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Activity Concentration and Soil to Plant Transfer Factor of Natural Radionuclides in Thai Lemongrass

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The Activity concentration of three natural radionuclides (^{226}Ra, ^{232}Th, and ^{40}K) in soil and lemongrass plant which are used in various Asia spices and traditional herb. The Lemongrass plant and their cultivated soils were collected from twelve locations in northern and northeastern Thailand under natural field conditions. The concentration of radionuclides was evaluated from gamma-ray spectrometry using HPGe detector. Soil-to-Plant transfer factors (TFs) for ^{226}Ra, ^{232}Th, and ^{40}K were investigated in stalk portions. The mean activities of ^{226}Ra, ^{232}Th, and ^{40}K in soil samples were 36 ± 2, 55 ± 3 and 477 ± 10 Bq/kg, respectively, while the mean activities in lemongrass were 1.4 ± 0.5, 3.2 ± 0.8 and 860 ± 14 Bq/kg, respectively. The mean TFs of ^{226}Ra, ^{232}Th, and ^{40}K were 0.05, 0.15 and 10.30, respectively. These are valuable source of baseline data for activity concentrations and TFs of natural radionuclides in Thailand for environmental radiation check-up in the future.

Key words: natural gamma radiation, transfer factors, lemongrass, Thailand

1. Introduction

Lemongrass (Cymbopogon citratus (De ex Nees) Stapf.) plant is well-known and widely used herb in Asia, Europe, and many tropical regions, especially in Thailand. It is a perennial in tropical and sub-tropical climates but it is treated as an annual in cold areas. Lemongrass, also called "ta-khrai" in Thai language, is a tall, stalky plant. It has traditionally been used as a spice, fragrance, and for a wide variety of medical conditions. Lemongrass has many medicinal benefits such as, relieving anxiety, lowering cholesterol, preventing infection, boosting oral health, and relieving bloating[1)].

Naturally occurring radioactive materials (NORMs) have always been present in our daily life. People are exposed to radiation sources from the environment every day through the food we eat, the water we drink, and the air we breathe[2)]. This is known as natural background radiation. Long-lived radioactive elements such as uranium, thorium and potassium and any of their decay products, such as radium and radon are examples of NORM. The presence of radionuclides in the environment

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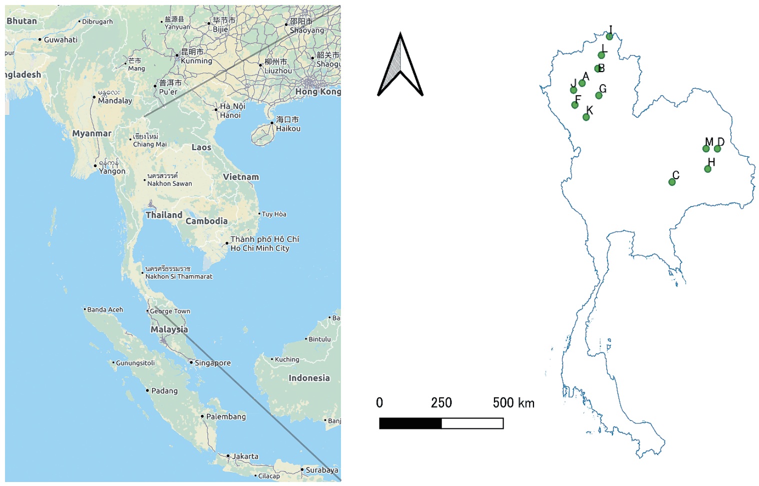

Fig. 1. Map of sampling locations.

causes the exposure of human life to the various types of radiations emitted by the radionuclides and intake of radionuclides through ingestion and inhalation. The fact, radionuclides can enter the terrestrial food chain by direct deposition onto forage and food crops or by plant uptake from soil or from irrigation water. Thus, contaminated plants can then be consumed directly by humans or ingested by animals with the transfer of the radioactivity to human food products[3]. Particularly ^{238}U ^{232}Th and ^{40}K, and their various decay products are the most common radionuclides in foods and water. These radionuclides appear in plants through the uptake of radionuclides from the soil via the root system. The addition of potassium in the form of fertilizer may cause an increase in the activity of ^{40}K in soil. Also, the fertilizers might cause chemical and biological change in the soil that influences transfer of radionuclides from soil to plants[4].

