANWA, P.C., Bioaccumulation of heavy metals in soil and selected food crops cultivated in Kogi State, north central Nigeria, Environmental Systems Research **6** (2017) 21.	66
UDOUSORO, I.I., ESSIEN, M.E., Transfer of metals from soil to Cucumis sativus fruit and possible health risk assessment under actual field condition, African Journal of Food, Agriculture, Nutrition and Development **15** (2015) 10077.	67
IBIKUNLE, S.B., AROGUNJO, A.M., AJAYI, O.S., Characterization of radiation dose and soil-to-plant transfer factor of natural radionuclides in some cities from south-western Nigeria and its effect on man, Scientific African **3** (2019) 1.	68
ELUDOYIN, O.S., OGBE, O.M., Assessment of heavy metal concentrations in pawpaw (Carica papaya Linn.) around automobile workshops in Port Harcourt metropolis, Rivers State, Nigeria, Journal of Health & Pollution **7** (2017) 48.	69
EBONG, G.A., AKPAN, M.M., MKPENIE, V.N., Heavy metal contents of municipal and rural dumpsite soils and rate of accumulation by Carica papaya and Talinum triangulare in Uyo, Nigeria, E-Journal of Chemistry **5** (2008) 281.	70
BHATTACHARYA, P., SAMAL, A.C., MAJUMDAR, J., SANTRA, S.C., Arsenic contamination in rice, wheat, pulses, and vegetables: a study in an arsenic affected area of West Bengal, India, Water, Air, & Soil Pollution **213** (2010) 3.	71
UDDIN, M.N., HASAN, M.K., DHAR, P.K., Contamination status of heavy metals in vegetables and soil in Satkhira, Bangladesh, Journal of Materials and Environmental Sciences **10** (2019) 543.	72
HAQUE, M., FERDOUS, M.J., Transfer of natural radionuclides from soil to plants in Savar Dhaka, Spanish Journal of Soil Science **7** (2017) 133.	73
KPEE, F., EDORI, O.S., Prevalence of some heavy metals in mango and pawpaw found in dumpsites of Obio/Akpo and Eleme local government areas in River State, Nigeria, Journal of Environmental Analytical Chemistry **4** (2017) 196.	74
AKTARUZZAMAN, M., FAKHRUDDIN, A.N.M., CHOWDHURY, M.A.Z., FARDOUS, Z., ALAM, M.K., Accumulation of heavy metals in soil and their transfer to leafy vegetables in the region of Dhaka Aricha Highway, Savar, Bangladesh, Pakistan Journal of Biological Sciences **16** (2013) 332.	75
BEN-BOLIE, G.H., ELE ABIAMA, P., OWONO ATEBA, P., EL KHOUKHI, T., CHERKAOUI EL MOURSLI, R., Transfer of ^{238}U and ^{232}Th from soil to plant in a high background radiation area of the southwestern region of Cameroon, Radiation Protection Dosimetry **157** (2013) 298.	76
HOSSEN, Md. A., FERDOUS, N., Determination of radiological hazards and the transfer factors of radionuclides from soil to vegetables in the southwestern district of Bangladesh, Journal of Physical Science **26** (2015) 83.	77
TENPE, S.P., PARWATE, D.V., Evaluation of elemental uptake of Citrus reticulata by nuclear analytical techniques, International Journal of Innovative Research in Science, Engineering and Technology **4** (2015) 2754.	78
AMAKOM, C.M., ORJI, C.E., EKE, B.C., OKOLI, U.A., NDUDI, C.S., The Influence of selected soil physicochemical properties on radionuclide transfer in cassava crops, International Journal of Plant & Soil Science **14** (2017) 1.	79

