

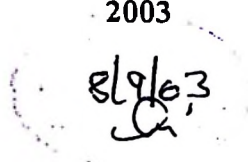
**HEAVY METAL UPTAKE BY SOME VEGETABLES GROWN ON SEWAGE
SLUDGE-TREATED SOILS**

BY

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**A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE
REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE (SOIL
SCIENCE AND LAND MANAGEMENT) OF SOKOINE UNIVERSITY OF
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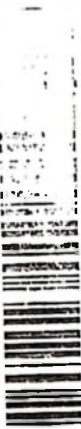
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ABSTRACT

A glasshouse pot experiment was conducted to determine the uptake of heavy metals by Chinese cabbage (*Brassica chinensis*), lettuce (*Lactuca sativa* L.) and cowpea (*Vigna unguiculata*) from sewage sludge-treated soils. A sandy loam (pH 6.9) and a loamy sand (pH 7.1) were amended with sewage sludge at rates of 0, 10, 20 and 30 ton/ha (oven-dry weight basis). Total and extractable heavy metals in soils and sludge, plant materials, vegetable heavy metals concentrations and uptake, were determined. Results on characterization of the soils and the sludge indicated that the soils contained small amounts of heavy metals, thus having a low potential for causing pollution and the sludge had elevated levels of heavy metals. Amendment with sewage sludge significantly ($P=0.05$) increased the yields of all vegetables. Chinese cabbage dry matter yields ranged from 3.34 to 15.89 and 9.83 to 17.09 g/plant for Msimbazi and Mjimpya soils, respectively. For lettuce they ranged from 3.43 to 14.29 and 6.69 to 13.63 g/plant for Msimbazi and Mjimpya soils, respectively. while for cowpea they ranged from 5.89 to 15.74 and 13.77 to 19.94 g/plant for Msimbazi and Mjimpya soils, respectively. The highest yields were observed with applications of sewage sludge at 30 ton/ha. The analysis of the edible parts of vegetables for heavy metals revealed higher uptake of Cd, Cu and Zn by all vegetable species with increased rates of sewage sludge application. The uptake of Pb and Cr by the vegetables was low and not consistent with the rates of sewage sludge application. There were significant differences between the uptake of heavy metals by the different vegetable species. DTPA-extractable Cu and Zn concentrations in post-harvest soil increased significantly with sewage sludge application rate. However, the increase of DTPA-extractable Pb and Cd was not



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consistent with the rates of application of sewage sludge. Chromium was not detected in the post harvest soil. Vegetables grown in amended soils showed higher N and P concentrations than control plants. The results indicate that there should be close monitoring over the use of the sludge for edible crop production.

DECLARATION

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

Signature.....*B. Msongaleli*.....Date.....*3rd April 2003*.....

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DEDICATION

To my father, the late Msolini Msongaleli, and my mother Leah Lupandisa who through their tireless efforts this achievement was possible. The work is also dedicated to my wife Bernadeta and our little son Bonaventura.

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LIST OF SYMBOLS AND ABBREVIATIONS

AAS	Atomic Absorption Spectrophotometry
Cd	cadmium
CEC	Cation Exchange Capacity
COSTECH	Commission for Science and Technology
Cr	chromium
Cu	copper
CV	Coefficient of Variation
DAT	days after transplanting
DTPA	diethylenetriaminepentaacetic acid
g	gramme
H ₂ O ₂	hydrogen peroxide
ns	not significant
OC	Organic Carbon
pH	negative logarithm of hydrogen ion activity
SEM	Standard Error of Mean
SUA	Sokoine University of Agriculture
t/ha	tonnes per hectare
URT	United Republic of Tanzania
WHO	World Health Organization
Zn	zinc

CHAPTER ONE

1.0 INTRODUCTION

Urban agriculture in Tanzania is widely carried out by people of different socio-economic status. The poor urban households in most Tanzanian cities and towns meet about 33 percent of their food needs through urban agriculture (Sanyal, 1986). In 1991, urban agriculture in the city of Dar es Salaam represented 5 percent of the informal sector enterprises (United Republic of Tanzania, 1991).

Urban agriculture in towns and cities can contribute to waste management and improvement of the environment. In Dar es Salaam, for example, haphazard dumping of solid wastes has been reduced, as they are used to fertilize vegetable gardens (Mlozi, 1995). Such wastes include sawdust, rice husks, remnants of vegetables, farmyard manure (FYM), and chicken manure. Additionally, for Morogoro gardeners, tobacco waste is currently being utilized.

Sewage sludge is the product of waste water treatment plants where sewage (and sometimes industrial wastes) is processed (Tan, 1994). Production of sewage sludge from wastewater treatment plants (oxidation ponds) is increasing in towns and cities of developing countries including those of Tanzania.

The possible use of this kind of organic waste is under constant review in developed countries because further degradation of the environment must be prevented and because their use as organic amendment would involve important savings in the use

of nitrogen, phosphorus and, to a lesser extent, potassium –based inorganic fertilizers (Moreno *et al.*, 1997). Peter and Carl (1990) found out that application of waste materials to agricultural land presented an opportunity for the recovery of essential plant nutrients. Most agricultural and sewage wastes contain valuable nutrients that could be recycled back onto the land in order to improve soil fertility and increase the sustainability of farming systems (Cameron *et al.*, 1997).

However, depending on the origin and composition, sewage sludge may contain variable amounts of toxic metals in addition to beneficial nutrients. Conway and Pretty (1991) stated that one of the major sources of land pollution was sewage sludge. Long-term application of sludge could result in heavy metal accumulation. Behaviour of heavy metals in soil from long-term application of sludge (Chang *et al.*, 1984; Dowdy *et al.*, 1991; Chino *et al.*, 1992), the availability of heavy metals from sludge-amended soil (Hue *et al.*, 1988; Kim *et al.*, 1988; Hooda and Alloway, 1993; Berti and Jacobs, 1996) and the relationship between the contents of soluble heavy metals and pH (Smith, 1994; Evans *et al.*, 1995) have been investigated. The reports indicated that long-term application of sludge resulted in accumulation of heavy metals including Cd, Zn and Cu in soils and absorption of the metals by plants.

Plants grown in contaminated soil may absorb these metals. The most serious consequences appear from use of largely untreated effluent and wastewater for irrigation, particularly for vegetables and salad crops such as amaranths, swisschard, lettuce and spinach (Shuval *et al.*, 1986). So far, very few studies on uptake of heavy metals by vegetables from sewage sludge-treated soils have been carried out in

Tanzania. In a recent study, Matemba (2001) showed that uptake of heavy metals by amaranth (*Amaranthus hybridus*) increased with increasing rates of sewage sludge application; but the contents of the hazardous elements, except for Cd, were below toxic levels even at the highest application rate (i.e. 60 ton/ha). This was however based on a single application.

In an earlier survey on heavy metal contents of vegetables sold in Dar es Salaam, Othman and Behemuka (1996) observed high levels of heavy metals beyond permissible levels set by World Health Organization (WHO). Chinese cabbage, for example, had 0.61-0.66 mg Cd/kg (against the standard set at 0.5 mg/kg) whereas African spinach (*Amaranthus spp.*) had 0.59 mg Cd/kg (against the permissible at 0.5 mg/kg). These vegetables were grown at Sinza and Buguruni Malapa-Relini in the Dar es Salaam City on soils enriched with city wastes.

Groundwater contamination by heavy metals from sludge is another possible threat of applying sewage sludge to land. However, the contamination is dependent on the chemical characteristics of the sludge and properties of the soil, and the depth to the water table. McBride *et al.* (1997) noted that large fractions of certain heavy metals applied through sludge amendment are able to re-distribute and move out of the soil surface by physico-chemical or biological processes thus increasing the potential for groundwater and surface water contamination. The greatest potential contamination would be where a shallow water table occurred beneath a sandy soil with low organic matter content.

Sandy soils are usually warmer and better aerated than fine-textured soils and therefore permit more rapid decomposition of organic matter (Troeh and Thompson, 1993). Due to their inherent properties, these soils are preferred to clay soils for the cultivation of vegetables. Therefore, if used, sewage sludge would continue to be a long-term source of pollution of crops grown on such soils.

Regarding disposal, a variety of industrial and domestic waste products are currently causing concern. The increased volume of sewage produced in towns and cities of our country due to increased population and the expansion of industrial activities has created and it will continue to create problems of enormous magnitude, unless deliberate efforts are taken to curb the situation. In Tanzania, the principle methods of sludge disposal are landfill, incineration, agricultural land application and disposal at sea.

Agricultural application of sewage sludge is increasingly becoming a common practice for both practical and economic reasons, as it provides an alternative means for its disposal, especially in urban areas. There is, however, very little information on the utilization and effects of sewage sludge in urban gardening in Dar es Salaam and other cities in Tanzania. There is a need, therefore, to document the occurrence and effects of heavy metals in sewage sludge as related to safety of crops grown on sludge-amended soils.

The overall objective of this study was to investigate the influence of sewage sludge-treated soils on heavy metal uptake by Chinese cabbage, lettuce and cowpea, which are the most widely, consumed leafy vegetables in urban and peri-urban areas.

The specific objectives were:

- i. To assess the public acceptance of sludge and its utilization in gardening in Dar es Salaam and Morogoro.
- ii. To assess the potential fertilizer value of sewage sludge obtained from the Mikocheni oxidation ponds in Dar es Salaam.
- iii. To determine the concentration of heavy metals in sewage sludge from the Mikocheni oxidation ponds in Dar es Salaam.
- iv. To determine the uptake of heavy metals by different vegetables grown on sewage sludge-treated soils.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Chemical composition of sewage sludges

Sewage sludge contains significant concentrations of nutrients particularly nitrogen phosphorus and other plant nutrients, and is recognized as having considerable potential as a fertilizer material and soil conditioner (Smith, 1996). The potassium content of all sludges is low and not sufficient to make any significant difference to the recommended quantities of fertilizer K necessary for most cropping situations. Organic matter is also a valuable component of sludge, which can be recycled.

Sewage sludge also has a potential as a source of sulphur (S) for crop growth, providing additional potential benefits to agriculture in areas where atmospheric deposition of S has declined and crop deficiencies are possible. Furthermore, sludge can supply a number of other nutrients (e.g. Mg, Ca, Zn and Cu) but their importance will depend on whether these are deficient in the soil. Therefore, the nutrient content of sewage sludge makes it attractive as fertilizer, hence a likely source of plant nutrients to vegetables and other crops.

Besides the benefits accrued from the utilization of sludges, their use on cropland is constrained by the presence of heavy metals. Metals and trace elements may persist in the soil indefinitely and may be absorbed by growing plants in a wide range of quantities to affect the health of plants and/or consumers (Adam *et al.*, 1989).

Moreover, the range of hazardous organic chemicals known to exist in sewage sludge is extensive and diverse and these compounds are potentially transferred to sludge-amended agricultural soils. The occurrence, fate and potential impact of trace organic contaminants in sewage sludge and sludge treated agricultural land have been extensively reviewed by Lester (1983).

2.2 Heavy metal contents of industrial and domestic wastes

Industrial wastes generally include wastes generated in any process of industry, manufacturing, trade or business and mining activities; while domestic wastes that require disposal are sewage and solid wastes (Cameron *et al.*, 1997). Heavy metals are present in these waste materials. Sewage sludge is probably the major source, but other wastes such as tannery effluents, pulp and paper sludge, landfill leachate, and piggery wastes can also contribute to heavy metal accumulation in soil (McLaren and Smith, 1996; Cameron *et al.*, 1997).

The disposal of urban and industrial wastes can lead to soil pollution from the deposition of aerosol particles emitted by the incineration of metal-containing materials. For example, the careless (or unauthorized) dumping or disposal of metal-containing items, ranging from miniature dry cell batteries to abandoned cars and car components [e.g. Pb-acid batteries) can give rise to small areas of very high metal (e.g. Ni, Cd and Hg) concentrations in soils (Alloway, 1990).

Furthermore, the disposal of some domestic wastes by burning on garden bonfires or burial in the garden can also result in localized but anomalously high concentrations of metals, such as Pb, in soils used for growing vegetables.

Certain animal wastes produced in agriculture also have the potential to cause metal contamination of the soil. Although most manure are seen, quite rightly, as valuable fertilizers, pig and poultry wastes may contain Cu and Zn added to diets as growth promoters (Chaney and Oliver, 1996). The manure produced from animals on such diets contains high concentrations of Cu and/or Zn, and can cause considerable build up of these metals if applied on the soil (McGrath *et al.*, 1982).

A comparison of heavy metals between different inputs show that farm yard manure (e.g. Cu-content in pig slurry resulting from fodder supplement) deposits heavy metals in the soil in the same order of magnitude as bio-compost or sewage sludge. It is clear from the above review, therefore, that substantial amounts of the wastes produced in urban and industrial areas provide the most likely sources of heavy metal contamination when applied to soil.

2.3 Build-up of heavy metals in soils upon addition of sludges

The application of sewage sludge to agricultural land causes retention of heavy metals in soil. Heavy metal pollution can affect all ecosystems in the environment but its effects are long lasting in soils due to the relatively strong adsorption of many metals onto the humic and clay colloids in the soils (Chang *et al.*, 1984; Alloway and Ayres, 1993).

In most soils, heavy metals are highly immobile and only a small percentage of the total content of metal in a soil is removed through crop uptake, leading to residence times of the order of hundreds to thousands of years (McGrath, 1987). For example, first half-lives of Cd, Cu, and Pb are in the range 15-1100 years, 310-1500 years and 740-5900 years respectively, depending on the soil type and their physico-chemical parameters.

Studies on the changes in the bioavailability of heavy metals with time have generally shown that high concentration of many metals remain available for several years after application of sludge (Alloway and Jackson, 1991). McGrath and Lane (1989) reported that more than 80% of toxic metals added to soil were still present 25 years after sludge application. In another study, McBride *et al.* (1997) reported that, the Zn and Cd remaining in the top soil (pH 6.5-7.0) after 15 years of sludge application was plant available, as indicated by excess uptake and severe phytotoxicity symptoms in vegetable crops.

Brallier *et al.* (1996) studied the plant metal uptake from sewage sludge amended soils applied 16 years previously with a rate of 500 t/ha and found that, metals were still available for plant uptake. Furthermore, Goto *et al.* (1997) reported that most of the Zn applied to the soil remained in both surface and middle soil layers 19 years after the application of the sludge to the field.

During recent years it has been realized that heavy metals from industrial effluents can accumulate in sewage sludge and constitute a hazard if taken-up by crops

growing on sludge-treated soils. Copper and Zn are two metals that are consistently added to soils in increasing quantities in the form of fertilizers, pesticides, livestock manures, sewage sludges and industrial emissions (Adriano, 1986).

Cadmium, being more highly soluble than other heavy metals, is a frequently detected contaminant as are nickel, copper and molybdenum (Tan, 1994). Contamination of soils with metals can arise directly as a result of the active disposal of wastes onto land, or indirectly as a result of some other agricultural, industrial or human activity (Merry and Tiller, 1991).

2.4 Factors affecting the behaviour of heavy metals in soils

Four attributes namely pH, organic matter content, soil texture and the content of sesquioxides are commonly used for evaluation of element adsorption in soils (Sommers *et al.*, 1987; McLaughlin *et al.*, 1996; Towers and Paterson, 1997). Msaky and Calvet (1990) reported that retention of heavy metals by soils depended on factors such as the nature of the mineral and organic constituents, the nature of the metal, the composition of the soil solution and the pH.

It is deemed necessary, therefore, to briefly review the connection between the total metal content and the concentration in the soil solution in relation to major soil parameters such as pH, soil organic matter content (SOM), CEC and secondary minerals.

2.4.1 Soil pH

Most heavy metals become quite insoluble in soils of about pH 6 or higher. With the exception of Mo, Se and As, trace element mobility decreases with increasing soil pH due to precipitation as insoluble hydroxides, carbonates and as organic complexes (Kiekens, 1984). Therefore increasing pH by liming reduces the absorption of heavy metals by plant roots. Adsorption onto clay minerals and organic matter is also raised by increasing soil pH value (Kiekens, 1984).