Soil-to-plant and plant-to-human body is one of the major pathways for the transference of radionuclides to human[5-6]. Therefore, it is important to study the spatial distribution of natural radioactivity in soil and related radiation exposures through specific land produced and foodstuffs. Soil-to-plant transfer factor (TF) is one of the key parameters to assess the impact of soil radioactivity on agricultural crops, also generally used for the estimation of internal radiation dose to human. There are worldwide studied on the determination of natural radionuclides activity such as ^{210}Po, ^{210}Pb, ^{226}Ra, ^{238}U, ^{232}Th, and ^{40}K in the food chain and estimated the soil-plant transfer[7-11]. However, in the case of Thai crops or herb, it is insufficient information on natural radionuclides; according to Thailand has wide-ranging biodiversity and large-scale plantation areas of various plants, while the information is limited only to small groups of plants.

In this work, the activity concentration of ^{226}Ra, ^{232}Th, and ^{40}K was determined in lemongrass and their cultivated soil. Base line data studies in Thailand are in progress. Therefore, we thought it is valuable to establish databases on the concentration of natural radioactivity (^{226}Ra, ^{232}Th, and ^{40}K) in soils and lemongrass as well as soil-to-plant transfer factor, since the lemongrass growing in the region are consumed by people living in both the local and other cities of Thailand.

2. Materials and Methods

2.1. Sample Collection

About 1 kg of lemongrass plants and 0.5 kg of their relevant soils were collected from 12 locations (total of 12 lemongrass and 12 soil samples) between latitudes 17°28′N to 20°18′N and longitudes 98°40′E to 100°21′E in the northern part and between latitudes 14°34′N to 16°38′N and longitudes 101°20′E to 103°79′E in the northeastern part of Thailand (Fig. 1). Latitude, longitude, altitude, geology, sampling time of lemongrass and soil type of the corresponding samples are listed in Table 1. These parts are the largest plantations zones of Thailand[11]. Lemongrass is a tropical plant which could be found in commercial farming and home gardening not only in the study areas but also across the country. Edible portion of lemongrass is near the base of the stalk under the tough. Lemongrass, both fresh and dry form can be used for medicinal and culinary purposes.

2.2. Samples Preparation and Analysis

Twelve soil samples were oven dried at a temperature of 110℃ until constant weight. The dried samples were pulverized into a fine powder and sieved through a 250-μm mesh sieve. Twelve lemongrass samples were washed with clean water for removing soil and dust and then were dried in an oven at 70-80℃ until a constant dry weight was obtained. All crop samples were ground

Table 1. Latitude, longitude, altitude, geology, sampling time and soil type of lemongrass and corresponding soil samples

Sample ID	Latitude(N)	Longitude(E)	Altitude(m)	Geology	Sampling Time	Soil type
The northern						
A	17°28′54.7″	99°09′29.7″	159	Sedimentary, Granite, Metamorphic	Feb., 2016	Silty clay loam
B	18°25′11.7″	98°40′03.5″	284	Sandstone, Shale	Feb., 2016	Sandy loam
C	18°13′51.2″	99°38′59.3″	348	Sedimentary, Granite, Metamorphic	Feb., 2016	Silty clay loam
D	19°09′42.4″	99°36′53.0″	426	Sedimentary, Granite, Metamorphic	Feb., 2016	Silty clay loam
E	18°39′32.5″	99°00′04.4″	297	Sandstone, Shale	Feb., 2016	Sandy loam
F	19°37′35.5″	99°45′28.3″	414	Sedimentary, Metamorphic, Granite	Feb., 2016	Loam
G	20°16′27.6″	100°04′48.0″	376	Sedimentary, Metamorphic, Granite	Feb., 2016	Clay Loam
H	17°54′16.0″	98°43′20.0″	278	Sedimentary, Metamorphic, Granite	Feb., 2016	Clay
The northeastern						
I	15°37′43.5″	103°48′58.8″	144	Sedimentary, Strass, Metamorphic	Mar, 2016	Sandy loam
J	15°12′07.7″	102°26′34.3″	158	Sedimentary, Metamorphic, Granite, Sludge	Mar, 2016	Sandy loam
K	16°19′11.5″	104°12′04.1″	174	Sedimentary, Strass, Metamorphic	Mar, 2016	Sandy loam
L	16°20′42.1″	103°48′36.0″	162	Sedimentary, Strass, Metamorphic	Mar, 2016	Sandy loam