Publication	ID number
BAMZI, F., MSAKI, P., MOHAMMED, N., Assessment of radioactivity of ^{226}Ra, ^{232}Th and ^{40}K in soil and plants for estimation of transfer factors and effective dose around Mikuju River project, Tanzania, Mining of Mineral Deposits **11** (2017) 93.	80
THONGSRI, T., VISOOTTIVISETH, P., KOSIYACHINDA, P., "Accumulation and distribution of heavy metals into Thai jasmine rice in Mae Sod paddy field, Thailand", Proceedings of 15th International Conference on Heavy Metals in the Environment (2010).	81
SEMBIRING, Y., MARPAUNG, H., ALFIAN, Z., PUDJADI, E., SIBURIAN, R., Study of natural radionuclide in some plants food from Karo District post eruption of Mount Sinabung North Sumatera, Chemical Science Review and Letters **6** (2017) 2222.	82
KANANKE, T.C., WANSAPALA, J., GUNARATNE, A., Pb and Cr contaminations of irrigation water, soils and green leafy vegetables collected from different areas of Colombo District, Sri Lanka, Pakistan Journal of Nutrition **14** (2015) 593.	83
KRANROD, C., CHANYOTHA, S., PORNNUMPA, C., KRITSANANUWAT, R., SRIPLOY, P., Baseline data of naturally occurring radionuclides in some native vegetables and fruits in southern Thailand, Radiation Protection Dosimetry **167** (2015) 270.	84
KLINSAWATHOM, T., SONGSAKUNRUNGRUENG, B., PATTANAMAHAKUL, P., Heavy metal concentration and risk assessment of soil and rice in and around an open dumpsite in Thailand, Environment Asia 10 (2017) 53-64.	85
NEERATANAPHAN, L. et al., Heavy metal accumulation in rice (Oryza sativa) near electronic waste dumps and related human health risk assessment, Human and Ecological Risk Assessment **23** (2017) 1086.	86
SATPATHY, D., REDDY, M.V., DHAL, S.P., Risk assessment of heavy metals contamination in paddy soil, plants, and grains (Oryza sativa L.) at the east coast of India, BioMed Research International 2014 (2014) 545473.	87
UMAMI, I.A., NOOR, J.A.E., HERWININGSIH, S., PUDJADI, E., Transfer factors analysis of ^{210}Pb and ^{40}K natural radionuclides from paddy fields to rice plants in Malang Raya, East Java, International Research Journal of Advanced Engineering and Science **4** (2019) 343.	88
BASAR, S., WESTENDORF, J., Mineral and trace element concentrations in Morinda citrifolia L. (Noni) leaf, fruit and fruit juice, Food and Nutrition Sciences **3** (2012) 1176.	89
JALIL, A. et al., "Soil to plant transfer factor of radiocesium by pot experiment", Issues and Trends in Radioactive Waste Management, IAEA-CN-90 (2003).	90
SULAIMAN, F.R., HAMZAH, H.A., Heavy metals accumulation in suburban roadside plants of a tropical area (Jengka, Malaysia), Ecological Processes **7** (2018) 28.	91
KANAKARAJU, D., MAZURA, N.A., KHAIRULANWAR, A., Relationship between metals in vegetables with soils in farmlands of Kuching, Sarawak, Malaysian Journal of Soil Science **11** (2007) 57.	92
MAIMON, A., KHAIRIAH, J., AHMAD MAHIR, R., AMINAH, A., ISMAIL, B.S., Comparative accumulation of heavy metals in selected vegetables, their availability and correlation in lithogenic and nonlithogenic fractions of soils from some agricultural areas in Malaysia, Advances in Environmental Biology 3 (2009) 314.	93
RASHID, Md.H. et al., Determination of heavy metals in the soils of tea plantations and in fresh and processed tea leaves: an evaluation of six digestion methods, Chemistry Central Journal **10** (2016) 7.	94

APPENDIX III. **SUPPLEMENTARY DATA FOR CHAPTER 4**

TABLE II.1. PLANT SPECIES INCLUDED IN THE ARID DATASET

Plant group	**Common name**	**Latin name**
Cereals	Barley	*Hordeum vulgare L.*
	Oats	*Avena sativa L.*
	Sorghum	*Sorghum*
	Wheat	*Triticum aestivum L.*
Maize	Maize, corn	*Zea mays L.*
Leafy vegetables	Cabbage	*Brassica oleracae L.*
	Jew's-mallow	*Corchorus olitorius*
	Lettuce	*Lactuca sativa L.*
	Spinach	*Spinacia oleracea L.*
Non-leafy vegetables	Cucumber	*Cucumis sativus L.*
	Eggplant	*Solanum melongena L.*
	Ladies' fingers (gumbo, okra)	*Abelmoschus esculentus*
	Onion	*Allium cepa L.*
	Pepper, bell pepper	*Capsicum annuum L.*
	Squash	*Cucurbita pepo L.*
	Tomato	*Lycopersicon esculentum Mill.*
Leguminous vegetables	Bean (field, kidney, French)	*Phaseolus vulgaris L.*
	Broad bean	*Vicia faba L.*
	Chickpea, garbanzo	*Cicer arietinum L.*
	Lentil	*Lens culinaris*
Tubers	Potato	*Solanum tuberosum L.*
Fruits	Apple	*Malus domestica Borkh.*
	Apricot	*Prunus armeniaca L.*
	Avocado	*Persea Americana Mill.*
	Date palm	*Phoenix dactylifera L.*
	Grapes	*Vitis L.*
	Nectarine	*Prunus persica*
	Olive	*Olea europaea L.*
	Orange	*Citrus sinensis (L.)*
	Watermelon	*Citrullus lanatus*
Grasses	Bamboo	*Bambusa arundinacea*
	Natural grass mixture	*Unidentified*

