

**OCCURRENCE OF SOME HEAVY METALS IN SEWAGE SLUDGE IN
SOME URBAN AREAS AND THEIR UPTAKE BY AMARANTHUS
(*Amaranthus hybridus*)**

BY

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**A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE
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ABSTRACT

A study was conducted to determine the occurrence of some heavy metals in sewage sludges from Morogoro and Dar es Salaam urban areas and their uptake by *Amaranthus hybridus*. A field study was conducted at the Horticultural Unit, Sokoine University of Agriculture Morogoro whereby, the soil was characterised for its physical and chemical properties prior to planting of the test crop. The analytical data showed that the experimental soil was texture mildly-alkaline with a pH value of 7.6, very low % O.C. The textural class of the soil was sandy clay loam. Available and total Cu, Zn, Mn, Cd and Pb ranged from medium to high as compared to established critical levels. The sewage sludge was collected from the disposing sites in Morogoro and Dar es Salaam. Prior to incorporation into the soil the sewage sludge was air dried and characterised for its chemical properties. The results showed that the available and total Cd, Mn, Cu, Zn and Pb ranged from medium to high as compared to established critical ranges. A field study was conducted to study the uptake of some heavy metals and other plants nutrients. In the field studies a Randomised Complete Block Design (RCBD) was used. The rates of sewage sludge application on air dry basis were 0, 10, 20, 40, and 60 tons/ha. *Amaranthus* seeds were measured by using 35 cm³ container and sowed in 1 m² plots which were separated by 0.5 m strips while the blocks were separated by 1 m strips. The uptake of N, P, K, Mg, Ca and heavy metals (Cu, Zn, Mn, Cd, Pb) were determined. Application of sewage sludge resulted in a marked increase

in metal content in *Amaranthus* plant especially for the highest rates of application during the first and second plantings. The uptake of other essential plant elements increased with increasing rate of sewage sludge application. No adverse effects due to application of sewage sludge were observed. At the end of the first growing season, the soil was analysed to evaluate the residual effects of sewage sludge on soil chemical properties. The results showed that sewage sludge application resulted in a marked increase in total and extractable metals as well as essential elements in the soil, except for total and extractable Mn. The application of sewage sludge resulted in a significant increase ($p < 0.05$) in the concentrations of Cd, Zn, Cu, and Pb. However, the metal content in the soil was below the limits generally accepted as toxic for most agricultural soils. A second planting was done in the same plots without further application of sewage sludge in order to determine the residual concentration of heavy metals in the soil from the previously applied sewage sludge. The results indicated that, the residual metal concentration in the soil had significantly increased. Plant dry matter yield of *Amaranthus* was determined for the first and second harvests. The application of sewage sludge from Dar es Salaam increased dry matter yield significantly ($P < 0.05$) at 60 tons/ha. The maximum yields obtained were 3.66 and 2.4 tons/ha for the first and second harvests respectively. The Dry matter yield as the result of application of Morogoro sewage sludge reached a maximum of 2.16 and 1.79 tons/ha at 60 tons/ha for the first and second crop respectively. Generally, the increase in the

rate of sewage sludge application resulted into a significant increase in dry matter yield .

DECLARATION

I, Lameck Eliawony Matemba, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is the result of my own original work and has not been submitted for a degree award in any other university.

Signature 

Date 22 March, 2001

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DEDICATION

This work is dedicated to my parents Eliawony Matemba and Martha Matemba, and to all those who have true scientific inquiry and striving in proving things they are investigating about as far as it is their ability.

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LIST OF ABBREVIATIONS

Cd	Cadmium
CEC	Cation Exchange Capacity
Cv	Coefficient of variation
DMRT	Duncan's Multiple Range Test
DTPA	diethylene triamine pentaacetic acid
EDTA	ethylene damine tetraacetic acid
FAO	Food and Agriculture Organization
FE-AAS	Flame Emission Atomic Absorption Spectrophotometer
Gm	Grand mean
kg	kilogram
L	liter
LSD	Least significant difference
m	metre
M	Molarity
Me	milliequivalent
ml	millilitre
ns	not significant
OC	Organic Carbon
Pb	Lead
ppb	parts per billion
ppm	parts per million

SCL	Sand Clay Loam
SUA	Sokoine University of Agriculture
t/ha	tonne per hectare
UK	United Kingdom
USA	United States of America
USDA	United States Department of Agriculture
WHO	World Health Organization

CHAPTER ONE

1.0 INTRODUCTION

Over the last decade the importance of urban agriculture in third world cities was recognised as a survival strategy of the urban population. On the other hand the quality of the produce is said to be questionable, following land application of organic wastes. In addition it has been said that agricultural activities can have negative effects on the already stressed urban environment (Smit and Nasr, 1992). It is also argued that the agricultural land use and resources available in urban areas can contribute to the conservation of the environment and better use of energy.

In recent years the dimension and implication of urban agriculture has been recognised and several studies around the world document its importance. Most urban cities in developing countries have to face a steady increasing demand of basic needs such as food, drinking water, health care, infrastructure and job opportunities (Mlozi, 1995). On the other hand urban agriculture is often seen as a pollution factor and cause of land degradation in the already stressed urban environment. A common perception is that vegetables fed by surface and/ or waste water, fertilised with sludges and grown in air polluted areas bear a health risk for the consumer (Mlozi, 1996).

The increased cost of artificial fertiliser with increasing cost of living for the urban population stresses a need to find an alternative source of plant nutrients for peri-urban and urban vegetable growers. Very few studies have been conducted to determine the importance and impact of using sewage sludge as a source of plant nutrients in urban environment (Smit and Nasr, 1992). Urban agriculture on the other hand can also be seen as a strategy to address environmental sustainability.

Recycling sewage sludge to agricultural land, to benefit from essential plant nutrients and organic matter, would seem a reasonable and rational method of managing a material which would otherwise need disposing of by some other non beneficial route (SI, 1989). Sludge also contains inorganic (including heavy metals), organic and biological contaminants/pollutants and therefore requires careful and responsible management to avoid potential environmental problems.

The pollution of soils and aquatic ecosystems by pollutants such as toxic heavy metals has recently been taken as a central theme in developing countries. Semu (1997) pointed out that the improvement of the quality of human life due to the advances in science and technology on many occasions has been parallel with the deterioration in the quality of the environment mainly the dispersion of hazardous substances such as heavy metals to the environment. The source of heavy metal pollutants in urban environments may be divided into pollutants from metal and

chemical industries, automobiles and municipal wastes and their incinerating plants (Komai, 1981).

At high concentrations, pollutants of soil and aquatic ecosystem such as toxic heavy metals may enter food chains and result in health hazards. The toxic heavy metals known to have caused health hazards whenever their concentrations exceed critical levels are cadmium, lead, copper, zinc, mercury, nickel, manganese and toxic organics such as Poly chlorinated Biphenuls (PCBs) (Luzadar, 1967). Muigai (1992) also reported that both essential and non-essential elements might exhibit toxic effects whenever their doses exceed the critical level.

Agricultural application of sewage sludge has become a common practice for both practical and economic reasons, as it provides an alternative means for their disposal in urban areas. Depending on the origin and composition, sewage sludge may contain variable amounts of toxic metals as well as beneficial nutrients. Peter and Carl (1990) concluded that the application of waste materials to agricultural land presents an opportunity for the recovery of essential plants nutrients. Many waste products contain concentration of plant nutrient elements sufficient to produce an agriculturally significant growth response, but recycling waste materials through agricultural systems requires an evaluation of both agronomic benefits and broader environmental consequences. The presence of toxic metals in sludge can affect plants, ground water or human health by contamination of the food chain. In

general, sewage sludge has been reported to contain a relatively large proportion of total toxic metals discharged from domestic, road run off, and industries (Hallsal *et al.*, 1993; Nriagu, 1992; Bowen, 1979; Webber *et al.*, 1984; Burrel, 1974).

In the past, environmental pollution was believed to be a problem in developed countries only. But now available information shows that many parts of the African continent are also polluted even though the pollution is more localised (Odero, 1998). To date, however, there is scanty information on environmental dynamics and public health implication of heavy metals within urban areas such as those located in Tanzania as a result of population increase and industrial sector development. So far, exhaustive investigations on the toxicity of such metals have been conducted in developed countries. Therefore, there is need to study and assess the occurrence of heavy metals in urban areas and suggest necessary recommendations for proper disposal of the industrial and domestic sewage sludge.

Final disposal of sewage sludge is one of the major problems in Tanzania. The principle methods of sludge disposal are landfill, incineration, agricultural land application, and disposal at sea (Smith, 1996). Sludge disposal by these methods is restricted due to the presence of toxic metals, but land application of sludge is one of the most economically attractive methods.

Field studies concerning the interactions between the vast variety of inorganic and organic compounds in sewage sludges and the inanimate particulates, are only envisaged. Therefore, studies involving the potential environmental effects of extensively used sewage sludge in agriculture should identify and describe in a broad range the concentrations of the hazardous substances present in the sewage sludge in order to get a better insight in their recycling strategies and to make a significant contribution to the main tasks of agriculture production and recycling.

Proper characterisation of the sludge may also offer an avenue for their qualification to be disposed of on agricultural land and thus improve nutrient dynamics in urban agricultural land. The general objective of the study was to assess the occurrence of some heavy metals in sewage sludge in some urban areas and their uptake by *Amaranthus*

The specific objectives of the study were:

1. To determine the concentration of heavy metals and nutrients in sewage sludge.
2. To study the uptake of selected heavy metals by *Amaranthus*.
3. To estimate the yield of *Amaranthus* as influenced by different rates of sewage sludge application.
4. To assess the residual concentration of heavy metals in soils as a result of sewage sludge application.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Global concern of heavy metals

Concern about long term effects of heavy metals pollution of soils has mobilised substantial research efforts within several environmental disciplines such as soil physics, soil chemistry and ecotoxicology. Case studies concerning the history of heavy metals emitters such as mining complexes, metal smelters, and foundries have gathered much information about the fate and impacts of heavy metals in the environment and on the human health (Alloway *et al.*, 1968).

Generally, the levels of heavy metals in the environment are on the increase and, consequently, this has resulted in much global concern. The concern for these metals is based on the toxicity of the heavy metals when their levels in the environment are higher than the established tolerable levels (Nriagu, 1992). Such metals as Mercury, Cadmium, Copper, Zinc and Lead are biologically non essential elements, whose toxicity is of environmental concern. Hay (1984), for instance, reported that approximately 200,000 tons of lead were deposited on the earth's surface annually, as a result of use of tetra-ethyl lead in fuels. This has resulted in pathological effects in man.

Oehme (1978), reported that exposure to lead has occurred in circumscribed areas of the world for 3000 years or more and was high among the Roman upper class population. Nriagu and Pacyna (1988), for instance, estimated the world wide fall out of Cr from the atmosphere to soil to be 5.1×10^3 kg/year. The majority of the total inputs come from disposal of wastes of various types on land. Kabata-Pendias and Pendias (1986), showed a steady increase in Zn in the air at different locations. They recorded values ranging from 0.002 - 6800 $\mu\text{g}/\text{m}^3$ in various parts of the world. These high values were attributed to Zn mineral smelting, thereby releasing exhaust fumes. Natural sources such as volcanic eruptions and aeolin dusts were also reported to contribute significantly to environmental Zn pollution (Alloway, 1990).

2.2 Heavy metals in soils

For ecological considerations, the concentration and kind of heavy metal species in the soil solution are of primary importance because of their mobility and availability which are closely related to the composition of the liquid phase (Brumner, 1986). Within the soil profile Cd, Zn, and Cu were found to be in high concentration in the surface horizons as a result of recycling through vegetation, atmospheric deposition and adsorption by the soil organic matter (Alloway, 1990). The total metal content in the soil is the result of inputs of metal from several sources such as parent materials, atmospheric deposition, fertilisers, agrochemical,

organic wastes and other organic pollutants, minus losses in minerals removed by crop materials, leaching and volatilisation (Bowen 1979; Webber *et al.*, 1984).

Bennet (1981) reported the average concentration of Cd in the earth's crust to be 0.2 mg/kg. The natural soil Cd concentration normally ranged from 0.01 - 0.7 mg/kg. The author further reported that the average Cd concentration in 91 soil samples from farming areas in USA was 0.57 Cd mg/kg. Khan (1980) reported that the Pb content in some agricultural soils in England and Wales was found to vary quite widely, with an average of 57 mg Pb/kg. The common lead concentration range in argillaceous soils was found to be 0.1 to 10 mg/kg (Kabata-Pendias and Pendias, 1986). McGrath (1987) in a survey of 6000 soils in England and Wales reported the geometric mean concentration of Cr to be 34 mg/kg. Williams (1988) gave the upper limit of Cr concentration in soils receiving sewage sludges as 150 - 250 mg/kg. Kabata-Pendias and Pendias (1984) reported values of 17 to 125 Zn/kg as background content of large numbers of surface soils of different countries. In Zn contaminated soils concentrations of 1000 to 10000 mg Zn/kg soil have been found (Alloway, 1990). Anna *et al.*, (1990) in the determination of forms of Cd, Pb, and Zn in contaminated soils found that the concentrations of metals ranged from background levels to levels well in excess of the maximum tolerable limits in agricultural soils. Thus, Pb, Cd, and Zn ranged from 0.2 to 103, 14 to 7100 and 20 to 10000 mg/kg soil respectively.

Lead is sometimes added to soils as a pesticide e.g lead arsenate or as impurity in certain fertilisers, such as Limestone and rock phosphate. Karamanos *et al.*,(1976) reported that lead contaminated soils result from combustion products of leaded gasoline, Pb arsenate pesticides, phosphate fertilisers, wastes from metal smelting and by sludge disposal practices. Road side dusts and soils from various non industrial districts in the USA had high concentrations of Pb when compared with background levels for normal soil. Pb concentration levels ranged between 15 - 25 mg/kg according to Aubert and Pinta (1977). Sewage sludges and effluent have high levels of trace metals. Therefore, when added to soil the level of micropollutants will be elevated.

Concern about metal contamination of soils relates directly to the extent to which natural background levels are exceeded and to the ease with which the metals are mobilised and made bioavailable. Background levels for trace metals in Polish soils are now reasonably well established and, recently, Kabata-Pendias *et al.* (1992) showed that overall mean contents of Cd, Pb, and Zn for polish soils were 0.5, 35, and 50 mg/kg respectively. The behaviour of trace metals in soils depends not only on the level of contamination as expressed by the total content, but also on the form and origin of the metal and the properties of the soils themselves. Soil pH, texture and organic matter content may be particularly important with respect to the form of the trace metal and its bioavailability.

2.3 Sewage sludge as a source of heavy metals in soils

Amending soils with sewage sludge is known to enhance a variety of soil physical and chemical properties. In general, land application of sewage sludge provides a cost effective method for disposal. However, sewage sludge may contain excessive amounts of heavy metals that may be toxic to soil microbiota if soil is not properly managed (Ibekwe *et al.*, 1995). A significant quantity of potentially toxic metals and organic compounds are incorporated into soil through the disposal of sewage sludge on land (Page *et al.*, 1987).

Final disposal of sewage sludge is one of the major problems in municipal and industrial waste water treatment. The principle methods of sludge disposal are land fill, incineration, agricultural land application, and disposal at sea. Sludge disposal by these methods is restricted due to the presence of toxic metals (Bruce and Davis, 1983). Land application of sludge as fertiliser is one of the most economically attractive methods. In USA, Europe and Canada, 30 to 40% of sewage sludge is disposed by this practice. However, the large quantity of toxic metals in sludge is a great obstacle to using this method, because toxic metals can find their way into the food chain via plants and animals (Adam *et al.*, 1989).

The range of organic compounds known to exist in sewage sludge is extensive and diverse and these compounds are potentially transferred to sludge amended agricultural soils. A review conducted by Drescher-Kaden *et al.* (1992), reported

that 332 organic pollutants, with the potential to exert a health or environmental hazard, had been identified in Germany sewage sludges. The occurrence, fate and potential impact of trace organic contaminants in sewage sludges and sludge treated agricultural land have also been extensively reviewed by Lester (1983).

The United States Environmental Protection Agency (USEPA) has set numerical limits for permissible concentrations of the most toxic heavy metals in sewage sludge (USEPA, 1993). These limits are based on intensive research to understand the potential toxic effects of heavy metals from sludge and possible transfer to the food chain. A report from Japanese farmers on injuries to their families from rice grain (*Oryza sativa*, L.) grown on Cd - contaminated sludges has become a major concern.

Studies on long-term sewage sludge plots at Rothamsted Experiment station (McGrath *et al.*, 1988) showed that only ineffective populations of *Rhizobium leguminosarum* bv. *Trifolii* survived in soil amended with sludge 30 to 50 yrs ago. But these authors observed a significant reduction in growth of white clover and a reduction in Nitrogen fixation compared to the unamended control. They concluded that sludge-borne heavy metals, primarily Cd, Zn, and Cu were responsible for this observation.

Peter and Carl (1990) in a study to evaluate sewage sludge incinerated ash as a P - fertiliser, determined trace metal availability, and assessed the liming potential of the ash. They found that, ash increased Diethylenetriaminepentaacetic acid (DTPA) extractable Cu, Zn, and Cd in the 0 - 15 cm soil depth and slightly buffered soil pH. Concentrations of Cu and Zn in plant tissue were consistently higher, and Mn consistently lower, with ash than with phosphate fertiliser. In 1990, ash also significantly increased tissue Cd and Mo in sweet corn.

