CHAPTER 1

INTRODUCTION

1.1 Health concerns of Pb and Cd in humans and the environment

Lead (Pb) and cadmium (Cd) are toxic metals whose contribution to environmental contamination is becoming a serious concern as they enter the air, food and water in increasingly significant amounts fed by continuous mining and use of metals (Elson and Haas, 2003). Besides Pb and Cd, other metals, such as zinc (Zn), copper (Cu), nickel (Ni), chromium (Cr), iron (Fe), silver (Ag) and mercury (Hg) are of great concern to the environment and human health. Pb and Cd are cumulative toxins that are indestructible and can only be eliminated through excretion (Moolenar and Lexmond, 1999). When they accumulate in the human body, Pb and Cd may cause health problems that include damage to the central nervous system and reduced intellectual capabilities (Wildlife, 2000) and hypertension (Staessen, 2002).

The major pathways of exposure to Pb and Cd in the non-smoking human population are: food and water for Pb and food via the addition of cadmium to agricultural soils and uptake by food and fodder crops, in the case of Cd (Scottish Executive Environment and Rural Affairs Department, 2002). Plants can take up Pb and Cd in high concentrations from the soil (Bazzaz, 1977; Johnston and Hones, 1995; Khan and Frankland, 1983) and hence provide a major pathway to the human food chain. Thus, a good understanding of uptake of Pb and Cd is critical in designing strategies for predicting uptake of the metals into the food chain.

1.2 Metal pollution from wastewater

Wastewater disposal on soils is a major source of metals to plants. The use of wastewater for irrigation is justified on the need to dispose of the water, utilize the scarce water resource, take advantage of the high nutrient content of wastewater and reduce the need for commercial fertilizers (Bayer et al, 1972). It is also a low cost method for sanitary disposal of municipal wastewater. However, disposal of wastewater on land has been widely reported to increase soil metal content, because wastewater contains heavy metals from domestic and industrial sources. Department for Environment, Food and Rural Affairs (DEFRA) and Environmental Agency (2002) noted that disposal of sewage sludge to land increased Cd concentration in soils. Janeic et al (1995) noted that Cd poses the greatest concern with respect to land application of sewage because ingestion of plants that contain large concentrations of the metal by humans and animals may result in Cd accumulation in livers and kidneys. Treated sewage is therefore a potential source of soil contamination that increases the possibility of uptake of Pb and Cd by plants that grow on the soils on which it is disposed.

In Zimbabwe, municipal wastewater is used for irrigation in many peri-urban areas and the practice is expected to increase with the expansion of the existing and creation of new urban centers. One of Harare's largest treatment plants, Firle Wastewater Treatment Plant, processes sewage coming from industrial and domestic sources and disposes mixed treated effluent and sludge on pasturelands at Firle farm. The pastureland consists of sandy soil on which mixed *Cynodon nlemfuensis* (star grass) and *Pennisetum clandestium Chiov*. (kikuyu grass) pasture is irrigated. Firle farm employs 32 farm workers and supports 3 000 beef cattle that are born and bred on the farm. The farm workers and animals may be subjected to hazards emanating from exposure to Pb and Cd. In addition, any hazards that may exist could spread wider, since the population at large consumes beef from animals bred on Firle farm.

1.3 Paucity of data on accumulation of Pb and Cd in star grass

Disposing treated sewage on pastures started over 30 years ago at Firle farm. It was considered to be a cheap method for secondary treatment of wastewater, unfit to be discharged directly into natural watercourses. Although the potential of Pb and Cd to accumulate in soil is known, their accumulation in soils has not been monitored at Firle farm. While there has been limited and inconsistent monitoring of heavy metal content in treated sewage no attempt has been made to quantify Pb and Cd uptake by grass or animals at Firle farm to ascertain compliance of metal content of grass with acceptable levels for grazing pastures. Therefore the health hazards posed by heavy metals to animals that feed on the grasses are not well documented.

To date, only a few short-term studies on the impact of sewage sludge disposal on soils have been carried out in Zimbabwe. One such study by Nyamangara and Mzezewa (1999) investigated the long-term effect of sewage sludge application on Pb, Zn, Cu and Ni levels in a clay loam soil. The study, which was carried out at Crowborough Sewage Treatment Works (one of Harare’s treatment works) concluded that sewage sludge significantly increased the levels of Pb, Zn, Cu and Ni in the soil. The results of the study raised questions regarding the potential uptake of large amounts of metals by pasture grass.

Although uptake of some heavy metals by grasses such as, *Lolium perenne* (rye grass), *Pennisetum purpureur* (elephant grass), *Agrotis stolonifera* (red top) and *Medicago sativa* (alfalfa) has been studied, limited research has been conducted on the genus *Cynodon* to which star grass belongs. No known study has determined Pb and Cd uptake characteristics of star grass. The absence of studies on Pb and Cd in star grass pastures represents a gaping hole in vital scientific information, considering that the grass is a widespread pasture grass in East, Central and Southern Africa and is grown in Zimbabwe using wastewater which potentially contains high levels of Pb and Cd.