Hooda *et al.* (1997) observed that soils with non-acidic pH and clayey texture tended to achieve better control of metal accumulation in food plants compared to those with an acidic reaction and a coarse texture. In their study, the results showed that liming soils to pH 7 effectively reduced the metal contents in carrots and spinach. Tisdale *et al.* (1993) pointed out that, when Cd is the main concern, sludge should be applied only to soils of pH 6.5 or above, and the maximum allowable rate for crops must not exceed 2.0 kg/acre.

A combination of CEC and pH probably takes into account a large part of the variability in the metal sorbing properties of the soil. In most soils, the organic matter and clay content contribute to the CEC of the soil (Stevenson, 1994).

2.4.2 Cation Exchange Capacity

Cation exchange capacity is recognized as one of the soil properties controlling the retention and toxicity of metals in sludge-treated soils (Logan and Chaney, 1983).

However, soil cation exchange is dependent on other soil factors including pH, organic matter content and soil texture (Brady, 1990).

Research has shown the link between soil CEC and metal bioavailability as a tenuous one. For example, Latterel *et al.* (1976) reported that uptake of Cd, Zn, Cu, Cr and Pb by soybean shoots remained constant as the soil CEC increased. When stepwise multiple regression analysis was applied to the accumulation of Cd by vegetables grown on contaminated soils, Alloway *et al.* (1990) showed that CEC was only important for two soils out of nine probably because of their higher organic matter content since in each case these had been treated with sewage sludge.

Furthermore, Sommers *et al.* (1987) stated that the relationship between CEC and metal uptake from sewage sludge-amended soils had not been conclusively demonstrated under field conditions.

2.4.3 Organic matter

The relationships between heavy metals and organic matter can act in two opposite directions, increasing the solubility of the former or contributing to their immobilization. Manunza *et al.* (1995) have studied the formation of soluble complexes of several metals with dissolved humic or fulvic acids. Organic matter present in some residues added to soils is likely to have complexing properties similar to those observed in humic substances and some evidence exists of the mobilizing effect of such residues. Evans *et al.* (1995) concluded that the retention

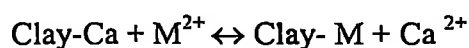
and mobility of toxic elements in soils receiving sewage sludge depend upon the content and nature of the organic fraction of the sludge.

Colloidal organic matter has a strong affinity for heavy metal cations, and the retention of added metals is often well correlated with the amount of soil organic matter. For example, the adsorption of cationic metals such as Cd^{2+} , Zn^{2+} and Cu^{2+} increases with increase in soil organic matter (Stevenson, 1991). The strong affinity of organic matter for heavy metal cations is due to ligands or groups that form chelates and/or complexes with the metals. The functional groups include carboxylic, phenolic, alcoholic and enolic-OH, and carbonyl ($\text{C}=\text{O}$) structures of various types (Stevenson and Ardakani, 1972).

2.4.4 Secondary minerals

Clay minerals are considered very important adsorbents because of their high specific surface area combined with the structural- and pH- dependent charge developed on their surfaces. Silicate and oxide minerals can lower heavy metal solubility and extractability in contaminated soils, although their effectiveness at low soil pH is less than that of organic matter for some metals (Eriksson, 1989).

Heavy metal cations take part in exchange 'reaction' with negatively charged surfaces of clay minerals as set out below:



In acidic soils the reaction is largely reversible and at about pH 5.5 some of the heavy metals, notably Cd^{2+} , are not much stronger competitors than Ca^{2+} for

adsorption by inorganic colloids. However as the pH increases above 5.5, adsorption increases abruptly and with many of the metals the reaction becomes partly irreversible i.e. the metal ion cannot be exchanged against, for example NH_4^+ or Na^+ .

2.5 Crop response to applied sewage sludge

The response of crops to sewage sludge is at least equal to the response to commercial fertilizer in the first year after application and may be somewhat greater in subsequent years because of residual effects of the added plant nutrients (Tisdale *et al.*, 1993). Good crop response, in particular higher barley grain yield and quality were obtained by applying sludge cake for all five years of cropping (Christie and Lindsay, 1997).

In their study, Weir and Allen (1997) showed that the yields of tomato and mustard (*Brassica juncea*) plants, grown on a low pH, compacted silt-loam soil, were generally significantly higher in plots treated with composted sewage sludge and composted yard wastes at 50t/ha each, than in plots receiving applications of commercial NPK fertilizer at 2.2t/ha. Sludge could have been a conditioner and effects were more due to amelioration of physical properties of the soil.

In another study undertaken to study the effects of sewage sludge and phosphate on wheat yield, nutrients content and soil fertility status in an alluvial soil, Gupta *et al.* (1989) observed a complementary effect of sewage sludge on nitrogen uptake by wheat.

2.6 Uptake of metals by plants, entry into the food chain and their effects on living systems.

Transfer of potentially toxic heavy metals from soils into shoots of higher terrestrial plants is typically low compared to those of macronutrients (Adriano, 1986). Typically, uptake of metals occurs from soil solution and particle surfaces (Sposito, 1989) but uptake from less soluble phases e.g. silicates, metal oxides and carbonates is probably kinetically limited.

There have been many studies examining the uptake of metals by plants, which show that for a given soil, the rate of metal absorption increases as the concentration of metal in the soil increases. In soils with low level of metal contamination, a linear correlation between the concentration of Cd and Zn in a given soil and their concentration in plants was frequently observed (Iyengar *et al.*, 1981; King, 1988; Zhao *et al.*, 1997).

However, metals added to the soil in wastes are rarely present on their own as simple salts; for example, sewage sludge contains a wide range of metals which are adsorbed by or bound strongly by the sludge solids, thus reducing their phytoavailability (Chaney, 1994).

Nevertheless, a more complicated relationship has been found when the uptake of Cd and Zn by plants growing in a soil treated with a wide range of metal concentrations is quantified. For example, Christensen and Tjell (1984) showed that while the uptake of Cd by six different crop plants increased linearly with metal concentration

in the soil at concentrations of Cd in the soil less than 4 mg/kg, the uptake of Cd by the plants was independent of the metal concentrations when the concentration of Cd in the soil was greater than 5 mg/kg.

Dowdy *et al.* (1978) reported that the concentration of Zn and Cu in bean leaf tissue increased with amount of metals supplied to soil through additions of sludge, until they reached a maximum concentration which did not respond to higher concentrations of the metals.

There are several mechanisms, which may act simultaneously, that could explain the observation that plant uptake of metal increased with increasing soil metal concentration until it reached a maximum and thereafter was independent of the total concentration of metal in the soil.

Firstly, in soils which have received inputs of metals as a result of repeated applications of sludge, there is evidence to suggest that the chemistry of the sludge may be important in controlling subsequent metal availability in the soil (Corey *et al.*, 1987). This is because sewage sludges typically contain a large proportion of organic and amorphous oxide components, which have a high capacity for specific sorption of metals. Secondly, precipitation reactions could limit metal solubility (Christensen and Tjell, 1984; Mahler *et al.*, 1978).

Moreover, other factors in soil have been shown to influence the uptake of heavy metals by plants. For example, Hinesly *et al.* (1984) reported decreased uptake of heavy metals by plants with increased pH.

Although metal concentrations in plants can be increased by additions of metals to soils, the uptake of most elements tends to be somewhat limited, such that humans, livestock and wildlife may not always be at any chronic risk from metals in the soil (Chaney and Oliver, 1996).

Plant uptake is one of the major pathways by which sludge-borne heavy metals enter the food chain. On the other hand, plant availability of heavy metals differs widely among crop species. For example, the accumulation of Cd, Cu, Ni, Pb and Zn in wheat, carrots and spinach grown on soils previously amended with sewage sludge differed greatly in each crop (Hooda *et al.*, 1997).

In their experiment, Tirmizi *et al.* (1996) showed that cucumber took up the most Pb (48.57 mg/kg) and chillies (*Capsicum*) took up the most Ni (108.57 mg/kg) and they concluded that for a given vegetable, uptake was dependent on soil metal ion concentration. Generally leafy vegetables may have a higher potential of contamination in human nutrition. Some studies have shown that heavy metal contents in crops decreased in the order: roots>stems (leaves)>assimilant storage organs (Il'in, 1991).

Of all the metals present in wastes, it is Cd that has received the most attention regarding its potential passage into the food chain. This is because Cd is readily bioavailable for plant uptake in sludge-treated soil (Vigerust and Selmer-Olsen, 1986). Cadmium can accumulate in the edible portions of crop plants to levels which could potentially be injurious to humans, if consumed for long periods of time and in large quantities, whilst having no apparent detrimental effects on crops themselves (Chaney and Oliver, 1996). For the general population the main exposure to Cd is via food and vegetable products (cereals, bulb crops and leafy vegetables).

Furthermore, contaminated soil can be ingested directly by grazing animals. The soil ingestion pathway was recognized as one of the pathways for risk assessment for potential transfer to humans and livestock of contaminants in sewage sludge-treated soils (Chaney and Oliver, 1996).

It has been demonstrated that elevated metal concentration can reduce soil microbial biomass levels, inhibit N₂ fixation by both free-living and symbiotic organisms, and reduce certain enzyme activities such as urease and phosphatase (Tyler, 1981; Baath, 1989; McGrath, 1994).

There is contradictory evidence relating to the effects of metals on soil biological activity, particularly when the metals are present in sewage sludge (Smith, 1991). Some studies have shown that applications of metal-containing sewage sludge to land can have deleterious effects on soil micro-organisms, particularly after sludge

application has ceased and the organic matter content of the soil has declined (Brookes and McGrath, 1984; McGrath *et al.*, 1988; Giller *et al.*, 1989).

2.7 Phytotoxicity of heavy metals due to use of sewage sludge.

Experiments investigating phytotoxicity due to application of sewage sludge have been reported (Johnston *et al.*, 1983; Chang *et al.*, 1992; Berti and Jacobs, 1996), but generally only where relevant application rate guidelines had been exceeded. This is because at lower levels of sludge application the amount of heavy metals taken up by the plants is almost in the same range as that of in the heavily fertilized plots.

For example, Johnston *et al.* (1983) observed little or no evidence of Cu or Zn toxicity in a field trial from single applications of up to 213 kg Cu/ha and 1610 kg Zn/ha in sewage sludge. Furthermore, Hyun *et al.* (1998) reported results from a field trial in California where cumulative loading of 1370 kg Cu/ha, 10234 kg Zn/ha and 720 kg Ni/ha in sewage sludge had no effect on growth of Swisschard (*Beta vulgaris*), lettuce (*Lactuca sativa*), radish (*Raphanus sativus*), turnip (*Brassica rapa*) and carrot (*Daucus carota*).

At high concentrations, therefore, heavy metals can be phytotoxic and may result in reduced growth and/or enhanced metal concentrations in plants. Studies described by Purves (1985), showed that addition of metal salts resulted in decreased plant growth or complete plant death.

Chang *et al.* (1992) pointed out that yield reduction is the most important measure of phytotoxicity for agronomic species, since it affects the profitability of crop production and may therefore limit the utility of land. Under field conditions yield reductions (25%) may be observed at leaf tissue concentrations of 500mg Zn/kg, 20-40 mg Cu/kg and 50-100 mg Ni/kg (dry matter) (Logan and Chaney, 1983).

Smith (1996) reviewed the literature on the phytotoxicity of sewage sludge-borne heavy metals, and concluded that phytotoxicity has only been observed in glasshouse pot or field trials when high-metal sewage sludge have been applied at high loadings, for example higher than 150 t/ha, to soil or when soils are acidic (pH water <5.5).

From an earlier review of literature on heavy metal toxicity to vascular plants Pahlsson (1989) concluded that the upper critical leaf concentrations of Zn and Cu affecting growth in most species were in the range 200-300 mg Zn/kg and 15-20 mg Cu/kg (dry matter).

From the above review it can be noted that, it is difficult to establish a good relationship between phytotoxicity and sewage sludge metal content. This is due to the variety of reactions that heavy metals undergo in soils and the range of soil characteristics that can mitigate plant uptake of metals from soil.

2.8 Remediation of polluted soils and sewage sludge

Soils that are contaminated with trace metals can pose a serious health threat to living organisms (humans included), therefore reliable remediation techniques are required for site clean-up.

Washing-based techniques may be a practical approach to soil remediation, provided that the solubilization of metals can be dramatically increased and, the flow of the mobilized metal contaminants in the drainage water (the leachates) can be adequately controlled. Since trace metals are sparingly soluble and occur predominantly in a sorbed state (Dowdy and Volk, 1983), washing of soils with water alone would be expected to remove too low an amount of metals to be adopted to clean up contaminated sites. To increase metal solubility and raise the concentration of cations in the leachates, chemical agents have to be added to the washing water (Davis and Singh, 1995).

In a study by Tejowulan and Hendershot (1998) to develop a technique to remove Cd, Cu, Pb and Zn from contaminated soils by means of washing the soils with HCl and ethylene diamine tetraacetic acid (EDTA) solutions, acid washing with $1 \times 10^{-3} \text{M}$ HCl was found to be ineffective in removing trace metals from the soils. In contrast, the extraction with EDTA at a low concentrations (6.84×10^{-4} , 1.37×10^{-3} and $2.74 \times 10^{-3} \text{M}$) removed large amounts of metals. In another procedure to remove metal-EDTA complexes from the leachates using anion exchange resin, 99% of the Cd, Cu and Zn, and 93% of the Pb were recovered from the soil.

In situ stabilization of metals, is another way of remediating polluted soils. It renders the metals immobile and reduces the risks of ground water contamination, plant uptake and exposure to other living organisms (Boisson *et al.*, 1999). Additives to the soil can achieve in situ stabilization of metals. Laperche *et al.* (1996) showed that application of synthetic hydroxyapatite (HA, $\text{Ca}_{10}(\text{PO}_4)_6(\text{OH})_2$) led to immobilisation of Pb in contaminated soils.

Therefore, remediation of soils is deemed important to curb the continued pollution of soils due to anthropogenic sources such as addition of sewage sludge to soils and the contamination of soils by heavy metals inherited from the geological parent materials.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Sewage sludge sampling

Sewage sludge was collected from the oxidation ponds of the Mikocheni area in Dar es Salaam city. The sludge was sun-dried, ground and sieved to pass through a 2mm sieve for chemical analyses and through a 6mm sieve for mixing with the soil for the pot experiment.

3.2 Soil sampling

Composite soil samples were obtained from sites along Msimbazi valley in Dar es Salaam located at 06°49'03.5"S and 39°15'14.8"E and; Mjimpya area in Morogoro located at 06°49'0.8"S and 37°40'18.3"E where vegetables are grown. Mjimpya soil was taken from undisturbed (non cultivated) places in a stretch of land used for vegetable growing along Morogoro River and adjacent to Kaloleni Primary School in Morogoro Municipality. The soil was Dystric Fluvisol (FAO-UNESCO) or Fluvents (US Soil Taxonomy) as described by Msanya *et al.* (2001). The same procedure was adopted to collect soil samples from Msimbazi valley, a Dystric Fluvisol (FAO-UNESCO) or Psammments (US Soil Taxonomy) as described by Msanya and Kileo (2000), close to Kawawa road and along Msimbazi River.

From each of the two sites, soil samples were collected from various points to a depth of 20 cm and thoroughly mixed to constitute a composite soil sample. The soil samples were air-dried, ground and sieved to pass through a 6mm sieve for the pot experiment and through a 2mm sieve for laboratory analyses.

3.3 Soil analysis

3.3.1 Soil pH

The soil pH was measured using a ratio of 1:2.5 (weight: volume) soil: water suspension. Ten g soil samples were mixed with 25 ml water. The mixture was shaken for 30 minutes on a reciprocating shaker and the pH determined using the glass electrode (Thomas, 1996).