Municipal sewage sludges, or biosolids, can be applied to crop lands to supply and recycle nutrients and organic carbon. Trace metals in sludges, however, may be of environmental concern. Nutrients and organic carbon can be recycled by applying municipal sewage sludges, or biosolids, to crop land. High loading to soils may increase the concentration of trace metals in the plants grown on these lands. These are capable of potentially affecting the growth of plants and/ or the health of animals when used as a food source. Only a few studies have examined the consequences of loading crop land with phytotoxic levels of one or more trace elements from the application of municipal sewage sludges (Bert and Jacobs, 1990).

2.4 Sewage sludge disposal

Disposal implies that no future action is contemplated with the exception of environmental monitoring or restrictions on future use of the disposal site. A constraint on the disposal of sewage sludge to land is the presence of potentially

toxic elements. Europe and the USA have statutory controls and codes of practice which limit the concentrations of these elements in soils treated with sewage sludge (Smith, 1996). However, a precautionary approach is still needed to ensure disposal of sewage to agricultural land without deleterious effects to agro-ecosystem. The need to treat sewage sludge effluents to maintain high quality discharges into receiving water courses ultimately produces a sewage sludge which requires safe and economical disposal. It is estimated that in the UK, more than 1.1 millions tonnes of sludge (dry solids) are produced annually and within the European Union (EU) the total amount is approximately 6.5 millions tonnes (dry solids) (Hall and Dalimier, 1994). Production levels in Tanzania cities are not known. Such information is important for planning purposes and especially disposal problems and strategies.

The ultimate options currently available for dealing with sewage sludge includes application to agricultural land, incineration, land reclamation, land fill forestry, sea disposal and dedicated sacrificial land. But among, the most attractive method is the agricultural/land application of sewage sludge. Sea disposal represents a relatively small outlet for sewage sludge world wide and this accounts for only 30% of the total sludges produced.

Before application of sewage sludge to land is practiced most sludges are treated to reduce its bulkiness and to avoid potential problems from odour and pathogens.

Such treatment processes affect the properties of the sludge products making them more amenable for reuse or disposal to particular outlets, and can influence their agronomic value.

2.5 Sewage sludge as a source of plant nutrients

Sewage sludge contains valuable plant nutrients and can act as a soil conditioner for most infertile soils. It contains appreciable amounts of N and P and has significant inorganic fertiliser replacement value for these major plant nutrients. Knowledge of direct and subsequent longer term turnover in soil of N derived from sewage sludge is important to maximise crop utilisation and minimise losses of nitrate to the environment. However, Chander *et al.*, (1995) reported that amount of inorganic N in soils treated with sewage sludge declines with time due to immobilisation or denitrification.

The K content of most sludges is low, and is not sufficient to make any significant impact to the recommended quantities of fertiliser K required for most cropping situations (Hall and Williams, 1984). Sewage sludge is also a potential source of sulphur(s) for crop growth providing additional benefits to agriculture in areas where atmospheric deposition of S has declined and crop deficiencies are possible (Elsewi *et al.*, 1978).

Ibekwe *et al.*, (1995) reported that application of sewage sludge to legumes significantly increases the shoot weight and total shoot N. Plants derived significant quantities of N from soil where sludge was applied many years ago. While studying the growth of *Brassica chinensis* Wong *et al.*,(1996), reported a slight increase in soil pH, electrical conductivity, soluble K, Ca, Mg, NH₄ and PO₄ contents following sludge application.

Sewage sludge can supply a number of other plant nutrients like, Mg, Ca, Zn, and Cu, but their importance will depend on whether these are deficient in the soil or not. The P requirement of agricultural crops is typically only about 10 - 25% of the quantity of N removed by crop plants from soil whereas sewage sludge generally contain approximately half as much as they do N (table 1). Consequently, the current practice of applying sewage sludges according to the N requirements of crops will supply P in excess of crop needs (Cooke, 1982).

Table 1. N and P content of sewage sludge (as spread; kg/m³ for liquids; kg/ton for cakes)

Sludge type	Dry matter %	Total		Available	
		N	P	N	P
Liquid undigested	5	1.8	0.6	0.6	0.3
Liquid digested	4	2.0	0.7	1.2	0.3
Undigested cake	25	7.5	2.8	1.5	1.4
Digested cake	25	7.5	3.9	1.1	2.0

Source: Hall (1986)

Application of sewage sludge to agricultural land is generally the most economical outlet for sludges and provides an opportunity to recycle beneficial plant nutrients and organic matter to soil for optimal crop production. Hall (1992), estimated that the potential savings in fertiliser provided by sewage sludge spread on farm land each year in UK were in excess of \$15 millions. Crop productivity can also be increased by improving soil physical properties through the application to soil of organic matter contained in sewage sludge (Smith *et al.*, 1992)

2.6 Heavy metals toxicity to humans and animals

One significance of environmental pollution by heavy metals is their toxicity to humans and animals via food chains. Both essential and non essential elements exhibit toxic effects whenever their doses exceed a certain level (Muigai, 1992). Underwood (1971), reported that chronic Cu poisoning occurs in animals through contamination of feeds from industrial pollution. Cu poisoning in man mainly occurred as an industrial hazard in workers engaged in Cu mining or processing. Industrial exposure has been the cause of Wilson's disease which is characterised by excessive Cu concentration in the tissues (Underwood, 1971). Chromium has been reported to have low toxicity to humans and animals.

Biological interest in Cd is its toxic properties, its possible relation to human hypertension and its interaction with Zn and other essential metals. In human and animal nutrition, Cd is a cumulative poison (Underwood, 1971). Chronic Cd

poisoning to long term low dosage has been observed in Cd industrial workers. The most serious case of health hazards due to chronic Cd was observed in Japan, after the world war (II). Ingestion of rice grown in the fields irrigated by polluted industrial waste water resulted into a disease called itai-itai kyo, whereby the affected person developed a syndrome that began with renal dysfunction and eventually resulted in painful bone changes (Friberg *et al.*, 1974).

Lead is known to be a direct health hazard for plants, animals and humans (Elinder and Kessler, 1983). Clinical lead poisoning in grazing livestock has been reported in horses, cattle and sheep. In children, chronic lead poisoning involves physical brain damage, with permanent sequelae, including behavioural problems, intellectual impairment and hyperactivity (Underwood, 1976 as cited by Assey, 1995). Masters (1974) and Alloway (1990) reported death of fish and other aquatic animals due to high levels of Mn, Cd, Hg, and Al in incoming waters.

2.7 Absorption of Heavy metals by plants

The uptake of heavy metals by plants is generally influenced by soil characteristics. Many workers have reported that the absorption and concentration of these micropollutants (heavy metals) in plants increase with increasing concentrations in soils, pH, organic carbon, cation exchange capacity and clay contents of the soil (Dowdy and Larson, 1975). Xing fung and Gholamhos (1989) reported that heavy

metal uptake by plants is controlled by some physiological factors of plant and more principally by plant availability of metals in soils.

Pahlsson (1989) concluded from a review of literature on heavy metal toxicity to vascular plants that the upper critical leaf concentration of Zn and Cu affecting growth in most species in the range 200 - 300 mg Zn/kg and 15 - 20 mg Cu/kg (dry matter). Macnicol and Beckett (1985) proposed more conservative critical levels above which a reduction in growth may occur. These levels were 100 mg/kg for Zn and 10 mg/kg for Cu and Ni in plant tissues based on an analysis of 1000 references on the subject. Under field conditions yield reductions (25%) may be observed at leaf tissue concentration of 500 mg Zn/kg, 20 - 40 mg Cu/kg and 50 - 100 mg Ni/kg (dry matter) (Logan and Chaney 1983). However, Davis and Carlton-Smith (1984), while studying the relative phytotoxicities of Zn, Cu and Ni to ryegrass grown in sandy loam soil (pH 7.0) by using sewage sludge of controlled metal content reported some upper critical total concentration of the soil as 319 mgZn/kg, 105mgCu/kg and 221 mg Ni/kg.

Chaney (1990) reported that no adverse effects on crop yields have been demonstrated for any level of Cr applied to soil in sewage sludge. The results of Carton-Smith and Davis (1983) and more recently of Smith *et al.*, (1992) also showed that Cr does not affect plant growth unless the concentrations are very high. Forage crops, radish and carrots grown in these studies showed little uptake of Cr

and no effect on yield for soil containing up to approximately 7000 mg Cr/kg. A significant uptake of Cr and detrimental effect on yield was observed by Smith *et al.*, (1992) only for one soil which contained 1.4% Cr representing a seriously contaminated soil.

Anna *et al.*, (1990) found that out of 756 vegetable samples taken from allotment soils of 12 towns in the Upper Silesia region in United State of America, only 170 met the standard for Pb and 17 for Cd. For the consumer, metal intake was two to five times higher for Pb than accepted standards. Cereals and potatoes (*Solanum* spp.) produced in the Tarnowskie Gory region, the most polluted area in the Upper Silesia, are contaminated with Zn and Pb, and particularly Cd. Dudka *et al.*, (1995) showed that 95% of the cereal and all potato samples examined by them had Cd concentration higher than the limit level in food (0.1 mg/kg). More remote agricultural areas may also be receiving contaminating metals, not only from industry but also from sewage sludge, fertilisers and gasoline, and it has been estimated that 2 to 4% of arable soils in Poland are contaminated, at least to some extent, by Cd, Pb, and Zn (Kabata-Pendias *et al.*, 1992).

2.8 Residual concentration of heavy metal in soils after sewage sludge application

One of the most important constrains that limits the land application of sewage sludge for crop production has been the heavy metals enrichment in soils and its

potential consequences on the quality of food crops and human health. Chang *et al.*, (1984) reported that Cd has limited downward mobility, long residence in surface soil, and high residual availability. This emphasises the need to limit the input of Cd into soils as well as to better understand how soil characteristics govern the plant availability of soil Cadmium so that uniform practices to control or reduce plant uptake of Cd can be developed. Brallier *et al.*, (1996), studied the plant metal uptake from sewage sludge amended soils applied 16 years ago at a rate of 500 t/ha found that, metals were still available for plant uptake but liming greatly reduced the availability of most metals. Also this resulted in high nitrification rates and subsequent lowering of soil pH before the uptake study started. Sewage sludge addition to soil increases biomass approximately 30% at the lowest rate of application (40t/ha) and approximately 4 - 5 fold at the highest rate (160 t/ha). The metal extractability decreases in the order Cd > Zn > Ni > Cu (Chander *et al.*, 1995).

Mench *et al.*, (1994) evaluated the heavy metal availability and their after effects on maize at the 8th year following the termination of sewage sludge application and found that metal inputs resulted in a marked increase in total and extractable metals in soils, except for extractable Mn and Cu. Total metal contents in the metal loaded top soil (0 - 20 cm) were lower, especially for Cd, Zn, and Ni than the expected value. The amount of metal taken up by plant from the control plot ranked as Fe > Mn > Zn > Cu > Ni > Cd and for sludge - treated soils was; Fe > Zn > Ni > Cd >

Cu > Mn. They concluded that sludge borne Cd and Ni can remain bioavailable in sandy soil for a long period of time. Addition of 21.2 kg Cd /ha in 100 t/ha of sewage sludge increases Cd concentration to about six fold from 0.11 to 0.64 mg/kg in barley grain and from 0.7 to 4.4 mg/kg in spinach beets, but decreased Cd concentration in the subsequent years (Gardiner *et al.*, 1995).

The redistribution of sludge borne Cd, Cu, and Zn in cultivated plot in the upper 0 to 20 cm was 66.7, 67.5 and 68 %; 15.2, 12.4 and 11.6 % into the 20 to 30 cm depth within a plot area after the application of 112 t/ha of sewage sludge respectively. There were no significant enrichment with trace metals from the sludge found below 30 cm, but 15.5, 18.1 and 21% dragged outside the plot area (Ying Ming and Corey, 1993).

Addition of sewage compost to soil slightly increases soil pH, and significantly increase the electrical conductivity and available K, Ca, Mg, NH₄ and PO₄ contents. Wong *et al.*, 1996 reported that not only the sludges application increased the accumulation of DTPA extractable heavy metals in tissues of *Brassica chinensis* but also increased the yield significantly. Brendecke *et al.*, (1993) predicted the effects of land application of municipal sewage sludge on long term effects on soil fertility for cotton growth at a loading rates of 8 and 24 t/ha per year (dry wt) for 4 years. They found that sewage sludge application had no significant effect on various measured soil physical, chemical properties and on soil microbial

population or activity other than increase in available $\text{PO}_4 - \text{P}$. The total metal contents were not affected by sludge application but some DTPA - TEA extractable metals (Zn, Cu, Pb and Ni) increased significantly with sludge treatment.

Fast growing tree species such as Willows (*Salix* spp), can benefit from sewage sludge application. Lambrecque *et al.*, (1995) reported the best growth for trees which received the highest dosage of sewage sludge of 120, 160 and 200 kg/ha. Plants were able to absorb Cd and Zn, but were less able to absorb Ni, Hg, Cu and Pb. Skousen and Clinger (1993), reported an increase in grass biomass with an increase in sewage sludge application rates at 0 to 65 on dry weight basis tons /ha, but decrease in legume biomass. The organic carbon increased from 15 to 22 g/kg, where soil pH remained constant. The DTPA extractable heavy metal concentration including Cu and Zn also increased with sewage sludge application.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Materials

Sewage sludge materials were collected from the disposing sites in Dar es Salaam and Morogoro centres. These towns are located in the eastern zone of Tanzania. The sewage sludges were of domestic and industrial origin.

3.2 METHODOLOGY

3.2.1 Sewage sludge sampling and preparation

Sewage sludge was collected from disposing sites in Dar es Salaam and Morogoro. The materials were collected from oxidation ponds in Dar es Salaam while for Morogoro they were randomly collected from different surface disposing sites as currently there are oxidation ponds in Morogoro. The sludges were packed into 100kg polythene bags for easy transportation to the research site. The materials were air dried and ground ready for chemical analysis and application in the field.

3.2.2 Soil Sampling and preparation

Soil sampling was done before starting the field experiment. Composite soil samples were obtained from the experimental field which had been tilled, using a zig-zag method of soil sampling at a depth of 0 - 20 cm. Samples were obtained

from each of the three blocks, air dried, ground and sieved through a 2 mm sieve ready for analysis. Also after each of the two harvests, soil sampling was done from each plot in order to determine the heavy metal residual concentrations.

3.3 Analytical methods for soil and sewage sludge analysis

Soil and sewage sludge pH were measured electrometrically in water and KCl using 1 : 2.5 soil: water, 1 : 2.5 soil : KCl and 1 : 2.5 sludge: water/ KCl ratio respectively (Mac Lean, 1986). Particle size distribution for the soil was determined by the Bouyoucos hydrometer method as described by Juo (1979). Organic carbon for soil and sewage sludge was determined by the wet digestion method of Walkley and Black (Nelson and Sommers, 1982). Total nitrogen was determined by the Micro-Kjeldahl digestion method (Bremner and Mulvaney, 1982). Available phosphorus was determined following the Bray and Kurtz 1 procedure (Olsen and Sommers, 1982). Cation Exchange capacity (CEC) was determined by the ammonium acetate saturation method (National Soil Service, 1987). The amount of exchangeable bases (K, Na, Ca and Mg) in the ammonium acetate extract was determined using Pye Unicam 919 Atomic Absorption Spectrophotometer (AAS). Available soil and sludge heavy metals (Cu, Zn, Mn, Cd and Pb) were extracted by the 0.005M DTPA method of Lindsay and Norvell (1978). After extraction the elements were determined directly in the soil and sludge extracts using Pye Unicam 919 Atomic Absorption spectrophotometer (AAS).

3.4 Total heavy metal concentration in soil and sludges

Total heavy metals were determined using the aqua regia digestion method. From the sieved samples of soil and sludges, 2g were weighed and transferred into 150 ml conical flask. To the flask 15 ml of concentrated hydrochloric acid and 5 ml of concentrated nitric acid (aqua regia) were added (Jeng and Bergseth, 1992) and the mixture was swirled and left to stand over night. The conical flasks containing the mixture were boiled at a temperature of 80 to 100 °C under the refluxing condition for about 2 hours. The refluxing process was stopped and the boiling continued until the sample dried but without caking. The sample was cooled and 10 ml of concentrated nitric acid were added. The mixture was quantitatively transferred into 100 ml volumetric flask and was made to volume using distilled water to make a 10% HNO₃ matrix. The mixture was filtered through Whatman no.1 filter paper and the filtrate transferred into 100 ml plastic bottle which had been prewashed by soaking with distilled water. Total Cu, Mn, Zn, Cd and Pb were determined using Atomic Absorption Spectrophotometer. The appropriate standards were prepared using a similar matrix of 10% HNO₃.

3.5 Field experiment

3.5.1 Experimental design

A field experiment was carried out following a Randomised Complete Block design. The plot size was 1m², and the plots were separated by 0.5 m strips while the blocks were separated by 1 m strips. The sludge was air dried before being

applied in the field. The experimental design included two types of sewage sludges, in three replicates of four treatments as shown in table No. 2 below:

Table 2. Amounts of sludge applied (tons d.m./ha)

Sludge	Treatments				
	1	2	3	4	5
Sludge from Dar es Salaam	0 (0)*	10 (1)*	20 (2)*	40 (4)*	60 (6)*
Sludge from Morogoro	0 (0)*	10 (1)*	20 (2)*	40 (4)*	60 (6)*

()* Amounts of sludge applied (kg d.m./plot)

A control treatment was included in which no sludge was applied. The sludge was mixed uniformly into the upper 20 cm of the soil and left for five days. *Amaranthus* seeds were planted in each plot. Daily watering was done. Also hand weeding was conducted to reduce plant/weed competition for nutrients.

