THE UPTAKE AND TOLERANCE OF SELECTED HEAVY METAL IONS AND THEIR DISTRIBUTION IN SWEET POTATO PLANTS (*Ipomoea batatas*) UNDER *in vitro* CONDITIONS

BY

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DECLARATION

This thesis is my original work and has not been presented for any award of a degree in this or any other University.

01/09/09

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I dedicate this work to my dear wife Patricia and the entire Ndathe family as well as those who contributed towards its success.

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ABSTRACT

Some heavy metals are essential while others may adversely affect human; the water and plant consumers. Pollution by heavy metals is a major problem globally and hence the need to identify sources of the metals and explore effective, yet low cost methods for environmental remediation. Phytoremediation is one such method, which involves uptake and degradation of organic and inorganic pollutants by plants from soil and groundwater. In case of inorganic, such as heavy metals, phytoremediation involves uptake and sequestration of these metals in foliage for easier disposal. Selected plants can therefore be used to restore environment contaminated with pollutants.

This research study was aimed at investigating the extent to which locally available sweet potato plant varieties (*Ipomoea batatas*) absorbed cadmium, zinc, lead and chromium from their respective heavy metal-containing solutions of known concentrations. The influence of the sweet potato plant varieties in electrical conductivity, pH and temperature of the heavy metal-containing solutions in which they were immersed was monitored and recorded during the experimental period. The study also involved investigation of the tolerance of the sweet potato plant varieties in varying concentrations of heavy metal-containing solutions.

Five sweet potato varieties namely UP-A, UP-B, UP-C, UP-D and UP-16 were used in this study. The plant cuttings of the size 15-20cm of the plant varieties were obtained from the garden at the University of Nairobi, College of Biological and Physical Sciences (CBPS). Their leaves were removed and then the stems pre-rooted in open plastic containers containing tap water for 30 days. The cuttings developed new leaves and roots. The pre-rooted plant varieties were then immersed in

sets of 200ml distilled water and the heavy metal-containing solutions in plastic containers and observations made on them for 14-21 days. The set ups were in triplicate.

While there were no significant changes in pH and temperature of the distilled water and heavy metal-containing solutions over the experimental period, the electrical conductivity of the heavy metal-containing solutions of cadmium, zinc and chromium with immersed sweet potato plant varieties increased over the experimental period compared to those without the plant varieties. However, the mean electrical conductivity of lead-containing solutions continuously increased for the first week and then decreased towards the end of the experimental period. .

The extent to which the heavy metals were absorbed and translocated from the heavy metal-containing solutions into the plant roots, stem and leaves was analysed using Atomic Absorption Spectroscopy technique. The amount of heavy metal taken up by the plant varieties depended on the initial concentration of the heavy metal containing solution and the dry weight of the plant tissue. It was observed that in almost all the plant varieties, the roots registered higher amounts of the heavy metals accumulation followed by the stem and the leaves.

Cadmium content obtained from sweet potato plant varieties immersed in 10ppm cadmium-containing solutions ranged from 653.51μg to 771.52μg per g of dry weight in while that from 20ppm solution ranged from 920.18μg to1032.70μg per g of dry weight. Results of zinc content in the plant varieties immersed in 10ppm zinc-containing solutions gave the range of 361.38μg to 499.79μg per g of dry weight and 505.44μg to 601.67μg per g of dry weight for plants immersed in 20ppm zinc-containing solution. However, lower range of between 308.63μg and 370.42μg per g of dry weight was recovered from plants immersed in 50ppm zinc-containing solution. The sweet plant varieties immersed in 10ppm lead-containing solution accumulated a range of 7.14μg to

108.10μg per g of dry weight while those immersed in 20ppm lead-containing solution gave a range of 1389.41μg to 1962.13μg per g of dry weight. Plant varieties immersed in 50ppm solution had lead content of between 2801.34μg and 3570.30μg per g of dry weight. Sweet potato plant varieties immersed in 10ppm total chromium-containing solution gave a range of 109.23μg to 164.64μg per g of dry weight while those immersed in 20ppm chromium-containing solution ranged from 159.13μg to 240.7μg per g of dry weight. Chromium content of the plants harvested from 50ppm solution ranged from 341.49μg to 685.69μg per g of dry weight.

From the results it was concluded that sweet potato plants can actually take up cadmium, zinc, lead and chromium and translocate them in their roots, stem and leaves. Therefore, the plants can be used to remediate heavy metal contaminated sites. The amount of heavy metals in the roots, stem and leaves increased with the increase in the concentration of its ions in the initial solutions in which the plant varieties were immersed. However, the percentage of the metals in each part of the sweet potato plant variety decreased with the increase in concentration of metal ions in the solutions, an observation attributed to possible toxicity of heavy metal to the plants. The variations in metal ions uptake by different varieties could not be fully explained.