3.3.2 Organic carbon.

Organic carbon was determined by the wet digestion method of Walkley-Black (Nelson and Sommers, 1996). One g soil samples were weighed and mixed with 10 ml 1N $K_2Cr_2O_7$ and 20 ml concentrated H_2SO_4 to oxidize the organic matter. The flasks were allowed to stand for 30 minutes when 200 ml of distilled water were added. One ml diphenylamine indicator solution was added and the excess dichromate titrated with 0.5M ferrous ammonium sulphate to deep green colour which marks the end point. The amount of dichromate reduced was a measure of organic carbon content in the soils after multiplying it with 1.33 as recovery factor.

3.3.3 Particle size analysis

Particle size analysis of the soils was determined by the hydrometer method as described in the National Soil Service (1987) laboratory procedures for routine soil analysis. Fifty g air-dried soil samples were weighed into 250 ml polyethene bottles and mixed with 50 ml of the dispersion agent (5% sodium hexametaphosphate solution). Distilled water was added to about 200 ml and left to shake overnight with the bottles in a horizontal position in a reciprocating shaker, at 150 revolutions per

minute (r.p.m). The suspension was transferred to sedimentation cylinders and the volume of mixture made to one litre with distilled water. Hydrometer readings were taken and the relative size proportions calculated.

3.3.4 Total N, available P, CEC and exchangeable bases

Total nitrogen was determined by 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 the Pye Unicam 919 Atomic Absorption Spectrophotometer (AAS).

3.3.5 Total heavy metal contents of the soils

Aqua regia extractable Cd, Cu, Cr, Ni, Pb and Zn, as estimates of total metal contents, were determined according to the procedure developed at the Department of Soil Sciences, Agricultural University of Norway (Jeng and Bergseth, 1992). Two g soil samples were weighed into conical flasks. Twenty ml of freshly prepared aqua regia were added. The flasks were covered with watch glasses with cold water on the top (for cooling and condensation of aqua regia vapour). The mixtures were left overnight and then very gently refluxed for 2h. After careful evaporation at very moderate temperatures the dry residues were warmed with 10 ml of conc. HNO_3 and made up to 100 ml with distilled water to make a matrix of 10% HNO_3 .

The mixtures were filtered through Whatman No. 42 filter paper. The metal contents of the filtrate were determined by AAS, using appropriate standards with the same matrix as that of samples (i.e. 10% HNO₃).

3.3.6 Extractable heavy metal contents of the soils

Cadmium, Cu, Cr, Ni, Pb and Zn were extracted by the DTPA method of Lindsay and Norvell (1978). The extracting solution was composed of 0.005M DTPA, 0.01M CaCl₂ and 0.1M triethanolamine adjusted to pH 7.3. Twenty g soil samples were shaken with 40mls of the extractant for two hours. The suspension was filtered through Whatman No. 42 filter paper. The elements in the soil extract were determined by AAS as for total metal contents.

3.4 Analysis of sewage sludge

3.4.1 pH of sludge

The pH was determined using 1:5.0 (weight:volume) sludge:water suspension (Cottenie *et al.*, 1982). Ten grams sludge samples were mixed with 50 ml water. The mixture was shaken for 30 minutes on a reciprocating shaker and the pH was determined electrometrically, using the glass electrode.

3.4.2 Organic carbon

The same procedure as that for the determination of organic carbon in soil samples (section 3.3.2) was used, except that 0.1 g sludge was weighed.

3.4.3 Total N, total P and total bases

Total nitrogen was determined by the semi micro-Kjeldahl digestion method (Bremner and Mulvaney, 1982) as was the case with that of soils (section 3.3.4). However for total P and the bases, dry ashing of sludge was done. A 1.5 g sample of sludge was weighed and placed in a muffle furnace and ashed for 3 hrs at 550°C. After cooling 10ml 6N HCl were added and mixture filtered through Whatman No. 42 filter paper. The filtrate was made to volume (i.e. 50 ml) using deionized water. From this filtrate, phosphorus, calcium and magnesium were determined by AAS whereas potassium and sodium were determined using flame photometry.

3.4.4 Total heavy metal contents of sludge

Aqua regia extractable Cd, Cu, Cr, Ni, Pb and Zn, as estimates of total metal contents in sludge, were determined as for soils (section 3.3.5).

3.4.5 Extractable heavy metal contents of sludge

Cadmium, Cu, Cr, Ni, Pb and Zn were extracted by the DTPA method of Lindsay and Norvell (1978) as described for soils.

3.5 Pot experiment

A pot experiment was conducted for 42 days (6 weeks) in a screenhouse at SUA, Morogoro. The two soils collected from Msimbazi valley area in Dar es Salaam and Mjimpya area in Morogoro were used for the pot experiment. Six kilograms of each soil were weighed into six-litre plastic pots. The pots had drainage holes at the bottom to avoid waterlogging of soils in the pots.

For each soil, four sewage sludge rates were used i.e. 0, 10, 20 and 30 t/ha corresponding to 0, 5.3, 10.5, and 15.8 g/kg soil. Three vegetable species, namely Chinese cabbage (*Brassica chinensis*), cowpea (*Vigna unguiculata*) and lettuce (*Lactuca sativa*.L.) were used. There were three replications in each treatment and all pots were arranged in a completely randomized design (CRD). Moisture content of the soils was maintained at field capacity by daily application of distilled water to replenish that lost due to evapotranspiration.

3.6 Plant harvesting and analysis

3.6.1 Plant harvesting

On the 42nd day, the Chinese cabbage, cowpea and lettuce were cut at soil level using a knife. All leaves of Chinese cabbage and lettuce were harvested. For cowpea, stems and leaves were harvested separately. The harvested plants were washed with distilled water to remove soil particles, and dried in a forced -air oven set at 70°C to constant weight. The dried plant materials were weighed and dry matter yield obtained. They were ground with a hammer mill prior to analysis for heavy metals and other elements.

3.6.2 Determination of total plant Cu, Cr, Cd, Pb and Zn concentrations

0.5g of the finely ground plant sample was weighed into a digestion tube. To the digestion tube 5 ml of 68% HNO₃ were added using a measuring cylinder (Møberg, 2000). The mixture was left to stand overnight. The digestion tubes containing the mixtures were placed in a digestion block and the temperature was set at 125 °C and the sample digested for one hour. The samples were allowed to cool and 5 ml of 30% H₂O₂ were added and heated to about 70 °C on the digestion block until the reaction stopped. The addition of 5 ml 30% H₂O₂ was repeated until the digest turned colourless. The digests were further heated on the digestion block at a temperature of 180 °C almost to dryness. The digestion tubes were removed from the digestion block and allowed to cool. To the digestion tube, 10 ml 10% HNO₃ were added and the mixture quantitatively transferred into a 50-ml volumetric flask and filled to the mark using distilled water. Cadmium, Cr, Cu, Pb, and Zn were determined using AAS.

3.6.3 Determination of total plant N, P, Ca, Mg, and K concentrations

Total N was determined by semi micro-Kjeldahl digestion followed by distillation (Bremner and Mulvaney, 1982). 0.2g of plant sample was digested with 20 ml of conc. H₂SO₄ in the presence of K₂SO₄, Cu, H₂SO₄ and selenium powder as catalyst, mixed together and swirled in the digestion tube. The tubes were then placed in the digestion block and heated at about 360°C until the digest was pale green. The tubes were then removed from digestion block and allowed to cool, followed by addition of 50 ml of distilled water, while swirling. Twenty ml of 4% boric acid indicator solution were measured into conical flasks and placed under the condenser tube tip.

The digest was distilled after adding about 50 ml of 40% NaOH. The liberated ammonium was collected in 4% boric acid-mixed indicator and then the distillate was titrated with standard 0.05M H₂SO₄ until the colour changed from green to pink. One blank was included for each set of determination. The titre was used to calculate the total N of the soil sample. The digest (section 3.6.2) was used for the determination of P, Ca, Mg, and K. Potassium, Ca and Mg in the digest were analyzed using AAS while phosphorus was determined colorimetrically after a series of dilutions.

3.7 Questionnaire administration

A short unstructured questionnaire (Appendix 1) was used to gather some information concerning the availability, acceptance, utilization and envisaged health effects from sewage sludge and from the crops grown on sludge-amended soils. A sample of 50 vegetable gardeners was included in the interviews. The respondents were selected randomly from areas in Dar-es Salaam and Morogoro where vegetables are grown.

3.8 Statistical analysis of data

Analysis of variance (ANOVA) was carried out on the total heavy metal concentrations of the vegetable plants, DTPA-extractable heavy metals in soils after harvesting, nutrient concentrations in vegetables and dry matter weight data to test for variation in the heavy metal levels, nutrients and yield between the treatments. Comparison of the influence of the soils to heavy metal uptake by vegetables was done using ANOVA (factorial design) where F-value indicated whether or not, there were statistical differences between the soils. The MSTATC computer program was used. The Duncan's New Multiple Range Test was used to rank the means.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Some properties of soils and sewage sludge.

The data pertaining to some physico-chemical properties of the soils used in the present study are indicated on Table 1 and are briefly discussed below. One soil was sandy loam and the other was loamy sand. The textural properties (class) of these soils are favourable for some vegetable production. According to Tindall (1992), for example, well-drained sandy loams are generally considered preferable for the growth of lettuce (*Lactuca sativa* L). Soil pH levels were neutral i.e. 6.9 and 7.1 while organic carbon and organic matter contents were very low and medium for Msimbazi and Mjimpya soils, respectively.

The concentrations of DTPA-extractable and total Cd, Cr, Cu, Pb, Ni and Zn were below the critical ranges stated by Landon (1991) for most agricultural soils. Soils normally contain small amounts of heavy metals like lead, zinc, copper and mercury.

Generally the background heavy metals were in accord with the estimates of normal levels in uncontaminated soils thus having a low potential for causing pollution. Since the soils used in this study were sampled from sites, which historically had not been used to grow vegetables, it is assumed that soil contamination by Cu fungicides or other sources were absent or negligible.

Table 1. Some physico-chemical properties of the experimental soils (0-20 cm)

Property	Location	
	Msimbazi	Mjimpya
pH in water	7.1	6.9
OC (%)	0.12	2.02
Extractable P (mg/kg soil)	0.65	1.67
CEC (Cmol (+)/kg)	19.1	25.1
Exchangeable bases (Cmol (+)/kg soil)		
Ca	5.83	6.48
Mg	2.24	1.40
Na	0.64	0.18
K	0.35	0.75
DTPA-Extractable metals (mg/kg)		
Zn	2.6	2.5
Cu	0.6	1.8
Cd	trace	trace
Pb	0.6	0.3
Cr	nd	nd
Ni	nd	nd
Total metals (mg/kg)		
Zn	38.5	48.6
Cu	2.8	23.6
Cd	0.09	0.35
Pb	0.96	0.49
Cr	7.65	trace
Ni	0.85	trace
Sand (%)	79.1	79.1
Silt (%)	11.3	6.5
Clay (%)	9.6	14.4
Textural class	Loamy sand	Sandy loam

*nd=not detected

Some properties of sewage sludge used in this study are given in Table 2 and are briefly discussed below. The sewage sludge had high organic carbon content (16.02 %) thus high organic matter. Also it had a high amount of N as evidenced by total N (2.01 %). There is a high possibility of increasing total N in the soil and consequently in the plants, upon addition of this sludge to land. Furthermore, the C: N ratio of this sludge is categorized under sludges with high mineralizable N (Chaussod *et al.*, 1986).

Generally the total and extractable heavy metal content of the sludge were well below the permissible levels commonly found in sewage sludge elsewhere. For example, limit concentrations of Cd, Cr, Cu, Pb, Ni and Zn, for safe sludge (unrestricted use) by EPA (1993) are 39, 1200, 1500, 300, 420 and 2800 mg/kg, respectively. The low heavy metal concentrations in this sludge as compared with those set by EPA in USA may be attributed to the source, that is, it was mainly derived from domestic sewage and that little amount of industrial wastes/sludge was mixed with this domestic sewage, hence low concentration of metals in the sludge.

Therefore, basing on those values, this sludge has a low potential for heavy metal pollution of garden soils. However, due to the tendency of heavy metals to accumulate in soils over the years, long-term use of this sludge may culminate in relatively high concentrations of the heavy metals and thus pose pollution threat to the soils and vegetables and subsequently to humans consuming those vegetables.

Table 2. Characterization of the sewage sludge used in the study.

Property	sludge
pH water	6.7
Organic Carbon (%)	16.0
OM	27.6
Total N (%)	2.0
C/N ratio	8.0
Total P (mg/kg)	9.7
C/P ratio	16498
Total bases (cmol(+)/kg)	
Ca	79.2
Mg	36.6
Na	6.8
K	3.1
DTPA-Extractable metals (mg/kg)	
Zn	271.5
Cu	11.3
Cd	0.06
Pb	5.9
Cr	nd
Ni	nd
Total metals (mg/kg)	
Zn	464
Cu	74.5
Cd	1.57
Pb	52.0
Cr	26.1
Ni	15.3

*nd=not detected

4.2 Overview of acceptance and utilization of sewage sludge and health effects of vegetables grown on sludge amended soils

A survey of the vegetable growing areas of Dar es Salaam revealed that gardeners in those areas were not using sewage sludge in vegetable production. From interviews with the gardeners, public acceptance of sewage sludge seems to be divided. About half of the respondents accepted that they would use sewage sludge provided that they were well informed of the benefits of using it. They were, however, not aware of objectionable aspects like presence of heavy metals in sludge.

Another half of the respondents considered sludge as being unaesthetic and they were concerned with the possibilities of contracting diseases such as cholera, dysentery and typhoid fever. They were not aware that sewage sludge might contain toxic heavy metals. It is, therefore, important to shed light on the manurial value of sludge as well as possible presence of heavy metals so that both groups may be better informed.

Results from the interviews (not statistically analyzed) with urban vegetable gardeners from some areas in Morogoro Municipality and Dar es Salaam City indicated that most gardeners were not aware of sewage sludge as being a possible fertilizer or soil amendment for increasing soil fertility in their gardens. The organic manures or amendments known to them and, thus, commonly used were poultry manure, wood shavings, rice husks and tobacco waste (for Morogoro gardeners). They were aware of the benefits of organic amendments to the vegetable gardens,

including their contribution in improving the moisture retention of the soils and/or improving soil fertility. Additionally, organic amendments such as tobacco waste, rice husks and saw dust were applied as a means of their disposal, instead of burning them.

All interviewees reported some use of some inorganic N fertilizers especially urea and ammonium sulphate, in that order of preference. The fertilizer was purchased, even in small quantities like 1 kg from retail shops. The amount of fertilizer applied per bed differed with the vegetable grown and the method of application. For example it was reported that for *Amaranthus* the little amount of fertilizer available was broadcasted; while for vegetables such as cowpea, chinese cabbages, lettuces and others, the fertilizer was added per hill with units ranging from teaspoonful to soda/beer bottle caps. From the interviews, it was not easy to arrive at fertilizer use rates in, say, kg/ha.

Therefore in order to convince urban vegetable growers to use sewage sludge for fertilization of their vegetables, the fertilizer value of sludge must be substantiated to them. Besides, caution should be given on possible deleterious effects of sludge to vegetable crops which, subsequently, may be passed on to humans. In this way, choice may be exercised in selecting the sludge, which may be devoid of toxic elements or pathogenic organisms.

4.3 Effect of sewage sludge on dry matter yields, N, P, K, Ca and Mg concentrations and uptake by vegetables.

Results on dry matter yields of Chinese cabbage, lettuce and cowpea are presented in Table 3. Tables 4 to 7 show the concentrations and uptake of N, P, K, Ca and Mg in the vegetables. Visual observations revealed N-deficiency symptoms in the control (0 t/ha of sludge) treatments in lettuce and Chinese cabbage (Plates 1 and 2).

These results showed that in both Msimbazi and Mjimpya soils, biomass yields of the vegetable species increased significantly ($P < 0.05$) with increasing rates of sewage sludge application. For example, dry matter yields for lettuce ranged from 3.4 to 14.5 and 6.7 to 13.6 g/plant for Msimbazi and Mjimpya soils, respectively. Similar increases were observed for the other vegetable species. In both soils the highest yields were obtained with sewage sludge application at 30t/ha.