3.6 Plant sampling, sample preparation and analysis

At the onset of flowering, (one month after planting) the *Amaranthus* plants were cut at soil level using a knife, washed thoroughly with distilled water and oven dried to constant weight at 65°C for 48 hours. The dried plant materials were weighed and the data recorded as weight of dry matter. The dried samples were cut into small pieces using a pair of scissors, finely ground using cyclone sample mill and stored in polythene bags ready to be used for determination of total heavy metal contents. A second planting in the same plots without further application of sewage sludge was done to determine the residual effect of the sludges, following

the same procedures as above, and then total heavy metal contents from the finely ground plant materials were determined.

3.7 Soil sampling and analysis after the first and second harvests

This was done in order to determine the residual concentration of heavy metals in the soil as a result of different rates of sewage sludge application. A composite soil sample was taken from each plot, air dried and sieved to pass through 2 mm sieve ready for analysis. Chemical analysis for available and total heavy metal concentration was done following the same procedures as per section 3.3 and 3.4 respectively.

3.8 Determination of total plant Cu, Mn, Zn, Cd and Pb by wet digestion

method

From a finely ground plant sample, 0.5g was weighed and transferred into a digestion tube. To the digestion tube 5 mls of 68% HNO₃ were added using a measuring cylinder (Morberg, 2000). The mixture was left to stand overnight. The digestion tubes containing the mixture were placed in a digestion block and the temperature was set at 125^o C and digested for one hour. The samples were cooled and 5mls of 30% H₂O₂ were added and heated to about 70^oC on the digestion block until the reaction stopped. The addition of 5mls 30% H₂O₂ was repeated until the digest turned colourless. The digests were further heated on the digestion block at a temperature of 180^oC almost to dryness. The digestion tubes were removed from

the digestion block and cooled. To the digestion tube, 10 mls of 10% HNO₃ were added and the mixture was quantitatively transferred into a 25 mls volumetric flask and filled to the mark by distilled water ready for Cu, Zn, Mn, Cd and Pb determination using Atomic Absorption Spectrophotometer. The appropriate standards were prepared using a similar matrix of 10% HNO₃.

3.9 Statistical Analysis.

The data obtained were subjected to analysis of variance using MSTATC computer program. The analysis of variance was run following the Randomised Complete Block Design (RCBD) as outlined by Snedecor and Cochran (1989). Also the data were subjected to Duncans New Multiple Range Test ($p < 0.05$) in order to separate the means.

CHAPTER. 4

4.0 RESULTS AND DISCUSSION

4.1 Some properties of the experimental soil.

Some physical and chemical properties of the soil used in the study are presented in Table 3.

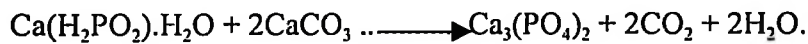
4.1.1 Soil texture

The data show that the soil is composed of 61.8 %, 29.2 % and 9.0 % sand, clay and silt respectively. The textural class of the soils from the study area is sandy clay loam. Due to the high amount of clay the availability of some heavy metals will be affected. High amount of clay in the soil has been reported to influence the content of heavy metals in respective soils. According to Mwalilimo, (1997), copper in such soils is normally translocated with clay and tends to be most abundance in the top soils when clay content is high, while zinc become precipitated or fixed in the crystal structure of the soil clays in a form which is not available for plant metabolism. The clay component of the soil is also important in water holding capacity and nutrient supply to plant. Thus, basing on soil texture, soils of the study area are suitable for the production of vegetables.

4.1.2 Soil pH.

The pH of the soil is 7.6. According to the classification system by Landon (1991), the soil of the study area is mildly alkaline. Soil pH influences nutrient availability. At this level of pH it is possible for P availability to be reduced. This is because P tends to be converted to Calcium phosphate at pH levels (7.0 - 8.5) (Landon, 1991).

This can be presented as:



Also there is an increasing possibility for deficiency of Co, Cu, Fe, Mn and Zn. Micronutrients and heavy metals accumulation generally decreases as pH increases.

4.1.3 Soil organic carbon and organic matter

The soil organic carbon content ranges from 1.01 % to 1.08 % with a mean of 1.05 %. This range is categorized by Landon (1991) as very low. The low Organic carbon content also indicates that the soil has low organic matter ranging from 1.74 - 1.81 %. The low organic carbon content could probably be associated with continuous cultivation on the same piece of land as the area is used for routine vegetable production without any application of organic fertiliser. Other studies done in soils of Morogoro and Coast regions (Semoka *et al*, 1996; Mnguu, 1997; Bashiru, 1992) indicated that soils from these regions are characterized by low organic carbon content. In order to increase the organic carbon content of the soil

for maximum crop production application of organic fertilisers like manure is recommended.

Table 3. Physical and chemical characteristics of the soil from the experimental field before planting.

Parameter	Block 1	Block 2	Block 3	Average
Particle size analysis				
% Sand	61.80	61.80	61.80	61.80
% Clay	29.20	29.20	29.20	29.20
% Silt	9.00	9.00	9.00	9.00
Textural class	SCL	SCL	SCL	SCL
PH (H ₂ O)	7.56	7.69	7.54	7.59
% N	1.19	1.19	1.26	1.21
Available.P (mg/kg soil)	72.69	80.27	72.69	75.22
% OC	1.05	1.01	1.08	1.05
Exchangeable bases And CEC (Cmol(+)/kg of soil)				
Ca	6.79	6.77	6.88	6.81
Mg	4.15	4.15	4.14	4.15
K	1.21	1.22	1.07	1.17
Na	1.45	1.48	1.44	1.46
CEC	13.40	13.90	13.40	13.57
Available heavy metal Concentration (mg/kg of soil)				
Cu	2.97	2.64	3.31	2.97
Zn	4.77	4.14	4.09	4.33
Mn	32.19	30.72	30.05	30.99
Pb	0.76	0.66	0.82	0.75
Cd	0.18	0.19	0.27	0.21
Total heavy metal Concentration (mg/kg of soil)				
Cu	28.45	24.70	24.47	25.87
Zn	51.55	46.10	46.30	47.98
Mn	455.00	426.25	403.75	428.33
Pb	2.30	2.37	1.63	2.10
Cd	0.86	0.56	0.45	0.62

Note: SCL = Sand Clay Loam

4.1.4 Total Nitrogen

Total nitrogen content in the area ranges from 1.19 % to 1.26 % with a mean of 1.21 %. According to the classification by Landon (1991), the total N content of the study area is in the high range.

The high content of total N regardless of low organic matter content of the soil is probably due to the continuous application of nitrogen fertilizers such as Urea, CAN and Sulphate of ammonia (S/A) as the area is used for optimum vegetables production.

4.1.5 Available Phosphorus

Available Bray -1 Phosphorus in the area ranges from 72.69 to 80.27 mg/kg of soil with a mean of 75.22 mg/kg. According to the classification by Singh *et al.*, (1977), available P is said to be high. This amount is adequate for the production of most vegetables including spinach. Baize (1993) has also reported that, when Bray -1 extractable P is > 50 mg/kg soil response to P is unlikely. The amount of available P is higher than the critical level for Morogoro soils which is 26 mg/kg (Semoka *et al.*, (1996). The use of P sources from artificial fertilisers such as TSP in the area of study has contributed much to the increase in available P to the soil.

4.1.6 Cation Exchange Capacity

The CEC of the soil from the experimental field ranges from 13.40 to 13.90 Cmol(+)/kg with a mean of 13.57 Cmol(+)/kg. According to Landon (1991) rating system, this range has been classified as medium for the top soils. The medium CEC obtained could probably be due to the influence of soil texture and the types of clay minerals in the soil. Clayey soils are reported to have medium to high CEC mainly due to changes that result from isomorphous substitution (Rhoades, 1982). The CEC usually gives an idea of the potential fertility of a soil and also helps to determine the capacity of the soil to retain nutrients against leaching. Baize (1993), has reported ranges from 15 - 25 Cmol(+)/kg to be satisfactory for the growth of most crops. CEC is an essential property of the colloidal fraction of soil, which is derived mainly from the clay and organic matter fractions.

4.1.7 Exchangeable bases

Calcium

The exchangeable calcium of the studied soil was found to be in the medium range (ILACO, 1991) varying between 6.77 to 6.88 Cmol(+)/kg with a mean of 6.81 Cmol(+)/kg. This indicates that the Ca content in the soils is adequate for plant growth for most crops. Calcium fertiliser response is normally expected when soil Ca level is < 0.2 Cmol(+)/kg. The results from this study indicate that Ca fertiliser response may be poor due to high soil Ca content.

Magnesium

The exchangeable magnesium ranges from 4.14 to 4.15 Cmol(+)/kg with a mean of 4.15 Cmol(+)/kg. This amount has been classified by Baize (1993), as very high. Under this category Mg is usually said to be sufficient in soil. The presence of large amounts of K and Ca causes deficiency of Mg in the soil. The Ca : Mg ratio for the soil is 2 : 1. When there is an increase in Ca : Mg ratio above about 5 : 1, Mg becomes less available to plant but the soil remains fertile over a long period of time. Following the above observations Mg content of the soil under study will be adequate for plant growth.

Sodium

The exchangeable Na in the experimental field ranges from 1.44 to 1.48 Cmol(+)/kg with a mean of 1.46 Cmol(+)/kg. This amount is classified as high by Landon (1991). Soils with exchangeable Na >1 Cmol(+)/kg are regarded as potentially sodic. Sometimes Na may be utilized by crops as a partial substitute for K but still this can not be regarded as essential nutrient. The presence of excessive amount of exchangeable Na in the soil will promote the dispersion and swelling of clay minerals. Ultimately the soil becomes impermeable to both air and water. Tillage will therefore become difficult and soil crusting will occur.

Potassium

The results show that K ranges from 1.07 to 1.22 Cmol(+)/Kg with a mean of 1.17 Cmol(+)/kg. This amount is classified as high according to Baize, (1993). The response to K fertiliser is likely to occur when the K value < 2 Cmol(+)/kg. The soil is sandy clay loam and this amount makes the soil to be rich in K. However, Doll and Lucas (1973) reported a critical content of K of 0.217 Cmol(+)/kg for sand and loamy sand for most field crops. The high level of K in the soil of the study area could probably be due to low/no leaching or the presence of micaceous clays and medium CEC of the soil hence high nutrient retention capacity of the sandy clay textured soils. Also Landon (1991) argued that K deficiency may appear when exchangeable K⁺ drops below 2% of the CEC. From these results plants grown on these soils may not suffer from K deficiency.

4.1.8 DTPA extractable and Total Micronutrients

DTPA extractable and Total Cu

The DTPA extractable and total Cu of the soil from the experimental field range from 2.64 to 3.31 mg/kg with a mean of 2.97 mg/kg and 24.47 to 28.45 mg/kg with a mean of 25.87 mg/kg respectively. For the total amount, this is said to be in a normal range of 2 - 250 mg/kg as proposed by Landon, (1991). Lindsay and Novel, (1978) suggested a critical level for DTPA Cu in the soil to be 0.2 mg/kg. The amount of DTPA extractable Cu is high probably due to the continuous use of Cu

fungicides such as Red copper (Cu_2O), Blue copper (CuSO_4), Bravo and Kocide in the production of different types of vegetables where the experimental field was conducted.

DTPA extractable and Total Zn

The DTPA extractable Zn and total Zn range from 4.14 to 4.77 mg/kg with a mean of 4.33 mg/kg and 46.10 to 51.55 mg/kg with a mean of 47.98 mg/kg respectively. In Tanzania DTPA- extractable Zn level of 1.9 - 7.9 has been reported in Mbeya (Kamasho, 1980). Knott, (1980) and Lindsay and Novell (1978) proposed a critical level for DTPA Zn to be 0.5 - 1.0 mg/kg for most agricultural soils. Following the results above amount of extractable Zn is above the proposed critical range and this indicates that the amount of Zn is high for the production of vegetables and probably could accumulate to toxic level.

DTPA extractable and Total Mn

The levels of DTPA- Mn and total Mn range from 30.05 to 32.19 mg/kg with a mean of 30.99 mg/kg and 403.75 to 455 mg/kg with a mean of 428.33 mg/kg respectively. Lindsay and Novell, (1978) reported a critical level for DTPA Mn to be 1 mg/kg. The amount in the experimental plot is above the proposed critical level. However, Sillanpaa (1982), proposed a range for DTPA extractable Mn where deficiency may occur to be 2 - 5 mg/kg. Values which are greater than 140 - 200 mg/kg for total Mn are said to be excessive and above this toxicity may occur.

The results above indicates that the amount of available and total Mn concentration in the soil are above the critical values set, hence, toxicity level is likely to be encountered.

DTPA extractable and Total Pb

The levels of DTPA extractable Pb and total HNO_3 - Pb range from 0.66 to 0.82 mg/kg with a mean of 0.75 mg/kg and 1.63 to 2.37 mg/kg with a mean of 2.10 mg/kg respectively. The total amount of Pb is below the approximate range of 35 mg/kg as proposed by Landon (1991). Also the extractable amount is below the critical range of 15 - 25 mg/kg (Aubert and Pinta, 1977) set for most agricultural soils where toxicity to plants and animal could occur.

DTPA extractable and Total Cd

The amount of extractable Cd and total Cd in the soil range from 0.18 to 0.27 mg/kg with a mean of 0.21 mg/kg and 0.45 to 0.86 mg/kg with a mean of 0.63 mg/kg respectively. Landon (1991), suggested an approximate mean of 0.35 mg/kg total Cd for most agricultural soils, where the usual range is 0.01 - 2.00 mg/kg. The amount for total and available Cd are within the normal range hence this will have no effect for the growth of most crops.

The concentration of Cu, Zn, and Mn have exceeded the critical level stated while Cd and Pd concentrations for the experimental soil are well within the normal level for most agricultural soils.

4.2 Some properties of the sewage sludge used in the study.

Some chemical properties of the sewage sludge used in the study are presented in Table 4 .

4.2.1 pH

The pH (H₂O) values were 6.7 and 9.8 for the sewage sludges from Dar es Salaam and Morogoro respectively. According to Baize (1993), the pH value for Dar es Salaam sludge is in the medium range while that of Morogoro sludge is considered as high. The pH of the sludges fundamentally, controls the behaviour and availability of heavy metals in soils. Adsorption of heavy metals onto clay minerals and organic matter will be increased by increasing soil pH. Thus, the availability of trace elements for plant uptake will generally be high when sewage sludge from Dar es Salaam is applied to the soil under study. Trace metals availability such as Co, Cu, Fe, Mn and Zn will be expected to be low when the sludge from Morogoro is applied to the experimental soil. On the other hand the Dar es Salaam sludge may be used as a buffering material for soils with high value of pH. This will also tend to lower the pH of the soil under study and reduce the potential of the soil to develop alkaline/sodic properties. Morogoro sludge can consequently be considered as the best material suited for acidic soils.

4.2.2 Organic Carbon and Organic matter

The sewage sludges show high organic carbon of 15.05 and 10.20% for Dar es Salaam and Morogoro respectively. These amounts are much higher than that of the experimental soil. Hence, both sludges can consequently be used for the improvement of the organic carbon of the soil under study. Skounsen and Clinger (1993), reported an increase in soil organic carbon and organic matter when sewage

Table 4. Chemical composition of the sewage sludges.

Parameter	Dar es Salaam sludge	Morogoro sludge
pH (H ₂ O)	6.7	9.8
pH (KCl)	6.5	9.3
% OC	15.05	10.20
% OM	25.95	17.58
%Total (N)	1.52	0.74
Available P (mg/kg soil)	4.77	3.68
Exchangeable bases (Cmol(+)/kg sludge)		
K	0.49	1.91
Na	1.03	10.58
Ca	27.78	10.96
Mg	4.24	4.62
CEC	56.80	68.60
Available heavy metal concentration (mg/kg sludge).		
Cd	0.40	0.48
Mn	50.33	70.86
Cu	2.24	50.50
Zn	123.03	27.89
Pb	7.69	1.78
Total heavy metal concentration (mg/kg sludge).		
Cd	3.64	1.53
Mn	189.88	393.00
Cu	41.00	180.00
Zn	275.50	165.00
Pb	23.78	17.90

sludge with high organic carbon was applied in the soil at a rate of 0 to 65 tons/ha on dry matter basis. The municipal sewage sludge can be applied to crop land to supply and recycle organic carbon to the soil. Hence, both sewage sludges can have a significant increase in soil organic carbon whenever they are applied to agricultural land.

4.2.3 Total Nitrogen

The amount of total nitrogen was 1.52 % and 0.74 % for Dar es Salaam and Morogoro respectively. These amounts fall under high range as classified by Baize (1993) when compared to the amount supposed to be in the soil for optimal crop production. It is evidenced by Ibekwe *et al* (1995), that application of sewage sludge with high N content in agricultural soil increases the total N in the soil as well as in the plant. Hence whenever these types of sewage sludges are applied to agricultural land including that of the study area a remarkable increase in total N will be expected.

4.2.4 Available Phosphorus

The levels of available Phosphorus in the sewage sludges are low with values of 4.77 and 3.68 mg/kg of dry sewage sludge for Dar es Salaam and Morogoro sludges respectively. These amounts are in the low range according to classification by Baize (1993). Following these results both sludges are said to be deficient in

available P and whenever they are applied to the soil deficient with P a supplemental source of P will be required. However, these amounts are low compared to the inherent soil P for the experimental soil and consequently application of these to the soil under study would probably bring no change.