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List of abbreviations

AAS- Atomic Absorption Spectroscopy

BOD- Biological Oxygen Demand

CBPS- College of Biological and Physical Sciences

CCA - Copper Chromium Arsenic

EPA- Environment Protection Agency

JICA -Japan International Cooperation Agency

KARI -Kenya Agricultural Research Institute

ND- Not Detected

NEMA- National Environment Management Authority

SBS- School of Biological Sciences

TCE- Trichloroethylene

UNEP- United Nations Environment Programme

WHO -World Health Organization

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the study

Pollution of the biosphere with toxic metals has accelerated with increase in industrialization. The primary sources of this pollution include burning of fossil fuels, mining, municipal wastes, fertilizers, pesticides and sewerage (Kabata and Pendias, 1989). Toxic metal contamination of soil, waste streams and ground water pose a major environmental and human health problem. There is a need for an effective and affordable method of removal or reducing the toxic metals from environment. Various physical, chemical and biological processes are already in use to remediate contaminated soil. These processes either decontaminate the soil or 'stabilize' the pollutant within it (Cunningham *et al.*, 1995).

Decontamination reduces the amount of pollutants within the soil by removing them. Stabilization does not reduce the quantity of pollutants at a site, but makes use of soil amendments to alter the soil chemistry and sequester or absorb the pollutant into a matrix so as to reduce or eliminate environment risks. Different remediation strategies have been applied depending on the nature of the contaminants. Soils contaminated with metals are usually excavated and land filled or treated by acid leaching, physical separation of contaminants or electrochemical process. Soils contaminated with organics are treated by vapor stripping or thermal desorption (for volatile and semi volatiles), soil washing (for leachable materials), incineration (for all organic not otherwise treatable) and some land filling (Cunningham *et al.*, 1995).

Microbial remediation has been successful for the degradation of certain organic contaminants but is ineffective at addressing the challenge of toxic metal contamination particularly in the soil (Raskin *et al.*, 1997).

Plants can be used for environmental remediation through a promising environmental technology called phytoremediation. Phytoremediation is defined as the use of green plants to remove pollutants from the environment or to render them harmless (Raskin *et al.*, 1997). All plants have the ability to accumulate from soil and water those metal ions which are essential for growth and development. These metals include Fe, Mn, Zn, Cu, Mg, Mo and possibly Ni. Certain plants also have the ability to accumulate heavy metals which have no known biological function which include Cd, Cr, Pb, Co, Ag, and Hg (Baker and brooks, 1989; Raskin *et al.*, 1994). Aquatic or semi aquatic plants that have been used in phytoremediation include water hyacinth (*Eichonia crassipes*) which had been reported by Dierberg *et al.*, (1987), Penny worth (*Hydrocotyle umbrellata*) as reported by Jain *et al*, (1989) and water velvet (*Azolla pinnata*) as reported by Mo *et al.*, (1989) can take up Pb, Cu, Cd, Fe and Hg from contaminated solutions.

Phytoremediation has limitations which include that the plant must be alive and that their roots require oxygen, water and nutrients. Soil texture, pH, salinity, pollutant concentrations and the presence of other toxins must be within the limits of plants tolerance. Phytoremediation is slower than physical- chemical processes and may be considered as a long term remediation processes. Advantages of this method include its use in cases of large surface areas of relatively immobile contaminants in soil surface and aquatic environment.

1.2 Statement of the problem

1.2.1. Industrial Pollution in Kenya

The manufacturing industry in Kenya plays a crucial role in transforming raw materials into high value goods, generate revenue and create jobs, all contributing to poverty eradication and creation of wealth. Industrial processes however, are associated with exploitation of natural resources, destruction of habitats and generation of waste and discharge of pollutants in the environment. The pollutants comprise of gaseous emissions, obnoxious smells, particulate matter, liquid effluents, solid wastes, heat and noise. Industrialization impacts negatively on the environment as the sector largely depends on old technologies such as leaded petroleum. The Mombasa oil refinery is not designed to produce unleaded petroleum. It is estimated to cost Kshs 300 million to modernize road and railway transport used to transport raw materials and industrial products. These modes of transport contribute to environmental degradation according to reports by the National Environment Management Authority (NEMA, 2003).

1.2.2. Municipal Waste

Kenya urban population has been growing at a rate of 8% per annum. Generation of solid, liquid and gaseous waste has been increasing at the same level as industrial development and diversification of consumption patterns. Non-bio degradable wastes to the environment including plastic, scrap metals and other goods. Per capita wastes generation ranges between 0.29 and 0.66 kg /day within the urban areas of the country (NEMA, 2003). Of the municipal waste generated in the urban centre, 21% emanate from industrial areas and 61% from residential areas. Generally about 40% of the total waste generated in urban centers is collected and disposed of at the designated sites. The rest of the waste, composed of chemical including heavy metals salts, detergents and medical waste is either dumped in unsuitable areas or disposed off in rivers that transverse the urban centers and other wet lands (NEMA, 2003).

According too a survey of Naivasha area, Kenya, the levels of cadmium in water, soil and plant samples were found to be higher than the recommended and expected values given in the literature (Muigai,1992). The sediment levels at the Fisherman's camp showed that zinc was 72.7μg/g, cadmium 1.0μg/g while lead was 16.7μg/g (Alala, 1981).