The increase in dry matter yields could be attributed to rapid mineralization of nitrogen and other nutrients resulting from the sewage sludge added, owing to presence of such nutrients in the sludge (Table 2). For example, Sommers (1977) reported that on an average, $\text{NH}_4^+\text{-N}$, $\text{NO}_3\text{-N}$ and organic nitrogen components comprised 47, 3 and 50 percent of the available nitrogen in sludge, respectively. Vlamis *et al.* (1978) obtained 3.3 and 1.1 percent of total N and 1.64 and 0.4 percent of total P in Oakland sludge and Pacheco sludge, respectively. They reported significant increase in yields of barley following application of those sludges onto soil. This is why sewage sludge enhances the crop yields, as it was the case of

Table 3. Dry matter yield of vegetables grown in sewage sludge-treated soils

Sewage sludge rate g/kg soil	ton/ha equivalent	Msimbazi soil.....		Mjimpya soil.....			
		Lettuce	Chinese cabbage	Lettuce	Chinese cabbage		
0	0	3.4c	3.3c	5.9b	6.7c	9.8b	13.7b
5.3	10	9.6b	9.3b	13.6a	10.6b	11.6b	14.7b
10.5	20	10.8b	13.9a	15.6a	11.7ab	11.1b	17.1ab
15.8	30	14.5a	15.9a	15.7a	13.6a	17.1a	19.9a
CV (%)		14.4	17.7	22.5	13.6	10.1	9.5
*SEM		0.79	1.07	1.65	0.83	0.72	0.90

* In this and subsequent Tables, SEM= Standard Error of Mean

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

Table 4. Effect of sewage sludge on N, P, K, Ca, and Mg concentration and uptake by lettuce

Sewage sludge rate		N		P		K		Ca		Mg	
g/kg soil	ton/ha equivalent	(%)	(mg/plant)	(%)	(mg/plant)	(%)	(mg/plant)	(%)	(mg/plant)	(%)	(mg/plant)
Msimbazi soil											
0	0	1.48a	50.4c	0.25b	8.8b	3.68b	153.6b	0.77b	26.4c	0.24c	8.5c
5.3	10	1.52a	143.8bc	0.49a	46.8a	4.09ab	501.4a	0.84b	80.3b	0.33b	30.9b
10.5	20	1.85a	234.0ab	0.47a	49.6a	4.43ab	435.5a	1.07a	113.8a	0.43a	49.2a
15.8	30	2.14a	260.1a	0.43a	61.4a	5.20a	528.1a	0.82b	118.8a	0.44a	63.9a
CV(%)		21.40	30.56	16.36	24.06	17.21	22.92	8.16	21.90	13.46	23.83
SEM		0.22	30.37	0.04	5.78	0.43	53.53	0.04	10.73	0.03	5.24
Mjimpya soil											
0	0	1.39b	94.9b	0.37a	25.7b	6.79a	464.6b	0.74a	49.8b	0.30a	20.3b
5.3	10	2.00ab	214.4a	0.44a	46.6ab	7.55a	802.5a	1.09a	115.5a	0.31a	33.3a
10.5	20	1.96ab	251.1a	0.43a	50.3ab	8.16a	952.9a	0.86a	100.6ab	0.31a	36.5a
15.8	30	2.15a	270.3a	0.44a	61.31a	6.68a	901.1a	0.98a	134.7a	0.33a	42.2a
CV(%)		20.06	30.96	18.40	30.84	10.61	18.65	24.13	30.11	14.26	20.48
SEM		0.22	37.12	0.05	8.18	0.45	84.04	0.13	17.41	0.03	3.91

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

Table 5. Effect of sewage sludge on N, P, K, Ca, and Mg concentration and uptake by Chinese cabbage

Sewage sludge rate y/kg soil	N		P		K		Ca		Mg		
	ton/ha equivalent	(%)	(mg/plant)	(%)	(mg/plant)	(%)	(mg/plant)	(%)	(mg/plant)	(%)	
Msimbazi soil											
0	0	1.35b	45.0c	0.25b	8.2b	3.40b	113.6c	1.62b	54.1c	0.27c	8.9c
5.3	10	1.78ab	190.7b	0.29ab	27.1b	3.81ab	355.1b	1.92ab	179.1b	0.32bc	29.14b
10.5	20	2.07a	245.7b	0.41a	58.3a	4.28a	590.1a	2.08ab	286.1a	0.34ab	48.0a
15.8	30	2.21a	354.2a	0.38a	60.3a	3.96ab	627.3a	2.39a	371.4a	0.38a	59.7a
CV(%)		17.24	26.65	22.11	32.6	7.89	13.43	16.78	26.17	10.74	23.54
SEM		0.18	32.14	0.04	7.2	0.18	32.68	0.19	33.61	0.02	4.95
Mjimpya soil											
0	0	1.12c	109.2c	0.45b	44.1c	3.63c	356.4c	1.70a	197.0c	0.26a	32.4b
5.3	10	1.60bc	186.4bc	0.72a	83.5b	5.70b	662.7b	2.07a	205.5c	0.28a	32.5b
10.5	20	2.06ab	228.1b	0.73a	82.5b	6.94a	764.1b	2.28a	286.0b	0.32a	35.4b
15.8	30	2.63a	448.8a	0.75a	112.1a	6.36ab	1078a	2.34a	396.5a	0.32a	54.4a
CV(%)		17.92	22.77	12.89	15.84	8.94	8.04	16.15	14.66	18.42	16.03
SEM		0.19	31.97	0.05	7.37	0.29	33.21	0.19	22.95	0.03	3.58

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

Table 6. Effect of sewage sludge on N, P, K, Ca, and Mg concentration and uptake by cowpea leaves

Sewage sludge rate		N		P		K		Ca		Mg	
g/kg soil	ton/ha equivalent	(%)	(mg/plant)	(%)	(mg/plant)	(%)	(mg/plant)	(%)	(mg/plant)	(%)	(mg/plant)
Msimbazi soil											
0	0	3.80a	134.4b	0.34a	1.1b	2.26a	70.0b	1.23b	3.8b	0.21c	0.7c
5.3	10	3.97a	257.6a	0.30a	2.6a	2.28a	145.2a	1.86a	11.9a	0.48b	3.2b
10.5	20	3.82a	272.4a	0.36a	2.6a	2.03a	145.4a	1.99a	14.3a	0.52b	3.8ab
15.8	30	3.97a	277.1a	0.32a	2.2a	2.04a	152.4a	1.89a	13.2a	0.67a	4.7a
CV(%)		7.99	20.52	13.05	17.2	11.24	19.844.	16.56	23.0	7.43	24.02
SEM		0.18	27.88	0.03	0.2	0.14	14.69	0.17	1.43	0.02	0.43
Mjimpya soil											
0	0	3.59b	223.3b	0.33a	2.1b	2.78a	173.5b	1.84a	11.5a	0.31b	2.0b
5.3	10	3.59b	283.5ab	0.35a	2.4ab	2.95a	193.1b	1.79a	11.9a	0.39a	2.6ab
10.5	20	3.96ab	292.9ab	0.34a	2.5ab	2.88a	213.8ab	1.63a	12.1a	0.35ab	2.6ab
15.8	30	4.29a	348.2a	0.35a	3.2a	2.77a	264.8a	1.62a	15.7a	0.37ab	3.6a
CV(%)		6.18	21.23	11.57	21.58	7.14	15.88	8.64	23.95	8.78	22.82
SEM		0.14	35.17	0.03	0.31	0.12	19.37	0.09	1.77	0.02	0.35

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

Table 7. Effect of sewage sludge on N, P, K, Ca, and Mg concentration and uptake by cowpea stems

Sewage sludge rate g/kg soil	ton/ha equivalent	N		P		K		Ca		Mg	
		(%)	(mg/plant)	(%)	(mg/plant)	(%)	(mg/plant)	(%)	(mg/plant)	(%)	(mg/plant)
Msimbazi soil											
0	0	1.08a	37.2b	0.37a	1.1b	1.68a	46.0b	0.44a	1.2b	0.30ab	0.9b
5.3	10	1.05a	75.8ab	0.30a	2.1ab	1.98a	135.7a	0.31a	2.4ab	0.28b	2.0ab
10.5	20	1.04a	89.7a	0.33a	2.8a	2.11a	179.5a	0.46a	2.8a	0.32ab	2.5a
15.8	30	1.30a	91.3a	0.35a	3.1a	2.13a	186.5a	0.40a	3.5a	0.38a	3.1a
CV(%)		15.80	30.71	13.42	26.83	11.62	24.88	22.87	30.90	14.21	36.90
SEM		0.10	13.04	0.03	0.35	0.13	19.67	0.05	0.44	0.02	0.45
Mjimpya soil											
0	0	0.96a	81.0ab	0.25a	1.9b	2.68a	217.2c	0.21a	1.6a	0.18b	1.4b
5.3	10	1.02a	90.2ab	0.25a	2.0b	2.89a	234.6bc	0.19a	1.7a	0.19b	1.9a
10.5	20	1.07a	74.4b	0.28a	2.2ab	3.27a	291.1a	0.23	2.0a	0.23ab	1.8ab
15.8	30	1.11a	104.7a	0.27a	2.8a	3.26a	336.3a	0.23	2.3a	0.28a	2.2a
CV(%)		8.97	14.75	8.05	18.02	12.21	12.35	20.03	23.67	13.47	12.96
SEM		0.05	7.46	0.03	0.24	0.21	19.24	0.03	0.26	0.02	0.14

Means within a column followed by the same letter are not significantly different ($P=0.05$) according to the Duncan's New Multiple Range Test.



Plate 1 Lettuce response to sludge addition in Mjimpya soil (42DAT)



Plate 2 Chinese cabbage response to sludge addition in Mjimpya soil (42DAT)

vegetable yields in the present study, since it supplied a considerable amount of available N, P and other plant nutrients.

Matemba (2001) reported an increase in the dry matter yield of *Amaranthus* with increasing rates of sewage sludge application up to 60 t/ha. Similar responses were reported by Weir and Allen (1997) of yields of tomato and mustard at a sludge application rate of 50t/ha. Similarly, Misra *et al.* (1995) reported increased yields of spinach at the sludge application rate of 30t/ha. The results of the present study continue to demonstrate the manurial value of sewage sludge in terms of provision of plant nutrients such as nitrogen and phosphorus, which are contained in sewage sludge (Table 2). This potential needs to be tapped when the sludge is known not to contain high levels of objectionable components like heavy metals or pathogens.

A comparable increase in the concentration of total N and corresponding N-uptake in vegetables was observed following addition of sewage sludge in both soils. There was a clear difference between the N concentration in plants growing in sludge-treated pots and those in untreated pots. The P concentration in vegetables was increased slightly by sewage sludge addition in both soils but the increase was not significant ($P=0.05$) among the treatments themselves other than between the control and other treatments, for all vegetables except for Chinese cabbage. For Chinese cabbage and lettuce higher P concentrations were obtained from the amended pots than in the unamended pots. The Ca concentration in vegetables also increased slightly, but as for the case of P, the increase was only significant in Chinese cabbage. The Mg concentration increased with increasing rate of sewage sludge

addition in Msimbazi soil and the increase was significant in all vegetables. The K concentration in vegetables increased with increasing rate of sewage sludge addition in Chinese cabbage and lettuce and a slight/no increase in cowpea leaves and stems where also relatively lower values of K were obtained.

The remarkable deficiency symptoms included yellow colouration in the leaves. However in the case of cowpea no obvious N-deficiency symptoms were observed, probably because of N-fixation.

From the above results it is obvious that sewage sludge can be applied to agricultural soils as a source of nitrogen to crops, including vegetables. Tisdale *et al.* (1993) reported that sewage sludge contained 50 to 90 % of N in organic forms; thus it is a potentially valuable fertilizer in that the N would eventually be mineralized for plant uptake.

Furthermore, sewage sludge addition did not significantly add P to soils and subsequently to plants. This may be due to incomplete mineralization of P from sewage sludge for the duration of 42 days of growth of vegetables. Moreno *et al.* (1996) reported that plants grown in sludge-amended soils showed higher P content than the control plants. However deficiencies of P in vegetable crops are less common and generally less devastating than those of N. Maynard (1979) reported that P deficiency symptoms are likely to appear when leaf P concentrations fall below 0.2% of the dry weight. In the present study, the P concentrations in all vegetables were above 0.2%, implying no deficiency of P in the vegetables.

The critical concentration of N, P, Ca, Mg and K in Chinese cabbage and lettuce as suggested by Maynard and Hochmuth (1997) are 3.5, 0.2, 2.0, 0.4 and 6%, respectively. The results showed that the Ca concentrations in these vegetables were adequate for the normal growth of the plants. Chinese cabbage and lettuce had Mg concentration below or close to the critical level of 0.4%. The normal range of Mg concentration found in vegetable crop leaves is between 0.3 and 0.8 % of the dry weight. However, in Mjimpya soil only a slight increase was observed in all vegetables. These results indicated that probably Mg concentration in this soil was adequate and that the concentration of Mg in sewage sludge was low. A similar trend was observed in the Mg uptake values in all vegetables.

Potassium concentration values in all vegetables were below or slightly above the critical level of 6% at maturity. This observation suggests that this sewage sludge contained low concentrations of K such that additional K requirements of the vegetable crops should be obtained from supplementary potassic fertilizers.

4.4 Influence of sewage sludge on heavy metal uptake by vegetables.

This section discusses the uptake of selected heavy metals by lettuce, Chinese cabbage and cowpea from sewage sludge-treated soils.

4.4.1 Lettuce

Table 8 shows the uptake of heavy metals by lettuce. Generally, higher rates of sewage sludge increased plant uptake of heavy metals in both soils. The uptake of heavy metals by lettuce at 0t/ha sludge application rate from Msimbazi soil was almost half that from Mjimpya soil. Following addition of sludge, however, the uptake for example, of Cd, Cu and Zn by lettuce were slightly higher in Msimbazi soil than in Mjimpya soil, especially at the higher sludge application rates.

The differences in heavy metal uptake by lettuce between the soils at 0t/ha sludge application rate may be attributed to the inherent heavy metal concentrations in both soils that is the Msimbazi soil had lower concentrations than those of the Mjimpya soil (Table 1). From these observations, the trend of increase in heavy metal uptake by lettuce with increased sludge application rates suggest that the sludge used was contaminated with the heavy metals and that the higher rate of sludge caused a subsequent increase of those heavy metals in the soil solution, which were readily absorbed by the vegetables.

Kabata-Pendias and Pendias (1986) reported a linear relationship between Cd, Cu, Pb and Zn contents in edible portions of cabbage or lettuce and total contents of these metals in the soil, implying that as the soil content of heavy metals increased, the

uptake by plants also increased linearly. A somewhat similar trend seems to emerge from the results of the present study. Therefore, lettuce grown on sludge containing high levels of heavy metals may pose health risks upon long-term consumption.

The concentrations of heavy metals in the vegetables (Appendices 2 to 4), as compared to the published critical and phytotoxic levels, showed that, despite the fact that heavy metal concentrations in vegetables were increasing, some metals concentrations were below, and others were slightly above the critical levels. For example, Gardiner *et al.* (1995) recommended a maximum concentration of Cd in spinach to be 0.5 mg/kg dry matter. Davis (1984) reported that field plants generally contained 0.02 to 1 mg Cd/kg dry weight with a mean of about 0.3 mg Cd/kg.

The concentrations of Cu in all vegetable species were below the critical concentrations. For example, Maynard and Hochmuth (1997) suggested critical concentrations for Chinese cabbage and lettuce to be 10 and 15 mg Cu/kg, respectively. Geraldson *et al.* (1973) reported the normal range of Cu in mature trifoliolate leaves of beans to be 15-30 mg/kg. Jarvis (1981) reported that 30 mg Cu/kg in plant tissue were the limit for most plants, above which toxicity symptoms may be observed. Compared with the published critical tissue concentration of 7.5 mg Pb/kg (Pollard, 1991) the concentrations of Pb in all vegetable species were below this value. Maynard and Hochmuth (1997) suggested 50 mg Zn/kg as the critical concentration for Chinese cabbage and lettuce. Based on the results of this study, concentration of Zn in these vegetables were either below or slightly above the critical concentration at the highest sewage sludge application rate.