4.2.5 Exchangeable bases

Calcium

The exchangeable calcium levels were high with values of 27.78 and 10.96 Cmol(+)/kg dry sewage sludge for Dar es Salaam and Morogoro sludges respectively. These amounts of Ca are much higher than the one present in the experimental soil. Hence their additions to the soil would consequently increase the inherent soil Ca level. Vlamis *et al*, (1978) reported sewage sludges with 2.18 and 2.26 Cmol(+)/kg of Ca as normal amounts whenever added into agricultural soil. On the other hand the addition of these sewage sludges to agricultural soil will assist in the formation of more stable soil aggregates and hence can promote the flocculation of the clay micelles.

Magnesium

The exchangeable Mg of the sewage sludges from Dar es Salaam and Morogoro were 4.24 and 4.62 Cmol(+)/kg of dry sewage sludge respectively. These amounts are classified as high according to Landon (1991) when applied to agricultural soils. In the Tropics, 0.5 Cmol(+)/kg Mg is often the deficiency threshold (ILACO,

1991). Generally, the amount of Mg present in both sludges is higher than the amount present in the experimental soil. Hence, additions of these materials to the soil will gradually increase the content of Mg in the soil as well as its availability for plant absorption.

Potassium

The concentration of K in the sewage sludges was 0.49 and 1.91 Cmol(+)/kg for Dar es Salaam and Morogoro sludges respectively. These amounts can be classified as being high according to the rating by Page (1974). The results strongly suggest that both sewage sludges are rich in K as they have values falling in and above the adequate range of 0.4 - 0.8 Cmol(+)/kg as established by Landon (1990). Hence, the application of these sludges may enrich the soil with K.

Sodium

The exchangeable Na for the sewage sludge from Dar es Salaam and Morogoro were 1.03 and 10.58 Cmol(+)/kg respectively. These amounts are classified as high according to Baize, (1993) system of classification. The amount of Na in Dar es Salaam sludge is much higher than the inherent Na concentration in the experimental soil while for Morogoro sludge it is lower. Following the above results it is evident that the sludge from Dar es Salaam will gradually increase the pH and Na content of the experimental soil and consequently this may lead the

formation of sodic soil. On the other hand increase in soil pH could result in reducing the availability of trace elements for plant absorption.

4.2.6 Cation Exchange Capacity

The CEC of the sewage sludges were 56.80 and 68.60 Cmol(+)/kg of dry sewage sludge for Dar es Salaam and Morogoro respectively. These amounts are classified as very high according to Baize (1993) system of classification. Both sludges have CEC values which are much higher than that of the experimental soil. Hence, the addition of these type of sludges to the soil under study will consequently increase the inherent soil CEC, therefore, increasing the capacity of the soil to retain nutrients against leaching. Also the high amount of CEC is mainly associated with high organic matter of the sewage sludges which are 25.95 % and 17.58 % for Dar es Salaam and Morogoro respectively.

4.2.7 DTPA - extractable and Total Micronutrients concentration of sewage

sludge

Extractable and Total Cadmium

The amount of available and total Cd were 0.44 and 3.64 mg/kg; 0.48 and 1.53 mg/kg of dry sewage sludge for Dar es Salaam and Morogoro sludges respectively. The amount of Cd concentration for Morogoro sludge is much less than for the Dar es Salaam sludge. The approximate mean Cd concentration in most soils is 0.35

mg/kg. Lorenz *et al*, (1994) reported an increase in Cd concentration in soil as a result of the addition of sewage sludge. The amounts of Cd present in the sewage sludges are much higher than the approximate mean concentration in agricultural soils. Hence, addition of these sludges to the soil under study will consequently increase the concentration of soil cadmium. So the addition of this type of sewage sludge to agricultural soil needs to be done with caution. There is a possibility for Cd toxicity to occur following repeated application of the sludge.

Extractable and total Manganese

The available and total Mn concentrations in the sewage sludges were 50.33 and 189.88; 70.86 and 393.00 mg/kg of dry sewage sludge for Dar es Salaam and Morogoro sludges respectively. The total amount of Mn in the sludge from Dar es Salaam and Morogoro can be ranked as low and medium respectively according to Baize,(1993) system of classification. However, Allaway (1968), reported a value of total Mn concentration of 300 mg/kg in sewage sludge as a high concentration. The amounts of available Mn are much higher than that of the experimental soil, hence a remarkable increase in soil Mn will be expected whenever these sludges are applied to the soil under study. Generally, high levels of total Mn in soils can be taken as those above 2000 mg/kg. Generally, the amounts of Mn present in the two sludges are not in a toxicity range. However, any additions to agricultural soil could result in a change in the present available and total Mn concentrations. Important

accumulation are therefore expected following repeated applications of the two sludges.

Extractable and total Copper

The extractable and total Cu concentrations were 2.24 and 41.00; 50.50 and 180 mg/kg of dry sewage sludge from Dar es Salaam and Morogoro respectively. However, Baerug and Martinsen (1977), reported a concentration of 2180 mg/kg and 140 mg/kg as high and low respectively. The normal mean for total Cu concentration for most soils range from 2 - 100 mg/kg. The amounts of Cu present in the sewage sludges are therefore high and whenever these are added to agricultural soils a possibility of increasing the soil Cu concentration will be expected. Vegetables such as *Amaranthus* are sensitive to Cu deficiency hence the sludges can be used in the production of vegetables in soils deficient with Cu. However, repeated applications may again lead to important accumulations of Cu even to toxic level.

Extractable and total Zinc

Extractable and total Zn concentration in the sewage sludge from Dar es Salaam and Morogoro were 123.03 and 275.50; 27.89 and 165.00 mg/kg of dry sewage sludge respectively. The results show that the amounts are much higher than the inherent soil Zn concentration. Therefore, addition of these sludges to the experimental soil will consequently increase the Zn content of the soil. On the other

hand the amounts of DTPA extractable Zn are much higher than the critical level of 0.5 - 1.0 mg/kg for most agricultural soils (Lindsay and Novell 1978). However, Vlamis *et al.*, (1978); Boan and Rasmussen (1971), reported concentrations of 2920 to 3910 mg/kg of Zn in sewage sludge as high and 250 to 440 mg/kg as low respectively. However, Sillanpaa (1972), reported a general concentration range of Zn in soils as 10 - 300 mg/kg. Chapman (1966), quoted values of above about 400 mg/kg as excessive for some crops. Total levels of Zn > 150 mg/kg in soils can be regarded as high and 40 - 150 mg/kg as medium. The sewage sludge from Dar es Salaam and Morogoro may be regarded as having high concentration of Zn and their addition to agricultural soils can result into increased Zn concentration probably to toxicity level.

Extractable and total Lead

The concentration of DTPA - extractable and total Pb in the sewage sludges were 7.69 and 23.78; 1.78 and 17.90 mg/kg of dry sewage for Dar es Salaam and Morogoro sludges respectively. FAO (1979), recommended a maximum concentration of 5 mg Pb/kg as a limit for any irrigation waters and 10 mg/kg as the concentration in fine textured soils with a pH 6 - 8.5. Hence, the concentration of Pb in this type of sewage sludge is above the approximate mean value. Repeated application to agricultural soil will gradually increase the concentration of Pb probably to toxic levels in a long run. Adverse effects to human health can occur if crops grown in such sludges are consumed in excess.

4.3 Influence of sewage sludge application on *Amaranthus* dry matter yield and soil properties

4.3.1 Dry matter yield

The first and second dry matter yields of *Amaranthus* as influenced by application of sewage sludge from Dar es Salaam and Morogoro are shown in Table 5 and Figure 1.

The dry matter yield of *Amaranthus* plants increased significantly ($p < 0.05$) with increasing rate of sewage sludge applications. The first harvest showed higher dry matter yield than the second harvest (Fig. 1). The *Amaranthus* dry matter yield reached a maximum at the highest rate of sewage sludge applied i.e 60 tons/ha. This is supported by Wong *et al.* (1996) whereby the highest dosage of sewage sludge application increased the yield of *B. chinensis* significantly. The dry matter yield resulting from application of Dar es Salaam sewage sludge range from 1.61 - 3.66 tons/ha and 1.56 - 2.40 tons/ha for the first and second harvests respectively, while the application of Morogoro sewage sludge range from (1.57 to 2.16 tons/ha) and (1.22 to 1.79 tons/ha) for the first and second harvest respectively. The dry matter yield for Dar es Salaam sludge increased by about 2 folds compared to the untreated plots.

Table 5. Dry matter yield of *Amaranthus* for the first and second harvest (tons/ha)
 Amaranthus Dry matter yield (tons/ha)

Treatment (tons/ha)	First harvest	Second harvest
Sludge from Dar es Salaam		
0	1.61c	1.56b
10	2.07c	1.63b
20	2.38bc	1.56b
40	3.07ab	2.14ab
60	3.66a	2.4a
GM	2.56	1.86
% Cv	16.79	18.70
LSD	0.8077	0.6549
Sx	0.2477	0.2008
Sludge from Morogoro		
0	1.57b	1.22bc
10	1.81ab	1.54ab
20	2.00ab	1.19c
40	1.97ab	1.35bc
60	2.16a	1.79a
GM	1.90	1.42
% Cv	15.08	12.03
LSD	0.539	0.3206
Sx	0.165	0.0983

Means within the same column followed by the same letter(s) were not significantly ($p < 0.05$) different according to Duncan's Multiple Range Test.

The increase in dry matter yield could probably be attributed to the building up of nitrogen and other nutrients in the soil resulting from the application of sewage sludge. A similar observation has also been reported by Hall, (1984). The decrease in dry matter yield for the second harvest is probably due to the nutrients uptake in the soil by *Amaranthus* during the first harvest.

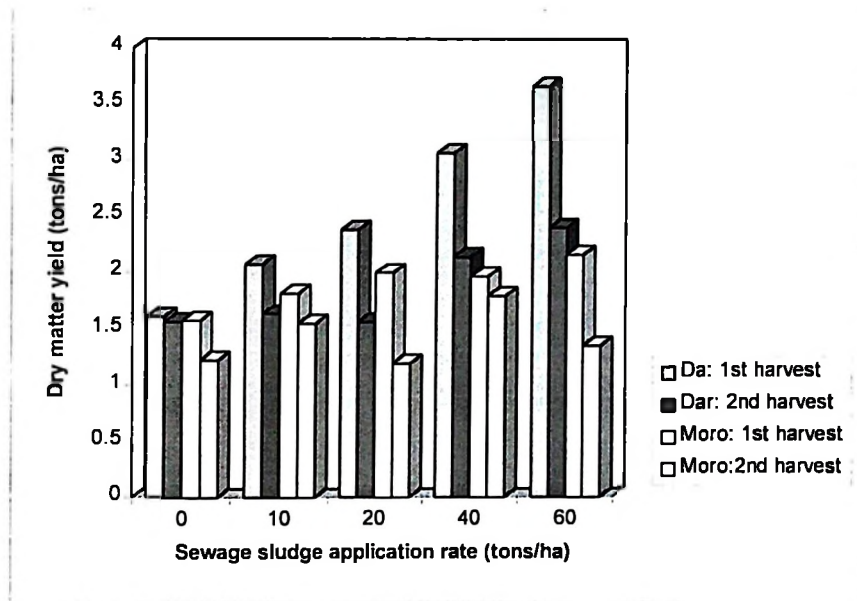


Figure 1. Effect of sewage sludge application on *Amaranthus* dry matter yield.

This indicates that the decomposition of sewage sludge was completed during the first season and the residual nutrient content of the sewage sludge is low. Generally, in order to have a sustainable increase in yield of *Amaranthus* plant, the application of sludges should be done for each growing season. Also no adverse effects on yield or symptoms of toxicity were observed at the end of the growing season.

4.3.2 Soil chemical properties.

Soil chemical properties following the application of sewage sludges from Dar es Salaam and Morogoro are shown in Table 6.

4.3.2.1 Soil pH.

The soil pH ranged from 7.1 - 7.5 and 7.5 - 8.3 for Dar es Salaam and Morogoro applied sludges respectively. There was a comparable significant ($p < 0.05$) decrease in soil pH following the application of sludge from Dar es Salaam, while for Morogoro sludge the soil pH increased significantly with increasing rate of applied sludges.

Consequently, the sludge from Dar es Salaam may act as a buffering material for the soil with a high pH value. On the other hand the sludge from Morogoro can be used in reclamation of acidic soils. Similar observations were reported by Smith, (1993) and Wong *et al.*, (1996). However, the UK regulations on the use of sewage sludge in agricultural soil (DoE, 1989; SI, 1989) have prohibited the use of sewage sludge on soils with pH value below 5.0 or above 7.0. Similar regulations have not been enacted or developed in Tanzania.

4.3.2.2 Available Phosphorus

Phosphorus content of the soil ranged from 72.78 to 94.41mg/kg and 56.51 to 75.56mg/kg following application of Dar es Salaam and Morogoro sludges respectively. These ranges can be classified as high according to Landon, (1991). Under these ranges response to P fertilizer is unlikely. The results show that the increase in soil P following the application of sewage sludge from Dar es Salaam was not significant ($P < 0.05$), while for Morogoro sludges the increase was

statistically significant especially for the high rate of applied sludges. A slight increase in soil P probably is due to the high amount of inherent P for the experimental soil. Similar observation was also reported by Brendecke *et al.*, (1993) where by after four years of sewage sludge application to agricultural land there was no significant change on other measured soil physical and chemical properties other than an increase in available P_{O_4} -P. However, Brendecke *et al.*, (1993) reported a considerable increase in available soil P following application of sewage sludge.

Table 6. Some chemical properties of the soil after the first harvest as influenced by the sewage sludge application.

Treat (t/ha)	pH (H2O)	P(mg/kg)	%N	%OC	Exchangeable bases and CEC (cmol(+)/kg)					
					CEC	K	Na	Ca	Mg	
Dar sludges										
0	7.5a	72.78a	1.24b	1.44a	15.87b	0.23a	0.13c	7.47b	4.60a	
10	7.5a	74.19a	1.49a	1.48a	15.87b	0.33a	0.27b	7.57b	4.30a	
20	7.4a	76.72a	1.49a	1.70a	15.60a	0.45a	0.28b	7.68b	4.35a	
40	7.2b	90.18a	1.59a	1.80a	16.13b	0.43a	0.30b	8.16a	4.24a	
60	7.1c	94.41a	1.63a	1.90	17.10a	0.49a	0.43a	8.52a	4.08a	
GM	7.3	81.66	1.49	1.66	16.11	0.39	0.28	7.88	4.32	
%Cv	0.81	17.76	7.91	15.61	2.51	32.75	6.00	2.53	10.16	
LSD	0.103	27.30	0.222	0.487	0.76	0.238	0.03	0.377	1.32	
Sx	0.032	8.37	0.068	0.149	0.233	0.073	0.011	0.115	0.405	
Moro sludge										
0	7.5c	74.19ab	1.24b	1.44d	15.87b	0.45a	0.13d	7.47d	4.60a	
10	7.9b	66.30ab	1.21b	1.59bc	16.27ab	0.44a	0.89cd	7.76cd	4.25a	
20	8.2ab	69.15ab	1.28b	1.48cd	16.93ab	0.57a	1.68c	8.32bc	4.29a	
40	8.1ab	75.46a	1.31b	1.74a	17.20ab	0.45a	2.58b	8.75b	4.42a	
60	8.3a	56.51b	1.45a	1.65ab	17.73a	0.56a	3.65a	9.51a	3.64a	
GM	8.0	68.322	1.30	1.58	16.80	0.49	1.79	8.36	4.24	
%Cv	2.55	12.98	5.53	4.29	4.84	17.97	26.49	4.11	14.36	
LSD	0.381	16.70	0.133	0.133	1.531	0.168	0.891	0.647	1.147	
Sx	0.117	5.121	0.041	0.041	0.469	0.052	0.273	0.198	0.352	

Means within the same column followed with the same letter(s) were not significantly ($p < 0.05$) different according to Duncan's Multiple Range Test.

4.3.2.3 Total Nitrogen

The N concentration of the soil for the treated plots was significantly higher than the control plots. Total % N ranged from 1.24 - 1.63 % and 1.21 - 1.45 % following application of Dar es Salaam and Morogoro sludges respectively. Under Baize (1993) these amounts can be classified as very high. The inherent soil N increased by about 2 folds following the application of sewage sludge from Dar es Salaam, while for Morogoro sludge the increase was from 1.21 - 1.30%. Generally there was comparable increase in total soil N as the result of increasing rate of sewage sludge application. The high amount of total N is probably due to the high amount of total N in the sludges. Similar results were also reported by Ibekwe *et al.*, 1995; Dutch and Wolstenholme, 1994; Lambrecque *et al.*, 1995) where by there was an increase in plant shoot and total N of the soil with increasing rate of sewage sludge application.

4.3.2.4 Soil Organic carbon

The organic carbon ranged from 1.44 - 1.9 % and 1.44 - 1.74 % following application of Dar es Salaam and Morogoro sludges respectively. These amounts are classified as very low according to Baize,(1993). The results indicate that different rates of sewage sludge application from Dar es Salaam did not cause a significant change in soil organic carbon, while for Morogoro sludge the increase in organic carbon was statistically significant ($p < 0.05$). On the other hand, the

organic carbon contents for the treated plots were much higher than the control plots. Generally, the organic carbon increased from 1.05 % - 1.66 % following application of sewage sludge from Dar es Salaam and from 1.05 - 1.58 for Morogoro sludge. Skousen and Clinger, (1993) have also reported an increase in soil organic carbon content from 15.% - 22 % following the application of Sewage sludge.

