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Environmental Contamination By Radionuclides And Heavy Metals Through The Application Of Phosphate RocksDuring Farming And Mathematical Modeling Of Their Impacts To The Ecosystem

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Abstract—Most of rock phosphates contain radioactive elements and heavy metals because theyoriginate from phosphate deposits. The application of these rock phosphates may result to the transfer of these dangerous materials into the ecosystem. Once these dangerous minerals become readily available for plants uptake and for animal consumptions, negative impacts may prevail, both to plants and animals esp. human beings.This review focuses on the environmental contamination by radioactive elements and heavy metals as a result of the application of rock phosphates during farming and the need to develop a mathematical model that can be used to predictthe associated impacts to the ecosystem.

Keywords— radioactivity, heavy metal, ecosystem,phytotoxic, rock phosphates, soil, plant.

INTRODUCTION

Research [1] has revealed that the main limiting plant-growth factor in highly weathered tropical acidic soils is phosphorus (P). These types of soils are characterized by low total and available phosphorus content and high phosphate retention capacities [2], [3]. They also have low P availability to crops and exhibit high capacity of fixing phosphorous and therefore phosphorous deficiency is a major constraint to crops production [4]. Research conducted in several areas, including Europe, America, Asia as well as Africa, have revealed that phosphorus deficiency is a widespread fertility constraint of many acidic and calcareous soils [5], [6], [7], [8], [9]. Furthermore, it is estimated that, 50% of all cultivated acidic soils in the United Republic of Tanzania (URT) have high deficiencies in phosphorous [10].

From 1950 to date, the application of plant nutrients such as rockphosphates to nutrient-deficient soils has increased substantially [8]. All over the world, farmers are advised to use phosphatic fertilizers,including RP to increase crop production and improve nutrients availability in the unfertile P deficient soils. However, the main source of phosphate fertilizers for small scale farmers especially in rural areas is through natural occurring phosphate deposits. For example, in East Africa, Minjingu phosphate rock is commonly applied directly to cropsduring farming [11], [12], [13].

Despite their positive values in enhancing crop productivity, research [9], [14], [15], [16], [17] has revealed that phosphate rocks contain a substantial concentration of uranium, thorium, radium and their decay products. It has also been estimated that when these phosphate rocks are applied to unfertile fields during farming, they could raise radioactivity levels in soils [18], [19], [20]. Furthermore, several studies [21], [22], [23], [24] conducted in different parts of the world have shown that phosphate rocks contain a substantial amount of heavy metals and rare earth metals. Also these phosphate rocks have been identified to be among the sources of heavy metal pollution to air, soil, water, plants and animals, through soil-plant-man chain [23], [24].

The transfer of natural radionuclides and heavy metals from the PR through the biosphere becomes an important study considering their presence, persistence and effects to the natural ecosystem [25]. Soil–plant–man is recognized to be one of the major pathways for the transfer of radionuclides to human being [26]. Contamination of cultivated lands by trace metals and some naturally occurring radioactive materials caused by application of these rock phosphatesmaybecoming a potential threat to human beings and animals [27]. The radionuclides accumulated in arable soil can be incorporated metabolically into plants and ultimately get transferred into the bodies of animals (including humans) when contaminated foods are consumed.

The radionuclides accumulated in different plant parts may be consumed by human beings or animals in form of food and finally accumulate in different organs of their bodies. Accumulation of radionuclides in human bodies may be harmful if the maximum dose is exceeded [28], [29] a situation which may cause serious health problems to human beings. For example, when ^{226}Ra is deposited in bone tissue, it has a high potential for causing biological damage through continuous irradiation of human skeleton over many years and may induce bone sarcoma [30]. On the other hand, leaching of these radioactive minerals is another source of dissemination and possible transfer to waters and finally to human beings and animals [16].

Likewise, heavy metals are toxic especially to plants and animal health. In plants, the excessive accumulation of toxic levels of heavy metals beyond established phytotoxic levels may cause growth abnormalities such as alterations in germination process, leaf chlorosis or death of the whole plant [22], [31], [33], [34]. Higher concentrations of heavy metals in soil may further pose health risks to animals, esp. human beings through either soil-plant-man or water-man or direct contact pathway. Excessive concentrations of some heavy metals in human beings are highly dangerous to human health, and may even cause death [31]. For example, some of heavy metals such as Cadmium, Nickel and Arsenic are known to be a major cause of different types of cancer to human beings[52].