APPENDIX IV. PUBLICATIONS USED TO BUILD THE ARID DATASET

The publications listed below relate to the identification (ID) numbers in the table presenting summary values of $CR_{plant\text{-}soil}$ for arid environments (see Table 4.1 of this publication). Letters added after certain ID numbers indicate that the data were compiled from multiple source references relating to the same study.

Publication	ID number
LARIONOVA, N.V., LUKASHENKO, S.N., KABDYRAKOVA, A.M., KUNDUZBAYEVA, A.YE., PANITSKIY, A.V., IVANOVA, A.R., Transfer of radionuclides to plants of natural ecosystems at the Semipalatinsk Test Site, J. Environ. Radioactiv. **186** (2018) 63.	1
LAVI, N., GOLOB, G., ALFASSI, Z.B., Monitoring and surveillance of radio-caesium in cultivated soils and foodstuff samples in Israel 18 years after the Chernobyl disaster, Radiat. Meas. **41** (2006) 78.	2
INTERNATIONAL ATOMIC ENERGY AGENCY, Classification of soil systems on the basis of transfer factors of radionuclides from soil to reference plants, IAEA-TECDOC-1497, IAEA, Vienna (2006).	3
OTHMAN, I, YASSINE, T., Transfer of radiocaesium from soil to some crops in semi-arid areas of Syria. Proceedings of an international symposium on environmental impact of radioactive releases organized by the international atomic energy agency and held in Vienna, 8-12 May (1995).	4
AL-MASRI, M.S., AL-AKEL, B., NASHAWANI, A., AMIN, Y., KHALIFA, K.H., AL-AIN, F., Transfer of ^{40}K, ^{238}U, ^{210}Pb, and ^{210}Po from soil to plant in various locations in south of Syria, J. Environ. Radioactiv. **99** (2008) 322.	5
MHEEMEED, A.K., NAJAM, L.A., HUSSEIN, A.KH., Transfer factors of ^{40}K, ^{226}Ra, ^{232}Th from soil to different types of local vegetables, radiation hazard indices and their annual doses, J. Radioanal. Nucl. Chem. **302** (2014) 87.	6
HARB, S., EL-KAMEL, A.H., EL-MAGEED, A.I. ABD., ABBADY, A., RASHED, W., Radioactivity Levels and Soil-to-Plant Transfer Factor of Natural Radionuclides from Protectorate Area in Aswan, Egypt, World J. Nucl. Sci. Technol. **4** 1 (2014) 7.	7
KADIM, S.S., REJHA, B.K., AL-ANI, N.H.K., ZAIR, Y.M., MEZAAL, A.A., Transfer factor of radionuclides from soil to plant, Int. J. Sci. Res. **6** 5 (2017) 189.	8
ALI, J.M., HAZAWI, A., AL-ABRDI, A.M., HASAN, H.M., The Natural Activity Concentration and Transfer Factor of Radionuclide in Soil-Plant In North Eastern Libya, IOSR J. Appl. Phys. **10** 4 (2018) 7.	9
ABDOU, N.Y., R.A. HEGAZY AND H.S. EISSA, Measurement of Gamma Activity from Clay Soil and the Leaves of Jew's-Mallow Plant Enhanced by Fertilizers. World Applied Sciences Journal **35** 1 (2020) 128.	10
SHAYEBA, M.A., ALHARBIA, T., BALOCHA, M.A., RAHMAN ALSAMHAN, O.A., Transfer factors for natural radioactivity into date palm pits, J. Environ. Radioactiv. **167** (2017) 75.	11
ALHARBI, A., EL-TAHER, A., A Study on Transfer Factors of Radionuclides from Soil to plant, Life Sci. J. **10** 2 (2013) 532.	12
ABABNEH, A.M., MASA'DEH, M.S., ABABNEH, Z.Q., AWAWDEH, M.A., ALYASSIN, A.M., Radioactivity concentrations in soil and vegetables from the northern Jordan rift valley and the corresponding dose estimates, Radiat. Prot. Dosim. **134** 1 (2009) 30.	13
ABU–KHADRA, S. A., M. F. ABDEL–SABOUR, A.T. ABDEL-FATTAH AND H.S. EISSA, Transfer Factor of Radioactive Cs and Sr from Egyptian Soils to Roots and Leafs of Wheat Plant. IX Radiation Physics & Protection Conference, 15-19 November 2008, Nasr City – Cairo (2008).	14
AL-OUDAT, M., ASFARY A.F., MUKHALALLTI, H., AL-HAMWI, A., KANAKRI, S., Transfer factors of ^{137}Cs and ^{90}Sr from soil to trees in arid region, J. Environ. Radioactiv. **90** 1 (2006) 78.	15