4.3.2.5 Cation Exchange Capacity

The CEC of the soil ranged from 15.60 - 17.10 Cmol(+)/kg and from 15.87 - 17.73 Cmol(+)/kg following application of sewage sludge from Dar es Salaam and Morogoro respectively. These ranges can be classified as medium according to Baize (1993). The CEC of the soil increased significantly with sewage sludge application especially at the highest rate of sludge application. Generally, the CEC has increased from 13.57 - 16.11 Cmol(+)/kg for sludge from Dar es Salaam, while for Morogoro the increase was from 13.57 - 16.80 Cmol(+)/kg before and after application of the sludges respectively. Similar results were also reported by Wong *et al.*, (1996), whereby addition of sewage sludge to soil caused a slight increase in soil CEC. In view of the above findings it can be concluded that the sludges did not cause a remarkable change in soil CEC hence alternative means such as incorporation of decomposed organic materials to rectify the situation are advocated.

4.3.2.6 Exchangeable bases

Potassium

The soil K ranged from 0.23 - 0.49 Cmol(+)/kg and from 0.44 - 0.57 Cmol(+)/kg following the application of Dar es Salaam and Morogoro sludges respectively. The amounts fall under high range according to ILACO, (1991). These results indicate that there was no significant change in soil K with increasing rate of sewage sludge application from Dar es Salaam and Morogoro. On the other hand there was a decrease in soil K from 1.17 - 0.39 Cmol(+)/kg following application of sludge from Dar es Salaam. The decrease in K is probably due to the remarkable uptake by *Amaranthus* plant during the first harvest. Also the antagonistic behaviour of K^+ with Ca^{2+} and Mn^{2+} in the soil can contribute to the low level of available K. The fact that the K^+ ions can more easily replace Ca^{2+} ions than they could replace Al^{3+} ions allows more of the K^+ ions to be removed from solution by cation exchange in the high calcium soil. In soils where a higher level of exchangeable calcium and magnesium are present, monovalent potassium ions are more able to replace them on the exchange complex. This also causes K to be more retained on the exchange complex. However, this is contrary to Wong *et al.*(1996) who found that the addition of sewage sludge to soil slightly increased soil soluble K.

Calcium

The Ca concentration ranged from 7.47 - 8.52 Cmol(+)/kg and from 7.47 - 9.51 following the application of Dar es Salaam and Morogoro sludges respectively.

These amounts can be classified as high according to Landon (1991) system of classification. The increase in exchangeable Ca concentration was significant following the application of sewage sludge from Dar es Salaam and Morogoro especially for the highest rates of applied sludge. On the other hand there was an increase in Ca content from 6.81 - 7.88 Cmol(+)/kg and 6.81 - 8.36 Cmol(+)/kg as the result of application of sludges from Dar es Salaam and Morogoro respectively. The concentration of Ca in the treated plots was also much higher than the control plots. Similar results were also reported by Wong *et al.*, (1996) where by the addition of sewage sludge resulted into a remarkable increase in soluble Ca. The high amount of Ca observed is probably due to the appreciable amounts which were present in the sludges. These in turn will assist in the formation of more stable soil aggregates and hence can also promote the flocculation of the clay micelles as well as increasing crop production.

Sodium

The increase in soil soluble Na following the application of sludges was significant ($p < 0.05$). The results show that the concentrations of Na in the control plots were significantly lower than the treated plots. The concentration of Na ranged from 0.13 - 0.43 Cmol(+)/kg and 0.13 - 3.65 Cmol(+)/kg following the application of sewage sludge from Dar es Salaam and Morogoro respectively. The amounts can be rated as high. However, when Na is present in the soil in significant quantities, particularly in relation to other cations, it can have an adverse effect, not only on

many crops, but also on the physical condition of the soil. Hence, addition of these types of sewage sludge to the soil must be done with precaution to avoid soil sodicity.

Magnesium

The concentration of soil Mg was not significantly different ($P < 0.05$) as the result of increasing rate of sewage sludge application. The Mg concentration in the soil ranged from 4.08 - 4.60 Cmol(+)/kg and 3.64 - 4.60 Cmol(+)/kg. The amounts can be classified as high according to Baize, (1993). On the other hand, there was a slight increase in Mg concentration from 4.15 - 4.32 mg/kg and from 4.15 - 4.24 Cmol(+)/kg before and after the application of Dar es Salaam and Morogoro sludges respectively. Similar results have also been reported by Wong *et al.*, (1996), whereby addition of sewage sludge increased the electrical conductivity as well as the soluble Mg in the soil. Hence, both sludges can be used to rectify the exchangeable Mg in soils deficient in Mg for optimum crop production.

4.4 Nutrient concentrations in *Amaranthus* as influenced by sewage sludge application

4.4.1 Heavy metals

The concentration of selected heavy metals in *Amaranthus* for the first and second harvests as a result of application of sewage sludge are shown in figures 2 - 6 and in Appendix 1.

4.4.1.1 Cadmium

The results show that there was a significant increase ($P < 0.05$) in Cd concentration in *Amaranthus* as a result of increasing rate of sewage sludge application (Appendix 1). This has also been reported by Gardener *et al.* (1995) whereby there was an increase in Cd concentration in spinach to about six folds from 0.7 to 4.4 mg/kg as the results of sewage sludge application. The second harvest showed higher Cd concentration than the first harvest. The higher concentration of Cd for the second harvest is probably due to the fact that Cd remains bioavailable in soil for a long period of time after the termination of Cd polluted sewage sludge application (Mench *et al.* 1994). The normal range of Cd concentration in plant tissue is reported to be 0.01 - 1 mg/kg dry matter.

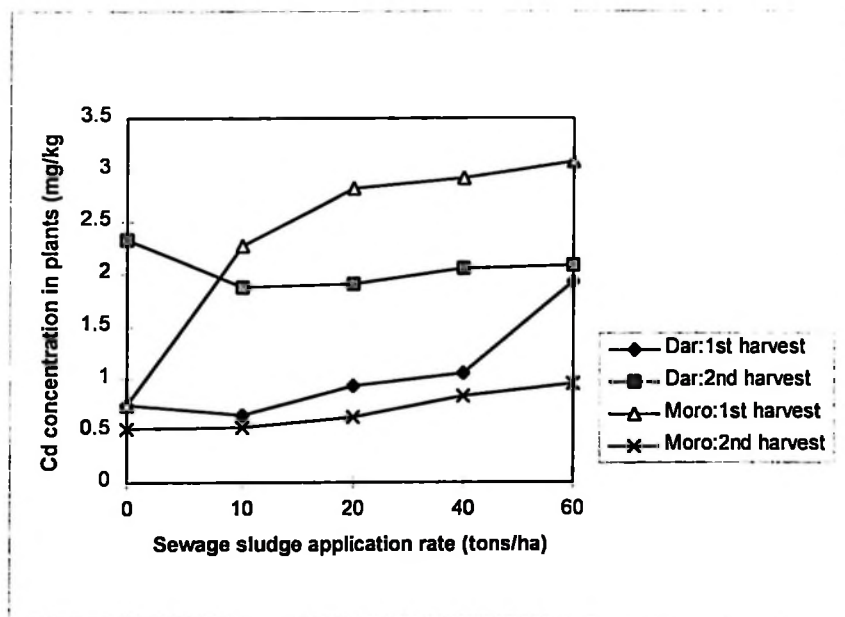


Figure 2. Concentration of Cd in *Amaranthus* as influenced by sewage sludge application rates.

However, Gardener *et al.*(1995) recommended a maximum concentration of Cd in spinach as 0.5 mg/kg dry matter. The concentration of Cd in *Amaranthus* for the first and second harvests were much higher than the value recommended by Gardener (1995). For Morogoro sludges the Cd concentration ranged from 0.75 - 3.08 and 0.52 - 0.95 mg/kg for the first and second harvests respectively (Fig 2). The grand mean concentration of Cd in *Amaranthus* was much higher for the first harvest than the second harvest with values of 2.37 and 0.70 mg/kg respectively. These amounts are much higher than 0.5 mg/kg which is the recommended critical value for Cd concentration in vegetables. Generally, the application of both sewage sludges i.e from Dar es Salaam and Morogoro must be done with care as Gardener *et al.* (1995) reported that Cd is considered to be a possible hazard in sewage sludge if used as a fertilizer. Following these results, both sludges are therefore unsuitable for spinach production especially when it is considered that these results are only from a single application of sludges.

4.4.1.2 Copper

The concentration of Cu in *Amaranthus* for the first and second harvests following the application of sludges from Dar es Salaam were influenced by the sewage sludge application. The concentration range from 5.57 - 7.78 mg/kg and 3.72 - 5.57 mg/kg for the first and second harvests respectively (Fig. 3).The concentration of Cu was much higher for the first than the second harvest for all rates of sewage

sludge applied with grand means of 6.32 and 4.45 mg/kg respectively. These concentrations are classified as sufficient for vegetables like *Amaranthus* according to Tandon (1995). In addition these concentrations are much lower than the critical value of 10 mg/kg which have shown that reduction in yield can occur (Breckett, (1985).

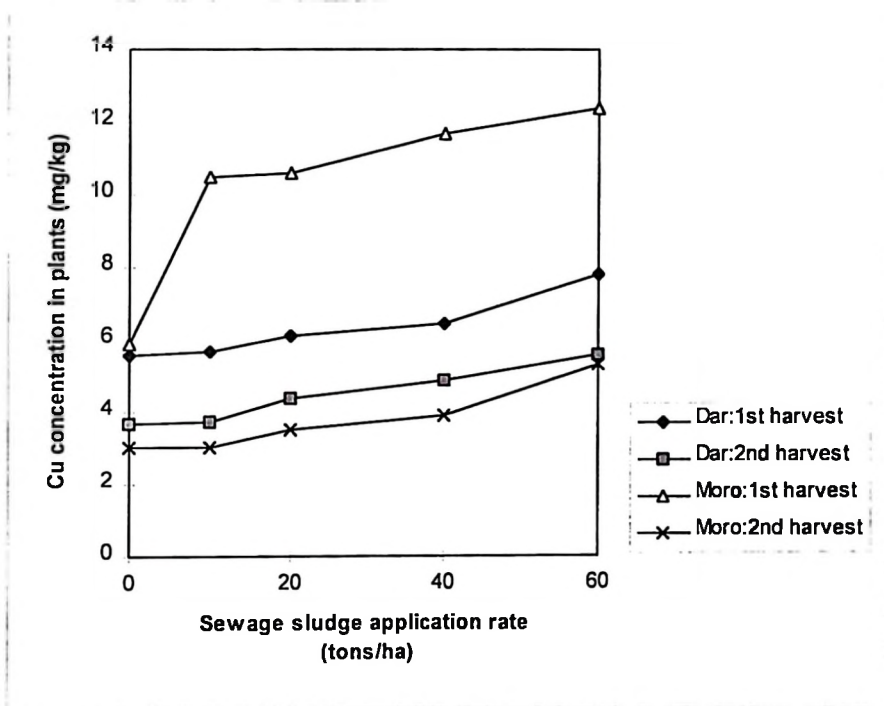


Figure 3. Concentrations of Cu in *Amaranthus* as influenced by sewage sludge application rates.

In a similar study LeRiche and Dowdy, (1968) found no influence in the concentration of Cu in cabbage yields after application of sewage sludge. However, Schemer and Kick (1978), reported a considerable increase especially after application of more than 1000 m³ wet sludge (6 % Dm/ha). The concentration of Cu

in the *Amaranthus* as the result of application of sewage sludge from Morogoro was also very much influenced by the rate of sewage sludge applied especially at the highest level of application. The concentration for the first harvest ranged from 5.90 - 12.40 mg/kg with a grand mean of 10.21 mg/kg, while the concentration for the second harvest ranged from 3.05 - 5.28 mg/kg with a grand mean of 3.75 mg/kg. The grand mean concentration for the first harvest can be classified as medium and for the second as low according to Tandon, (1995) for most vegetables. Generally, there was a significant increase ($P < 0.05$) in Cu concentration in *Amaranthus* with increasing rate of sewage sludge application from Dar es Salaam and Morogoro for the first and second harvests (Appendix. 1).

There was a remarkable increase in Cu concentration in the *Amaranthus* for the first harvest with increasing rate of sewage sludge application. This has also been reported by Dowdy and Larson (1975), who found that increases in the rate of sewage sludge application to as much as 45 t/ha moderately increased the concentration of Cu in plants.

4.4.1.3 Zinc

The concentrations of Zn in *Amaranthus* shoots increased significantly ($P < 0.05$) between the highest rates of sewage sludge application i.e. 60 t/ha and other treatments for the first and second harvests as the result of application of sewage sludge from Dar es Salaam and Morogoro (Appendix 1). The ranges were 22.92 -

51.15 mg/kg and 32.70 - 59.45 mg/kg with grand means of 31.53 and 42.35 mg/kg for the first and second harvest respectively for Dar es Salaam sludge, while for Morogoro sludge the range was from 22.92 - 54.53 mg/kg with a grand mean of 37.81 mg/kg and 32.70 - 45.28 mg/kg with a grand mean of 38.54 mg/kg (Appendix 1 and Fig 4). Zn concentration in *Amaranthus* for the second harvest was much higher than for the first harvest, suggesting that availability of Zn in sewage sludge treated plots increases with time, also probably the sewage sludge mineralization was still not incomplete during the first harvest. This has also been reported by LeRich ,(1968) whereby several vegetables grown on a soil treated with sewage sludge over a period of 19 years contained abnormal amount of Zn but did not affect yield.

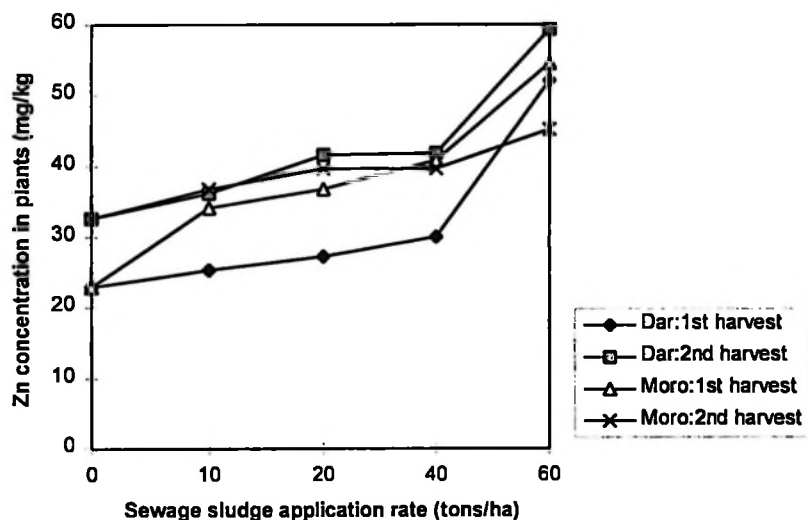


Figure 4. Concentrations of Zn in *Amaranthus* as influenced by sewage sludges application rates.

However, Dowdy and Larson (1975) reported no increase in Zn concentration in spinach after dressing with 30 t/ha of sewage sludge high in Zn concentration. Even the highest concentration of Zn in *Amaranthus* i.e. 59.45 mg/kg, can be considered as low when compared to the normal content of 500 - 100 mg/kg above which an injury to animals and human can occur (King and Morris, 1972). These amounts can be classified as sufficient for most vegetables like *Amaranthus*. Generally, the Zn content in *Amaranthus* as found in this study is below the amounts which can cause adverse effects to plants and animals

4.4.1.4 Manganese

The concentration of Mn in *Amaranthus* increased with increasing rate of applied sludges from Dar es Salaam and Morogoro (Fig 5). The lowest Mn concentration recorded was 16.12 mg/kg and the highest was 25.07 mg/kg for Dar es Salaam sludge. The second harvest showed no significant difference ($P < 0.05$) in Mn concentration as the result of sewage sludge application, although there was a slight increase in Mn concentration for rates higher than 20 t/ha (Appendix 1). The range of Mn concentration for the second harvest was 22.88 - 28.17 mg/kg with a grand mean of 27.71 mg/kg.

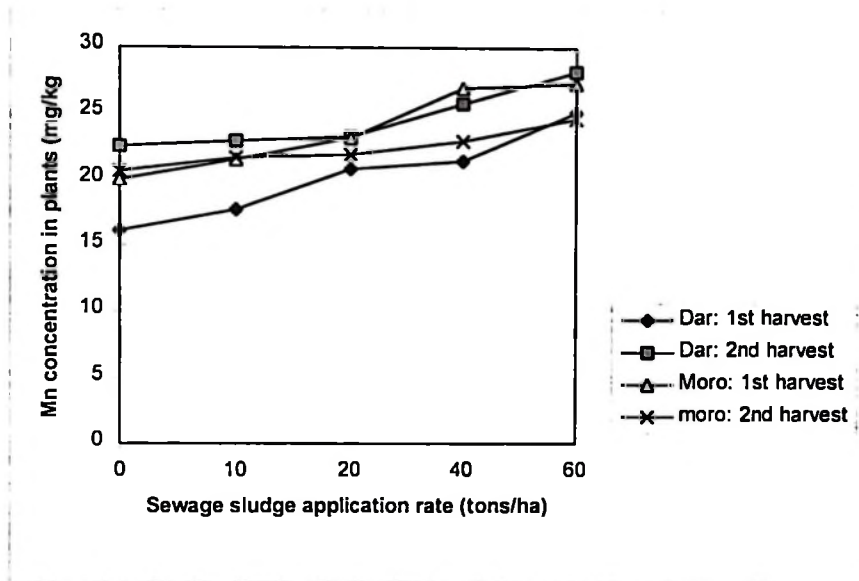


Figure 5. Concentrations of Mn in *Amaranthus* as influenced by sewage sludge application rates.