The transfer of nutrients through soil-plan-man pathway has been described mathematically by some authors through mathematical modeling [35], [36], [37], [38]. In this context, mathematical modeling is a vital tool when investigating the impacts of variation of different parameters in the farming environment against plant mineral uptake, especially radioactive elements such as Uranium and heavy metals such as Cadmium and others that in one way or another may cause negative effects to plants. Soil and nutrient properties, through their influence on nutrient diffusion rates in the soil, may play a key role in determining the outcome of plant competition for nutrients [38].

AIM OF THIS REVIEW

The main aim of this paper is to provide a review on the environmental contamination by radioactive elements and heavy metals as a result of the application of rock phosphates during farming and mathematical modelling of the associated impacts to the ecosystem. This review is intended to gather useful information on the topic as highlighted by other authors/researchers as well as unleashing research gap/s that need/s attention for further research and experimentation to be undertaken.

A. RADIONUCLIDES AND HEAVY METALS CONTAMINATION IN SOIL AND PLANTS AND THEIR ASSOCIATED HEALTH RISKS

Research has revealed that phosphate deposits contain a wide range of heavy metals i.e. Hg, Cd, As, Pb, Cu and Ni [21], [22], [23], [24] and naturally occurring radioactive materials (NORM) i.e. U, Th, and K [9], [14], [15], [16], [17], [30]. These phosphate ores can be used directly (without any industrial processes) to increase fertility to many unfertile soils of the world. Several studies conducted on rock phosphates to investigate the amount of heavy metals and NORM also revealed a substantial concentration of both heavy metals [21], [22], [23], [24] and NORMs [39], [40], [41], [42].

Although it is common for farmers to use rock phosphates to increase crop production and improve nutrients availability in the unfertile soils [14], it is very unfortunate that to date, there are no standards associated with the acceptable levels of concentrations of either heavy/toxic/radioactive minerals for rock phosphates to be safe for agriculture use [26], [28], [29], [43]. This brings a rather challenging concern on the use of these rock phosphatesduring farming as long as their distribution and health effects might be significant to our natural environment. In lieu of that, it is therefore very important to undertake studies on the levels of contamination caused by the application of such rock phosphates in agricultural soils and the transfer of dangerous minerals (radionuclides and heavymetals) to plants and animals. This will serve two purposes; one is to determine the level of toxicity these toxic elements may posse toplants and animals (including human beings) and two is to establish minimum limits of such elements in rock phosphates for safe application during farming.

a) In soil

i. Radionuclides

Research [25], [39], [40], [44], has shown that the use of rock phosphatesduring agricultural activities is one of the mechanism through which significant amounts of radioactive materials i.e. uranium, thorium, potassium, radium and its decay products are redistributed throughout the agricultural soils of the world. Although radioactivity measurements in soil may bring different results from one soil type to another, research [5] has shown that one of the sources of radioactivity in soils, apart from those of natural origin is mainly due to extensive use of rock phosphatesduring farming.

In 1968, Menzel [40] undertook a study to measure Uranium, Radium, and Thorium content in phosphate rocks and their possible radiation hazards in Florida, Unites States of America (USA). In this study, it was shown that phosphate rocks in Florida, contain a substantial amount of Uranium, Radium and Thorium. Furthermore, another study was undertaken in Jordan and Pakistan by Tufail *et al.,* in 2006[46] to measure radioactivity levels in rock phosphates. Results from this study showed that the activity mass concentrations of ^{238}U (^{226}Ra) in the rock phosphates(428 +/- 11 Bqkg(-1) in Jordan and 799 +/- 10Bq kg(-1)in Pakistan) were higher than the world average ranges [47].

Furthermore, another study was undertaken in Brazil by Saueia and Mazzilli [42] in 2006 to study the distribution of natural radionuclides in the production and use of phosphate fertilizers in agriculture. One of the main components of the study was to predict increase in the concentrations of radionuclides in the soil as a result of the application of phosphate fertilizers during farming. The study used the following mathematical formula to estimate the increase in activity concentrations in the soil;

$$C_{s,i} = \frac{C_{f,i}\ X\ a_f(1-e^{\lambda_{E,i}\ X\ t_d})}{P\ X\ \lambda_{E,i}}$$

Whereby;

Cs,i = radionuclide activity concentration i in soil (Bq/Kg)

Cf,i = radionuclide activity concentration i in fertilizer (Bq/Kg)

af = surface application rate of fertilizer (Kg/m2/y)

λE,i = effective rate constant for reduction of the activity concentration of radionuclide i in the root zone of soil (1/y). λE,i = λi + λs

λi = rate constant for radioactive decay of radionuclide i (1/y).

