International Journal of Plant & Soil Science
14(1): 1-7, 2017; Article no.IJPSS.30913
ISSN: 2320-7035

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The Influence of Selected Soil Physicochemical Properties on Radionuclide Transfer in Cassava Crops

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Authors' contributions

This work was carried out in collaboration between all authors. Author CMA designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors CEO and BCE managed the analyses of the study. Authors UAO and CSN managed the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJPSS/2017/30913
Editor(s):
(1) Francisco Cruz-Sosa, Biotechnology Department, Metropolitan Autonomous University Iztapalapa Campus, Av. San Rafael Atlixco 186, 09340, México City, México.
Reviewers:
(1) Michael Adigun, Crawford University, Nigeria.
(2) Sibaway B. Mwango, Mlingano Agricultural Research Institute, Tanzania.
Complete Peer review History: http://www.sciencedomain.org/review-history/17478

Original Research Article

Received 7th December 2016
Accepted 2nd January 2017
Published 10th January 2017

ABSTRACT

Radionuclide contamination through the food chain is a major pathway for radiotoxicity to man. The radionuclides of natural origin are absorbed from the soil just like every other nutrient the plants needs for their survival. A study on the effects of some soil physicochemical parameters on the radionuclide transfer factors from soil to plant was carried out. The soil physicochemical properties obtained from the study suggest that the soil in this study fell within the sand category with a pH range of 5.06 – 6.08. Radionuclide activity concentrations for the soil samples ranged from 9.73±0.92 – 56.38±3.29, 35.91±1.71 – 147.26±4.06 and 137.09±4.20 – 247.33±3.42 Bq/Kg for the radionuclides ^{226}Ra, ^{232}Th and ^{40}K respectively. For the cassava samples, the activity concentrations ranged from 19.28±5.29 – 89.22±5.09, 70.46±1.59 – 203.48±1.56 and 39.34±5.59 – 442.45±6.99 for ^{226}Ra, ^{232}Th and ^{40}K respectively. From the correlation statistics, the soil pH and silt content made the most significant contribution in the radionuclide transfer factors.

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Keywords: Soil; physicochemical properties; radionuclides, transfer factor; cassava; correlation statistics.

1. INTRODUCTION

Plants have been known to take up radionuclides from soil, and this is commonly expressed as soil-to-plant transfer factor (TF). The transfer factors are widely used for calculating radiological human dose through the ingestion pathway. For nuclear facilities, the soil-to-plant TF is regarded as one of the most important parameters in environmental safety assessment [1]. For environmental transfer models, the TF is a useful tool in the prediction of radionuclide concentration in agricultural products.

Improved methods and technology in the field of terrestrial ecosystems studies is vital to assess the impact of pollutants on terrestrial ecosystems and biodiversity and biota interactions, these include reliable study of radionuclide and heavy metal content in soils. Creation of data bases for long term environmental management of pollution; evaluation of ecological impact of human activities and management of sustainable environment – agricultural, domestic sand, industrial zones, including assessment and forecasting techniques, is needed to understand the impacts of various activities on ecosystems, to contribute to protect the ecosystems from pollution and to develop long-term models for management of the environment [2].

There have been scarce data regarding radionuclide transfers in the tropical regions as most of the studies were limited to temperate regions and very few from other climatic zones [3]. However, in the previous two decades new data on tropical and subtropical environments are becoming available. Although studies have shown that there are no methodical differences of soil-to-plant transfer factors (TF) between climatic zones, but some extreme values have been reported in individual environments in tropical and subtropical environments [4,5]. A wide variation between the radionuclide transfer for plants and grasses were also recorded by [6]. The observed disparities were attributed to the rapid decomposition of organic materials that reaches the soil surface which subsequently leads to minimal accumulation of organic matter on the soil surface or the use of fertilizers during agricultural practices.

Cassava (*Manihot esculenta*) crop is one of the most widely cultivated food crops in Nigeria and the world's highest cultivator of cassava [7]. It is one of the most important staple food in the country [8] which made it a strong pathway for radionuclide contamination through the food chain. There have been numerous researches on the radionuclide contamination in the natural environment in Nigeria, but data is scarce on the influence of soil physicochemical properties on the transfer of these radionuclides along the food chain.

Since problems of elevated food chain contamination by radionuclides may be influenced by many soil physicochemical properties—such as the clay, sand, silt, and organic matter content, bulk density, soil pH and exchange K^+ [3].