The concentration of Mn in the first harvest for Morogoro sludge ranged from 19.97 - 27.30 mg/kg, while the concentration in the second range was from 20.63 - 24.62 mg/kg. Generally, the Mn content in the second harvest was much higher than for the first harvest. The reason for this can probably be explained that, during the first crop an appreciable amount of Mn were immobilized by soil colloids and with time the sewage sludge released more Mn^{2+} into the soil solution for plant absorption. However, neither the first nor the second crop showed signs of Mn toxicity as both were in the low range for vegetables according to Tandon (1995). Therefore, Mn can not be a problem in using the two sludges for vegetable production in the Horticultural Unit, however, repeated application of the sludges can lead to Mn toxicity.

4.4.1.5 Lead

The concentration of Pb in *Amaranthus* plants ranged from 4.60 to 6.53 mg/kg and 2.50 to 6.50 mg/kg for the first second harvests respectively for Dar es Salaam sewage sludge, while the range for Morogoro sludge was 5.92 to 12.15 mg/kg and 1.17 to 4.25 mg/kg for the first and second harvests respectively. The amount of Pb taken up by the plants increased with increasing amount of applied sludges (Fig 6). However, the increase in Pb concentration in *Amaranthus* was not significant for the first harvest while for the second planting the increase was significant (Appendix 1).

Vlamiš *et al.*, (1978) also found only a small influence in Pb concentration in Barley grain with increasing rate of sewage sludge application.

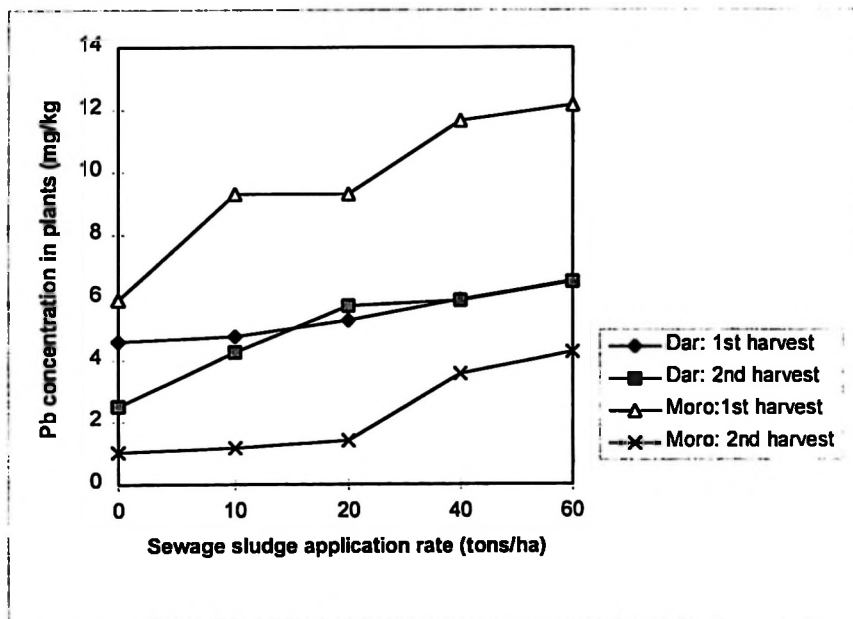


Figure 6. Concentrations of Pb in *Amaranthus* as influenced by sewage sludge application rates.

4.4.2 The concentrations of other plant nutrients in *Amaranthus* shoots

The results on the concentration of other plant nutrients in *Amaranthus* shoots are presented in Table 7.

4.4.2.1 Total Phosphorus

The concentrations ranged from 0.62 % - 0.78 % and 0.53 % - 0.71 %, with grand means of 0.7 % and 0.64 % for Dar es Salaam and Morogoro respectively. The uptake of P by *Amaranthus* as a result of sewage sludge application from Dar es Salaam was significantly different at ($P < 0.05$) especially for the highest rate of application (Table 7). On the other hand the uptake of P, as a result of sewage sludge application from Morogoro showed no significant difference. The highest rate of sewage sludge application resulted in the lowest amount of total P. However, other treatments showed high amount of total P compared to the control. Similar results have also been reported by Moreno *et al.*,(1996) whereby plants grown in amended soils showed higher P content than the control plants.

4.4.2.2 Total Nitrogen

There was a comparable increase in total N in plants following different rates of sludges application from Dar es es salaam and Morogoro ($P < 0.05$) for all the treatments. The uptake ranged from 0.97 % - 1.19 % and 0.96 % - 1.16 % for Dar

es Salaam and Morogoro sewage sludges respectively. The amended plots showed higher N content than the unamended plots. A similar observation has also been reported by Abdelsabour and AboEl Seoud, (1996). The results are consistent with those reported by Moreno *et al.*(1996), where by plants grown in sewage sludge amended soils showed higher N content than the control plants. The increase in total N is probably due to the high amount of N which was present in the two sludges.

Table 7. Concentrations of Phosphorus, Nitrogen, Calcium, Magnesium, and Potassium in *Amaranthus* as influenced by sewage sludge application rates.

Treatment (t/ha)	P	N	Ca	Mg	K
Dar es Salaam sludge					
0	0.71a	1.03a	1.02a	0.55a	0.31a
10	0.78a	0.97a	1.13a	0.57a	0.35a
20	0.68ab	0.99a	1.08a	0.57a	0.26a
40	0.72ab	1.09a	1.17a	0.61a	0.28a
60	0.62b	1.19a	1.22a	0.65a	0.26a
Grand mean	0.70	1.05	1.12	0.59	0.30
%Cv	7.64	12.50	13.34	8.76	25.64
LSD	0.10	0.25	0.24	0.10	0.15
Sx	0.03	0.08	0.07	0.03	0.04
Morogoro sludge					
0	0.71a	1.00a	1.17b	0.65b	0.31ab
10	0.65a	0.96a	1.25ab	0.65b	0.28b
20	0.65a	1.02a	1.34ab	0.67b	0.33ab
40	0.66a	1.03a	1.40ab	0.74ab	0.35ab
60	0.53a	1.16a	1.47a	0.89a	0.39a
Grand mean	0.64	1.03	1.33	0.72	0.33
%Cv	13.74	16.77	10.17	11.64	12.58
LSD	0.17	0.33	0.25	0.16	0.08
Sx	0.05	0.10	0.08	0.05	0.03

Means within the same column followed by the same letter(s) were not significantly ($p < 0.05$) different

4.4.2.3 Calcium

The Ca content in *Amaranthus* ranged from 1.02 - 1.22 Cmol(+)/kg and 1.17 - 1.47 Cmol(+)/kg for sludge from Dar es Salaam and Morogoro respectively. These amounts can be classified as sufficient and high respectively.

The increase in calcium content of *Amaranthus* plant following application of sewage sludge from Dar es Salaam was not significant ($P < 0.05$). On the other hand for Morogoro sludge the increase was comparable except for the highest rate of sewage sludge and the control.

Generally, increasing the rate of sewage sludge application also resulted into a comparable increase in the Ca content of *Amaranthus* plant. This is probably due to the inherent high amount of Ca in the soil. Hence the addition of any Ca source material to the soil will have no remarkable change in soil Ca as well as for calcium in plants. However, as expected the amount of Ca concentration for the plants grown in amended plots were much higher than the plants grown in control plots.

4.4.2.4 Magnesium

Increasing the rate of sewage sludge application resulted into a significant change in Mg content in *Amaranthus* plants following application of sludge from Dar es Salaam, while for Morogoro sludge there was a comparable increase in Mg concentration especially for the highest rate of sludge applied. The Mg content ranged from 0.55 - 0.65 Cmol(+)/kg and 0.65 - 0.89 Cmol(+)/kg for Dar es Salaam

and Morogoro sludges respectively. For *Amaranthus* plant, these amounts can be rated as low and sufficient respectively according to Tandon (1995). As expected, the amount of Mg concentration in the plants grown in amended plots was higher than was the case for the plants grown in control plots.

4.4.2.5 Potassium

The K content in *Amaranthus* shoots ranged from 0.26 - 0.35 Cmol(+)/kg and 0.28 - 0.39 Cmol(+)/kg with grand means of 0.30 and 0.33 Cmol(+)/kg for Dar es Salaam and Morogoro sewage sludge respectively. These amounts can be classified as low according to Tandon (1995). The low level of K is a reflection of several factors like, antagonistic effect between K and other cations like Ca and Mg (Ranganathan and Natesan, 1985; Wilson, 1975). Also the results show that the change in K content of *Amaranthus* following the application of sludge from Dar es Salaam was not significant, while the application of sludge from Morogoro showed a significant change in K content between the highest rate of sewage sludge applied and 10 tons/ha. The critical level of K for most vegetables, including spinach and cabbage is 6 cmol(+)/kg (Knott, 1980).

4.5 Residual concentration of Heavy metals in the soil as a result of application of sewage sludge

4.5.1 Heavy metals concentration after the first crop

The available and total heavy metal residual concentrations in the soil after the first crop of *Amaranthus* plants are shown in appendices 2 and 3.

4.5.1.1 Cadmium

There was a significant increase ($P < 0.05$) in available and total Cd concentrations in the soil as a result of sewage sludge application (Appendix. 2).

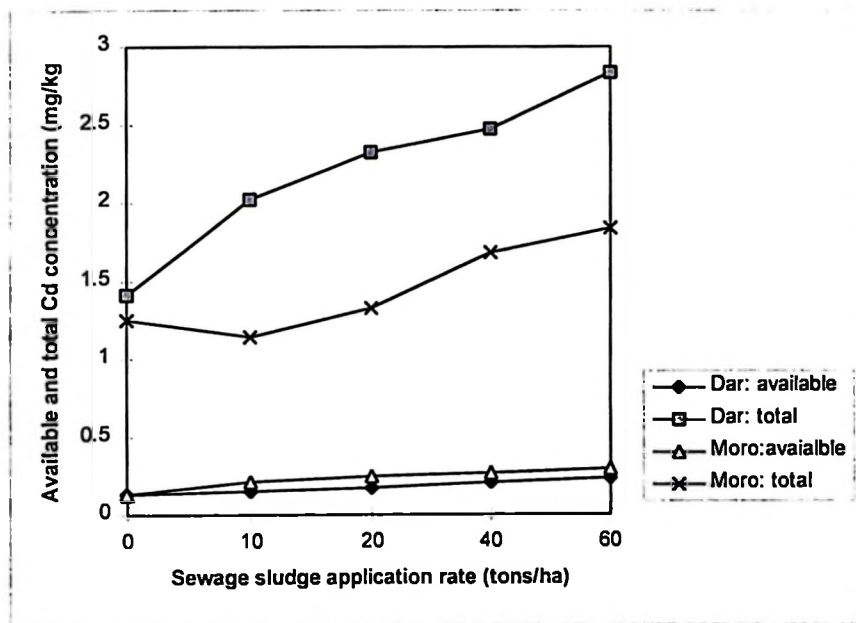


Figure 7. Residual Cd concentration in the soil after the first harvest as influenced by rates of sewage sludge applied.

The available and total Cd concentrations for sewage sludge from Dar es Salaam ranged from 0.13 - 1.23 mg/kg and 1.41 - 2.82 mg/kg respectively. On the other hand residual available and total Cd in the soil from Morogoro sludge ranged from 0.13 - 0.29 mg/kg and 1.14 - 1.83 mg/kg respectively (Fig. 7). Generally, there was an increase in Cd residual concentration after the first harvest following sludge application. Similar observations have also been reported by (Mench *et al.*, 1994; Ying ming and Corey, 1993; Bert and Jacobs, 1996 and Moreno *et al.*, 1996). The total residual Cd concentration in the soil was much higher than the adequate mean concentration set by Landon (1991) which was 0.35 mg/kg. The application of both sewage sludge from Dar es Salaam and Morogoro to agricultural land must be carried out with care as Cd may be a problem in the long run. The mean total residual concentration of Cd in the soil is still higher than the acceptable levels in soils.

4.5.1.2 Copper

The available and total Cu residual concentration as the result of application of sludge from Dar es as salaam ranged from 3.11 - 3.94 mg/kg and from 24.53 - 30.05 mg/kg respectively, while for Morogoro sludge ranged from 2.50 - 4.62 mg/kg and 23.43 - 30.63 mg/kg for available and total Cu respectively (Fig. 8).

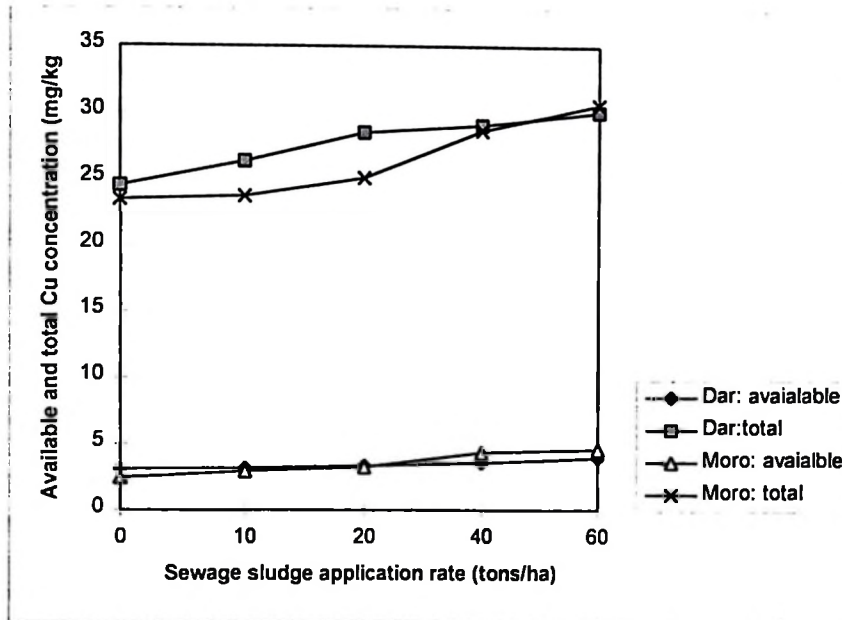


Figure 8. Residual Cu concentration after the first harvest as influenced by rates sewage sludge applied.

The results show that the increase in residual Cu concentrations was significant ($P < 0.05$) with increasing rate of sewage sludge application (Appendix. 2).

Generally, there was a slight increase in available and total residual Cu concentration in the soil as the result of increasing rate of sewage sludge application, while available remained more or less the same for both sources of sludge (Fig. 8). This has also been reported by Baerug and Martinsen (1974) who found that application of sewage sludge to agricultural soil moderately increased readily soluble Cu concentration in the soil even after the termination of the treatments. Boswell, (1975) also reported a slight increase in soluble Cu in the soil after application of 5.6 t/ha of sludge dry matter. The soil analysis in this

experiment indicates that more of applied Cu from the sewage sludge was fixed in slowly available form as the levels were almost similar to those which were initially found in the soils. The levels were below the established phytotoxic level of 100 mg/kg for most soils.

4.5.1.3 Zinc

The results show that increasing the rate of sewage sludge application resulted into a significant ($p < 0.05$) increase in available and total residual Zn in the soil both for Dar es Salaam and Morogoro sludges (Appendix 2). For Dar es Salaam sludge, the residual available Zn concentration increased from 4.44 - 13.10 mg/kg. On the other hand residual total Zn ranged from 45.07 - 70.35 mg/kg respectively. The results on the sludge from Morogoro indicate that the residual available Zn ranged from 3.95 - 4.80 mg/kg while the total residual Zn ranged from 45.07 - 58.27 mg/kg (Fig 9). The residual available Zn concentrations in all plots treated with Morogoro sludge were not very much influenced by the previous application of sewage sludge. The levels of available Zn after the first harvest were almost similar to those levels initially found in the soils before sewage sludge application. This implies that almost all the applied zinc was either absorbed by the plants or fixed in the soil. However, since the total residual amounts increased, then an important portion of Zn was fixed by the soil colloidal particles. Similar results have also been reported by Brallier *et al*, 1996; Chander *et al*, 1995; Brendecke *et al.*, 1993 and Ying ming and Corey, 1993.