λs = rate constant for reduction of the concentration of material deposited in the root zone of soils owing to processes other than radioactive decay (1/y).

td = time of deposition in soil (y)

P = surface density for the effective root zones in soil (Kg/ m2).

Bq = Becquerel

Y = Year

It was found that there was an increase of up to 0.87 Bq/Kg for grain crops and 7.6 Bq/Kg for green crops.

Another study by Wassila and Ahmed [9] was also undertaken in 2011, to measure radioactivity levels in soil and phosphate fertilizers in Algeria. In this study, both virgin and fertilized soil samples from Setif, Algeria were collected. Results of this study showed that there was a significant increase in radionuclides in the fertilized soils compared with virgin soils. However, the measured concentrations of radionuclides i.e. K, U, Th and Ra were within the world average ranges [47].

From a research point of view[9], [25], [39], [40], [42], [44-47], it is purely evident that a significant amount of radionuclides are distributed in farm soils as a result of the application of phosphate fertilizers during agricultural activities.Very little is known about the distribution of such dangerous minerals in the farm soils of the East African Region such as Tanzania as a result of the application of rock phosphates, especially the ones that are locally mined from the Minjingu Phosphate Deposit (MPD).Based on this fact, there is a great demand of undertaking further studies to measure concentrations of radioactive elements in Tanzanian farm soils as a result of the application of locally availablerock phosphates. This will provide good information to the environmental stakeholders and may trigger the establishment of minimum allowable limits of such elements in rock phosphatesby relevant organs i.e. World Health Organization (WHO) and Food and Agriculture Organization (FAO).

ii. Heavy metals

Research [21], [22], [23], [40] has also shown that continuous application of rock phosphates in farm-soils could increase the concentration of heavy metals to levels above natural abundances in soils. According to a study [48], concerns on heavy metals in soil is mainly observed in acidic soil with low cation exchange and low phosphorous fertility and which is fertilized with phosphate rock fertilizers.It is revealed through research [49] that normal agricultural practices do not pose a sound impact on heavy metal content of farm-soils, but the use of rock phosphates in a long run, could cause dangerous heavy metals to accumulate in farm-soils. A review [50] by Jiao *et al.,* in 2012 on environmental risks of trace elements associated with long-term P-fertilizers application concluded that the application of P-fertilizers can significantly contribute to potentially dangerous heavy metals and trace elements i.e. Arsenic, Cadmium and Lead in farm soils.

In 2001, Abdel-Haleem*et al.* undertook a study [21] that aimed at determining the elemental pattern in phosphate ingredients/raw materials (rock phosphate, limestone and sulfur) as well as in the produced phosphate fertilizer.In this study it was revealed that there was existence of elevated contents of heavy metals Fe, Zn, Co, Cr and Sc as well as rare earth elements La, Ce, Hf, Eu, Yb and Sm in all the phosphate related materials that were investigated.Another study by Giuffré*et al.,* in 1997, [22] to determine concentrations of chromium, cadmium, copper, zinc, nickel and lead in common-used fertilizers in Argentina, revealed that rock phosphate contained the highest levels of cadmium and zinc, chromium. The study also concluded that continuous application of P-fertilizer in farm-soils increased the concentration of heavy metals to levels above natural abundances in soils. The study also recommendedthat special attention should be put in looking at the transfer of these metals to the human food chain.

Another study by Javied*et al.,* in 2008 [24] for the purpose of investigating heavy metal pollution from phosphate rock used for the production of fertilizer in Pakistan revealed that phosphate rock is among the sources of heavy metal pollution to air, soil, water, and to the food chain. The study therefore concluded that there is a need to remove heavy metals from the rock prior to its use as the presence of such dangerous heavy metals in phosphate rock may cause detrimental effects to both human and plants. A field trial to determine the ideal rock phosphate (RP) and the level of cow dung fertilizer combination with respect to heavy metal contamination of soil and crops was undertaken in Nigeria by Awotoye*et al.* [23] in 2010. The obtained results reported an increase in the levels of Pb, Zn, Cu and Cd in the measured soils.In 2008, a research by Nziguheba and Smolders [51] was undertaken in 12 different European countries for the purpose of establishing the concentrations of trace elements in agricultural soils as a result of the application of phosphate fertilizers. The results of the research concluded that mineral P-fertilizers are one of major sources of heavy metals accumulation in agricultural soils.