This worked is aimed at looking at the influence of some selected soil physicochemical properties on the transfer of radionuclides in cassava crops.

2. MATERIALS AND METHODS

2.1 Sampling Location

The sampling area was the Iva valley, which is located in the city of Enugu, in Enugu state. The locality is the site of the Okpara Coal Mine: one of the five defunct and distinct mines (Onyeama, Obwetti, Okpara, Iva Valley and Ribadu) in the Enugu area which was opened in 1952 by the Nigerian Coal Cooperation (NCC). Production in the mine declined from a peak of 3,040 tons in 1984 to 1016 tons in 1990 and was closed down. The mine was later reopened in 1999 and operated till 2004/2005 when it was abandoned due to economic reasons [9].

2.2 Sample Collection and Preparation

A total of 8 soil samples and 8 cassava samples were collected within the Iva-Valley area using a hand trowel and black polyethylene bags. The soil samples were collected exactly from the point where the cassava samples were collected. About 0.5 kg of each sample was collected and these were divided for the gamma activity concentration analysis and the soil physicochemical parameters.

2.3 Analysis of Soil Physical Properties

2.3.1 Soil pH

A glass electrode pH meter was used to determine the soil pH. The air dried soil was passed through a 2-mm sieve to remove stones and root particles, then 20 g of the sieved soil was measured into a 50-ml beaker. 20 –ml of distilled water was added to the soil and was allowed to stand for 30-minutes. After which the mixture was occasionally stirred with a glass rod. The pH meter electrode was then inserted into the partly settled suspension and the pH was recorded.

2.3.2 Soil organic carbon

The soil samples were passed through a 0.5-mm sieve after which 2.00 g was transferred into a 250-ml Erlnmeyer flask. 10-ml of $1NK_2Cr_2O_7$ was pipette into the flask and swirled gently. Conc. H_2SO_4 was rapidly added using an automatic pipette and the flask was swirled gently and was allowed to stand on an asbestos sheet for about 30-minutes. 100-ml of distilled water was added and then 3-4 drops of O-phenanthroline-ferrous complex and was titrated with 0.5N ferrous sulfate solution. The results were calculated using the appropriate formula as given by [10].

2.3.3 Soil exchangeable K

5.00 g of the sample was measured out and 30-ml of 1N NH_4OAC was added and shaked on a mechanical shaker for 2-hours. After centrifuging for about 10-mins, the clear supernatant was carefully decanted into a 100-ml volumetric flask, after which 30-ml of NH_4OAC solution was added, shaked for 30-mins, centrifuged, and transferred into the same volumetric flask. The K was determined on a flame photometer and calculated as given by [10].

2.3.4 Sand, clay and silt

The Hydrometer method of soil mechanical analysis as given by [11,12] was used.

2.4 Sample Preparation for Gamma Analysis

The cassava samples were rinsed with pipe born water to remove dust and mud. All the samples were then dried under direct sun and humidity condition for 5 days. Soils were well mixed after removing extraneous materials such as roots, mat portions, pieces of stone and gravel. Samples were weighed and dried using an electric oven at 105°C until a constant dry weight was obtained. The soil samples were sieved to grain size of less than 0.63 mm and were sealed in a plastic cylindrical container of about 250 cm^3. The cassava samples were individually dried in an electrical oven of about 80°C to obtain a constant dry weight and were also sieved to grain size of less than 0.63 mm and sealed in a plastic container. The samples were transported to the Center for Energy Research and Development (CERT), Ahmadu Bello University, Zaria, where they were kept for at least 30 days before the measurement of gamma activity concentration. The wait was to enable secular equilibrium between thorium and radium and their decay products.

The other samples were sealed in transparent polyethylene bags and sent to the Department of Soil Science, Federal University of Technology, Owerri where the soil physicochemical analysis was carried out using appropriate methods.

2.5 Gamma Ray Spectroscopy

The gamma-ray spectrometry set-up is made up of a 7.62 cm by 7.62 cm NaI (TI) detector housed in a 6 cm thick lead shield (to assist in the reduction of the background radiation) and lined with cadmium and copper sheets [13]. The samples were placed on the detector surface and each counted for about 29,000 seconds in reproducible sample detector geometry. The configuration and geometry was maintained throughout the analysis, as previously characterized based on well established protocol of the laboratory (at the Centre for Energy Research and Training, Zaria). A computer based Multichannel Analyser (MCA) MAESTRO Programme from ORTEC was used for data acquisition and analysis of gamma spectra. The 1764 keV Gamma-line of ^{214}Bi for ^{238}U was used in the assessment of the activity concentration of ^{226}Ra, while 2614.5 keV Gamma-line of ^{208}Tl was used for ^{232}Th. The single 1460 keV Gamma-line of ^{40}K was used in its content evaluation.