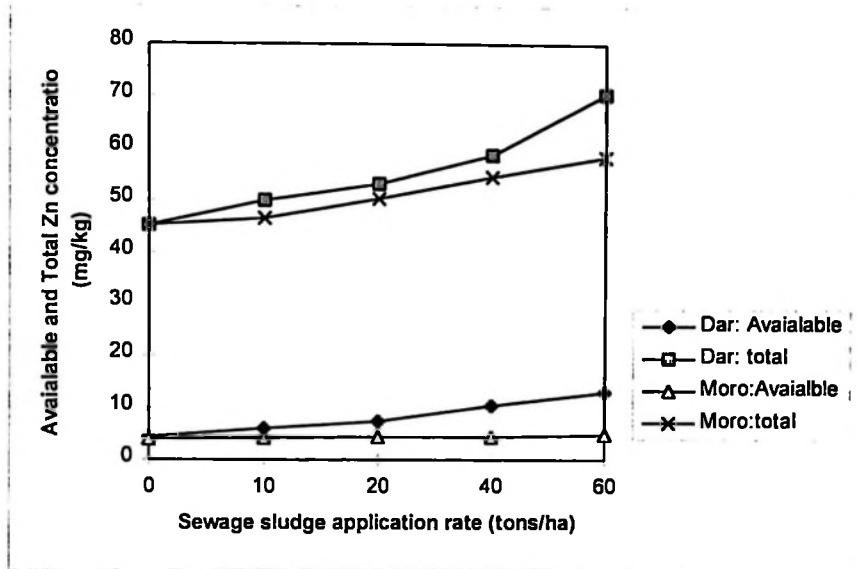


Figure 9. Residual Zn concentration in the soil after the first harvest as influenced by rates of sewage sludge applied.

The critical available Zn concentration for most soils is between 0.5 - 1.0 mg/kg, while the total concentration is 90 mg/kg (Knott, (1980) and Landon (1991)). The available residual Zn concentration is much higher than the above critical range, while the total is below the stated critical amount. In view of the above observation, Zinc can cause toxicity problems if the sewage sludge is used as a fertiliser. Bearing in mind that only single application of sludges was done, repeated annual sludge treatment at the same location could consequently lead to soil toxicity. Hence, proper rates of application must be studied and recommended well in order to document sludge effects on soil properties and crop performance. However, long

term effects through the use of the sludges on soil properties and crop performance must be studied in the same location.

4.5.1.4 Manganese

The increase in residual available and total Mn in the soil as the result of increasing rate of sewage sludge application for both sludges from Dar es Salaam and Morogoro was not significant ($p < 0.05$) (Appendix 2). The residual available Mn for the sewage sludge from Dar es Salaam ranged from 28.82 - 34.83 mg/kg, while the total amount ranged from 416.80 - 456.70 mg/kg. For the Morogoro sewage sludge residual available Mn concentration ranged from 25.87 - 30.34, while the total residual concentration ranged from 387.0 - 449.70 mg/kg (Fig. 10). The total residual manganese in the soil can be classified as medium range according to Landon (1991). The results show that application of sewage sludge did not cause a remarkable change in soil Mn residual concentrations.

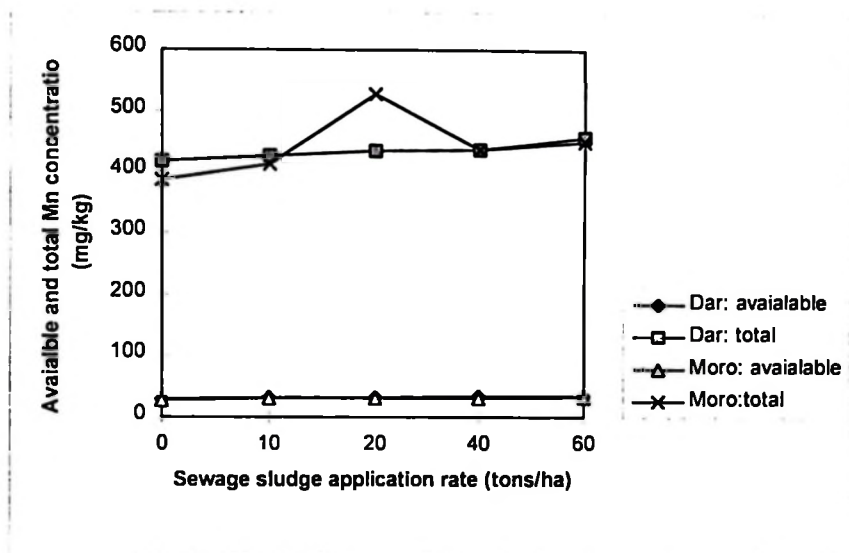


Figure 10. Residual Mn concentration after the first harvest as influenced by rate of sewage sludge applied.

4.5.1.5 Lead

There was a significant increase ($p < 0.05$) in residual available and total Pb concentrations in the soil as the result of increasing rate of sewage sludge application (Appendix 2). For Dar es Salaam sludge residual available Pb concentration ranged from 0.53 - 0.89 mg/kg, while the total residual Pb ranged from 15.45 - 19.72 mg/kg. On the other hand for Morogoro sludge the residual available Pb concentration ranged from 0.56 - 0.95 mg/kg, while the residual total ranged from 11.37 - 15.31 mg/kg (Fig. 11).

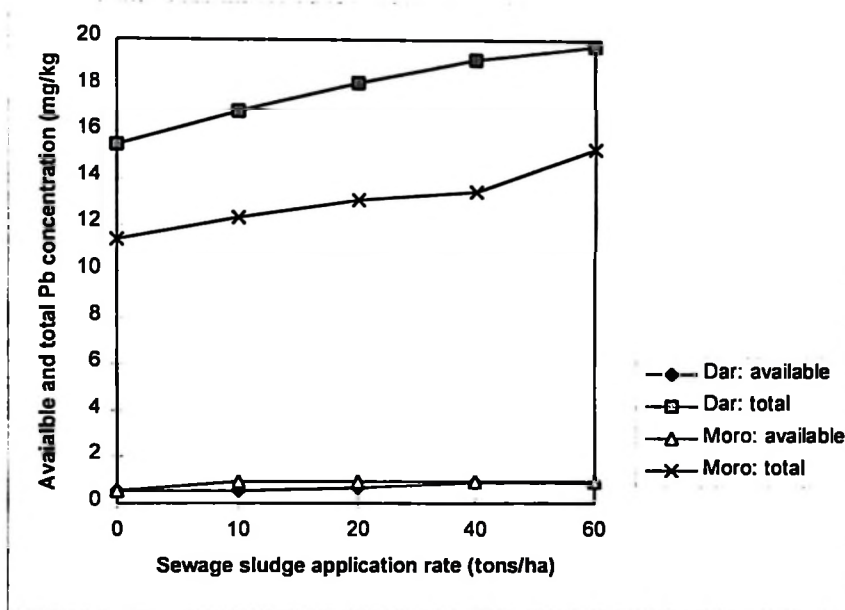


Figure 11. Residual Pb concentration in the soil after the first harvest as influenced by rates of sewage sludge applied.

The chemical analysis for available Pb in the soil showed small changes in available Pb with rate of sewage sludge application, while for the total the change was greater. The results strongly indicate that the amount of Pb applied has been fixed in the soil by the soil colloidal particles or Mn^{2+} in an almost unavailable form or an important portion was absorbed by the plants. Similar observation was also reported by LeRich and Dowdy, (1968).

4.5.2 Heavy metals concentration in the soil after the second crop

The available and total residual concentrations of selected heavy metals in the soil after the second harvest of *Amaranthus* plants are shown in Figures 12 to 16 and Appendices 4 and 5.

4.5.2.1 Cadmium

There was a significant quantity ($p < 0.05$) of available and total Cd remaining in soil after the second harvest (Appendix 4).

The residual available Cd concentration in the soil after the second harvest following the application of sludge from Dar es Salaam ranged from 0.24 to 0.52 mg/kg, while the total Cd concentration ranged from 0.43 to 0.95 mg/kg. The application of sludge from Morogoro had a remarkable change also in available and total residual Cd concentrations in the soil. The residual available Cd concentration ranged from 0.13 to 0.29 mg/kg, while the residual total Cd ranged from 1.14 to 1.83 mg/kg (Fig. 12).

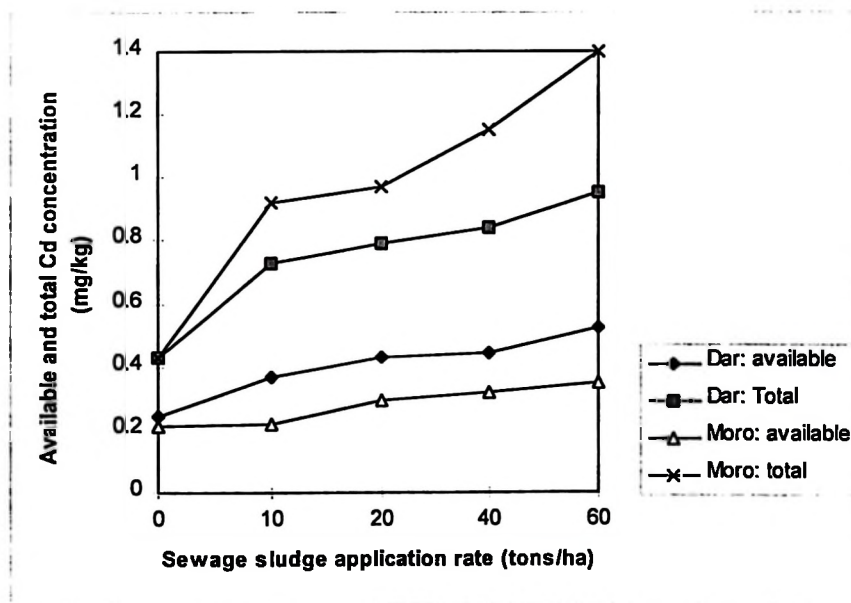


Figure 12. Residual Cd concentration in the soil after the second harvest as influenced by rates of sewage sludge applied.

The total Cd residual concentration is much higher than the approximate mean value of 0.35 mg/kg for most agricultural soils. Generally, the residual Cd concentration in the soil is high even after the termination of sludges application. Similar results were also found by Mench *et al*, (1994) who found that Cd remains bioavailable in sandy soil for a long time even after the termination of application of metal polluted sewage sludge. It was also found from this study that the available residual Cd concentration after the second harvest is much higher than after the first harvest, suggesting that availability of Cd in sewage sludge treated soils increases with time.

4.5.2.2 Copper

The increase in residual available and total Cu in the soil was significant ($p < 0.05$) following the sludge application from Dar es Salaam and Morogoro (Appendix 4). The results on application of sludge from Dar es Salaam show that residual available Cu concentration in the soil ranged from 1.67 to 2.57 mg/kg, while the total residual Cu ranged from 22.57 - 27.27 mg/kg. On the other hand, the residual available and total Cu for Morogoro sludge ranged from 2.07 to 5.25 mg/kg and 22.90 to 28.72 mg/kg respectively (Fig 13). Generally, there was a decrease in available and total residual Cu concentration after the second harvest when compared to the first harvest. The decrease in available and total Cu is probably due to the significant uptake by plants during the first and second harvest and perhaps retention by organic matter. However, the amount of DTPA Cu which

remaining in the soil after the second harvest is still higher than the critical level of 0.2 mg/kg as suggested by Lindsay and Norvell, (1978). Similar results were also reported by Moreno *et al.* (1996) whereby there was a high amount of residual Cu concentration in the soil even after the termination of sewage sludge application. Also in an experiment to evaluate the long-term effects of municipal sewage sludge on an arid soil, Brendecke *et al.*, 1993 found a significant increase in available Cu with sludge treatment.

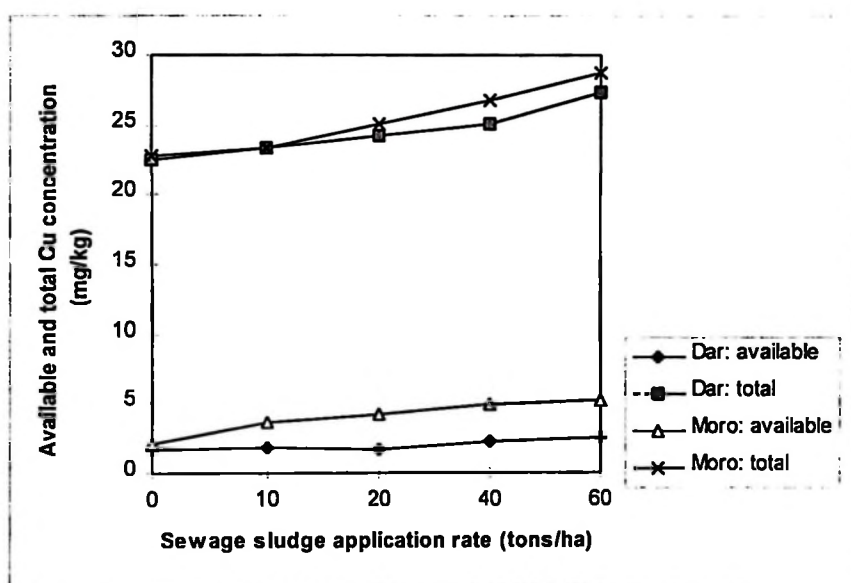


Figure 13. Residual Cu concentration in the soil after the second harvest as influenced by rates of sewage sludge applied.

Generally, the residual available and total Cu concentrations were lowest for the check plots and increased as the rate of sewage sludge application was increased. A similar observation have been reported by Skousen and Clinger ,(1993) whereby

the DTPA- extractable total Cu in the soil increased with increasing rate of sewage sludge application.

4.5.2.3 Zinc

The residual Zn concentrations in the soil after the second harvest following application of sewage sludge from Dar es Salaam and Morogoro increased significantly ($p < 0.05$) (Appendix 4). The residual available Zn concentration for Dar es Salaam sludge ranged from 2.89 to 13.30 mg/kg, while the total residual Zn concentration ranged from 43.53 to 67.87 mg/kg. On the other hand the residual available and total Zn in the soil for Morogoro sludge ranged from 2.89 to 4.22 mg/kg and 46.87 to 55.60 mg/kg respectively (Fig 14). Generally, the residual Zn concentration for available and total amounts increased as the rate of sewage sludge was increased.

The concentrations of DTPA-extractable Zn are within the range of 1.9 to 17.9 mg/kg for most agricultural soils in Tanzania as reported by Kamasho, (1980). Injury to animals have been reported at Zn concentration above 500 - 1000 mg/kg. Hence the amount present in the soil is far below the injurious limits.

It can also be concluded that, the residual Zn concentration in the soil following the application of sewage sludge was low and this implies that almost all the applied Zn was either fixed in the soil or absorbed by the plants.

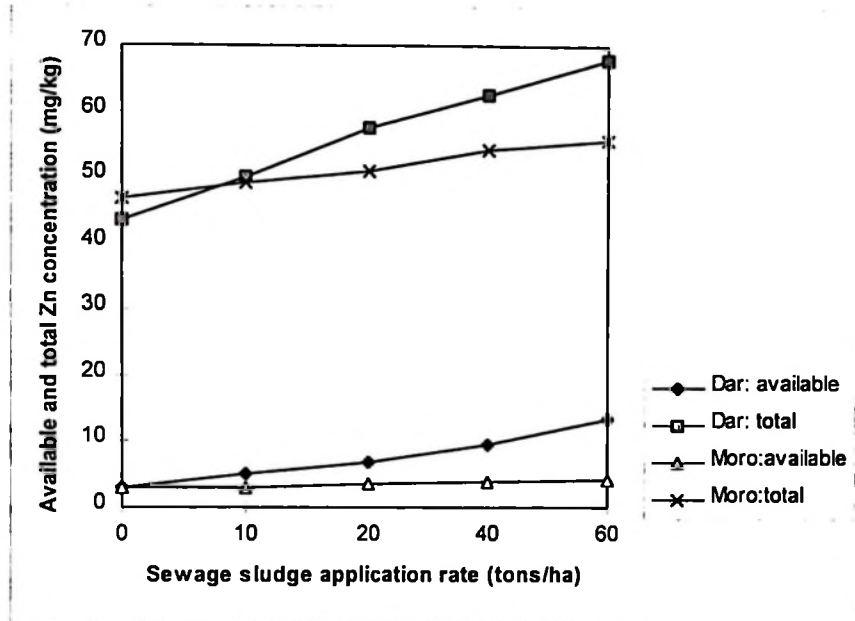


Figure 14. Residual Zn concentration in the soil after the second harvest as influenced by rates of sewage sludge applied.

4.5.2.4 Manganese

The residual available Mn concentration remaining in soil after the second crop for Dar es Salaam sludge ranged from 28.91 - 32.10 mg/kg, while the total ranged from 298.7 - 378.70 mg/kg. For Morogoro sludge available concentrations ranged from 25.25 - 31.17 mg/kg, while the residual total Mn ranged from 298.80 - 453.20 mg/kg (Figure 15). However, the increase in residual Mn concentration for Dar es Salaam sludge was not significant while for Morogoro sludge the increase was significant with increased rate of sludge applied during the first harvest (Appendix 4). Similar observations were also reported by Mench *et al.*, (1994) when studying the effects of metals in soil following sludge application. They observed that, there

was no marked increase in residual Mn in the soil with respect to different rates of sewage sludge applied. Generally, the residual available Mn concentration in the soil is much higher than the critical range proposed by Sillanpaa (1982) which is 2 - 5 mg/kg. On the other hand the total residual is above the critical range of 140 - 200 mg/kg set by Landon (1991). This indicates that there was a high amount of Mn remaining in the soil even after the second planting. However, these concentrations are much lower than after the first harvest probably due to the uptake during the first and second harvests of *Amaranthus* plants and also this may be an indication of fixation as well.