The review presented above [21-24], [40], [51] brings a sound concern on the presence of dangerous heavy metals in farms soils where rock phosphateshave been applied to increase agricultural productivity of crop lands. Many studies conducted in East Africa and Tanzania in particular where Minjingu Phosphate Rock is mined and used do not provide satisfactory information on the concentrations of these particular toxic elements in farm soil where therock phosphates have been applied for agricultural purposes. In this way, it seem very important to undertake studies that will bring better information on the amount of heavy metals that are distributed to farm soils as a result of theapplication of local phosphate rocks. This information will be vital to the environmental stakeholders and may assist in the process of establishing critical levels of such elements in phosphate rocks.

iii. Health impacts to animals, human and plants

The presence of radioactive elements i.e. K, U, Th and Ra, as well as heavy metals i.e. Cd, Pb, Ni and As in agricultural soils is associated with negative impacts to the ecosystem [21], [25], [31-34]. Danger may be posed to both, animals, human beings and plants [28-29], [31], [34]. Detrimental effects may be caused either directly or indirectly, through different pathways i.e. direct ingestion/inhalation, drinking of contaminated water, contact with contaminated soil and the food chain [21], [25], [52].

The transfer of radionuclides from farm soils to human bodies may be harmful if the maximum dose is exceeded [28-29], [47] a situation which may cause serious health problems to human beings. For example, once radionuclides accumulate in human body tissues at higher levels than the standard limit [43], they may cause severe health problems such as cancer [22], [27]. Also, when ^{226}Ra is deposited in bone tissue, it has a high potential for causing biological damage through continuous irradiation of human skeleton over many years and may induce bone sarcoma [30].

Heavy metal contamination in soil may pose risks and hazards to human beings. Excessive concentrations of some heavy metals in biological systems, especially animals (human beings in particular) are highly dangerous to human health, and may even cause death [31]. For example, heavy metals such as Cadmium, Nickel and Arsenic are carcinogenic. Table 1 gives a summary of some dangerous heavy metals that are commonly present in farm soils and their health impacts to human beings [52].

Table 1: Dangerous heavy metals and their health impacts to human beings (as stipulated by Wuanaand Okieimen [52])

Heavy Metal	Health Impact/s
Pb	Mental lapse or even death
Cr	Allergic dermatitis
As	Skin damage, cancer, affects kidney and central nervous system
Zn	Zinc shortages can cause birth defects
Cd	Affects kidney, liver and GI tract
Cu	Anaemia, liver and kidney damage, and stomach/intestinal irritation
Hg	Kidney damage
Ni	Various kinds of cancer

The contaminated soils with heavy metals may also cause health impacts to plants [31], [34]. In plants, the excessive accumulation of toxic levels of heavy metals, beyond established phytotoxic levels may cause growth abnormalities such as alterations in germination process, leaf chlorosis or death of the whole plant. Table 2 gives a summary of toxic limits (concentration-mg/Kg) of few heavy metals in soil and their health impacts to plants [31], [32], [33].

Table 2. Toxic levels of some heavy metals in soil and their health impacts to plants

Heavy Metal	**Phytotoxic limits in soils**(mg/Kg)	**Health Impacts to plants**	**Reference**
Cd	4	Chlorosis, necrosis, purple coloration	[31]
Pb	50	Dark-green leaves	[31]
Ni	30	Decrease in leaf area, chlorosis, necrosis and stunting	[33]
Cr	1	Alterations in the germination process, stunted growth, reduced yield and mutagenesis	[31]
Zn	50	Stunting and reduction of leaves elongation	[32]
Cu	100	Chlorosis in plants, yellow coloration, inhibition of root growth and less branched roots	[33]
Fe	100	Dark green foliage. Thickening of roots, brown spots on leaves	[31]
Mn	300	Marginal chlorosis and necrosis of leaves, crinkled leaves	[31]