Table 8. Uptake of heavy metals by lettuce after 42 days of growth in pots

Sewage sludge rate g/kg soil	Msimbazi soil					Mjimpya soil				
	Cd	Cr	Cu	Pb	Zn	Cd	Cr	Cu	Pb	Zn
0	0.94b	0.67b	10.67c	Trace	86.11c	2.18b	1.09c	20.26c	Trace	171.02b
5.3	3.17b	3.56b	41.97b	Trace	304.60b	3.55ab	5.56bc	38.14bc	2.78c	311.74b
10.5	2.81b	3.73b	66.31b	15.27b	474.80b	3.08ab	8.60b	54.99ab	10.43b	411.01ab
15.8	7.98a	14.18a	97.34a	24.39a	725.40a	6.05a	16.05a	67.80a	21.12a	624.23a
CV (%)	66.40	60.10	30.40	43.97	28.59	46.30	34.99	32.47	38.81	34.13
SEM	1.43	1.92	9.49	2.52	65.65	0.99	1.58	8.49	1.92	74.78

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

4.4.2 Chinese cabbage

The uptake of heavy metals by Chinese cabbage is shown in Table 9. Generally there was an increase in the uptake of heavy metals with increased rates of application of sewage sludge in both soils. The uptake of heavy metals by Chinese cabbage at 0 t/ha treatment was the lowest and the highest was at 30 t/ha in both soils. As similarly noted in section 4.3.1, the uptake of heavy metals by Chinese cabbage was higher from Mjimpya soil than from Msimbazi soil in the control treatment.

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The increase in the uptake of heavy metals by Chinese cabbage with increased sewage sludge application rate in both soils may be attributed to enrichment of the soils with heavy metals upon addition of sewage sludge, as discussed in section 4.3.1.

Table 9. Uptake of heavy metals by Chinese cabbage after 42 days of growth in pots

Sewage sludge rate	Msimbazi soil										Mjimpya soil									
	g/kg soil	ton/ha equivalent	Cd	Cr	Cu	Pb	Zn	Cd	Cr	Cu	Pb	Zn	Cd	Cr	Cu	Pb	Zn			
0	0	Trace	0.54c	12.51b	Trace	90.95b	Trace	1.61c	11.45b	Trace	302.82c	Trace	1.61c	11.45b	Trace	302.82c				
5.3	10	Trace	6.15bc	29.84b	Trace	301.74b	Trace	6.17b	17.60b	Trace	421.94bc	Trace	6.17b	17.60b	Trace	421.94bc				
10.5	20	6.02	9.45b	70.33a	14.78	710.52a	3.79	8.12b	32.64b	7.96	471.41b	7.96	8.12b	32.64b	7.96	471.41b				
15.8	30	7.89	18.66a	89.90a	26.50	952.51a	8.39	19.84a	104.60a	25.62	839.53a	25.62	19.84a	104.60a	25.62	839.53a				
CV (%)		28.18	38.16	29.84	18.48	41.90	39.65	26.05	30.86	5.35	14.89	5.35	26.05	30.86	5.35	14.89				
SEM		0.57	11.02	228.40	3.64	46377.10	1.46	1.34	7.41	0.26	43.76	0.26	1.34	7.41	0.26	43.76				

Means within a column followed by the same letter were not significantly different (P=0.05) according to the Duncan's New Multiple Range Test.

4.4.3 Cowpea

The uptake of heavy metals by cowpea leaves and stems is shown in Table 6. There was a general increase in the uptake of heavy metals by cowpea leaves with increased rates of sewage sludge application in both soils. However, some heavy metal concentrations were not detectable in cowpea stems i.e. Cr and Pb, while others were in low concentrations, hence low uptake, except for Cu.

The increase in the uptake of heavy metal by cowpea with increased sewage sludge application rate in both soils may be attributed to enrichment of the soils with heavy metals upon addition of sewage sludge, as discussed in section 4.3.1.

Moreover, differences observed in the uptake of heavy metals by cowpea in both soils may be attributed to the physico-chemical properties of the soils such as clay content, organic carbon and pH and other factors such as environmental and botanical factors as discussed in section 4.5.

Table 10. Uptake of heavy metals by Cowpea leaves and stems after 42 days of growth in pots

Sewage sludge rate		Mjimpya soil									
g/kg soil (ton/ha) equivalent		Msimbazi soil					Mjimpya soil				
		Cd	Cr	Cu	Pb	Zn	Cd	Cr	Cu	Pb	Zn
.....mg/plant.....											
Cowpea leaves											
0		Trace	Trace	7.377b	0.29c	79.44c	Trace	1.13c	40.26b	Trace	186.1b
5.3		Trace	0.71c	20.24b	3.13b	195.8b	Trace	2.85bc	55.49ab	Trace	288.3ab
10.5		2.57	2.52b	42.85a	9.98a	308.1a	2.72	5.30b	66.09ab	3.16	315.3ab
15.8		2.17	3.20a	46.51a	12.14a	273.3ab	2.47	11.18a	77.34a	2.68	414.6a
CV (%)		12.64	23.45	31.21	20.58	20.52	24.32	31.03	32.06	16.08	28.79
SEM		0.09	0.22	5.27	0.76	25.37	0.18	0.92	11.07	0.14	50.05
Cowpea stems											
0		0.00b	nd*	16.17c	nd	58.07b	0.00b	nd	6.33c	nd	139.0b
5.3		0.00b	nd	41.30b	nd	150.6a	0.00b	nd	20.66c	nd	138.9b
10.5		3.34a	nd	70.11a	nd	202.5a	3.16a	nd	46.78b	nd	215.9a
15.8		2.90a	nd	81.99a	nd	207.8a	3.35a	nd	69.21a	nd	275.7a
CV (%)		32.42	nd	22.83	nd	25.31	41.79	nd	33.15	nd	17.37
SEM		0.29	nd	6.91	nd	22.61	0.39	nd	6.84	nd	19.29

*nd = not detected
 Means within a column followed by the same letter were not significantly different (P=0.05) according to the Duncan's New Multiple Range Test.

4.5 Comparative uptake of heavy metals among different vegetable species

The heavy metal uptake by the vegetable species at different rates of sludge application is presented in Table 11. Generally, there were differences in the uptake of some heavy metals with different sludge application rates while for some other metals there were no significant ($P=0.05$) differences.

Cadmium

Generally there was significantly ($P=0.05$) higher uptake of Cd by Chinese cabbage, compared to other vegetable species, in both soils at the 20t/ha and 30t/ha while significantly ($P=0.05$) lower uptake of Cd were observed in cowpea leaves at the same sludge rates. Trace amounts of Cd uptake by the vegetables were observed at the lower sludge rates, that is 0t/ha and 10t/ha, probably due to inherently lower/trace concentrations of the metal in the soils and the sludge.

Chromium

There was no significant ($P=0.05$) difference in the concentration, hence uptake, of Cr in all vegetable species at all rates of sewage sludge application in Mjimpya soil with the exception of the uptake at 10 and 30 tons of sludge/ha. Some differences in the uptake of Cr were observed in Msimbazi soil in all vegetable species, but no significant ($P=0.05$) difference was observed between the more leafy vegetables namely lettuce and Chinese cabbage at the highest sludge application rate. Similarly, as noted in the case of Cd, Chinese cabbage continued to exhibit relatively higher uptake of Cr than other vegetable species.

Table 11. Comparative uptake of heavy metals by different vegetable species

Sludge rate (t/ha)	Vegetable species	Msimbazi soil										Mjimpya soil									
		Cd	Cr	Cu	Pb	Zn	Cd	Cr	Cu	Pb	Zn	Cd	Cr	Cu	Pb	Zn					
0	Lettuce	0.95	0.53	10.67ab	trace	86.11ab	2.18	1.091a	20.26b	trace	171.0b										
	Chinese cabbage	trace	0.68	12.51ab	trace	90.95a	trace	1.61a	11.45c	trace	302.8a										
	Cowpea leaves	trace	trace	7.38b	trace	79.44ab	trace	1.03a	40.26a	trace	186.1ab										
	Cowpea stems	trace	nd	16.17a	nd	58.07b	trace	nd	6.37c	nd	139.0b										
10	Lettuce	3.17	3.56b	41.97a	trace	304.62a	3.55	5.56a	38.14ab	2.78	311.7ab										
	Chinese cabbage	trace	6.15a	29.84ab	trace	301.71a	trace	6.17a	17.6b	trace	421.9a										
	Cowpea leaves	trace	0.71c	20.24b	3.13	195.8ab	trace	2.87b	55.49a	trace	288.3b										
	Cowpea stems	trace	nd	41.30a	trace	150.6b	trace	nd	52.04ab	trace	228.9b										
20	Lettuce	2.81b	3.73b	66.31ab	15.30a	474.8ab	3.08a	8.60a	54.99ab	10.43a	411.0ab										
	Chinese cabbage	6.03a	9.48a	70.33ab	14.78ab	710.5a	3.79a	8.12a	32.64b	7.96b	471.4a										
	Cowpea leaves	2.58b	2.52b	42.85b	9.98b	308.1bc	2.71a	5.30a	66.09a	2.71c	315.3bc										
	Cowpea stems	3.33b	nd	77.89a	nd	202.5c	3.15a	nd	46.78ab	nd	215.9c										
30	Lettuce	7.98a	14.18a	97.34a	24.39a	725.4a	6.05a	16.05ab	67.80a	21.12a	624.2ab										
	Chinese cabbage	7.89a	18.66a	89.90a	28.24a	952.5a	8.39a	19.84a	104.6a	25.62a	839.5a										
	Cowpea leaves	2.08b	3.20b	46.51b	12.14b	273.3b	2.47b	11.18b	77.34a	2.47b	414.6bc										
	Cowpea stems	2.90b	nd	81.99ab	nd	207.8b	3.35b	nd	69.21a	nd	275.7c										

For each sludge rate, means within a column followed by the same letter were not significantly different ($P=0.05$) according to the Duncan's New Multiple Range Test.

Copper

There were significantly ($P=0.05$) lower Cu uptake by the edible portions of the vegetable species at all levels of sludge, except at 10t/ha, in Msimbazi soil. However, Cu uptake by cowpea stems were significantly ($P=0.05$) higher in Msimbazi soil. On the other hand there were some significant ($P=0.05$) differences in Cu uptake by the edible portions of the vegetable species in Msimbazi soil. While in Mjimpya soil some significant ($P=0.05$) differences in Cu uptake, were observed, except for uptake at the highest sludge application rate. For the cowpea, clear differences were observed in the uptake of Cu between the leaves and stems. For example, in Msimbazi soil cowpea stems had significantly ($P=0.05$) higher uptake of Cu than cowpea leaves and the vice versa was observed in Mjimpya soil.

Lead

There was significant ($P=0.05$) difference in the concentration, hence, uptake of Pb by all vegetable species at 20t/ha rate of sewage sludge application in Mjimpya soil, but no significant ($P=0.05$) difference was observed between the more leafy vegetables namely lettuce and Chinese cabbage at the highest sludge application rate. Significantly ($P=0.05$) higher Pb uptake by lettuce and Chinese cabbage, among the vegetable species, were observed in Msimbazi soil at 20t/ha and 30t/ha; but no significant ($P=0.05$) difference in the Pb uptake was observed between lettuce and Chinese cabbage at the highest sludge application rate. Trace amounts of Pb uptake by the vegetables were observed at the lower sludge rates, that is 0t/ha and 10t/ha, probably due to inherently lower/trace concentrations of the metal in the soils and the lack of translocation of Pb from roots to shoots. This argument is supported by

Aldrige and Alloway (1993) who concluded that there is minimal risk of Pb in sludge-treated soils contaminating the human food chain due to crop uptake.

Zinc

There was significant ($P=0.05$) difference in the uptake by the edible portions (lettuce, Chinese cabbage and cowpea leaves) at all sludge application rates in both soils. Zinc uptake by Chinese cabbage was significantly ($P=0.05$) higher at all sludge application rates in both soils. In all rates, however, uptake of Zn by cowpea stems in both soils were significantly ($P=0.05$) lower than in other vegetable parts.

The observation of the uptake of heavy metals by the different vegetable species shown in Table 11 reveals some differences among the vegetable species to accumulate heavy metals. Vegetables vary in their capacity to accumulate heavy metals and some metals are more subject to accumulation than others. The capacity of lettuce, for instance, to accumulate Cd even at the control treatments is in agreement with the results of Jackson and Alloway (1991) who investigated the availability of Cd to lettuce and cabbage in soils previously treated with sewage sludge. Their results showed that lettuce accumulated Cd more readily than cabbage. Furthermore a comparative study by Vlamis *et al.* (1978) of vegetables grown in sludge-amended soil showed that lettuce is an accumulator of metals, but potatoes and carrots are excellent non-accumulators.

The significantly ($P=0.05$) higher uptake of Zn, another mobile metal like Cd, by the different vegetable species in Mjimpya soil; could further be attributed to the

variations in the capacities of the vegetable species to accumulate heavy metals. While significantly ($P=0.05$) lower heavy metal uptake by the vegetables observed in Msimbazi soil may be explained by soil factors, in addition to the vegetable species variations. In general the transfer of Zn from roots to shoots of plant species grown in sludge-treated soils seems to be complicated in the sense that while in some species there is an increase in the uptake of Zn with increased rate of sludge application, in others there is no increase. For example, Dowdy and Larson (1975) reported no increase in the uptake of Zn by spinach after dressing with 30t/ha of a sewage sludge high in Zn concentration.

Therefore, despite the variations in the vegetable species to accumulate heavy metals, the trend of the increase in heavy metal uptake by vegetables with increased sludge application rate has an important bearing on the effects on human health upon long-term consumption of the vegetables grown on sludge-treated soils.

4.6 Comparative uptake of heavy metals between soils

The comparative heavy metal uptake by the vegetables between the two soils is presented in Table 12. The results show that significant ($P=0.01$) differences were obtained in the uptake of heavy metals, except Cd, by cowpea leaves between the two soils. Lead uptake by Chinese cabbage was significantly ($P=0.01$) higher in Msimbazi soil than in Mjimpya soil. However, on the contrary, chromium uptake by lettuce was significantly ($P=0.05$) higher in Mjimpya soil than in Msimbazi soil.

Table 12. Comparative uptake of heavy metals by vegetables between soils

Heavy metal	Statistical differences between soils			
	Cowpea		Chinese cabbage	Lettuce
	leaves	stems		
Cd	ns	ns	ns	ns
Cr	**	nd	ns	*
Cu	**	ns	ns	ns
Pb	**	nd	**	ns
Zn	**	**	ns	ns

*=significant at P=0.05

**= significant at P=0.01

ns= not significant

nd=not determined

From the above observations, it is clear that soils influenced the uptake of some heavy metals in cowpea leaves, while statistically there was no significant influence of soils on the metal uptake by other vegetables. The soil factors that may have contributed to the differences in the heavy metal uptake by the vegetables could be the organic carbon and clay content. First, the lower organic C, hence lower organic matter, in Msimbazi soil than in Mjimpya soil could have led to less adsorption of heavy metals by the soil following addition of these metals contained in sewage sludge. Copper and Cd would clearly illustrate this phenomenon due to their strong binding property/tendency to soil organic matter. The results of this study are in agreement with those of Jarvis (1981) who reported low uptake of Cu into shoots of plants being due to soil organic matter. MacLean (1976) also found that the concentration of Cd was lower in lettuce grown in a soil with the higher amount of

organic matter. Furthermore, Karapanagiotis *et al.* (1991) estimated that the decreasing stability of organo-metal complexes in sludge-amended soil at pH 5.6 was $\text{Cu} > \text{Cd} > \text{Zn} = \text{Pb} > \text{Ni}$, indicating strong binding of Cu to organic matter compared with that of Cd or Zn.