1.2.3. Soil Contamination

According to the Country profile on Environment (2002) report compiled by the Planning and Evaluation Department of Japan International Cooperation Agency- Kenya (JICA), there is concern about soil contamination by heavy metals in Kenya. It is possible that soil is being contaminated by the lead processing industry, exhaust gases and cadmium from the agricultural fertilizer. Research carried out at Nakuru in 2001 showed that there is heavy metal contamination on soils in various hotspots where some industries and municipals dump their waste (Country profile on Environment, 2002)

1.2.4 Pollution in Nairobi water basin

Rapid population growth, urbanization and industrialization have put enormous pressure on land and water bodies in Nairobi. For example, untreated industrial effluents, raw sewage and liquid and solid waste from human settlements situated along Nairobi River have turned the once clear water into a sludge causing health hazards, accelerated eutrophication and stress on the aquatic ecosystem according to a report released by United Nations Environmental Programme (UNEP 2000).

A sewage treatment study commissioned by Nairobi City Council in 1987 and carried out by Howard Humphreys Kenya Limited established high levels of metals in the sewage. The metals identified were lead, zinc and cadmium. According to National Environment Management Authority (NEMA, 2000), 143 out of 175 local authorities were set up with no sewage disposal network, providing an opportunity to drain the raw effluent into individual farms. Many industries do not have a proper method of treating industrial waste, yet they use chemicals which are hard to destroy once they penetrate the food chain.

Kariobangi sewage treatment works in Nairobi treats sewage effluent from domestic and industrial producers in the city and its environs. A study of the heavy metal analysis on the sewage sludge by Maina (1984) indicated the ranges of selected heavy metals in the sewage sludge as follows: cadmium was less then 5ppm, chromium 90-530ppm, lead 248-580ppm and zinc 1350-2400ppm. Plants grown in the soils in the treatment works showed uptake of the heavy metals from the soil and their translocation in their tissues. For example, cow pea results showed accumulation of 158ppmZn, 14ppmPb and 10ppmCr in the leaves; 86ppmZn, 6ppmPb in the roots and 105ppmZn, 5ppmPb in the stem. Spinach grown in the same site had taken up 233ppmZn, 10ppmPb and 7ppmCr in the leaves while tomato fruit had 133ppmZn, 8ppmCr and 8ppmPb. However there was no cadmium detected in the plants analysed (Maina, 1984).

A report from UNEP on environmental pollution and impact on public health done on Dandora Municipal dumpsite in Nairobi, Kenya showed high levels of lead, zinc, chromium, mercury and cadmium in soils in and around the dumpsite (UNEP report,2002). Concentration of lead in soil sample ranged from 50-590 ppm, while samples within the waste dump site manifested a value of

13,500ppm which is a clear indication of high lead levels. Samples collected from waste dump exhibited value of 46.7 ppm of mercury while those collected along the river bank registered value of 18.6 ppm, both values exceeding World Health Organization (WHO) acceptable exposure level of 2ppm. Mean concentration of cadmium in soil sample adjacent to the dump site were 8 times higher than those prescribed by Dutch and Taiwanese Authorities (5ppm) in both surface and subsurface soil level. The mean chromium concentrations were slightly above critical standard soil levels hence no major negative impact on the environment.

Zinc concentration from Dandora soils also exceeded the recommended standard values. The report also indicated that high levels of lead in soil sample in Dandora dump site impacted negatively on the communities living near the dumpsite as was evidenced by the fact that half of children examined had blood lead levels equal to or exceeding internationally accepted toxic levels (10 μg /ml of blood). This in turn led to clinical symptoms for example headache, chest pains and muscular weakness being manifested in children.

1.2.5 Heavy metal pollution in Kenyan lakes

A study on heavy metal concentration in Lake Victoria indicated that zinc present at the car wash area near the lake was 184μg/l, cadmium 7μg/l and lead 18μg/l. The sediment sample concentrations at the car wash analysed using AAS technique indicated that lead was the highest contaminant with 206.7μg/g, zinc 104 μg/g and cadmium 3μg/g (Alala, 1981). The high levels of the lead according to the study were attributed to lead from gasoline in cars washed at the site. Another source of lead could have been from car battery acids and exhaust from the boats which are gasoline fuelled. Car and boat paints also could account for lead concentration. Available data on Lake Naivasha along the Fisherman's Camp showed water with concentrations of 148μg/l Zn, 4μg/l Cd and 7μg/l Pb while at the park entrance of Lake Nakuru zinc concentration of water was 160μg/l, while cadmium had 40μg/l and lead 92μg/l (Alala, 1981).

1.3 Justification of the study

This project seeks to provide an alternative method of environmental remediation by use of sweet potato plants to completely remove of reduce heavy metal from the soil. By identifying hardy plants that can effectively remediate the pollutants, the plants can be applied in projects that involve removal of heavy metals from soils. Sweet potato (*Ipomoea batatas*) is a hardy stress-tolerant, fast growing plant that grows well in almost every part of eastern and central Africa. It has an extensive, branching root system that is well suited for phytoremediation application. The study is intended to investigate the effectiveness of using sweet potato plant (*Ipomoea batatas*) in absorbing heavy metal pollutants from soil. The heavy metals selected for this study are cadmium, chromium, lead and zinc.

Previous studies done have indicated that these heavy metals are accumulated in soil and water bodies in levels above those recommended by National Environmental Management Authority (NEMA) in Kenya. This study was also aimed at investigating the tolerance levels of different sweet potato plant varieties in their respective heavy metal ion- containing solution, as well as their accumulation and distribution in the plant roots, leaves and stems.