Reviews [21-22], [25], [27-29], [30-34], [43], [47], [52] on health impacts associated with the application of rock phosphatesin farm soils has shown that the presence of heavy metals in soil brings more negative impacts to plants than to animals. This is because plants tend to accumulate these dangerous minerals directly into their systems through roots during plant mineral uptake for nutritional purposes. In this way, plants are more affected than animals, whose direct contamination from soil is mainly through exposure. It is therefore very necessary to study uptake and distribution of these heavy metals in plants and measure levels of concentrations of these toxic elements as a result of the application of rock phosphates to farm soils. This will help to identify which elements are taken up by plant species in excessive amounts from the locally available rock phosphates. The information may be used by environmental planners and activists to claim for restriction or control of the elements inrock phosphates and hence minimising negative impacts to plants.

b) In plants

i. Radionuclides

The study of transfer mechanism and plant mineral uptake of natural radionuclides such as^{238}U and other dangerous heavy metals through our natural environment is of high importance regarding their complexity in terms of existence and persistence [25], [48]. Minerals uptake by plants is usually described as concentration ratio (CR), which is sometimes known as transfer factor (TF) [53]. CR is calculated by dividing the mineral concentration in the plant by mineral concentration in soil. The most dominant factor for mineral nutrient acquisition by plants is the root surface properties [37]. This includes root size (and its increase with time), nutrient inflow into the roots as related to nutrient concentration in the soil solution near the root surface (this incorporates both kinetic and plant demand factors), and nutrient transport in the soil by convection or diffusion.

Dreesen *et al.* in 1978 [54] undertook a study to investigate contaminant transport, revegetation and trace element studies at inactive uranium mill tailing piles in USA. In this study, amongst other objectives, the uptake of toxic trace elements and radionuclides by vegetation growing in soils-covered tailings was also examined as a mechanism of contaminant transport. Results of this study showed that the uptake of trace elements and radionuclides may constitute a significant contaminant transport mechanism, particularly from covered tailings area. Measurements of As, Se and Ra showed that the uptake of radionuclides by plants depends on the plant species, the type of radionuclide and on substrate characteristics.

In 1985, Rumble and Ardell [56] undertook a study to measure the concentrations of Uranium and Radium in plants growing in soils around a Uranium mill tailing in South Dakota, USA. In this study, it was observed that plants growing in the study sites had elevated levels of Uranium and Radium compared withcontrol sites. It was also observed that the amount of radionuclides taken up by plants from soils depends on the radionuclide form, soil moisture and chemical and mineralogical composition of the soil.

In 2003, another study by Pulhani*et al.* [25] was undertaken to investigate uptake and distribution of natural radioactivity in wheat plants from soil in India. In this study, the uptake of Uranium, Thorium, Radium and Potassium by wheat plant from two morphologically different types of soils was studied under natural field conditions. The transfer factors were calculated and were used to study uptake of essential and nonessential elements by plants. It was observed that the availability of Calcium and Potassium in soil for uptake affects the Uranium, Thorium and Radium content of the plant. The availability of these radionuclides in soil for plants was also observed to be hindered by the fact that Illite clays of alluvial soil do trap potassium in its crystal lattice and that phosphates form insoluble compounds with thorium. It was also observed that a major percentage (54–75%) of total ^{238}U, ^{232}Th and ^{226}Ra activity in the plant is concentrated in plant roots.

Mlwilo*et al.* [20] undertook a study in 2006 to measure radioactivity levels of staple foodstuffs and dose estimates for most of the Tanzanian population. In this study, staple food products including maize and rice from various localities of the United Republic of Tanzania were measured to establish radioactivity levels of ^{40}K, ^{232}Th and ^{238}U. Results showed that one type of foodstuff (maize) contained relatively high average concentrations of the measured radionuclides and this was due to the extensive use of rock phosphates during farming for maize.

Research [20], [25], [37], [48], [53-56] has shown that a significant amount of radionuclides are distributed in foodstuffs as a result of the application of rock phosphates in farm soils during agricultural activities. Information about this phenomenon in East Africa and Tanzania in particular where different forms of Phosphate Rock fertilizers are used by farmers is almost negligible. Studies of the same nature should be undertaken inthese areasto determine the actual levels of radioactive elements present in plant species as a result of the application of rock phosphates. This will provide good information on the extent of danger that plants species in Tanzania stand, through the application of rock phosphates in farm soils.

ii. *Heavy metals*

A study by Mortvedt and Beaton [48] in 1995 to investigate heavy metal and radionuclides contaminants in phosphate fertilizers indicates significant differences among plant species in their ability to take up different types of heavy metals supplied through the application of phosphate fertilizers. The toxic impacts of heavy metals within a plant system are associated with their accumulation in different plant tissues [31]. For instance, studies [57-58] have shown that different plants will accumulate certain heavy metals in different concentrations in their leaves, stems and roots, and in which critical levels may vary amongst themselves (see Table 2).