The activity concentration (C) in Bq/kg of the radionuclides in the samples was calculated after decay correction using the expression [14].

$$C_S(Bq/Kg) = \frac{C_a}{\varepsilon_\gamma \times M_s \times t_c \times P_\gamma} \quad (1)$$

Where C_S = Sample concentration, C_a = net peak area of a peak at energy, ε_γ = Efficiency of the detector for a γ-energy of interest, M_s =Sample mass, t_c = total counting time, P_γ = the abundance of the γ-line in a radionuclide.

Table 1. Soil groups

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

Source: [3]

2.6 Transfer Factor (TF)

The soil-to-plant TF measures the transfer of radionuclides from soil to plant taken through the plant roots. From observed activity concentrations of the radionuclide in the plant and in the corresponding soil, the TF values were calculated according to the equation [15], which is:

$$TF = \frac{\text{Concentration of radionuclide in plant } (Bq/Kg)}{\text{Concentration of radionuclide in soil } (Bq/Kg)} \quad (2)$$

2.7 Statistical Analysis

Correlation statistics was carried out using the Microsoft excel statistical tool package.

2.8 Soil Classification

Soils can be classified into sand, loam, and organic. Table1 shows soil groups classification.

3. RESULTS, ANALYSIS AND DISCUSSION

3.1 Preliminary Results

The preliminary results are based on the results obtained for the soil physicochemical properties.

The physicochemical properties considered were the percentage organic carbon (%OC), potassium content (K), Hydrolytic acidity (pH), percentage sand, percentage clay and percentage silt. The result is presented in Table 2.

From the classification of soil groups in Table 2, the soil group for our results mostly fell in the sand category when their clay content is considered. Only soil sample SD fall in the loam soil category.

3.2 Soil Activity Concentrations

The result of the soil activity concentrations are presented in Table 3. The activity concentrations for ^{226}Ra, ^{232}Th and ^{40}K ranged from 9.73±0.92-56.38±3.29, 35.91±1.71-147.26±4.06 and 137.09±4.20-274.33±3.42 Bq/Kg respectively.

3.3 Food Crop Radioactivity

The radionuclide activity concentration measured in the cassava samples are presented in Table 4. The activity concentration ranged from 19.28 – 89.22, 70.46 – 203.48 and 39.34 – 442.45 Bq/Kg for ^{226}Ra, ^{232}Th and ^{40}K respectively.

3.4 Analysis and Discussion

A correlation statistics was carried out on the soil-to-plant TF and the soil physicochemical parameters. The radionuclide transfer factors are shown in Table 5 while the result of the correlation statistics is shown in Table 6. The transfer factor varies from 0.40 – 5.03, 0.81 – 4.84 and 0.24 – 2.12 for the ^{226}Ra, ^{232}Th and ^{40}K respectively. These were higher than what was observed for wheat grains in an environment with

Table 2. Soil Physicochemical parameters

Sample code	pH	%OC	K	%SAND	%CLAY	%SILT
SA	5.65	0.778	0.083	79.32	18.28	5.40
SB	5.06	0.618	0.096	79.32	7.28	13.40
SC	6.10	1.197	0.111	73.32	19.28	7.40
SD	5.71	0.579	0.106	71.36	21.24	7.40
SE	5.58	1.018	0.107	79.32	7.28	13.40
SF	5.90	0.898	0.100	63.32	19.28	17.40
SG	5.84	0.559	0.096	35.32	5.28	9.40
SH	6.08	0.500	0.075	90.32	8.30	1.40

SA=sample A, SB=sample B etc.

Table 3. Soil activity concentration

S/No.	Code	^{226}Ra	^{232}Th	^{40}K
1	SA	34.97±1.11	129.34±2.37	145.23±5.09
2	SB	17.72±2.20	51.19±3.53	167.02±3.57
3	SC	37.31±2.06	147.26±4.06	154.35±3.23
4	SD	9.73±0.92	44.35±0.79	274.33±3.42
5	SE	23.87±2.66	35.91±1.71	179.16±2.64
6	SF	16.23±3.49	98.32±1.02	194.28±4.28
7	SG	42.09±6.29	87.93±0.89	137.09±4.20
8	SH	56.38±3.29	116.42±1.94	199.49±6.20

SA=sample A, SB=sample B etc.