While metal-organic matter complexation well explains the low availability and uptake of Cu and Cd by lettuce, however, some studies show that adsorption of Cd to organic matter is low (Sposito *et al.*, 1982; Keefer *et al.*, 1984 and Baron *et al.*, 1990).

The second factor that may have contributed to differences in heavy metal uptake by lettuce between the two soils was their clay content. Msimbazi soil had lower clay content than Mjimpya soil, thus its limited capacity to adsorb heavy metals. Therefore, the heavy metals added to Msimbazi soil via sewage sludge remained in a relatively more available form that was easily taken up by the plants. On the other hand the relatively high clay content of Mjimpya soil probably favoured greater retention of the heavy metals by this soil, resulting in lower solution concentration and hence lower uptake by the vegetable plants.

The lack of significant differences in the uptake of heavy metals by the other vegetable species between the two soils may be attributed to soil pH. Soil pH strongly modulates the behaviour and availability to plants of heavy metals in soil. The near neutral pH precipitate the metals as insoluble hydroxides, carbonates and/or as organic complexes than the lower pH. This is due to increasing negative soil

surface charge as the solution pH becomes more alkaline. As such there is a progressively larger electrostatic attraction between the negatively charged surfaces and the metal cations as the pH increases. Since the pH (6.9 and 7.1) of the soils used in the present study were high (nearly neutral), it could be supposed that this high soil pH contributed to the lack of significant difference in the heavy metal uptake by the vegetables between the soils. Smith (1994); Kiekens (1984) and Moreno *et al.* (1996) reported the precipitation of metals at high pH.

Moreover, other factors besides soil factors may have contributed to the differences in the heavy metal uptake by the vegetables between the soils. These factors include botanical differences and environmental factors such as temperature and moisture (Ansari *et al.*, 1998).

Therefore, the fact that many soil properties other than pH, and a variety of other environmental factors unrelated to soil type greatly influence the availability of metals in any given soil, the botanical factor should not be discounted.

4.7 Post harvest DTPA-extractable heavy metals in the soil

Data on post harvest DTPA-extractable heavy metals sludge-treated soils are presented in Tables 13 to 16. These DTPA-extractable heavy metals are considered as estimates of the residual amounts of the heavy metals remaining in the soils which would be available for plant uptake in case a subsequent crop were planted without further addition of sludge.

It has been established that once applied to soil, the heavy metals may remain in the upper layers of the soil for long periods of time (McGrath and Lane, 1989), even without any further addition of sludge. It is thus of interest to determine the quantities of these residual heavy metals.

4.7.1 Cadmium

Despite the fact that very small concentrations of DTPA-extractable Cd were present in sludge, and subsequently in sludge-treated soils, some traces of Cd were left in soils even after harvesting of the vegetables (Table 13). These small quantities of Cd did not show any reproducible trend with increasing rates of sludge application.

The small quantities of exchangeable Cd, sometimes at trace levels, associated with the sludge treatments, imply that most of the Cd added with this particular sewage sludge was adsorbed by these soils.

Table 13. DTPA-extractable Cd of soils at harvesting of the vegetables

Sewage sludge rate g/kg soil	Msimbazi soil				Mjimpya soil			
	(ton/ha) equivalent	Lettuce	Chinese cabbage	Cowpea	Lettuce	Chinese cabbage	Cowpea	
0	Trace	0.03	0.01	Trace	0.02	0.02	0.02	
5.3	0.03	0.02	Trace	Trace	0.02	0.02	0.01	
10.5	0.01	0.03	Trace	0.08	0.03	0.03	0.01	
15.8	0.1	0.03	Trace	0.08	0.05	0.05	Trace	
CV (%)	121.6	18.9	195.2	31.7	17.6	17.6	49.0	
SEM	0.00	0.00	0.00	0.01	0.00	0.00	0.00	

4.7.2 Copper

DTPA-extractable Cu in soils increased with increasing rate of sewage sludge (Table 14); but the increase was only significant ($P=0.05$) in Msimbazi soil while in Mjimpya soil no significant ($P=0.05$) difference was observed. The amounts of DTPA-Cu were relatively higher in Mjimpya soil whose organic matter content is higher than in Msimbazi soil (Table 2), probably owing to the factors limiting Cu-bioavailability in sludge-treated soils, mainly Cu-complexation with organic matter.

Thus, the results in Table 14 clearly demonstrate that large amounts of Cu are retained as highly stable organo-copper complexes and are not immediately available to plants as also observed by McBride (1978). Matamba (2001) also observed a decrease in the Cu concentration in the second crop of *Amaranthus* probably showing an increase in the adsorption of Cu by soil after addition of sewage sludge.

Table 14. DTPA-extractable Cu of soils at harvesting of the vegetables

Sewage sludge rate g/kg soil	(ton/ha) equivalent	Msimbazi soil				Mjimpya soil			
		Lettuce	Chinese cabbage	Cowpea		Lettuce	Chinese cabbage	Cowpea	
0	0	0.57b	0.51c	0.49c	1.65a	1.54c	1.39b		
5.3	10	0.70ab	0.60bc	0.65bc	1.84a	1.77b	1.51b		
10.5	20	0.63ab	0.70ab	0.68b	1.68a	1.78b	1.71a		
15.8	30	0.74a	0.74a	0.89a	1.71a	1.90a	1.72a		
CV (%)		12.1	10.4	12.9	5.9	2.7	5.4		
SEM		0.03	0.03	0.05	0.03	0.04	0.05		

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

4.7.3 Lead

The amounts of DTPA-extractable Pb were not consistent with the rates of sewage sludge addition in all the vegetable species. However, a clear difference between the control treatment and sludge-amended treatments was observed.

The low availability of Pb even after sludge amendment could be attributed to the soil pH being high such that availability could not be substantial. Davies (1995) and Chlopecka *et al.* (1996) reported that exchangeable Pb could be accounted for in the very acid soil conditions.

Another reason may be the short duration of growth period of the vegetables or, more precisely, the time of contact of soil and sludge, such that it is difficult to conclusively explain the longterm availability (DTPA-extractable) of Pb in these soils.

Table 15. DTPA-extractable Pb of soils at harvesting of the vegetables

Sewage sludge rate	Msimbazi soil				Mjimpya soil			
	g/kg soil	ton/ha equivalent	Lettuce	Chinese cabbage	Cowpea	Lettuce	Chinese cabbage	Cowpea
0	0		0.31b	1.05b	1.17a	0.35b	0.51b	1.08a
5.3	10		0.80a	0.60c	1.30a	1.00ab	1.07ab	1.10a
10.5	20		0.76a	1.57a	1.05a	1.38a	1.38a	1.42a
15.8	30		0.63ab	1.39a	1.27a	1.66a	1.53a	1.40a
CV (%)			30.2	8.9	11.7	37.0	38.01	15.26
SEM			0.07	0.11	0.05	0.18	0.16	0.07

Means within a column followed by the same letter were not significantly different (P=0.05) according to the Duncan's New Multiple Range Test.

4.7.4 Zinc

DTPA-extractable Zn in soils increased significantly ($P=0.05$) with increasing rate of sewage sludge addition in both soils (Table 16). However, the amounts of DTPA-Zn in Mjimpya soil were relatively higher than in Msimbazi soil.

The increase in the DTPA-extractable Zn in soils after adding sludge was probably due to the contribution of this particular sludge owing to its high content of Zn, thus highest accumulation potential in sludge-treated soils. On the other hand the higher amounts of DTPA-Zn in Mjimpya soil than in Msimbazi soil could be attributed to the higher inherent/background concentration of Zn in Mjimpya soil than in Msimbazi soil. Additionally, it may be implied that the Zn present in available form in the sludge and that released during sludge mineralization was probably not fixed by the soil.

The time from addition of sludge to the determination of DTPA-extractable heavy metals may have a significant contribution to their amount or concentration in the soil; i.e. the shorter the time the lower the availability and vice-versa. In laboratory incubation study Bierman and Rosen (1994) observed that DTPA-extractable Zn, Cu, Cd and Pb increased with incubation time at the higher sewage sludge incinerator ash rates up to 280 days. Earlier, Dowdy and Larson (1975) found that incubation for a one year period increased the release of Zn and Ni but not Cu to plants from an acid soil. Matemba (2001) observed an increase in the concentrations of Zn in the second crop of *Amaranthus* suggesting that availability of Zn in sewage sludge-treated soils increased with time.

Table 16. DTPA-extractable Zn of soils at harvesting of the vegetables

Sewage sludge rate g/kg soil (ton/ha) equivalent	Msimbazi soil				Mjimpya soil			
	Lettuce	Chinese cabbage	Cowpea		Lettuce	Chinese cabbage	Cowpea	
0	3.24d	3.16d	3.17c	7.27c	7.30d	6.99b		
5.3	4.85c	4.43c	4.68c	9.60b	9.36c	7.66b		
10.5	6.12b	5.76b	6.26b	9.76ab	10.20b	10.63a		
15.8	8.25a	7.10a	8.31a	10.73a	11.50a	11.50a		
CV (%)	10.0	4.6	41.6	5.8	4.6	5.9		
SEM	0.57	0.45	0.61	0.4	0.47	0.59		

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

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

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

- i. Acceptance of sewage sludge seemed divided, despite its high fertilizer value. Ignorance on the effects (beneficial and deleterious) of the sludge utilization contributed significantly to that situation.
- ii. Sewage sludge at low rates (<30 t/ha) could be used without causing detrimental effects to soils or on edible parts of the vegetable crops.
- iii. Sludge application to coarse-textured soils resulted in heavy metal accumulation in the soil and increased metal uptake by some vegetable crops. Thus if the fertilizer value of sewage sludge is to be exploited for vegetable production, sludge rates and frequency of application should be based on the heavy metal content of the sludge, the type of the soil receiving the sludge and the type of crops to be grown.
- iv. The differing responses of vegetable species contribute to the differences in uptake of heavy metals from soils. Some species readily absorb heavy metals while others do not, probably due to some plants having some selective mechanisms, which prevent the movement of metals to the edible parts. Generally, leafy vegetables accumulate more heavy metals than non leafy vegetables.
- v. Vegetables growing on sludge treated soils may absorb very little heavy metals, even if their total amount in the sludge may be high. This trend was observed in

case of Cr, Cu and Pb. However, in the case of Cd and Zn, their higher concentrations in sludge led to their higher accumulation in the vegetables, lettuce in particular.

- vi. High concentrations of Zn and Cu and low concentrations of Cd and Pb were noticed in the post-harvest soil indicating that residual effects would be obtained in case of subsequent vegetable cropping and the continued threat of heavy metal pollution to vegetables and humans. Subsequent sludge application will also lead to more important residual effects.
- vii. The sludge had elevated levels of heavy metals but the levels were not toxic, as compared with published toxic levels at other places.

5.2 Recommendations

In view of the results of this study, the following are recommended for future consideration:

- i. Further research on the most suitable, environmentally safe, and agronomically appropriate land application practices of sewage sludge is recommended to minimize any negative impact on the soil and the environment.
- ii. The chemical nature of sludges needs to be further described, to include organic pollutants and pathogens, before predictions about long-term fate of heavy metals are possible.
- iii. Owing to long-term effects of sludge-borne heavy metals to crops and soils due to accumulation effects, long-term experiments/trials on heavy metal accumulations by vegetables are recommended.

- iv. Low application rates (10-20 t/ha) of sludge should be adopted for addition to vegetable gardens, since relatively good dry matter yields are obtained, meanwhile ensuring little adverse effects due to accumulation of heavy metals.
- v. Since sludge can be collected from open areas, awareness on availability and dangers associated with the handling and use of sludge should be underscored to vegetable gardeners.

6.0 REFERENCES

- Adam, C. A.; Bell, P. F. and Mulch, C. (1989). Residual metal concentration in soils and leaf accumulation in tobacco a decade following farmland application of municipal sludge. *Environmental Pollution* 56: 113-126.
- Adriano, D. C. (1986). *Trace Elements in Terrestrial Environment*. Springer-Verlag, New York. pp. 533.
- Aldrige, K. and Alloway, B. J. (1993). Lead in soils and food crops. A literature review for Food Science Division 1, Ministry of Agriculture, Fisheries and Food. Queen Mary and Westfield College, University of London.
- Alloway, B. J. (1990). *Heavy Metals in Soils*. John Wiley and Sons, Inc., New York. pp. 339.
- Alloway, B. J. and Ayres, D. C. (1993). *Chemical Principles of Environmental Pollution*. 1st Ed. Blackie Academic and Professional, London. pp. 291.
- Alloway, B. J. and Jackson, A. P. (1991). The behaviour of heavy metals in sewage sludge-amended soils. *The Science of the Total Environment* 100: 151-176.
- Alloway, B. J.; Jackson, A. P. and Morgan, H. (1990). The accumulation of Cd by vegetables grown on soils contaminated from a variety of sources. *The Science of the Total Environment* 91: 223-236.
- Ansari, T. P.; Kazi, T. G. and Kazi, G. H. (1998). Bioavailability to vegetables of trace and toxic elements from agricultural soil and sludge amended soil. *Hamdard Medicus* 92 (1): 63-67.
- Baath, E. (1989). Effects of heavy metals in soil on microbial processes and populations (a review). *Water Air and Soil Pollution* 47:335-79.

- Baron, J., Legret, M. and Astruc, M. (1990). Study of interactions between heavy metals and sewage sludge. Determination of stability constants and complexation capacities of complexes formed with Cu and Cd. *Environmental Technology* 11: 151-162.
- Berti, W. R. and Jacobs, W.R. (1996). Chemistry and phytotoxicity of trace elements from repeated sewage sludge applications. *Journal of Environmental Quality* 25(6): 1025-1032.
- Bierman, P. M. and Rosen, C. J. (1994). Sewage sludge incinerator ash effects on soil chemical properties and growth of lettuce and corn. *Communications in Soil Science and Plant Analysis* 25: 2409-2437.
- Boisson, J. ; Ruttens, A. ; Mench, M. and Vangronsveld, J. (1999). Evaluation of hydroxyapatite as a metal immobilizing soil additive for the remediation of polluted soils. Part 1. Influence of hydroxyapatite on metal exchangeability in soil, plant growth and plant metal accumulation. *Environmental Pollution* 104: 225-233.
- Brady, N. C. (1990). *The Nature and Properties of Soils*. 10th Edition. Macmillan Publishing Company, New York. pp. 543.
- Brallier, S.; Harrison, R. B.; Henry, C. L. and Xue, D. (1996). Liming effects on availability of Cd, Cu, Ni and Zn in a soil amended with sewage sludge 16 years previously. *Water Air and Soil Pollution* 86(1/4): 195-206.
- Bremner J. M. and Mulvaney C. S. (1982). Total Nitrogen. In: *Methods of Soil Analysis, Part 2 (Edited by Page, A. L.; Miller, R. H. and Keeney, D .R.)*. American Society of Agronomy Madison, Wisconsin. pp. 149-157.

- Brookes, P. C. and McGrath, S. P. (1984). Effects of metal toxicity on the size of the soil microbial biomass. *Journal of Soil Science* 35: 341-346.
- Cameron, K. C.; Di, H. G. and McLaren, R. G. (1997). Is soil an appropriate dumping ground for our wastes. *Australian Journal of Soil Research* 35: 995-1035.
- Chaney, R. L. (1994). Trace metal movement: soil-plant systems and bioavailability of biosolids-applied metals. In: *Sewage Sludge: Land Utilization and Environment*. (Edited by Clapp, C. E; Larson, W. E and Dowdy, R. H.). Soil Science Society of America. Madison, WI. pp. 27-31.
- Chaney, R. L. and Oliver, D. P. (1996). Sources, potential adverse effects and remediation of agricultural soil contaminants. In: *Contaminants and the Soil Environment in the Australasia-Pacific Region*. (Edited by Naidu, R.; Kookana, R. S.; Sumner, M. E.; Harder, R. D. and Tiller, K. G.). Kluwer Academic Publishers, Dordrecht. pp. 323-359.
- Chaney, R. L and Honrick, S. B. (1978). Accumulation and effects of cadmium in crops. In *Cadmium 77: Proceedings of the 1st International Cadmium Conference*. San Francisco Metal Bulletin Ltd, London. pp. 125-140.
- Chang, A. C; Granato, T. C. and Page, A. L. (1992). A methodology for establishing phytotoxicity criteria for chromium, copper, nickel, and zinc in agricultural land application of municipal sewage sludges. *Journal of Environmental Quality* 21:521-536.
- Chang, A. C.; Warneke, J. E.; Page, A. L. and Lund, L. J. (1984). Accumulation of heavy metals in sewage sludge-treated soils. *Journal of Environmental Quality* 13: 87-91.