In 1974, Bazzaz *et al.* [59] conducted a study to investigate the effect of heavy metals on plants in Illinois, USA. The measured heavy metals included Pb, Ni, Cd and Tl. The plant used was sunflower (*Helianthus Annuus*L.). In this study, it was revealed that relatively low concentrations of Pb, Cd, Ni and Tl inhibited photosynthesis and transpiration of detached sunflower leaves. The primary mode of action is the interference with stomatal functions that results in reduction of photosynthesis by 50%, when leaf tissue concentration (in ppm) is 63, 96, 193 and 79 for Tl, Cd, Pb and Ni respectively.

In 1975, Kumar *et al.* [60] undertook a study to investigate the use of plants to remove heavy metals from soils. This study was supported by previous research that had shown great possibilities of some wild plants grown on metal-contaminated soil to accumulate large amounts of heavy metals. In this study, various crop plants were compared for their ability to accumulate heavy metals i.e. Pb, Cr, Cd, Ni, Zn and Cu. It was finally found that *Brassica juncea* (L.) Czern accumulated large amounts of heavy metals i.e. Pb, Cr, Cd, Ni, Zn and Cu both in roots and shoots. The plant (*Brassica juncea* (L.)Czern) was therefore termed as favourite phytoextraction agent.

Furthermore, Wenzel and Jockwer in 1999 [61] undertook a research to study the accumulation of heavy metals in plants grown on mineralized soils of the Austrian Alps. In this study, a field survey of higher terrestrial plants growing on eighteen metalliferous sites of the Austrian Alps was conducted to identify species that accumulate exceptional large concentrations of selected heavy metals (Cd, Cu, Ni, Pb and Zn). Results showed that several plant species (*Minuartiaverna*,*Biscutella laevigata*, *Thlaspi rotundifolium ssp. cepaei-folium, Cardaminopsishaller and Thlaspi goesingense*) were found to contain elevated levels of heavy metals and were therefore categorised as hyperaccumulators.

Awotoye*et al.* in 2010 [23] conducted field experiments to determining the ideal rock phosphate (RP) and the level of cow dung fertilizer combination with respect to heavy metal contamination of soil and crops. Plants used in these experiments were maize (*Zea mays* (L)) and okra (*Abelmuscusesculentum*). Results showed that the application of RP in combination with various levels of cow dung elevated the Pb, Zn and Cu content in the tissue of maize relative to the control. Only Cu and As were found in excessive amounts in okra.

Review on heavy metals in plants [23], [31], [48], [57-61]has revealed that potential heavy metals are found in plants that are grown in farm soils where extensive use of phosphate fertilizers is common. In East Africa and Tanzania in particular, few studies have been undertaken to date to investigate the amount of dangerous heavy metals that are present is plant species grown in farm soils that have been supplied with row phosphate rock fertilizers or of similar origin. It is therefore very important to quantify the amount of these dangerous elements in plants so as to avoid the transfer of such minerals to animals, especially human beings through consumption of food products from plants. Furthermore, these dangerous minerals may be one of the reasons for under-productivity of certain species of plants, so it is of high importance to investigate their presence in plants.

iii. Health impacts

One of the major pathways through which radioactive materials are transferred to human beings from farm soils is “soil–plant–man” [26]. In this regard, plants play a key role in the transfer of radionuclides from soil to human beings. Other pathways include direct inhalation of contaminated air, drinking of contaminated water as well as direct contact with contaminated soils [21], [25], [53]. Many studies conducted in many areas of the world [20] [25], [48], [52] to measure dose rates due to the intake of radionuclides by human beings as a result of consumption of plant foodstuff have shown that the concentrations are lower than the recommended doses for the general public [26], [28-29], [62-65].