The sweet potato varieties used were UP-A, UP-B, UP-C, UP-D and UP-16. The different sweet potato plant varieties were used to investigate the uptake of cadmium, zinc, lead and chromium. The data obtained from this research will lead to further research of remediating environment of other heavy metal pollutants. By the use of sweet potato plants in absorbing the heavy metals from contaminated sites, it is hoped that the method will provide less expensive, less intensive and more aesthetically pleasing alternative to the existing methods of heavy metal remediation. Industrial producers, private companies as well as municipal councils generating water and solid wastes contaminated with toxic heavy metals could therefore use phytoremediation method by sweet potato plants for removal of their toxic metal waste.

1.4 Objectives of the study

The general aim of this study was to investigate the extent to which locally available sweet potato plant (*Ipomoea batatas*) varieties absorbed and translocated cadmium, chromium, lead and zinc from their respective heavy metal-containing solutions of known concentrations.

The specific objectives of the study were:

i) To investigate the influence of sweet potato plant varieties in the electrical conductivity, temperature and pH of heavy metal-containing solutions of varying concentrations in which they were immersed over the experiment period.

ii) To investigate the tolerance of the five different sweet potato plant varieties in varying cadmium, chromium, lead and zinc ion concentrations.

iii) To investigate the uptake and distribution of cadmium, chromium, lead and zinc ions in the roots, stems and leaves of five different sweet potato plant (*Ipomoea batatas*) varieties.

1.5. Hypothesis

Sweet potato plants absorb dissolved cadmium, chromium, lead and zinc ions from contaminated environment and translocate them in their roots, stems and leaves.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Phytoremediation process

The basic idea that plants can be used for environmental remediation is very old and cannot be traced to any particular source. Phytoremediation is defined as the use of green plants to remove pollutants from the environment or to render them harmless. Phytoremediation of metals is a cost effective green technology based on the use of metal –accumulating plants to remove toxic metals, including radioactive substances from soil and water. It takes advantage of the fact that a living plant can be considered as a solar-driven pump, which can extract and concentrate particular elements from the environment (Raskin *et al.*, 1997). Phytoremediation takes advantage of the ability of certain plant cellular components including proteins to bind the metals. This ability is particularly important for rhizofiltration which relies on the ability of hydroponically grown plant roots to absorb toxic metals from water.

2.2 Mechanisms of heavy metal ion uptake by plants.

2.2.1. Phytoextraction process

The optimum plant for the phytoextraction process should be able to tolerate and accumulate high levels of heavy metals in its harvestable parts as well as have a rapid growth rate and the potential to produce a high biomass in the field (Salt *et al.*, 1995). Phytoextraction process involves high biomass metal accumulating plants and appropriate soil amendments are used to transport and concentrate metals from the soil into the above ground shoots (Raskin *et al.*, 1997) Most plants growing on contaminated soils effectively exclude heavy metals from their tissues.

Although plants take up and accumulate certain essential nutrients from soil to concentration as high as 1-3%, levels of heavy metals only accumulated to 0.1-100mg/kg in most plants (Cunningham *et al.*, 1995).

2.2.2 Phyto filtration (rhizofiltration)

This process takes place in the soil immediately surrounding plant roots which absorb, precipitate and concentrate toxic metals from polluted effluents (Dushenkov *et al.*, 1995). An ideal plant for rhizofiltration should have rapidly growing roots with the ability to remove toxic metals from solution over extended period of time. Mechanisms of toxic metal removed by plant roots are not necessarily similar for different metals. In case of lead, sorption by root is probably the fastest component of such physical and chemical processes as chelation, ion exchange and specific absorption. Biological processes such as intercellular uptake, vacuolar deposition and translocation to the shoots are responsible for slower components of metal removal from solution (Cataldo & Wildung, 1978, Kumar *et al.*, 1995). Rhizofiltration is particularly effective and economically compelling when low concentrations of contaminants and large volumes of water are involved.

2.2.3. Phytostabilization process

In this process heavy metal tolerant plants are used to reduce the mobility of heavy metals, thereby reducing the risk of further environmental degradation by leaching into the ground water or by air borne spread. A good phytostabilizing plant should tolerate high levels of heavy metals and immobilize these metals in the soil via root uptake, precipitation or reduction. The plants produce chemical compounds to immobilize contaminants at the interface of roots and soil (Raskin *et al.*, 1997).

Phytostabilization technique is most appropriate for relatively immobile materials and large surface areas, and may work better with heavier textured soils and soil with high organic matter content. The technique is acceptable for remediation at mining sites (Cunningham *et al.*, 1995).

2.3 Plant Biology and Heavy Metal Accumulation

Heavy metal accumulation in plants can be divided into three major areas namely, the biology of heavy metal uptake, translocation and resistance.

2.3.1 Root Uptake

For plants to accumulate soil-bound metal they must first mobilize them into the soil solution. This can be achieved by metal-chelating molecules being secreted into the rhizosphere to chelate and solubilize 'soil bound' metals. For example magineic acid and avenic acid serve as phytosiderophores (metal-chelating molecules) of graminaceous species (Kinnersely, 1993). These phytrosiderophores are released in response to Fe and Zn deficiency and can mobilize Cu, Zn and Mn from soil (Romheld, 1991).