CONTENT OF THE SUPPLEMENTARY FILE (ANNEXES I–XVI)

(The supplementary file for this publication can be found on the publication's individual web page at www.iaea.org/publications.)

In 1993, the IAEA and IUR initiated a Coordinated Research Project (CRP) entitled "Transfer of Radionuclides from Air, Soil, and Freshwater to the Food Chain of Man in Tropical and Sub-tropical Environments". The main objective of the CRP was to provide radionuclide transfer parameter values from soil to plant and from freshwater to fish in sub-tropical and tropical environments, applicable for incorporation into assessment models. An additional objective of the CRP was to determine whether the transfer parameters derived in tropical and sub-tropical environments differed significantly from those reported for temperate climates. The CRP was completed in 1997 and the resulting work therefrom is presented in Annexes I–XVI which are published online as a Supplementary File to this publication.

A list, in alphabetical order, of the CRP participants is given in Annex I, Table I-1, with research groups identified by the name of the group leader. Most participants to the CRP were experts from tropical and sub-tropical countries (many from South East Asia) who responded to a call for research proposals. A number of observers, nominated by the IUR, also took part in the CRP.

The CRP was carried out in three phases:

— In the first phase, available information on radioecological transfer parameter data that had been identified through a literature search was evaluated. The availability of additional relevant unpublished data from tropical and sub-tropical countries was also explored. The outcome of these initial activities showed that the few available data were insufficient to determine whether the data for temperate environments were applicable to tropical or sub-tropical environments.

— In the second phase, terms of reference were agreed for the CRP which focused on soil-to-plant, vegetation-to-animals, and freshwater-to-fish transfer parameters. Although some protocols existed both within the IUR and the IAEA, the development of a suitable protocol for the planned radioecological experiments was considered an important part of the CRP. Experiments were planned according to a specified protocol to ensure that the data produced were representative of the environment in which the measurements were made.

— The third phase encompassed the research activities. Most participants carried out soil–to–plant experiments and three carried out fish uptake studies. It was not possible to study the uptake of radionuclides by agricultural animals. Another important activity undertaken was the collection of other relevant radioecological data in the participants' countries from sources that were not readily available or published.

Four Research Coordination Meetings (RCMs) were held over the duration the CRP. The first meeting (Jakarta, Indonesia: 1–5 November 1993) focused mainly on the development of protocols and the selection of crops, soils, agricultural systems, and other experimental conditions. It was agreed to compile all relevant data into one dataset. The second (Damascus, Syria: 12–16 December 1994) and third meetings (Istanbul, Turkey: 6–10 November 1995) focused on reporting preliminary and intermediate results and discussing the outcomes. At the fourth meeting (Vienna, Austria: 16–20 June 1997) a plan and schedule for the preparation of the final report was established. At the last meeting, the draft of the final report was discussed, modified and approved.

Descriptions and summaries of the activities carried out within the framework of the CRP by each individual participating research group are presented in Annexes IV–XVI (available as an electronic Supplementary File). Experimental work carried out during the project was conducted according to an agreed protocol for measuring soil-to-plant (see Annex II) and freshwater-to-fish (see Annex III) radionuclide transfer to ensure that the transfer parameters determined during the project could be used to provide representative values for these regions. Soil-to-plant transfer parameter data resulting from these CRP studies (see Annexes VII, VIII, X, XIV, XVI) represent valuable information which were not published by the CRP participants in open literature; these data have now been collated into the MODARIA II dataset for soil-to-plant transfer parameters in tropical environments (see Chapter 3 of this publication).