The paucity of data on heavy metal pollution is not unique to Zimbabwe, but spread across the developing world. World Health Organisation (WHO) Working Group on Cd, (http://www.icsu-scope.org/cdmeeting/cdwgreport.htm) noted that while the developed world is more concerned about food quality and public health, the developing world and tropical areas in particular face persistent challenges of malnutrition and food security that take precedence over food quality and public health. It further confirmed that tropical areas have relatively few data on Cd accumulation in tropical soils and crops despite them covering a large part of the globe in which two thirds of the world's population lives. Such data would be important for both local public health and international trade. Recognition of the potential hazards caused by heavy metals and the need to protect the environment has resulted in greater investment into research, legislating and enforcing permissible limits of the metals by developed countries. This recognition has spread to developing countries and hence many scientists have called for more research on heavy metal pollution in the developing world.

1.4 Challenges in modelling plant metal uptake from soils

Researchers face many challenges in generating data and analysing it to develop tools for use in minimising environmental and health hazards associated with heavy metals. Many countries worldwide have legislated maximum permissible heavy metal levels (guideline values) in soils, some plants, irrigation water and food for human consumption. However legislated metal limits differ from one country to another, depending on the context in which they were developed. DEFRA and Environmental Agency (2002) stated that soil guideline values may differ from one country to another depending on the conceptual models behind the guidelines, reasons why the assessment criteria were developed, management context, legislation, policy and differences in site conditions, such as soil pH and soil type. Therefore a generic heavy metal permissible limit in soils may not be applicable to all countries and situations.

The soil-plant pathway has attracted research attention since it is a major contributor to transmission of metal pollutants to animals and humans. Efforts have been made to develop soil-plant tissue metal uptake models for predicting plant metal concentrations. Soil-plant tissue uptake models have been used in soil-plant nutrient analysis for a long time. The models have been extended to heavy metal analysis in soil-plant systems and used for predicting levels of pollutant metals in plants on the basis of metal levels in soils. Soil metal levels and plant metal content are central to the development of these models. Factors that affect these two parameters have to be taken into account in developing soil-plant tissue uptake models.

1.4.1 Soil metal concentrations and soil sampling depth

Total soil metal concentrations are widely used in the soil-plant tissue metal uptake models. One major advantage of their use is that standard methods of measuring total metal concentrations in soils are available. However the challenge is that total metal concentrations are increasingly being regarded as inadequate for predicting plant metal content and for public health assessments (Bak and Jensen, 1998). Like-wise, soil-vegetative tissue metal uptake factors (Baes et al 1984) vary with total metal concentrations and can over- or under-predict concentrations of some metals in plants, because they are based on total metal concentration (US Department of Energy, 1998).

The depth of soil from which soils are sampled to determine soil concentrations may introduce errors in relating concentrations of metals in soils and plants because concentrations vary with soil depth. According to the US Department of Energy (1998), the depth interval at which various plants in different environments obtain water and nutrients and the relative biomass of feeder roots at different depths are unknown. Therefore the challenge is what depth one should use in modelling so that the concentrations of metals in that depth reflects uptake of metals by a particular plant.

Soil-plant tissue metal uptake models have been developed from existing data measured at different sites across the world. This approach has presented challenges to modelling plant uptake. US Department of Energy (1998) noted that non-uniformity of soil sampling depth, scarcity of data and variations in methods used to measure soil metal concentration presented constraints to modelling soil-plant metal uptake.

Suggestions have been made to overcome some of the challenges. Bio-available (also known as plant available) levels of metals have been reported to correlate better with plant metal concentration. However, the absence of an agreed standard method for measuring bio-available metal levels in soils (http://www.icsu-scope.org/cdmeeting/cdwgreport.htm) has constrained their use. Another suggestion to improving soil-plant tissue metal uptake models is to incorporate factors that influence availability of metals to plants, such as pH (Jesper and Jensen, 1998). This approach has received considerable attention and although models were developed, site-specific experiments were encouraged (Sample, 1998) to obtain site-specific data for developing models.

1.4.2 Differences in uptake characteristics of plants

Research has also shown that different plant species and cultivars have different metal uptake characteristics and capacities (Kabata-Pendias, 2001). Furthermore, different organs (leaves, fruit, roots, stem) of the same plant have different metal uptake capacities. Therefore uptake characteristics of a particular plant or its organs can only be known if an experiment is carried out on a particular element. The absence of any known studies on Pb and Cd uptake by star grass implies that soil-star grass uptake and growth characteristics, such as metal uptake and yield response, are not known. In addition, the critical metal uptake levels of star grass, such as toxicity levels, are not known and cannot be extrapolated from other grasses that have been studied so far. Therefore, uptake of large quantities of Pb and/or Cd by animals grazing on the treated sewage irrigated star grass pastures could not be ruled out on the basis of available information.