On the other hand, several studies [66-69] have shown that heavy metals in foodstuff derived from plants are associated with health hazards to human beings. For example, a research was conducted in Tianjin, China by Wang *et al.* in 2005 [66] to study health effects of heavy metals i.e. Cu, Zn, Pb, Cd, Hg, and Cr to the general public through consumption of vegetables and fish. Results showed that consumption of both vegetable and fish at once may lead to potential health risks especially to children because the target hazard quotient (THQ) of the two foodstuff sums up to greater than the recommended value [29], [62], [64-65]. Health risk to adults from consumption of both vegetable and fish was mainly associated with Cd only.

Another study was conducted by Zeng *et al.* in 2007 [67] to investigate health risks associated with Hg, Pb, Cd, Zn, and Cu to the inhabitants around Huludao Zinc plant in China through consumption of vegetables. Results showed that the THQfor Cd and Pb were found to be higher than the recommended value [29], [62], [64-65] for both adults and children. This may lead to potential health risks since the THQs for the two heavy metals i.e. Cd and Pb exceed maximum allowed limits in foodstuff.

In 2008, Khan *et al.* [68] studied health risks associated with heavy metals in contaminated soils and food crops i.e. vegetables irrigated with wastewater in Beijing, China. Results from this study indicated that there is a substantial buildup of heavy metals in wastewater-irrigated soils collected from the study sites. Heavy metal concentrations in plants grown in these sites we found to exceed the permissible limits set by the State Environmental Protection Administration (SEPA) [70-71] in China and the World Health Organization (WHO) [72-73]. However, health risk index values was less than one indicating a relative absence of health risks associated with the ingestion of contaminated vegetables.

In 2009, another study was conducted by Zhuang *et al.* [69] around Dabaoshan mine, South China. This study aimed at investigating health risks from heavy metals (Cu, Zn, Pb and Cd) consumed from food crops. Plants investigated in this study include rice and vegetables. Results showed that the estimated daily intake (EDI) and THQs for Cd and Pb of rice and vegetables exceeded the FAO/WHO permissible limit[72-73].

According to thesestudies[21-22], [25], [27-29], [30-34], [43], [47], [52], few investigationshave reported the presence of excessive concentrations of heavy metal above the permissible limits in plant foodstuff such as rice and vegetables. It is important, therefore to study uptake and distribution of these heavy metals in plants and measure levels of concentrations of these toxic elements as a result of the application of rock phosphates to farm soils. This will help to identify which elements are taken up by plant species in excessive amounts from the locally available rock phosphates.

B. MATHEMATICAL MODELING

Plants’ nutrients uptake from soil is dependent to the inner interactions between plants themselves and soil [74]. However, the concentration of a particular nutrient, available at the root surface of the soil solution, dictates the rate of uptake of that nutrient. Research shows that mathematical models on nutrient uptake by plants have been usefully used to investigate the effect of various soil and plant factors on nutrient flux to plant roots [36]. However, most mathematical models that describe processes involved in nutrient uptake through root system in soil integrate values for root size (usually length) and its increase with time, nutrient inflow into the roots as related to nutrient concentration in the soil solution near the root surface (this incorporates both kinetic and plant demand factors), and nutrient transport in the soil by convection or diffusion [35], [37], [38]. Root hairs which are lateral extensions of epidermal cells are also involved, and these root hairs increase the effective surface area of the root system available for water and nutrient uptake [35].

Soil and nutrient properties, through their influence on nutrient diffusion rates in the soil may play a key role in determining the outcome of plant competition for nutrients [38]. Epstein [75] and Nielsen [76] quantitatively described the existing relationship between nutrients concentration and its rate of uptake. Another study by Barber [77]has shown that the transport of nutrients from soil to plant, through plant roots is a function of mass flow and diffusion.

In early 1980, a mathematical model was developed by S.A. Barber and J.H. Cushman (Barber-Cushman Model) to simulate nutrient uptake by roots [77]. The model assumes that plants roots are evenly distributed in the soil and nutrient flow in the soil to the roots can be described by a one dimensional radial flow. The main governing formulae for the development of this model were as follows;

i. The concentration in the liquid is linearly related to the solid concentration

$$C_i^t = b * c_{liquid\ \ i}^t$$

ii. The flux of a nutrient from one node to another is described by the combined effect of diffusion (fix law) and mass flow (works on liquid concentration and needs therefore be multiplied with b)

$$\int_l^t = D_e * \frac{\partial C^t}{\partial r} + \frac{V_l^t}{b} * C_{l,l+1}^t$$

iii. The flux from the most inner node into the root is described by Michealis-Menten kinetics.