- Chaussod, R.; Catroux, G. and Juste, C. (1986). Effects of anaerobic digestion of organic wastes on carbon and nitrogen mineralization rates: Laboratory and field experiments. In: *Efficient Land Use of Sludge and Manure*. (Edited by Dam Kofoed, A.; William, J. H. and L'Hermitte, P.). Elsevier Applied Science Publishers Ltd, Barking. pp. 24-36.
- Chino, M.; Goto, S.; Kumazawa, K.; Owa, N.; Yoshioka, O.; Takechi, N.; Inanaga, S.; Inou, H.; De-Long, C. and Youssef, R. A. (1992). Behaviour of zinc and copper in soil with long-term application of sewage sludges. *Soil Science and Plant Nutrition* 38: 159-167.
- Chlopecka, A.; Bacon, M. J.; Wilson, M. J. and Kay, J. (1996). Forms of cadmium, lead and zinc in contaminated soils from South West Poland. *Journal of Environmental Quality* 25: 69-79.
- Christensen, T. H., and Tjell, J. C. (1984). Interpretation of experimental results on cadmium crop uptake from sludge amended soil. In: *Processing and use of Sewage Sludge*. pp. 358-370. Proceedings 3rd International symposium. Brighton, England. September, 1983.
- Christie, P. and Lindsay, E. D. (1997). Alkaline stabilized sewage sludge cake as an organic fertilizer for spring barley. In: *Plant Nutrition for Sustainable Food Production and Environment*. (Edited by Ando, T.; Fujita, K.; Mae, T.; Matsumoto, H.; Mori, S. and Sekiya, J.). Vol. 78. Kluwer Academic Publishers, Japan. pp. 589-590.
- Conway, G. R. and Pretty, J. N. (1991). *Unwelcome Harvest: Agriculture and Pollution* Earthscan Publications Ltd, London. pp. 645.

- Corey, R. B.; King, L. D.; Lue-Hing, C.; Fanning, D. S.; Street, J. J. and Walker, J. M. (1987). Effects of soil properties on accumulation of trace elements by crops. In: *Land Application of Sludge, Food Chain Implications* (Edited by Page, A. L.; Logan, T. J. and Ryan, J. A.). Lewis Publishers, Chelsea, MI. pp. 25-51.
- Cottenie, A.; Verloo, M.; Kiekens, L.; Velghe, G. and Camerlynk, R. (1982). Chemical Analysis of plants and Soils. IWONL, Brussels, Belgium.
- Davies, B. E. (1995). Lead. In: Alloway, B. J. (Ed), *Heavy Metals in Soils*, Second edition. Blackie Academic and Professional, Glasgow. pp. 206-223.
- Davis, A. P. and Singh, I. (1995). Washing of zinc (Zn) from contaminated soil column. *Journal of Environmental Engineering* 121: 174-185.
- Davis, R. D. (1984). Cadmium-A complex environmental problem: II. Cadmium in sludges used as fertilizers. *Experimentia* 40: 117-126.
- Dowdy, R. H. and Volk, V. V. (1983). Movement of heavy metals in soils. In: *Chemical Mobility and Reactivity in Soils Systems*. (Edited by Nelson, D. W.; Elrick, D. E.; Tanji K. K.; Kral, D. M. and Hawkins, S. L.). Special publication number 11. Soil Science Society of America. Madison, Wisconsin. pp. 229-240.
- Dowdy, R. H.; Latterel, J. J.; Hinesly, T. D.; Grossman, R. B. and Sullivan, D. L. (1991). Trace metal movement in an Acric Ochraqualf following 14 years of annual sludge applications. *Journal of Environmental Quality* 20: 119-123.
- Dowdy, R. H. and Larson, W. E. (1975). The availability of sludge-borne metals to various vegetable crops. *Journal of Environmental Quality* 4: 278-282.

- Dowdy, R. H.; Larson, W. E.; Titrud, J. M. and Latterel, J. J. (1978). Growth and metal uptake of snap beans grown on sewage sludge amended soil: A four year field study. *Journal of Environmental Quality* 7: 252-257.
- Eriksson, J. E. (1989). The effects of clay, organic matter and time on adsorption and plant uptake of cadmium added to the soils. *Water Air Soil Pollution* 48: 317-335.
- Evans, L. J.; Spiers, G. A. and Zhao, G. (1995). Chemical aspects of heavy metal solubility with reference to sewage sludge amended soils. *International Journal of Environmental Analytical Chemistry* 59: 291-302.
- EPA; Environmental Protection Agency (1993). Part 503. Standards for the use and disposal of sewage sludge. *Federal Register* 58: 9387-9404.
- Gardiner, D. T.; Miller, R. W.; Badamchian, B.; Azzari, A. S. and Sisson, D. R. (1995). Effects of repeated sewage sludge application on plant accumulation of heavy metals. *Journal of Agriculture Ecosystem and Environment* 55(1): 1-6.
- Geraldson, C. M.; Klacan, G. R. and Lorenz, A. O. (1973). Plant analysis as an aid in fertilizing vegetable crops. In: *Soil Testing and Plant Analysis*. (Edited by Walsh, L. M. and Beaton, J.). Soil Science Society of America. Madison, Wisconsin. pp. 365-379.
- Giller, K. E.; McGrath, S. P. and Hirsch, P. R. (1989). Absence of nitrogen fixation in clover grown on soil subject to long term contamination with heavy metals is due to survival of only ineffective rhizobium. *Soil Biology and Biochemistry* 21: 841-848.

- Goto, S.; Chino, M.; Yamagishi, J. and Kumazawa, K. (1997). Effects of long-term applications of sewage sludge on Zn and Cu retention in sludge-treated soil. In: *Plant Nutrition for Sustainable Food Production and Environment*. (Edited by Ando, T; Fujita, K.; Mae, T.; Matsumoto, H.; Mori, S. and Sekiya, J.). Vol. 78. Kluwer Academic Publishers, Japan. pp. 603-604.
- Gupta, A. P.; Narwal, R. P. and Antil, R. S. (1989). Effect of different levels of nitrogen and sewage sludge on wheat. *Journal of Indian Society of Soil Science* 37: 576-580.
- Hinesly, T. D.; Redberg, K. E.; Pietz, R. I. and Ziegler, E. L. (1984). Cadmium and Zn uptake by corn (*Zea mays* L.) with repeated applications of sewage sludge. *Journal of Agriculture and Food Chemistry* 32: 155-163.
- Hooda, P. S. and Alloway, B. J. (1993). Effects of time and temperature on the bioavailability of Cd and Pb from sludge-amended soils. *Journal of Soil Science* 44: 97-110.
- Hooda, P. S.; McNulty, D.; Alloway, B. J. and Aitken, M. N. (1997). Plant availability of heavy metals in soils previously amended with heavy applications of sewage sludge. *Journal of the Science of Food and Agriculture* 73 (3): 446-454.
- Hue, N. V.; Silva, J. A. and Arifin, R. (1988). Sewage sludge-soil interactions as measured by plant and soil chemical composition. *Journal of Environmental Quality* 17: 384-390.
- Hyun, H.; Chang, A. C.; Parker, D. R. and Page, A. L. (1998). Cadmium solubility and phytoavailability in sludge-treated soil: effects of soil organic carbon. *Journal of Environmental Quality* 27: 329-334.

- Il'in, V. B. (1991). Heavy metal pollution of vegetable garden soils and crops in the cities of Kuzbas. *Soviet Soil Science* 23(10): 104-114.
- Iyengar, S. S.; Martens, D. C. and Miller, W. P. (1981). Distribution and plant availability of soil zinc fraction. *Soil Science Society of America Journal* 45: 735-739.
- Jackson, A. P. and Alloway, B. J. (1991). The bioavailability of cadmium to lettuce and cabbage in soils previously treated with sewage sludges. *Plant and Soil* 132: 179-186.
- Jarvis, S. C. (1981). Copper concentration in plants. In: *Copper in Soils and Plants*. (Edited by Loneragan, J. F.; Robinson, A. D. and Graham, R. D.). D. Reidel Publishing Company, Dordrecht. pp. 265-285.
- Jeng, A. S. and Bergseth, H. (1992). Chemical and mineralogical properties of Norwegian alumshale soil, with special emphasis on heavy metal content and availability. *Acta Agriculturae Scandinavica, Section B, Soil and Plant Science* 42: 88-93.
- Johnston, N. B.; Beckett, P. H. T. and Waters, C. J. (1983). Limits of zinc and copper toxicity from digested sludge applied to agricultural land. In: *Environmental Effects of Organic and Inorganic Contaminants in Sewage Sludge*. (Edited by Davis, R. D.; Hucker, G. and L'Hermite, P.). D. Reidel Publishing Company, Dordrecht. pp. 75-81.
- Kabata-Pendias, A. and Pendias, H. (1986). *Trace Elements in Soils and Plants*, First edition CRC Press, London. pp. 458.

- Karapanagiotis, N. K.; Sterrit, R. M. and Lester, J. N. (1991). Heavy metal complexation in sludge-amended soil. The role of organic matter in metal retention. *Environmental Technology* 12: 1107-1116.
- Keefer, R. F.; Codling, E. E. and Singh, R. N. (1984). Fractionation of metal organic complexes extracted from a sludge-amended soil. *Soil Science Society of America Journal* 48: 1054-1059.
- Kiekens, L. (1984). Behaviour of heavy metals in soil. In: *Utilization of Sewage Sludge on Land: Rates of Application and Long-term Effects of Metals*. (Edited by Davis, R. D.; Hermite, P. and Reidel, L.). Reidel Publishing Company, Dodrecht. pp. 126-134.
- Kim, S. J.; Chang, A. C.; Page, A. L. and Warneke, J. E. (1988). Relative concentrations of cadmium and zinc in tissue of selected food plants grown on sludge-treated soils. *Journal of Environmental Quality* 17: 568-573.
- King, L. D., (1988). Effect of selected soil properties on cadmium content of tobacco. *Journal of Environmental Quality* 17: 251-255.
- Landon, J. R. (1991). *Booker Tropical Soil Manual*. A handbook for soil survey and agricultural land evaluation in the tropics and subtropics. Longman, New York. pp. 450.
- Laperche, V.; Traina, S. J.; Gaddam, P. and Logan, T. J. (1996). Chemical and mineralogical characteristics of Pb in a contaminated soil: Reactions with synthetic apatite. *Environmental Science Technology* 30: 3321-3326.
- Latterell, J. J.; Dowdy, R. H. and Ham, G. E. (1976). Sludge-borne metal uptake by soybeans as a function of soil cation exchange capacity. *Communications in Soil Science and Plant Analysis* 7: 465-476.

- Lester, J. N. (1983). Occurrence, behaviour and fate of organic micropollutants during waste water and sludge treatment processes. In: *Environmental Effects of Organic and Inorganic Contaminants in Sewage Sludge*. (Edited by Davis, R.D.; Hucker, G. and L'Hermite, P.). D. Reidel Publishing Company, Dodrecht. pp. 3-18.
- Lindsay, W. L. and Norvel, W. A. (1978). Development of DTPA soil test for Zn, Fe and Cu. *Soil Science Society of America Journal* 42: 421-428.
- Logan, T. J. and Chaney, R. L. (1983). Utilization of municipal wastewater and sludge on land. In: *Proceeding of the 1983 Workshop, on Utilization of Municipal Wastewater and Sludge on Land*. (Edited by Page, A. L.; Logan, T. J. and Ryan, J. A.). Sponsored by EPA, ACE, USDA, NSF and University of California-Kearney Foundation of Soil Science. University of California, Riverside, CA. pp. 235-326.
- MacLean, A. J. (1976). Cadmium in different plant species and its availability in soils as influenced by organic matter and additions of lime, P, Cd and Zn. *Canadian Journal of Soil Science* 56: 129-138.
- Mahler, R. J.; Bingham, F. T. and Page, A. L. (1978). Cadmium-enriched sewage sludge application to acid and calcareous soils: Effect on yield and cadmium uptake by lettuce and chard. *Journal of Environmental Quality* 7: 274-281.
- Manunza, B.; Deiana, S.; Maddau, V.; Gessa, C. and Seeber, R. (1995). Stability constants of metal-humate complexes: Titration data analyzed by bimodal Gaussian distribution. *Soil Science Society of American Journal* 59: 1570-1575.

- Matemba, L. E. (2001). Occurrence of some heavy metals in sewage sludge in some urban areas and their uptake by Amaranth (*Amaranthus hybridus*). Unpublished Dissertation for Award of MSc Degree at Sokoine University of Agriculture, Morogoro, Tanzania. pp. 85-98.
- Maynard, D. N. (1979). Nutritional disorders of vegetable crops. A review. *Journal of Plant Nutrition* 1 (1): 1-24.
- Maynard, D. N. and Hochmuth, G. J. (1997). *Knott's Handbook for Vegetable Growers*. 4th Ed. John Wiley and Sons, Inc. London. pp. 582.
- McBride, M. B. (1978). Retention of Cu^{2+} , Ca^{2+} , Mg^{2+} and Mn^{2+} by amorphous alumina. *Soil Science Society of America Journal* 42: 27-31.
- McBride, M. B.; Richards, B. K.; Tammo, S.; Russo, J. J. and Sebastien, S. (1997). Mobility and solubility of toxic metals and nutrients in soil fifteen years after sludge application. *Soil Science* 162(7): 487-500.
- McGrath, S. P. (1987). Pollutant Transport and Fate in Ecosystems. Special Publication No. 6 of the British Ecology Society. Blackwell Scientific, Oxford. pp. 301-317.
- McGrath, S. P. (1994). Effects of heavy metals from sewage sludge on soil microbes in agricultural ecosystems. In: *Toxic Metals in Soil-Plant Systems*. (Edited by Ross, S. M.). John Wiley, Chichester. pp. 231-236.
- McGrath, S. P.; Chang, A. C.; Page, A. L. and Witter, E. (1994). Land application of sewage sludge: Scientific perspectives of heavy metal loading limits in Europe and the United States. *Environmental Reviews* 2: 108-118.

- McGrath, D.; Fleming, G. A.; McCormak, R. F. and Poole, D. B. R. (1982). Effects of applying copper-rich pig slurry to grassland. 2. Land-spreading trial. *Irish Journal of Agricultural Research* 21: 49-60.
- McGrath, S. P. and Lane, P. W. (1989). An explanation for the apparent losses of metals in a long-term field experiment with sewage sludge. *Environmental Pollution* 60: 235-256.
- McGrath, S. P.; Brookes, P. C. and Giller, K. E. (1988). Effects of potentially toxic metals in soils derived from past applications of sewage sludge on nitrogen fixation by *Trifolium repens* L. *Soil Biology and Biochemistry* 20: 415-424.
- McLaren, R. G. and Smith, C. J. (1996). Issues in the disposal of industrial and urban wastes. In: *Contaminants and the Soil Environment and Australasi-Pacific region*. (Edited by Naidu, R.; Kookana, R. S.; Sumner, M. E.; Harter, R. D. and Tiller, K. G.). Kluwer Academic Publishers, Dordrecht. pp. 183-212.
- McLaughlin, M. J.; Tiller, K. G.; Beech, T. A. and Smart, M. K. (1994). Soil salinity causes elevated cadmium concentrations in field-grown potato tubers. *Journal of Environmental Quality* 23: 1013-1018.
- McLaughlin, M. J.; Tiller, K. G.; Naidu, R. and Stevens, D. P. (1996). Review: the behaviour and environmental impact of contaminants in fertilizers. *Australian Journal of Soil Research* 34: 1-56.
- Merry, R. H. and Tiller, K. G. (1991). Distribution and budget of cadmium and lead in an agricultural region near Adelaide, South Australia. *Water Air and Soil Pollution* 57/58: 171-180.