1.4.3 Influence of uptake by other metals

Besides plant species and soil metal concentration, other chemicals in the soil influence uptake of metals by plants (Moolenar and Lexmond, 1999). Other chemicals present in a soil may interact with a particular metal causing an increase or reduction of uptake of the metal by a plant. Khan and Frankland (1983), Miller (1977), Carlson and Rolfe (1979) and others found different and sometimes conflicting results on the influence of Pb on Cd and *vice versa*, where the two metals co-existed in the soil. Preliminary indications were that Pb and Cd were present in treated sewage disposed on Firle farm. Therefore interactions of the two metals could not be ruled out.

In view of the preceding arguments, a long-term study was considered necessary to determine uptake of Pb and Cd by star grass growing on a sandy soil on which treated sewage is disposed of. The following objectives were formulated to investigate the issues.

1.5 Objectives of study

The general objective of this study was to establish the effect of irrigating pastures with a mixture of sewage effluent and sludge from bio-filtration plants on contamination of pasture grass by Pb and Cd. The specific objectives were:

1) To determine the long-term Pb and Cd accumulation in soils subjected to sewage effluent and sludge mixture application

2) To evaluate changes in pasture grass yield level, response to Pb and Cd concentrations and toxicity levels in grass under effluent and sewage sludge mixture application in combination with different levels of added heavy metals

3) To determine Pb and Cd accumulation in pasture grass under effluent and sewage sludge mixture application

4) To determine the maximum level of Pb and Cd concentrations in sewage effluent and sludge mixture that would allow optimisation of yield of grass and prevent heavy metal loading from exceeding acceptable limits

1.6 Scope of study

This study postulated that if star grass was exposed to very high levels of Pb and Cd, then cattle could accumulate high levels of the metals in their body organs through consumption of grass. This could lead to humans also accumulating high levels of the metals through consumption of meat from those animals. To contribute to this wide area of research, this study focused on accumulation of Pb and Cd in soils and star grass. In addition, it focused on developing soil-vegetative metal uptake models that could be used to predict metal uptake in grass using measured soil bio-available metal levels. Within this scope, the study was limited to the main areas of focus described below.

A literature review was undertaken to gather detailed information on Pb and Cd hazards in the environment and to identify gaps for research. This study is therefore based on the gaps identified. The study was conducted on one study site only since the limited financial resources only allowed a limited number of expensive chemical analyses. Recommended levels of the metals in soils and pasture grass where extracted from literature.

Data from chemical tests carried out by the City of Harare on the treatment process were incorporated in the study to save on time and costs of obtaining similar data within the context of this study. Interviews and visits to the treatment plant were undertaken to familiarize the author with the sewage treatment and disposal systems.

A greenhouse pot experiment where soils and grasses were subjected to high levels of Pb and Cd was undertaken to assess uptake of the metals and be able to define toxicity. This was complemented by a field experiment meant to assess uptake under real life conditions and determine what levels of Pb and Cd could be allowed in the soil to ensure that grass did not exceed recommended levels. In the greenhouse experiment uptake was assessed on single added Pb and Cd and the two metals combined. The latter was intended to investigate interactions of Pb and Cd in soils and grasses. One method of extracting bio-available soil metal levels was selected and used throughout the study to ensure consistency.

Since numerous soil and plant factors affect metal accumulation in soils and plants, only selected soil factors, like soil pH, cation exchange capacity (CEC), clay content and organic matter were investigated to assist in the interpretation of Pb and Cd uptake by grass. This implies that other important factors such as plant physiology and interaction of Pb and Cd with other chemical species like calcium (Ca) and zinc (Zn) were excluded from the study in order to make it focused.

The focus of this study was to relate soil metal content and metal content in organs of star grass that were consumed mostly by cattle. In this study, these organs were taken to be above-ground tissue of grass although it is acknowledged that animals sometimes consume roots and even soils as they graze. This study defined above-ground plant tissue as all plant tissue (stems and leaves) 5 cm above the ground on the assumption that cattle cut grass at 5 cm above the ground as they graze. This is the plant tissue in which growth parameters of yield and metal content were measured for use in modelling. The study therefore excluded below-ground organs such as roots.

1.7 Organisation of thesis

This thesis is organized into 8 chapters. Chapter 2 consists of a literature review that brings out gaps in knowledge that motivated this study. Chapter 3 presents the 'General Methodology' of the study, in which the overall study design and components of the study are discussed. In this chapter, the approaches and methods used in each component of the study are discussed at a general level. Detailed methods and materials are presented in each component to facilitate a better understanding of the link between the detailed methods, the results and discussions for that particular component of the study. Each component of the study constitutes a chapter, from Chapter 4 to Chapter 6. An overall discussion is presented in Chapter 7 while the conclusions and recommendations are presented in Chapter 8.