An intercomparison exercise was conducted for the CRP participants to ensure the quality of laboratory measurements, as part of the quality criteria for the collated data (see Annex I). In addition, a large amount of previously reported data was identified through a literature search for relevant papers.

The CRP text in Annexes I–XVI was edited by J. Twining, B. Howard and A.R. Harbottle; however, no substantial change was made to its scientific content. The text has been made more concise, with the priority focused on the summary data reported by each participant country (to facilitate further data use and comparisons with data from this publication).

The individual reports submitted by the CRP participants and the IUR dataset compiled before 1997 are unfortunately no longer readily available. All these individual reports are included in Annexes IV–XVI and appended as a Supplementary File. In Annex XV, the opportunity has been taken to include some additional data to supplement the work undertaken under the CRP.

In addition, the discussion in the overall CRP report did not take into account subsequent studies and relevant data reported after it was written. Therefore, the text in the original unpublished version of the CRP report, which compared the CRP data with other literature available up to 1997 has not been presented. However, some useful information to support the individual report is included in Annexes I–III.

The IAEA acknowledges the contributions of all the participants to the CRP at the time when it took place between 1993 and 1997. Mr W.L. Robison (United States of America) and M. Frissel (Netherlands) chaired the RCMs, supervised the calibration programmes, reviewed the individual submissions, collated all CRP participant data and drafted the final CRP report.

LIST OF ABBREVIATIONS

AI	aridity index
AM	arithmetic mean
BIOMASS	IAEA Programme on Biosphere Modelling and Assessment, 1996–2001
BARC	Bhabha Atomic Research Centre, India
CEA	Commissariat á l'Energie Atomique, France
CEC	cation exchange capacity (or concentration)
CEH	UK Centre for Ecology and Hydrology, United Kingdom
CIEMAT	Departamento de Medio Ambiente, Spain
CNEN	National Nuclear Energy Commission, Brazil
CNESTEN	Centre National de l'Energie des Sciences et des Techniques Nucléaires, Morocco
ÇNAEM	Çekmece Nuclear Research and Training Center, Turkey
CR	concentration ratio
CRP	Coordinated Research Project
EAEA	Egyptian Atomic Energy Authority, Egypt
EMBRAPA	Brazilian Enterprise for Agricultural Research, Brazil
EMRAS	IAEA Programme on Environmental Models for Radiation Safety, 2003–2007
EMRAS II	follow-up to EMRAS, 2009-2011
EPA	Environmental Protection Agency, Republic of Ireland
ERISS	Department of the Environment and Energy, Environmental Research Institute of the Supervising Scientist (ERISS), Australia
FANR	Federal Authority for Nuclear Regulation, United Arab Emirates
FAO/UNESCO	Food and Agriculture Organization of the United Nations / United Nations Educational, Scientific and Cultural Organization
GAEC	Greek Atomic Energy Commission, Greece
GM	geometric mean
GSD	geometric standard deviation

IAEA	International Atomic Energy Agency
IARI	Indian Agricultural Research Institute, India
ICRU	International Commission on Radiation Units and Measurements
ID	Identification (number(s))
IRD	Institute for Radioprotection and Dosimetry, Brazil
IRSN	Institute for Radiological Protection and Nuclear Safety, France
IUR	International Union of Radioecology
K-G	Köppen-Geiger climate classification
KUSTAR	Khalifa University of Science, Technology and Research, United Arab Emirates
LLNL	Lawrence Livermore National Laboratory, United States of America
MODARIA	IAEA Programme on Models and Data for Radiological Impact Assessments, 2012–2015
NIRS	National Institute of Radiological Sciences, Japan
NNRA	Nigerian Nuclear Regulatory Authority, Nigeria
NORM	naturally occurring radioactive material
OM	organic matter
REIA	radiological environmental impact assessments
SD	standard deviation
TECDOC	(IAEA) Technical Document
TRMC	The Taiwan Radiation Monitoring Center, Taiwan
TRS	(IAEA) Technical Report Series
UNCCD	United Nations Convention to Combat Desertification
UNEP	United Nations Environment Programme
USDA	United States Department of Agriculture, United States of America

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31 October – 4 November 2016, 30 October – 3 November 2017, 22–25 October 2018, 21–24 October 2019

Interim Working Group Meetings, MODARIA II Working Group 4, Subgroup 3

Athens, Greece: 6–7 April 2017
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† Deceased.

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