Another process of mobilization of ' soil bound' metals involve roots reducing soil-bound metal ions by specific plasma membrane bound metal reductases Pea plants deficient in Fe or Cu have an increased ability to reduce Fe(III) and Cu (II) which is complete with an increased uptake of the Cu, Mn, Fe and Mg (Welch *et al*, 1993). Plant roots can also solubilize heavy metal by acidifying their soil environment with proteins extended from the roots. A lower pH release 'soil –bound' metals into the soil solution. Solubilized metal ions may enter the roots either via extracellular (apoplastic) or intracellular (symplastic) pathways. Most metal ions enter plant cells by an energy-dependent, saturable process via specific or generic metal ion carriers or channels (Clarkson and Luttge, 1989).

Non essential heavy metals may effectively compete for the same transmembrane carriers as used by essential heavy metals. This relative lack of selectivity in transmembrane in transport may partially explain why non-essential heavy metals can enter cells even against concentration gradient. For example, kinetic data demonstrates that such essential Cu and Zn and non essential Ni and Cd compete for the same transmembrane carrier (Clarkson and Luttge, 1989).

2.3.2 Transport within plants

Metal ions inside the roots can be stored or exported to the shoot. Metal transport to the shoot probably takes place in the xylem. However, metals may redistribute in the shoot via the phloem (Stephan and Scholz, 1993). Metal ions must first cross the casparian strip to enter the xylem vessels. The casparian strip divides the endodermis and the epidermis. To cross this strip of water impermeable cell wall metal ions must move symplastically, as apoplastic transport is blocked. It is therefore feasible that symplastic transport of metals within the endodermis is a rate limiting step in metal translocation to the shoot.

2.3.3 Heavy Metal Resistance

For plants to resist the toxic effect of heavy metals they must limit their cellular uptake (Cumming and Taylor, 1990), detoxify the heavy metals once they enter the cells or develop heavy metals resistant metabolisms. Once heavy metals accumulate within cells they will need to be detoxified. This can occur in a number of ways depending on the metal, either through chelation compartmentalization or precipitation. For example, Zn may be chelated by organic acids and accumulated within the vacuole (Mathys, 1977; Brookes *et al.*, 1981). Cadmium is also known to accumulate within the vacuole (Van Steveninck *et al*, 1990) where it associates with the family of thiol rich peptides called phytochelatins (Rauser, 1990; Steffens, 1990).

2.3.4. Metal Tolerance in Plants

Tolerance to heavy metals in plants may be defined as the ability to survive in a soil that is toxic to other plants, and is manifested by an interaction between a genotype and its environment (Macnair *et al.*, 2000). Some plant species, however, have evolved tolerant races that can survive and thrive on such metalliferous soils, presumably by adapting mechanisms that may also be involved in the general homeostasis of, and constitutive tolerance to, essential metal ions as found in all plants. Plants have a range of potential mechanisms at the cellular level that might be involved in the detoxification and thus tolerance to heavy metal stress. These all appear to be involved primarily in avoiding the build-up of toxic concentrations at sensitive sites within the cell and thus preventing the damaging effects described above, rather than developing proteins that can resist the heavy metal effects. Thus, for example, there is little evidence that tolerant species or ecotypes show an enhanced oxidative defense; rather tolerant plants show enhanced avoidance and homeostatic mechanisms to prevent the onset of stress (de Vos *et al.*, 1991; Dietz *et al.*, 1999).

Elevated concentrations of both essential and non-essential heavy metals in the soil can lead to toxicity symptoms and the inhibition of growth of most plants. The toxicity symptoms seen in the presence of excessive amounts of heavy metals may be due to a range of interactions at the cellular/molecular level. Toxicity may result from the binding of metals to sulphydryl groups in proteins, leading to an inhibition of activity or disruption of structure, or from the displacing of an essential element resulting in deficiency effects (Van Assche and Clijsters, 1990).

Metal tolerance has generally been studied as an example of natural selection in plants, with the evidence that the ability to colonize contaminated areas depends on the ability to evolve ecotypes tolerant to heavy metals. In a study comparing (*Typha latifolia*) populations from uncontaminated and contaminated sites, Mc Naughton *et al.*, (1974) Taylor & Crowder (1984) and Ye, *et al.*, (1997) found that whatever the origin of the population, there was no difference in tolerance. The authors concluded that the species exhibited a constitutive tolerance to Zn, Pb and Cd throughout its range.

Arabidopsis halleri is well known for its heavy metal tolerance and hyper accumulation (Brooks, 1998). It is usually described as a plant which belongs to a heavy metal plant community and is associated with degraded areas which contain significantly elevated level of Zn, Pb and Cd resulting from human activities such as the metallurgical industries, mining, refuse sites and heavy metal emissions (Baker & Brooks, 1989; Brooks, 1998).

2.3.5. Heavy Metal Uptake by Plant

In a study of lead phytoextraction efficiency from contaminated environment comparing corn (*zeamays*) and ragweed (*Ambrosia artemisiiforia* L), Huang and Cunningham, (1996) reported significant species differences in Pb accumulation for both roots and shoots. Compared with corn, ragweed demonstrated a much high efficiency in the root lead accumulation. After two weeks exposure of lead in100 μM hydroponics, root Pb concentration was 24,000mg Pb/kg for ragweed and 4900mg Pb/ kg for corn. In contrast to root-Pb concentration, shoot-Pb concentration was significantly higher in corn (560mg/kg) than in ragweed (30mg/kg).