into a fine powder. All homogenized samples were analyzed for activity concentration of ^{226}Ra, ^{228}Ra and ^{40}K using gamma spectroscopy. The samples were packed into airtight plastic containers and sealed to prevent the escape of radon (^{222}Rn) and thoron (^{220}Rn) gases. Prior to measurement, the sample was stored for at least four weeks in order to establish secular equilibrium between ^{226}Ra and ^{228}Ra and their radioactive progenies. Activity concentrations in the samples were measured using a high-purity germanium (HPGe) detector with a relative efficiency of 30% in a low background configuration. Energy and efficiency calibrations of the detector were carried out using three different IAEA standard reference materials including IAEA-RGU-1, IAEA-RGTh-1, and IAEA-RGK-1. Counting time for each sample was set at 24 h for soil and 48-60 h for the lemongrass. By assuming secular equilibrium with their progenies in the ^{238}U and ^{232}Th decay chain, the activity concentration of ^{226}Ra was calculated using gamma-rays associated with decay products of ^{214}Bi (609.3 keV) and ^{214}Pb (351.9 keV). In the case of ^{232}Th activity concentration, the gamma-ray lines of 911.2 keV from ^{228}Ac and 583.2 keV from ^{208}Tl were used. The activity concentration of ^{40}K was derived directly from the measured intensity of its photon peak at energy 1,460.8 keV[12-13].

Activity concentrations in soil and lemongrass plant samples were calculated to represent the distribution of radionuclides in the samples and compared with the worldwide average values reported by UNSCEAR.

Soil-to-plant transfer factor (TF), representing the transfer mechanism of radionuclides, is widely used to describe plant uptake from soil. The activity concentrations of radionuclides in lemongrass and their cultivated soil are assumed to be linear and they were used for calculating TFs according to the equation (1)[12, 14-16]:

$$TF = \frac{A_p}{A_s} \tag{1}$$

Where A_p is the radionuclide concentration in plant (Bq/kg) and A_s is radionuclide concentration in soil (Bq/kg).

The annual effective ingestion dose to man due to consumption of lemongrass as medicine and food is calculated using the expression (2)[16]:

$$E = C_p \cdot A_i \cdot DCF_i \cdot 10^3 \tag{2}$$

Where E is the annual effective ingestion dose (μSv/y), C_p is the consumption rate of radionuclides (kg/y), A_i is the activity concentration of each radionuclide (Bq/kg), and DCF_i is the dose conversion factor for ingestion of each radionuclide (i.e., 2.8×10^{-4} mSv/Bq, 2.3×10^{-4} mSv/Bq, and 6.2×10^{-7} mSv/Bq for ^{226}Ra, ^{232}Th, and ^{40}K, respectively, for an adult)[15].