Table 4. Radionuclide activity concentration in food crop samples

S/No.	Code	^{226}Ra	^{232}Th	^{40}K
1.	SA	42.70±3.56	114.45±3.80	185.56±6.75
2.	SB	89.22±5.09	70.46±1.59	39.34±5.59
3.	SC	34.12±5.87	119.10±2.46	193.07±3.20
4.	SD	20.97±1.85	118.92±6.84	442.45±6.99
5.	SE	49.13±2.54	173.77±2.50	162.83±1.86
6.	SF	25.32±4.39	132.47±2.39	178.32±3.94
7.	SG	19.28±5.29	154.38±3.11	221.38±6.26
8.	SH	22.38±4.20	203.48±1.56	423.42±4.29

SA=sample A, SB=sample B etc.

higher pH values and the default values given by IAEA as reported by [16]. The variation of the soil-to-plant TF were in several orders of magnitude; this result is in agreement with what was found by [3] for different soil types. The highest transfer factor was recorded for the ^{226}Ra, followed by ^{232}Th. This observation was in agreement with the findings of [17] which they attributed to soil pH and texture. Most of the observed transfer factors were greater than unity which spells a greater chance of radionuclide contamination through the food chain [18], and since cassava crop is a staple food in Nigeria, the consumers are at a high risk of radionuclide contamination. The correlation statistics, the coefficient of determinant (r^2), showed that pH and silt content contributed 82% and 24% respectively for the transfer of ^{226}Ra. The transfer of ^{226}Ra has been reported to decrease with increasing pH while the transfer of ^{232}Th reaches a maximum at about pH of 6.5 [19]. Only K was observed to contribute 11% in the transfer of ^{232}Th where other factors were almost insignificant. For ^{40}K, pH contributed 57%, silt content contributed 60%, K contributed 16% while organic carbon contributed 12% in the transfer.

Table 5. Radionuclide transfer factors

S/no	226Ra	232Th	40K
1.	1.22	0.88	1.28
2.	5.03	1.38	0.24
3.	0.91	0.81	1.25
4.	2.16	2.68	1.61
5.	2.06	4.84	0.91
6.	1.56	1.35	0.92
7.	0.46	1.76	1.61
8.	0.40	1.75	2.12

Table 6. Correlation statistics

Sample	r	r^2	Sample	232Th	r^2	Sample	40K	r^2
226Ra	1	1	232Th	1	1	40K	1	1
PH	-0.91068	0.829345	PH	-0.19365	0.037502	PH	0.759078	0.576199
%OC	-0.09507	0.009038	%OC	0.081052	0.006569	%OC	-0.35466	0.125784
K	0.23811	0.056696	K	0.335144	0.112321	K	-0.41069	0.168668
%sand	0.261766	0.068522	%sand	0.103439	0.0107	%sand	-0.06802	0.004627
%clay	-0.14229	0.020246	%clay	-0.34187	0.116873	%clay	0.070494	0.004969
%silt	0.498158	0.248161	%silt	0.236193	0.055787	%silt	-0.77581	0.601875

4. CONCLUSION

Soil physicochemical properties were measured using standard methods while radionuclide activity concentrations in soil and food crop samples were measured using gamma ray spectroscopic analysis. No artificial radionuclide was measured, only radionuclides of natural origin—^{226}Ra, ^{232}Th and ^{40}K were detected. There was a wide variation in the radionuclide transfer factors. The soil physicochemical properties suggest that most of the sampled soils fell within the sand category with a pH range of 5.06 – 6.10. From the correlation statistics, the pH contributed 82% while the silt content contributed 24% of the ^{226}Ra transfer. The other properties contributions were almost insignificant. For the ^{232}Th, both K and clay content contributed 11% each while the other properties were less significant. And for ^{40}K, sand and clay content has insignificant contribution while pH, %OC, K and silt content has a contribution of 57%, 12%, 16% and 60% contribution respectively. From our study we were able to deduce that some of the soil physicochemical properties contributed to the soil-to-plant transfer of radionuclides in the cassava crops.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
http://sciencedomain.org/review-history/17478