Dicagno *et al.*, (1999) studied the effect of cadmium on growth of (*Healinthus anuus*) seedlings. Results of the study demonstrated that Cd accumulated in the roots exceeded that in the shoots. Cadmium was strongly accumulated in the roots but also translocated as demonstrated by the higher concentration found in the leaves of the cadmium treated plants. Nugget marigolds have been used to remove arsenic from contaminated environment (Chintakovid, *et al.*, 2007). The study results indicated that marigolds took up a large amount of arsenic in the tissues and also grew well in arsenic contaminated soil. The concentration of arsenic in the plants was however highest in the leaves.

In Naivasha area, Kenya, research carried out on a floating aquatic fern *Salvinia molesta,* showed that it had absorbed highest level of mercury, with considerable high levels of cadmium and lead (Muigai, 1992). The fern according to another study was reported to have accumulated 400µg/g Zn, 130µg/g Pb but no cadmium was detected. A plant species found in Lake Nakuru *Laevigatus L.* accumulated 186µg/g Zn, 26.5µg/g Pb but no cadmium was detected (Alala, 1981). The authors concluded that the plants could be used as indicators of heavy metal pollution in aquatic environment.

2.4. Heavy metals pollutants: Their occurrence, health effects and recommended levels.

Heavy metal pollutants are classified as minor chemical constituents and are present in concentrations of less than 1.0mg/l. They include trace metals; arsenic, barium, cadmium, chromium mercury, nickel, vanadium and zinc (Weiner, 2000). These metals tend to be strongly absorbed by soil constituents' especially organic matter (Harrison, 1992).

2.4.1 Cadmium

Chemistry

Cadmium is a d-block metallic element and belongs to group 12 and period 5 of the periodic table. It has an atomic number of 48 and an atomic mass of 112.411. It is a solid at 298K and has a density of 8.7g/cm^3 at 293K. The electronic shell of cadmium has [Kr] 4d^{10}5s^2.

Occurrence

Cadmium is usually present in soils and rocks. It occurs naturally in zinc, lead and copper ores, in coal and other fossil fuels and shales. The absorption of cadmium ont o soils and silicon or aluminum oxide is strongly pH dependent increasing as conditions becomes more alkaline. Below pH 6-7 cadmium is desorbed from these materials

Uses of Cadmium

Cadmium is used for batteries, alloys, pigment, metal protective coatings and as a stabilizer for plastics (Weiner, 2000).

Environmental Pollution

Cadmium is released to the environment in waste water and its pollution is caused by contamination from fertilizer and local air pollution. Contamination in drinking water may also be caused by impurities in the zinc of galvanized pipes and solder of some metal fittings (WHO, 1998). Because cadmium is chemically similar to zinc, an essential nutrient for plants and animals, it is readily assimilated into the food chain. Plants absorb cadmium from irrigation water.

Health concerns

Cadmium is acutely toxic; a lethal dose of about 1g acute exposure and causes nauseas, vomiting, muscle clamps, liver injury, convulsions, shock and renal failure. Long term exposure to low levels of cadmium in air, food and water leads to a build up of cadmium in the kidney and may cause kidney disease, lung damage and fragile bones (WHO, 1998; Weiner, 2000).

Drinking water standards

A guideline value for cadmium is 0.003 mg/l (WHO, 1998), 0.01 mg/l (NEMA).

The available treatment technologies are, coagulation and filtration, ion – exchange, lime softening and reverse osmosis.

2.4.2 Chromium

Chemistry

Chromium is a d-block metallic element and belongs to group 6 and period 4 of the periodic table. It has an atomic number of 24 and an atomic mass of 51.9961. It is a solid at 298K and has a density of 7.19 g/cm^3 at 293K. The electronic shell of chromium has [Ar] $5d^5 4s^1$.

Occurrence

Chromium occurs in minerals mostly as chrome iron ore or chromites ($FeCr_2 0_4$) as Cr (III). Chromium in soils occurs mostly as insoluble chromium oxide ($Cr_2 0_3$) as Cr (VI). In natural water, dissolved chromium exists as either Cr^{+3} cations or in anions as chromate ($Cr0_4^{2-}$) and dichromate ($Cr_2O_7^{2-}$). Though widely distributed in soils and plants, it generally is present in low concentrations in natural water. Trivalent chromium (Cr^{+3}) readily sorbs to negatively charged soils with minerals. Hexavalent chromium (Cr^{6+}) existing in negatively charged complex is not sorbed to any extent by soil or particulate matter and is much more mobile than Cr (III). However, Cr (VI) is a strong oxidant and reacts readily with any oxidizable organic material present with the formation of Cr (III) (Weiner, 2000)

Uses of chromium

It is used in stainless steel and super alloys in jet engines (Weiner, 2000). It is also used in nuclear power plants, chemical resistant valves and other applications in which a material that resists heat and chemicals required. It is also used in leather tanning and in preparation of treated copper chromium arsenic (CCA) lumber which resists fungal decay and termites (Manahan, 2005).