- Misra, S. G.; Tiwari, S. D. and Dinesh-Mani, M. (1995). Response of sludge along with Mussorie Rock Phosphate on the biomass and heavy metals uptake by spinach. *Current Agriculture* 19 (1): 59-61.
- Mlozi, R. S. (1995). Information and problems of urban agriculture in Tanzania: Intention and Realisation. Unpublished PhD. Thesis. Sokoine University of Agriculture, Tanzania. pp. 300- 302.
- Møberg, J. P. (2000). Soil and Plant Analysis Manual. Chemistry Department, KVL, Copenhagen, Denmark.
- Moreno, J. L.; Garcia, C.; Hernandez, T. and Ayuso, M. (1997). Application of composted sewage sludges contaminated with heavy metals to an agricultural soil. Effect on lettuce growth. *Soil Science and Plant Nutrition* 43: 565-574.
- Moreno, J. L.; Garcia, C.; Hernandez, T. and Pascual, J. A. (1996). Transference of heavy metals from a calcareous soil amended with sewage sludge compost to barley plants. *Bioresource Technology* 55: 251-258.
- Msaky, J. J. and Calvet, R. (1990). Adsorption behaviour of copper and zinc in soils, influence of pH on adsorption characteristics. *Soil Science* 150: 513-522.
- Msanya, B. M.; Kimaro, D. N.; Kimbi, G. G.; Kileo, E. P. and Mbogoni, J. D. J. (2001). Land resources inventory and suitability assessment for the major land use types in Morogoro Urban District, Tanzania. Soils and Land resources of Morogoro Rural and Urban Districts, Volume 4. Department of Soil Science, Faculty of Agriculture, Sokoine University of Agriculture, Morogoro, Tanzania. pp.66.

- Msanya, B. M. and Kileo, E. P. (2000). Feasibility study for the production of Paprika and Marigold flowers in Mapinga Farm, Bagamoyo District, Tanzania: Consultant report prepared for Mapinga farm. pp. 16
- National Soil Service (1987). Laboratory procedures for routine plant analysis. MALD. Agricultural Research Institute Mlingano. Tanga, Tanzania. pp. 238.
- Nelson, D. W. and Sommers, L. E. (1996). Total Carbon, Organic carbon, Organic matter. In: *Methods of Soil Analysis*. Part 3. (Edited by Sparks, D. L.; Page, A. L.; Helmke, P. A.; Loepfert, R. H.; Soltanpour, P. N.; Tabatabai, M. A.; Johnston, C. T. and Sumner, M. E.). Chemical Methods. SSSA. Book Series 5. Madison, Wisconsin. pp. 961-1010.
- Olsen, S. R. and Sommers, L. E. (1982). Phosphorus. In: *Methods for Soil Analysis*. Part 2. (Edited by Page, A. L. Miller, R. H. and Keeney, D. R.). American Society of Agronomy. Madison, Wisconsin. pp. 403-430.
- Othman, O. C. and Behemuka, T. E. C. (1996). *A study of levels of cadmium, lead, zinc and copper in vegetables from Dar-es-Salaam*. Proceedings of COSTECH Workshop, Dar-es-Salaam, Tanzania. 6-8 March, 1996. pp. 48.
- Pahlsson, A. M. B. (1989). Toxicity of heavy metals (Zn, Cu, Cd, Pb) to vascular plants. A literature review. *Water Air and Soil Pollution* 47: 287-319.
- Peter, M. B. and Carl, J. R. (1990). Phosphate and trace metal availability from sewage sludge Incinerator Ash. *Journal of Environmental Quality* 23: 822-830.
- Pollard, G. (1991). Sites with a long history sludge disposal: Phase II (ET 9500). Progress Report to the Department of the Environment: October 1990 to March 1991. WRC Report No. DoE 2769-M. WRC Medmenham, Marlow.

- Purves, D. (1985). *Trace Element Contamination of the Environment*. Elsevier, Amsterdam. pp.486.
- Sanyal, B. (1986). Urban cultivation in East Africa. Tokyo. The Food Energy Nexus Programme, The United Nations University.
- Shuval, H. I.; Adin, A.; Fattal, B.; Ravitz, E. and Yekatiel, P. (1986). Waste Water Irrigation in Developing Countries, World Bank Technical Paper. No.51, Washington.
- Smith, S. R. (1991). Effects of sewage sludge application on soil microbial processes and soil fertility. *Advances in Soil Science* 16: 191-212.
- Smith, S. R. (1994). Effects of soil pH on availability to crops of metals in sewage sludge-treated soils. I. Nickel, copper and zinc uptake and toxicity to ryegrass. *Environmental Pollution* 85: 321-327.
- Smith, S. R. (1996). *Agricultural Recycling of Sewage Sludge and the Environment*. CAB International 1996, Wallingford. pp. 382.
- Sommers, L. (1977). Effects of sewage sludge on nutrient content and yield of barley. *Journal of Environmental Quality* 6: 225-229.
- Sommers, L.; van Volk, V.; Giordano, P. M.; Sopper, W. E. and Bastian, R. (1987). Effects of soil properties on accumulation of trace elements by crops. In: *Land Application of Sludge, Food Chain Implications* (Edited by Page, A. L.; Logan, T. J. and Ryan, J. A.). Lewis Publishers Inc., Chelsea. pp. 25-51.
- Sposito, G. (1989). *The Chemistry of Soils*. Oxford University Press, New York. pp. 234.

- Sposito, G.; Lund, L. J. and Chang, A. C. (1982). Trace metal chemistry in arid-zone soils amended with sewage sludge. 1. Fractionation of Ni, Cu, Zn Cd and Pb in solid phases. *Soil Science Society of American Journal* 46: 260-264.
- Stevenson, F. J. (1991). Organic matter-micronutrient reactions in soil. In: *Micronutrients in Agriculture*, 2nd Ed Soil Science Society of America Book Series. pp. 145-186.
- Stevenson, F. J. (1994). *Humus Chemistry: Genesis, Composition Reactions*, 2nd Ed. Wiley, New York. pp. 496.
- Stevenson, F. J. and Ardakani, M. S. (1972). In: Organic matter reactions involving micronutrients in soils. In : *Proceeding of Soil Science Society of America*, (Edited by Mortvedt, J. J.; Giordano, P. M. and Lindsay, W. L.). D. Reidel Publishing company, Dordrecht. pp. 79-114.
- Tan, Kim H. (1994). *Environmental Soil Science*. Marcel Dekker, Inc. New York. pp. 304.
- Tejowulan, R. S. and Hendershot W. H. (1998). Removal of trace metals from contaminated soils using EDTA incorporating resin trapping techniques. *Environmental Pollution* 103:135-142.
- Thomas, G. W. (1996). Soil pH and Soil Acidity. In: *Methods of Soil Analysis, part 3* (Edited by Sparks, D. L., Page, A. L., Helmke, P. A., Loeppert, R. H., Soltanpour, P. N., Tabatabai, M. A., Johnston, C. T., and Sumner, M. E.). American Society of Agronomy, SSSA. Book Series 5. Madison, Wisconsin. pp. 475-489.
- Tindall, H. B. (1992). *Vegetables in the Tropics*. MacMillan Education Ltd., London. pp. 512.

- Tirmizi, S. A.; Javed, I.; Saeed, A. and Samina, F. (1996). A study of the inorganic elements in vegetable and soil samples of the polluted and nonpolluted areas of Bahawalpur city (Pakistan). *Hamdard Medicus* 39(3): 90-95.
- Tisdale, S. L.; Nelson, W. L.; Beaton, J. D. and Havlin, J. L. (1993). *Soil Fertility and Fertilizers* 5th edition. Prentice-Hall, Simon & Schuster/ A Viacom Company. Upper Saddle River, New Jersey. pp.634.
- Towers, W. and Paterson, E. (1997). Sewage sludge application to land-a preliminary assessment of the sensitivity of Scottish soils to heavy metal inputs. *Soil Use Management* 13: 149-155.
- Troeh, F. R. and Thompson, L. M. (1993). *Soils and Soil Fertility*. Fifth edition. Oxford University Press, Inc., New York. pp. 462.
- Tyler, G. (1981). Heavy metals in soil biology and biochemistry. In: *Soil Biochemistry* (Edited by Paul, E. A and Ladd, J. N.) Vol. 5. Marcel Dekker, Inc., New York. pp. 371-414.
- United Republic of Tanzania (1991): Tanzania: The national informal sector (TNIS). Dar es Salaam. Government Printer.
- Vigerust, E. and Selmer-Olsen, A. R. (1986). Basis for metal limits relevant to sludge utilization. In: *Factors Influencing Sludge Utilization Practices in Europe.* (Edited by Davis, R. D.; Haeni, H. and L' Hermite, P.). Elsevier Applied Science Publishers, Barking. pp. 26-42.
- Vlamiš, J.; Williams, D. E.; Fong, K. and Corey, J. E. (1978). Metal uptake by barley from field plots fertilized with sludge. *Soil Science* 126 (1): 49-55.

7.0 APPENDICES

Appendix 1:

QUESTIONNAIRE

Date.....
 Residence:
 Street.....Ward.....Division.....
 District/Town/Municipality.....
 Gardening area.....

A. BACKGROUND INFORMATION

1. Farmer's name (optional)
 Gender.....Marital status.....
2. Age of the gardener.....Years in vegetable growing.....

B: VEGETABLE PRODUCTION

3. Do you grow vegetables Yes/No
- 4: Which vegetables do you grow?
 - i.
 - ii.
 - iii.
5. How do you rank the yield of your vegetables?
 - I. Very good
 - II. . Good.
 - III. . Fair.
 - IV. . Poor.

C: INFORMATION ON THE USE OF FERTILIZERS, MANURES AND/OR SEWAGE SLUDGE

6. Do you apply any chemical fertilizer to your garden? Yes/No
 7. If yes, which fertilizer?.....and where do you get them?.....
 8. What quantity do you apply per bed ?.....
 9. Do you apply sewage sludge to your garden? Yes/No
 10. If Yes what amount do you apply per bed?.....
 11. If no in 9, why? (circle the most appropriate)
- Reasons for not applying sewage sludge
- I. Problem of availability
 - II. Expensive
 - III. Lack of knowledge on the processing and handling of the sludge
 - IV. Lack of transport
 - V. Not economical
 - VI. Mere dislike
 - VII. Others, specify

12. What other solid wastes do you apply in your garden?

I.

II.

III.

IV.

13. Where do you obtain wastes?

I. Domestic refuses

II. Oxidation ponds

III. Dumping site

IV. Any other place? (Mention)

14. What are the advantages of applying sewage sludge onto your garden?

To improve soil fertility

II. To increase moisture retention of the soil

III. To prevent soil erosion

IV. As means of disposal

V. Others,specify.

Appendix 2: Heavy metal contents of Chinese cabbage after 42 days of growth in pots

Sewage sludge rate g/kg soil	Msimbazi soil					Mjimpya soil				
	Cd	Cr	Cu	Pb	Zn	Cd	Cr	Cu	Pb	Zn
0	Trace	Trace	3.69ab	Trace	27.28c	Trace	0.17c	1.16c	Trace	30.10c
5.3	Trace	Trace	3.18b	Trace	32.25bc	Trace	0.53b	1.53c	Trace	36.35bc
10.5	0.41	0.43	5.34a	1.09	50.15ab	0.30	0.73b	2.99b	0.73	42.64ab
15.8	0.48	0.50	5.61a	1.79	59.16a	0.39	1.16	6.11a	1.20	49.15a
CV (%)	11.77	25.14	23.24	22.88	24.15	43.93	23.35	24.07	13.43	11.97
SEM	0.02	0.02	0.60	0.10	5.89	0.05	0.09	0.41	0.04	2.74

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

Appendix 3: Heavy metal contents of lettuce after 42 days of growth in pots

Sewage sludge rate g/kg soil	Msimbazi soil					Mjimpya soil				
	Cd	Cr	Cu	Pb	Zn	Cd	Cr	Cu	Pb	Zn
0	0.27a	0.20b	3.07b	Trace	24.94c	0.26a	0.17c	3.03b	Trace	25.57b
5.3	0.33a	0.38b	4.42b	Trace	32.36bc	0.33a	0.53b	3.56ab	0.27c	29.55b
10.5	0.26a	0.36b	6.32a	1.40	45.56ab	0.27a	0.73b	4.70a	0.89b	35.10ab
15.8	0.53a	0.95a	6.69a	1.69	50.12a	0.43a	1.16b	4.91a	1.53a	44.62a
CV (%)	52.16	37.66	19.01	21.29	21.13	44.48	23.60	20.64	20.58	19.69
SEM	0.11	0.10	0.56	0.09	4.67	0.08	0.09	0.48	0.08	3.83

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

Appendix 4: Heavy metal contents of Cowpea leaves and stems after 42 days of growth in pots

Sewage sludge rate		Msimbazi soil										Mjimpya soil									
g/kg soil		mg/kg										mg/kg									
ton/ha equivalent		Cd	Cr	Cu	Pb	Zn	Cd	Cr	Cu	Pb	Zn	Cd	Cr	Cu	Pb	Zn	Cd	Cr	Cu	Pb	Zn
0	0	Trace	Trace	2.42b	Trace	25.43c	Trace	0.17d	6.47b	Trace	29.76a	Trace	0.43c	8.36a	Trace	43.26a	Trace	0.43c	8.36a	Trace	43.26a
5.3	10	Trace	0.11c	3.12b	0.49c	31.65bc	Trace	0.43c	8.36a	Trace	43.26a	Trace	0.43c	8.36a	Trace	43.26a	Trace	0.43c	8.36a	Trace	43.26a
10.5	20	0.27	0.35b	5.92a	1.39b	43.01a	0.24	0.73b	8.92a	0.30	42.40a	0.24	0.73b	8.92a	0.30	42.40a	0.24	0.73b	8.92a	0.30	42.40a
15.8	30	0.36	0.46a	6.65a	1.75a	38.98ab	0.36	1.16a	8.77a	0.24	43.28a	0.36	1.16a	8.77a	0.24	43.28a	0.36	1.16a	8.77a	0.24	43.28a
CV (%)		25.77	21.56	20.85	17.09	14.65	25.77	21.71	11.04	25.77	19.30	25.77	21.71	11.04	25.77	19.30	25.77	21.71	11.04	25.77	19.30
SEM		0.08	0.03	0.54	0.09	2.94	0.02	0.08	0.52	0.03	4.42	0.02	0.08	0.52	0.03	4.42	0.02	0.08	0.52	0.03	4.42
Cowpea stems																					
0	0	Trace	nd*	5.86b	nd	20.35a	Trace	nd	Trace	nd	18.23b	Trace	nd	Trace	nd	18.23b	Trace	nd	Trace	nd	18.23b
5.3	10	Trace	nd	5.94b	nd	21.11a	Trace	nd	Trace	nd	17.12b	Trace	nd	2.54b	nd	17.12b	Trace	nd	2.54b	nd	17.12b
10.5	20	0.39	nd	8.29a	nd	23.91a	0.49	nd	5.94a	nd	28.43a	0.49	nd	5.94a	nd	28.43a	0.49	nd	5.94a	nd	28.43a
15.8	30	0.33	nd	9.35a	nd	23.81a	0.36	nd	6.85a	nd	26.82a	0.36	nd	6.85a	nd	26.82a	0.36	nd	6.85a	nd	26.82a
CV (%)		31.60	nd	12.47	nd	9.37	31.49	nd	33.47	nd	11.47	31.49	nd	33.47	nd	11.47	31.49	nd	33.47	nd	11.47
SEM		0.03	nd	0.53	nd	1.21	0.03	nd	0.74	nd	1.49	0.03	nd	0.74	nd	1.49	0.03	nd	0.74	nd	1.49

*nd = not detected

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