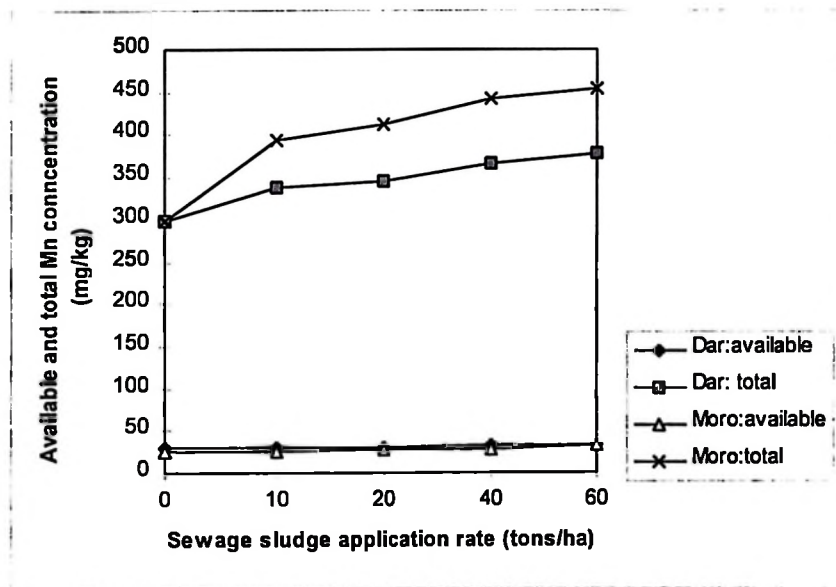


Figure 15. Residual Mn concentration in the soil after the second harvest as influenced by rates of sewage sludge applied

4.5.2.5 Lead

There was no significant increase in residual available and total Pb in the soil after the second harvest following different rates of sewage sludge application from Dar es Salaam. However for Morogoro sludge a significant increase in residual available and total Pb concentration was observed only between the highest rate of sewage sludge application and the control treatment (Appendix 4). For Dar es Salaam sewage sludge residual available Pb concentration after the second crop ranged from 0.24 - 0.75 mg/kg, while the total ranged from 6.87 - 18.75 mg/kg (Figure 16). The results indicate that the total amount of Pb is well below the mean

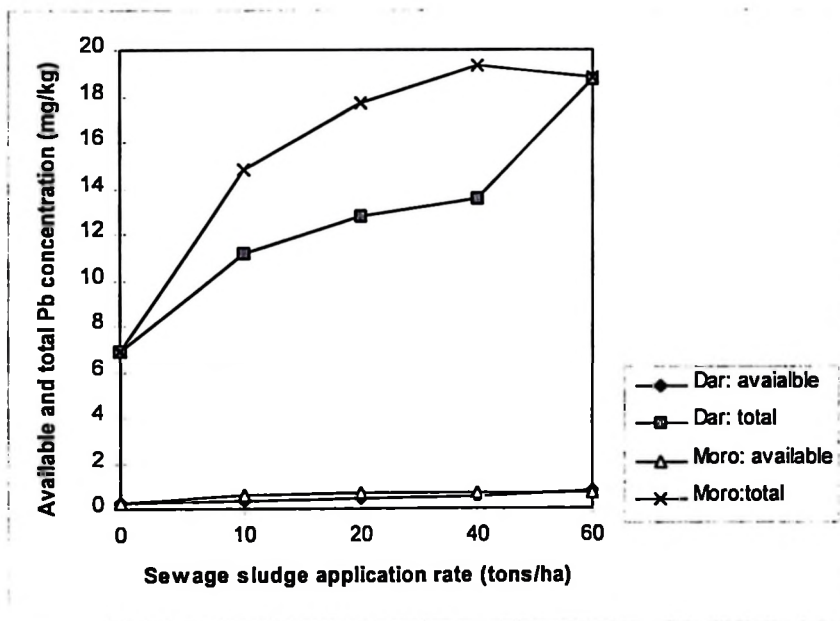


Figure 16. Residual Pb concentration in the soil after the second harvest as influenced by rates of sewage sludge applied.

concentration of 35 mg/kg proposed by Landon, (1991). Also the extractable amount is below the critical range of 15 - 25 proposed by Aubert and Pinta (1977). Generally, the amount of Pb remaining in the soil after the second harvest was low. The available residual amount had decreased from 0.71 to 0.46 mg/kg while the total residual amount had decreased from 17.87 to 12.61 mg/kg from the first and second harvest respectively. The decrease in residual available Pb concentration is probably due to the uptake by plants during the first and second harvest and also possibly due to the fixation of soluble Pb to unavailable form by the crystal structure of the soil clays.

In spite of the sludges having appreciable amount of plant nutrients such as K, Ca, Mg, N and Na, some of the residual heavy metals content in the soil such as Cd and Mn are found to exceed the established critical levels for most agricultural soils. Hence, repeated use of these sludges on the same area may consequently lead to harmful effects especially Cd which has the tendency of remaining bioavailable in soils for a long time even after the termination of sludge application.

CHAPTER: 5

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSIONS

In view of findings from this study, the following conclusions can be drawn;

- (i) Given a soil of moderate acidity , texture and mineralogical composition, it is possible to grow vegetable crops such as *Amaranthus* for a long period of time using 20 - 40 tons/ha of both sludges from Dar es Salaam and Morogoro without causing damage to soil as well as endangering the health of mankind.
- (ii) No symptoms of toxicity were observed as a result of different rates of sewage sludges applied and analysis of the *Amaranthus* plants showed that the content of possibly hazardous elements was well below toxic levels.
- (iii) An excellent crop of *Amaranthus* was produced on soil fertilised with the two sewage sludges. The increase in the rates of sewage sludge application, also resulted into a remarkable increase in the dry matter yield of *Amaranthus* plants
- (iv) The residual concentrations of heavy metals in the soil was high especially for the highest rates of sewage sludges applied.

- (v) Sewage sludge represents an important source of plant available N, P, and K and has significant and beneficial fertiliser replacement value for these major plant nutrients.
- (vi) The analysis showed that Zn and Cu are the principal elements which can limit sewage sludge recycling to agricultural land in the long term. Both elements can limit sludge applications to similar extent given the sewage sludge quality. Also Cd may limit the use of sewage sludge as the metal can remain bioavailable in the soil for a long period of time as compared to other studied heavy metals. Pb is also limiting as important soil accumulations are possible whenever repeated application is done on the same area.
- (vii) Both sludges should not be disposed on agricultural land due to high contents of heavy metals. However, much of the work completed has been short term, and that long-term effects of repeated annual sludge treatments, at the same location are needed to document long term sludge effects on soil properties and crop performance.

5.2 RECOMMENDATIONS

- (i) For the successful use of organic waste material such as sewage sludge in agriculture, benefits to crop production and/or soil properties must be demonstrated without adverse effects to public health and/or environmental quality.

- (ii) Vegetables produced locally by farmers in urban and rural areas using sludges as fertiliser should be screened for their heavy metal contents.

- (iii) Further research should be carried out to determine conclusively the long term effects of using sewage sludge on agricultural land, its effect on animal nutrition and soil micro-biological processes.

- (iv) Construction of more oxidation ponds for sewage sludge disposal in Dar es salaam is highly recommended. Most of the available ponds are far away from poor urban and peri urban farmers for easy access to the sludges. On the other hand sewage sludge in Morogoro centers are currently disposed randomly on land fills and on areas which are not currently used for agriculture activities. However, in Morogoro the oxidation ponds are now under construction.

- (v) The study covered only the agronomic aspects of the sewage sludge in agriculture. The microbiological aspects were not covered due to lack of facilities, hence further research is advocated on the study of the microbiological part.

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APPENDICES

Appendix 1. The concentration of selected heavy metals in plant for the first and second harvest (mg/kg)

Treatment	Cd		Cu		Zn		Mn		Pb	
	first harvest	second harvest	first harvest	second harvest	first harvest	second harvest	first harvest	second harvest	first harvest	second harvest
Dar es Salaam sludge(tons/ha)										
0	0.75cd	2.33a	5.57b	3.72c	22.92b	32.70c	17.72b	22.88a	4.60a	2.50c
10	0.65d	1.87d	5.68b	3.70c	25.28b	36.17c	16.12b	23.18a	4.75a	4.27b
20	0.93bc	1.90cd	6.13b	4.37bc	27.28b	41.90b	20.75ab	25.77a	5.25a	5.88b
40	1.05b	2.05bc	6.42b	4.88ab	30.00b	41.52bc	21.43ab	22.53a	6.53a	5.73ab
60	1.92a	2.08b	7.78a	5.57a	52.15a	59.45a	25.07a	28.17a	5.92a	6.50a
Gm	1.06	2.05	6.32	4.45	31.53	42.35	20.22	24.71	5.41	4.98
% Cv	13.19	3.96	7.60	9.28	11.32	10.74	13.22	17.09	46.37	18.51
LSD	0.266	0.1575	0.903	0.7763	6.72	8.564	5.031	7.948	4.723	1.735
Sx	0.0816	0.0483	0.2769	0.24	2.061	2.526	1.543	2.437	1.448	0.532
Morogoro sewage sludge (tons/ha)										
0	0.75c	0.52d	5.90c	3.05b	22.92c	32.70b	19.97b	22.88a	5.92a	1.17b
10	2.27b	0.53cd	10.47b	3.03b	34.05bc	36.78b	21.48ab	20.636a	9.30a	1.05b
20	2.82ab	0.63c	10.62b	3.50b	36.80b	39.68ab	26.93a	21.60a	9.32a	1.42b
40	2.92a	0.83b	11.65ab	3.90ab	40.77b	39.73ab	23.12ab	21.90a	12.15a	3.55ab
60	3.08a	0.95a	12.40a	5.28a	54.53a	45.28a	27.30a	24.62a	11.67a	4.25a
GM	0.70	0.70	1021	3.75	37.81	38.54	23.76	22.33	9.67	2.29
% Cv	8.49	7.76	24.21	24.21	16.55	9.60	12.90	20.44	52.54	57.28
LSD	0.5522	0.103	1.491	1.711	11.79	7.02	5.769	8.594	5.566	2.466
Sx	0.1693	0.032	0.4572	0.5247	3.614	2.15	1.769	2.635	2.933	0.756

Means within the same column followed by the same letter(s) were not significantly ($p < 0.05$) different according to Duncan's Multiple Range Test.

Appendix 2. Available and total heavy metal concentration in the soil after the first harvest (mg/kg soil)

Treatment (Average of replicates)	Cd		Cu		Zn		Mn		Pb	
	Available	Total	Available	Total	Available	Total	Available	Total	Available	Total
Dar es Salaam sludge (tons/ha)										
0	0.13c	1.41c	3.11b	24.53c	4.44d	45.07d	28.82c	416.80a	0.53b	15.45b
10	0.15c	2.02b	3.16b	26.35b	6.05c	49.88cd	32.33b	426.70a	0.54b	16.90ab
20	0.17bc	2.32b	3.38b	28.50a	7.41c	53.20c	33.04b	435.20a	0.67b	18.13ab
40	0.20b	2.47ab	3.60ab	29.02a	10.51b	58.67b	33.76a	437.20a	0.88a	19.17ab
60	0.230a	2.83a	3.94a	30.05a	13.10a	70.35a	34.83a	456.70a	0.89a	19.72a
GM	0.18	2.21	3.44	27.69	8.31	55.43	32.36	434.50	0.70	17.87
% CV	9.69	12.30	7.65	3.25	10.29	4.70	1.98	6.71	10.64	11.57
LSD	0.032	0.512	0.4946	1.797	1.609	4.91	1.209	54.86	0.1458	3.895
Sx	0.0983	0.1571	0.1517	0.5203	0.4933	1.506	0.3706	16.82	0.04472	1.194
Morogoro sludge (tons/ha)										
0	0.13b	1.25b	3.24abc	23.43c	4.20a	45.07d	25.87a	387.00a	0.56b	11.37c
10	0.21ab	1.14b	2.50c	23.68c	3.95a	46.47d	28.09a	412.80a	0.94a	12.35bc
20	0.24a	1.32b	2.92bc	25.05c	4.32a	50.33c	30.34a	426.70a	0.95a	13.08bc
40	0.26a	1.68a	4.34ab	28.62ab	4.41a	54.48b	31.01a	436.80a	0.93a	13.45ab
60	0.29a	1.83a	4.62a	30.63a	4.80a	58.27a	32.04a	449.70a	0.92a	15.31a
GM	0.26	1.44	3.52	26.28	4.34	50.92	29.47	422.80	0.86	13.11
%Cv	18.92	8.59	21.36	8.46	14.51	2.95	10.99	9.42	12.66	7.71
LSD	0.084	0.231	1.42	4.19	1.19	2.83	6.098	74.98	0.206	1.903
Sx	0.026	0.071	0.43	1.28	0.87	0.87	1.87	22.99	0.063	0.583

Means within the same column followed by the same letters are not significantly ($p < 0.05$) different according to Duncan's Multiple range Test.

Appendix 3. Available and total concentration of heavy metal in soils after the first harvest (mg/kg soil)

Dar sludge	Block 1		Block 2		Block 3		Average	
	Available	Total	Available	Total	Available	Total	Available	Total
Cu	3.27	28.48	3.30	27.54	3.74	27.05	3.44	27.69
Zn	9.48	53.57	7.92	56.44	7.51	56.29	8.30	55.43
Mn	35.46	451.50	31.25	428.00	30.36	424.00	32.36	434.5
Pb	0.63	16.07	0.71	19.38	0.78	18.17	0.71	17.85
Cd	0.14	2.28	0.18	2.03	0.20	2.31	0.17	2.21
Sewage sludge from Morogoro								
Cu	3.75	24.95	2.65	25.28	4.18	28.62	3.53	26.28
Zn	4.98	54.46	4.15	50.73	3.91	51.58	4.35	53.26
Mn	29.70	437.50	30.05	416.90	28.68	414.00	29.48	422.80
Pb	0.81	15.05	0.89	11.41	0.88	12.87	0.86	13.11
Cd	0.20	1.58	0.29	1.21	0.28	1.54	0.26	2.17

Appendix 4. Available and total heavy metal concentration in the soil after the second harvest (mg/kg soil).

Treat ment	Cd		Cu		Zn		Mn		Pb	
	Avail	Total	Avail	Total	Avail	Total	Avail	Total	Avail	Total
Dar es Salaam sludge(tons/ha)										
0	0.24b	0.43b	1.74b	22.57c	2.89e	43.53d	28.91a	298.70a	0.24a	6.87a
10	0.37ab	0.73ab	1.86b	23.38bc	5.13d	50.02c	28.91a	337.80a	0.38a	11.15a
20	0.43ab	0.79ab	1.67b	24.23bc	6.95c	57.35b	30.46a	346.76a	0.44a	12.77a
40	0.44ab	0.84ab	2.31ab	25.08b	9.62b	62.47b	31.17a	366.80a	0.51a	13.55a
60	0.52a	0.95a	2.57a	27.27a	13.30a	67.87a	32.10a	378.7a	0.75a	18.73a
GM	0.40	0.75	2.03	24.51	7.58	56.25	30.31	345.73	0.47	12.61
%Cv	25.24	30.73	16.79	4.26	4.30	4.72	6.43	41.29	57.16	54.90
LSD	0.188	0.434	0.6413	1.966	0.613	5.125	3.668	275.60	0.5017	13.37
Sx	0.0577	0.1329	0.1966	0.603	0.188	1.533	1.125	82.41	0.1538	3.998
Morogoro sludges (tons/ha)										
0	0.21c	0.43c	2.07b	22.90c	2.89d	46.87c	25.25d	298.80b	0.24b	6.87b
10	0.22c	0.92b	3.70ab	23.38c	3.11cd	49.02bc	26.13c	394.3ab	0.71a	17.67a
20	0.29b	0.97b	4.15ab	25.08bc	3.53bc	51.02abc	26.51c	412.3ab	0.70a	19.30a
40	0.32ab	1.15ab	4.88ab	26.78ab	3.96ab	54.07ab	27.34b	442.20a	0.64a	18.83a
60	0.35a	1.40a	5.25a	28.72a	4.22a	55.60a	31.17a	453.20a	0.60a	14.83ab
GM	0.28	4.01	4.01	25.37	3.54	51.31	27.28	400.17	0.58	15.50
%Cv	11.97	14.19	13.01	5.55	8.53	6.07	5.70	17.06	16.76	30.00
LSD	0.05954	0.26	2.84	2.652	0.568	5.867	0.476	128.50	0.1178	8.75
Sx	0.01826	0.0796	0.8702	0.8132	0.17	1.799	0.1461	39.41	0.055	2.68

Means within the same column followed by the same letter(s) were not significantly ($p < 0.05$) different according to Duncan's Multiple Range Test.

Appendix 5. Means for available and total heavy metal concentration in the soil after the second harvest (mg/kg soil).

Dar sludges	Block 1		Block 2		Block 3		Average	
	Available	Total	Available	Total	Available	Total	Available	Total
Cu	1.16	23.26	1.77	23.90	3.16	26.36	2.03	24.51
Zn	8.03	52.94	7.42	58.36	7.28	57.44	7.58	56.25
Mn	32.25	415.10	28.86	305.3	29.83	316.86	30.31	345.75
Pb	0.38	8.71	0.38	13.82	0.63	15.31	0.46	12.61
Cd	0.21	0.46	0.43	0.57	0.55	1.21	0.40	0.75
Morogoro sewage sludges								
Cu	3.27	24.84	3.35	24.67	5.40	26.61	4.01	25.35
Zn	3.98	51.16	3.30	51.02	3.35	51.76	3.54	51.31
Mn	27.87	414.50	27.91	384.60	26.07	401.40	27.28	400.17
Pb	0.72	16.74	0.43	15.48	0.58	14.28	0.58	15.50
Cd	0.26	0.94	0.34	1.06	0.24	0.92	0.28	0.97