$$\int_0^t = \frac{J_{max}\ * C_1^t}{K_m\ * C_1^t} - Efflux$$

Where;
Efflux is independent of the Concentration outside the root. Sometimes E is represented by a minimum uptake concentration C_{min} for which C is corrected.

iv. The Flux over the outside boundary is zero.

$$\int_k^t = 0$$

In 1983, Silberbush and Barber [22] used Cushman simulation model, with its eleven plant and soil parameters, for a sensitivity analysis of the parameters involved in P uptake. Simulation models were verified for P uptake by corn and soybeans. In that study, it was revealed that, root growth rate and root radius were the most sensitive parameters influencing P uptake from the soil. It was also found that soil P supply parameters were more sensitive than root physiological uptake parameters. Furthermore, P concentration in soil solution affected P uptake more than the diffusion coefficient and buffer power. On reducing root radius while keeping root volume constant, P uptake was increased.

Also, in 1986 an important step in the overall process of nutrient uptake from soil was reached when a test was undertaken to compare measured and calculated nutrient depletion next to root surfaces [76]. A mathematical model was first developed based on the idea of ion transport from the soil to the roots by mass flow and diffusion and on Michaelis-Menten kinetics of nutrient uptake from soil solution by plant roots. The model had based on a study by Nye and Marriott [80], which describes the transport of nutrients to the root by mass flow and diffusion.

$$\frac{dC_1}{dt} = \frac{1}{r}\frac{d}{dr}\left(r.D_e.\frac{dC_1}{dr} + \frac{v_o.r_o.C_1}{b}\right)$$

Where;
C_1 = concentration of the soil solution
r = radial distance from the root axis
ro = root radius
D_e = effective diffusion coefficient
b = buffer power
V_o = rate of water uptake
t = time

As it was described by Barber [80], a comparison between calculated and measured total K uptake by a growing root system under different soil conditions was done. The obtained results showed that the developed model is useful in simulating uptake of available nutrients in soil by plants.

In 2000, another study by Adhikari and Rattan [81] used Barber-Cushman mechanistic nutrient uptake model to describe and predict nutrient uptake by crop plants at different stages of crop growth. The aim of the study was to compare the predicted Zn uptake at different stages of growth to the measured Zn uptake by rice cultivars grown on sandy loam soil under green-house conditions. At the end of the experiments, the predicted Zn uptake was significantly collated with the observed uptake (r^2=0.99).

In 2003, Barber-Cushman mechanistic P uptake model was used to examine the predictability of phosphorous uptake in maize plants [82]. This study was undertaken in South Dakota, U.S.A. and the primary goal was to examine how phosphorus (P) fertilizer affected the predictability of phosphorous uptake in maize when applied to a silt loam soil. Results showed that the model predicted 86-90% of the observed P uptake. This shows that mathematical models have become vital tools in estimating mineral uptake by plants.

Most studies [22], [35-38], [74-77], [80-81] have shown that many existing mathematical models integrate values for root size (usually length) and its increase with time, nutrient inflow into the roots as related to nutrient concentration in the soil solution near the root surface and nutrient transport in the soil by convection or diffusion. There is a need to develop a mathematical model that can be able to use input parameters i.e. soil type (acidity, organic matter content, cation exchange capacity), type of fertilizer, amount of fertilizer, time of application of the fertilizer, amount of water, to predictthe amount of radionuclide/heavy metal to be taken up by certain species of a plants and take precautionary control measures of contamination and health risks.

CONCLUSION

From this review, it has been shown that the application of rock phosphates during farming may be a major source of radionuclides and heavy metals contamination to farm-soils, plants and animals other than that of natural origin. Several studies have recommended establishment of allowable limits for both radionuclides and heavy metals in rock phosphates for safe application during farming. It was also recommended that whenever possible, radioactive elements and heavy metals should be removed before rock phosphates are used for farming. Furthermore, it has been recommended that studies on the investigation of levels of these dangerous elements (radionuclides and heavy metals) in farm-soils of the Eastern African Region as a result of the application of rock phosphates during farming should be undertaken for environmental purposes. Also is has been revealed that mathematical models that exist are not sufficient to predict the outputs i.e. mineral concentrations when inputparameters are given i.e. soil parameters and fertilizer type.

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