Environmental Pollution

The main environmental source is weathering of rocks and soil. Major anthropomorphic sources include metal alloy production, metal plating, cement manufacturing and incineration of municipal refuse and sewage sludge.

Health Concerns

Trivalent chromium is an essential trace nutrient and plays role in prevention of diabetes because it is usually non toxic. The harmful effect of chromium to human health is caused by hexavalent chromium since oxidants such as chlorine or ozone readily oxidizes trivalent chromium to the toxic hexavalent form. Water quality limits are usually given for total chromium concentration. EPA has found that chromium potentially cause skin irritation or ulceration due to acute exposure at levels above maximum contaminant level. Chromium also has the potential to cause liver damage, kidney circulatory and nerve tissues and dermatitis due to long term exposure at level above minimum contaminant level.

Drinking Water Standards

According to the EPA standards the trivalent and hexavalent forms of dissolved chromium (Cr^{3+} and Cr^{6+} respectively) have maximum total Cr contamination level of 0.1 mg/l (Weiner,2000) and 0.05mg/l for Chromium (VI) (NEMA).

The available treatment technologies include coagulation and filtration, ion – exchange, reverse osmosis lime softening (for Cr (III) only).

2.4.3 Lead

Chemistry

Lead is a p-block metallic element and belongs to group 14 and period 6 of the periodic table. It has an atomic number of 82 and an atomic mass of 207.2. It is a solid at 298K and has a density of 11.34 g/cm^3 at 293K. The electronic shell of lead has [Xe] $4f^{14}5d^{10}6s^{2}6p^{2}$.

Occurrence

Lead minerals are found mostly in igneous metamorphic and sedimentary rocks. The most abundant lead mineral is galena (PbS). Metallic lead and common lead minerals have very low solubility. Mining, milling and smelting of lead and metal associated with lead, such as zinc, copper, silver, arsenic and antimony are major sources as are combustion of fossil fuels and municipal sewage. Commercial products that are major sources of lead pollution include lead acid storage batteries, electroplating, construction material, ceramics and dyes, r adiation shielding, paints, ammunition, piping roofing, gasoline additives such as tetra methyl lead and tetra ethyl lead (Weiner, 2000 and Manahan, 2005). Levels of dissolved lead in natural waters are generally low.

Uses of Lead

Main uses of lead include in batteries, pigment, solders, cables sheeting and in ammunitions (Weiner, 2000 and Manahan, 2005). The organic lead compounds: tetra ethyl lead and tetra methyl lead have been used extensively as antiknock and lubrications agents in petrol (WHO, 1998).

Environmental Pollution

Lead in drinking water results from corrosion of materials containing lead and copper in distribution system and from lead and copper plumbing materials used to plumb houses. However, the amount of lead dissolved from plumbing system depends on pH, temperature, and water hardness, total alkalinity and dissolved inorganic carbonates (WHO, 1998, Weiner, 2000).

Health Concerns

Short term exposure to lead at relatively low concentration can cause interference with red blood-cell chemistry. This delays normal physical and mental development in babies and young children, hearing and learning abilities of children and slight increase in blood pressure of some adults. Long term exposure of lead in humans result in cerebrovascular and kidney disease (Weiner, 2000). Lead is also toxic to both central and peripheral nervous system, including subence phalopashic neurological and behavioral effects.

Drinking Water Standards

The drinking water standard guidance value for lead is 0.01mg/l (WHO, 1998), 0.05 mg/l (NEMA)

Available treatment technologies include ion exchanges, lime softening, reverse osmosis, coagulation and filtration

2.4.4 Zinc

Zinc is a d-block metallic element and belongs to group 12 and period 4 of the periodic table. It has an atomic number of 30 and an atomic mass of 65.406. It is a solid at 298K and has a density of 7.11 g/cm^3 at 293K. The electronic shell of zinc has [Ar] $3d^{10}4s^2$.

Occurrence

Zinc is a common contaminant in surface and ground water, storm water runoff and industrial waste streams. Zinc is not found free in nature but is always associated with one of many zinc minerals. Zinc occurs as ZnS (a mineral called sphalerite) and Wurtzite. Zinc minerals are associated with minerals of other metals particularly lead, copper, cadmium, mercury and silver. Zinc occurs in natural waters in both suspended and dissolved forms. The dissolved zinc is readily sorbed to or occluded in mineral clays and humic colloids in water of low alkaline and below pH 7 Zn^{2+} is the dominant form (Weiner, 2000).

Uses of Zinc

One of larger uses of zinc is as a corrosion –resistant coating on steel. This application, refined to a high degree in the automotive industry in recent years has significantly lengthened the life span of automotive bodies and frames. Zinc is used along with copper to make the alloy called brass. Zinc oxide is used as an accelerating and activating agent for hardening in other products, zinc chloride used in dry cells as a disinfectant and vulcanize rubber and zinc sulphate for manufacture of insecticide (Manahan, 2005).