The effective internal dose of lemongrass is dependent on several factors that differ from person to person. At this time, there is a lack of information from clinical trials to provide dosing recommendations for lemongrass. Generally, lemongrass is recognized as safe under conditions of intended use as a flavoring substance[17]. However, dose and time-dependent adverse effects of lemongrass on renal function have been reported[18]. A suggested safe limit for humans (based on an experiment in rats) is 0.7 mg/kg/day the essential oil for a medicinal purpose[19]. A survey of spices ingredient labels available for food in domestic markets was found that lemongrass is used approximately 5-25 g in one Thai dish. Thus, if a reference man[20] eats food contained lemongrass every day, in one year a consumption rate of lemongrass estimates range from 1.83-9.13 kg/y. On the basis of this information and the unavailability of a well-accepted, an annual intake rate for medicinal herb and food, a

Table 2. Activity concentration of natural radionuclides in lemongrass and corresponding soil samples and transfer factors from northern and northeastern of Thailand

Sample ID	Activity concentration in Lemongrass (Bq/kg)			Activity concentration in soil (Bq/kg)			Transfer Factor (TF)		
	^{226}Ra	^{232}Th	^{40}K	^{226}Ra	^{232}Th	^{40}K	^{226}Ra	^{232}Th	^{40}K
The northern									
A	4.4 ± 1.4	4.5 ± 2.9	1330 ± 42	60 ± 1	92 ± 2	642 ± 13.51	0.074	0.049	2.071
B	7.1 ± 1.1	5.4 ± 1.6	261 ± 9	26 ± 1	43 ± 1	319 ± 8.04	0.278	0.126	0.818
C	0.5 ± 0.3	3.1 ± 1.2	703 ± 18	88 ± 2	146 ± 4	1103 ± 22.53	0.006	0.021	0.638
D	< 0.2	< 0.1	780 ± 24	70 ± 1	140 ± 3	1106 ± 21.60	< 0.003	< 0.001	0.706
E	< 0.2	1.2 ± 0.8	561 ± 13	21 ± 5	25 ± 9	1560 ± 33.27	< 0.009	0.050	0.360
F	< 0.2	< 0.1	1289 ± 25	23 ± 1	34 ± 2	72 ± 2.04	< 0.009	< 0.003	17.812
G	0.8 ± 0.5	3.4 ± 1.2	2390 ± 49	44 ± 1	48 ± 1	327 ± 8.01	0.017	0.071	7.320
H	< 0.2	< 0.1	488 ± 11	38 ± 1	41 ± 2	414 ± 9.84	< 0.005	< 0.002	1.180
The northeastern									
I	< 0.2	7.2 ± 0.5	38 ± 2	20 ± 3	62 ± 2.78	82 ± 9.58	< 0.010	0.116	0.470
J	< 0.2	< 0.1	1181 ± 37	13 ± 1	14 ± 0.92	48 ± 3.49	< 0.015	< 0.007	24.811
K	< 0.2	10.0 ± 1.2	610 ± 19	12 ± 1	9 ± 0.65	12 ± 2.66	< 0.017	1.068	49.896
L	2.9 ± 1.1	2.8 ± 2.1	689 ± 15	18 ± 1	8 ± 0.97	39 ± 4.34	0.167	0.333	17.540
Range	< 0.2-7.1	< 0.1-10.0	38-2390	12-88	8-146	12-1560	< 0.003-0.278	< 0.001-1.068	0.360-49.896
Average	1.4 ± 0.5	3.2 ± 0.8	860 ± 14	36 ± 2	55 ± 2	477 ± 10	0.051	0.154	10.302

consumption rate of 9.13 kg/y was assumed for all ingesting of lemongrass used in this study.

3. Results and Discussion

3.1. Radioactivity concentration of ^{226}Ra, ^{232}Th and ^{40}K in soil

The activity concentrations of terrestrial radionuclides (^{226}Ra, ^{232}Th and ^{40}K) in lemongrass samples and their cultivated soils which collected from northern and northeastern of Thailand are shown in Table 2. The activity concentrations of ^{226}Ra for soils were found to be within the range of 12 to 88 Bq/kg. The average value for ^{226}Ra in soils was found to be 36 ± 1 Bq/kg which close to the world average of 35 Bq/kg[21]. The average activity concentration of ^{232}Th in soils was 55 ± 2 Bq/kg with a range of 8 to 146 Bq/kg. The soils contained high levels of ^{232}Th compared to the world average value of 40 Bq/kg[21]. The radioactivity concentration of ^{40}K ranged from 2 ± 1 to 1106 ± 22 Bq/kg with an average value of 860 ± 14 Bq/kg which is considerable higher than the world average of 400 Bq/kg[21].

The activity concentrations of natural radionuclides in all soil samples were in the order ^{40}K > ^{232}Th > ^{226}Ra. ^{40}K markedly exceeded over others wherewith it is a minor isotope of naturally occurring potassium which is the seventh most abundant element on the earth, making up 2.6% of the weight of the Earth's crust. Therefore, the high concentration of ^{40}K in soil may enhanced by the extensive use of fertilizer which is the main source of radioactivity in soil other than its natural origin[22]. The higher activity concentration of ^{232}Th compared to ^{226}Ra may be related to difference in chemical speciation and solubility of their parents, ^{232}Th and ^{238}U respectively, in a natural environment. In the Earth's crust, thorium and uranium tend to occur together due to similar ionic size and bond character. Also, it is evident from the fact that thorium is 1.5 times higher than that of uranium in the Earth's crust[23]. However, they are commonly fractionated during surficial processes, i.e. weathering, transportation and deposition. In almost all natural environments, thorium has a very low solubility and preferentially accumulated on particular phases due to limited stability of Th (IV) complexes; whereas under an oxidizing environment, U(IV) is oxidized to U(VI)[24].

3.2. Radioactivity concentration of ^{226}Ra, ^{232}Th and ^{40}K in Lemongrass

Radioactivity of ^{226}Ra, ^{232}Th, and ^{40}K was measured in stalks of lemongrass corresponding to the soils given in Table 2. Results revealed that the concentration of ^{226}Ra in lemongrass samples varied between < 0.2 and 7.1 Bq/kg with an average value of 1.4 ± 0.5 Bq/kg. The highest activity was found in sample B (7.1 ± 1.1). The activity of ^{232}Th ranged from < 0.1 to 10.0 Bq/kg with an average value of 48.1 ± 1.3 Bq/kg. The activity concentrations of ^{232}Th in lemongrass were higher than those of ^{226}Ra. The highest activity of ^{232}Th was found in sample K. Concentration of ^{40}K in lemongrass ranged from 38 to 2390 Bq/kg with an average value of 860 ± 14 Bq/kg. Lemongrass sample A was the highest of ^{40}K. Also, ^{40}K was found to pile up in large in lemongrass which was much higher than the activity concentration of ^{226}Ra and ^{232}Th in all lemongrass samples. This higher activity of ^{40}K might be a credit to the higher biological requirement of plants for potassium due to it is the third main essential

Table 3. Annual effective ingestion dose of natural radionuclides in lemongrass

Sample ID	Annual effective ingestion dose (μSv/y)		
	^{226}Ra	^{232}Th	^{40}K
The northern			
A	1.9 ± 1.3	7.1 ± 2.4	13.5 ± 0.3
B	1.3 ± 0.8	6.5 ± 2.5	4.0 ± 0.1
C	< 0.5	< 0.2	7.3 ± 0.1
D	< 0.5	< 0.2	2.8 ± 0.1
E	< 0.5	2.6 ± 1.8	3.2 ± 0.1
F	18.2 ± 2.7	11.3 ± 3.4	1.5 ± 0.1
G	11.3 ± 3.7	9.5 ± 6.2	7.5 ± 0.2
H	< 0.5	< 0.2	4.4 ± 0.1
The northeastern			
I	7.5 ± 2.9	5.8 ± 4.4	3.9 ± 0.1
J	< 0.5	15.2 ± 1.1	0.2 ± 0.1
K	< 0.5	< 0.2	6.7 ± 0.2
L	< 0.5	21.0 ± 2.5	3.5 ± 0.1
Range	< 0.5-18.2	< 0.2-21.0	0.2-13.5
Average	3.7 ± 1.4	6.7 ± 2.0	4.9 ± 0.1

macronutrient. Moreover, plants have the tendency to absorb soluble of potassium more than they need if the sufficiently large amount of it is present by adding the fertilization for agricultural purposes, termed as extra resource consumption[25, 26)]. Addition, mobility of potassium in soil is high[24, 27)]. Thus, the activity of ^{40}K in lemongrass showed very high value in the present study.

3.3. *Soil to plant transfer factor in natural radionuclides*

The transfer factors for the 3 natural radionuclides of the present study is displayed in Table 2. The TF of ^{226}Ra of lemongrass ranged from < 0.003 to 0.278 with an average of 0.051. The highest TF of ^{226}Ra was found in sample H. The results of ^{232}Th showed the TF of ^{232}Th ranged from < 0.001 to 1.068 with an average of 0.154. Sample L showed the highest value. Next, the lowest value of both ^{226}Ra and ^{232}Th were found in sample H. The TF of ^{40}K in ranged from 0.360 to 49.896 with an average of 10.302. Sample E showed the lowest TF whereas sample L had the highest TF. Moreover, TF value of ^{40}K in lemongrass was higher than those of other radionuclides. The high TF of ^{40}K was probably due to the intake and high mobility in soil by plants. By the way, plant uptake from soil was probably influenced by various factors such as soil characteristics, amount and physico-chemical form of radionuclides in soil, plant species, temperature, rainfall, and agricultural management, these parameters should be further investigated in the future study.

3.4. *Ingestion dose to human*

The annual effective ingestion dose due to the intake of ^{226}Ra, ^{232}Th, and ^{40}K from the consumption of lemongrass were presented in Table 3. The ingestion dose was calculated by assuming the annual consumption rate is 3.3 kg/y. The annual effective dose from ingestion of ^{226}Ra varied from < 0.5 to 18.2 μSv/y with a mean of 3.7 ± 1.4 μSv/y, < 0.2 to 21.0 μSv/y with a mean of 6.7 ± 2.0 μSv/y for ^{232}Th and 0.2 to 13.5 μSv/y with a mean of 4.9 ± 0.1 μSv/y for ^{40}K. These obtained values are significantly below the average worldwide effective dose from the ingestion of ^{226}Ra and ^{232}Th (120 μSv/y) and for ^{40}K (170 μSv/y), with a total annual dose of 290 μSv/y, which reported by UNSCEAR 2000. The annual effective dose from the ingestion of lemongrass in the present study was found very much lower than the world average value for all samples.

4. Conclusions

The activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K have been measured in lemongrass and their related soils collected from 12 provinces in the northern and north-eastern parts of Thailand. The obtained results under investigation showed large variation and non-uniform distribution in lemongrass and soil samples for the investigated natural radionuclides. The activity concentrations of ^{226}Ra and ^{232}Th in lemongrass were much lower than in the cultivated soils, whereas ^{40}K concentrations of not all samples were higher than those of their cultivated soils.

It also found that the activity concentration and the uptake of ^{40}K were higher than other radionuclides in all lemongrass samples. This may be due to higher uptake of plant from soil which probably influenced by various factors such as bioavailability, presence of organic matter and application of phosphorus fertilizers in agricultural fields, competition with major ions present in the soil-plant system, the effects of rhizosphere processes and soil micro-organisms on bioavailability, recent novel electro-physiological and genetic techniques[28, 29)]. In addition, the annual effective ingestion dose values obtained from this study were considered below the worldwide dose of 290 μSv/y. The present study indicates that consumers of Thai lemongrass, which planted in the study area, in food and medicines might not pose any major radiation hazard to the population. Thus, the collected data from this study will help to develop a baseline database on TFs of natural radionuclides in Thailand so that any change in this respect in future due to the nuclear phenomenon or any industrial activities can be detected and radiation safety measurements may be taken accordingly. Moreover, it is important to understand the distribution of natural radionuclides in soil and medicinal plant is useful information because of continuous intake of radionuclides through the food-chain may lead to dangerous health effects on individuals in the long term. Consequently, investigations should be further carried out in the future to determine the concentration of radionuclides in soil and various medicinal plants and also their transfer factor in order to take necessary radiological and dosimetric measures with the aim of minimizing the harmful effects of ionizing radiation.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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