Environmental Pollution

Industries with waste streams containing significant levels of zinc include steel works with galvanizing operations, zinc and brass metal works, zinc and brass plating and production of viscose rayon yarn, ground wood pulp and newsprint paper (Weiner, 2000). Zinc oxide fumes and dust however result into metal fume fever (Waldron, 1985). Most zinc compounds including zinc chloride may be hazardous in terms of toxicity (Hunter, 1978). Lethargy, vomiting, pancreatitis, respiratory distress and pulmonary fibrosis are some of the disorder likely caused by zinc toxicity (Braunwald *et al*, 1987).

Health Concerns

Zinc is an essential nutrient and is not toxic to humans. About 1g/day may be ingested without ill effect. Recommended dietary allowance is 15mg/day for adult (WHO, 1998 and Weiner, 2000).

Drinking Water Standard

The EPA has no primary drinking water standard for zinc. The EPA secondary drinking water standards is 5mg/l based on metallic taste detectable by many people above that level (Weiner, 2000). No health based guideline value has been proposed for zinc in drinking water. Water containing zinc at concentrations in excess of 5mg/litre may appear opalescent and develop a greasy film on boiling although their effect may also be noticeable at concentration as low as 3mg/l (WHO, 1998) and 1.5mg/l (NEMA).

Best available treatment technologies are chemical precipitation, ion exchange, evaporative recovery of salts, reverse osmosis and electrolytic plating.

2.5 Sweet potato (*Ipomoea batatas*)

Figure 2.1: Sweet potato plants (*Ipomoea batatas*) farm in KARI Kakamega.

2.5.1. Description

Sweet potato is tuberous rooted perennial, usually grown as annual herbaceous, stems forming a running vine up to 4m long. It is usually prostrate and slender, with milky juice, lateral stem and branches arising from the short term and usually not branched. Leaves have ovate-cordate, borne on long petioles, angular or lobed depending on variety green or purplish in color (Reed, 1976). Sweet potato plants are widely grown in East and Central Africa (figure 2.1).

2.5.2. Ecological requirements

Sweet potato plant is reported to tolerate annual temperature of 8.4- 28.5 °C, rainfall of 3.1- 42.9 ml and pH 4.3- 8.7 (Reed, 1976). Soil rated suitable for sweet potatoes include moderately deep, sandy loams or loamy fine sands.

2.5.3. Sweet Potato uses

The plant is mainly cultivated for tubers. The tuber is used a vegetable; eaten boiled, baked, fried or dried and ground into flour. Leafy tops are eaten as vegetables and sold in markets in Malaysia. Dry vines have food value which compared favorably with alfalfa hay as forage (Reed, 1976). Sweet potato is source of β-carotene; 100 g of sweet potato can provide β-carotene quantities that are sufficient to yield from 0-100% of recommended daily vitamin A requirement, which is at least 350 μg per day for infants and 400 μg day for young children (1-6 year) (Carey *et al.*, 1999).

2.5.4. Chemistry

For a 100g the sweet potato root is reported to contain 108-121 calories, 68.5 – 72.3 H_2O, 1.0- 1.7 protein, 21-36 mg Ca, 38-56mg P, 0.7- 2.0mg Fe, 10-36 mg Na, 210- 304 mg K, 35- 5, 280 μg β-carotene equivalent. Sweet potato tubers contain 30mg Ca, 373 mg K, 13 mg Na, 49mg P, 85 mg Cl, 26 mg S and 0.8mg Fe per 100 g. manganese, copper and zinc are present in traces. Analysis of dry vine gave 90.7% dry matter, 12.6% protein, 3.3 % fat, 19.6% fiber, and 51.7% total digestible nutrients. Of more than a dozen African vegetables, sweet potatoes were the richest in foliate (1.93- 1.96 mg/g (Hug *et al.,* 1983).

2.5.5. Sweet Potato in Kenya

Sweet potato plant was introduced to Kenya from tropical America by the Portuguese. It is grown as a staple food in many parts of the country (Abubaker, 1990). Sweet potato combine a number of advantages that make it a choice crop of sustainable food security, namely; improves nutrition and income generation (Ewell, 2002). The production for sweet potato in Kenya in 1983 exceeded 200,000 tons from 30,000 ha. The government of Kenya is giving sweet potato a high priority as part of national strategy to guarantee food security.

Nyanza province leads in sweet potato production in Kenya. In 1988, it produced more than 110,000 tons followed by western province 40,000 tons, central province 22,000 tons and coast province about 10,000 tons (Abubaker, 1990).

2.5.6 Sweet Potato and Phytoremediation

The extensive, branching root system of sweet potato makes it well- suited for phytoremediation applications and it has shown to take up certain chlorinated compounds effectively (de Araujo *et al.*, 2004). Hairy root cultures of sweet potato had the highest peroxidase specific activity, compared with cultures from carrot and kangaroo apple, for catechol, phenol, chlorophenol, and dichlorophenol (de Araujo *et al.*, 2004). Other members of the *Ipomoea* genus such as *Ipomoea aquatica* (water spinach) also have been used in phytoremediation project where the presence of heavy metals in the environment is a concern (Gothberg *et al.*, 2002).

2.6. Hydroponics Culture

Hydroponics culture is a technology used for growing plants in nutrient solutions without use of artificial medium for instance sand, gravel, rock wool, peat moss and sawdust to provide mechanical support. Liquid hydroponics systems have no other supporting medium for the plant roots. This technology has been used in Japan, Europe and USA for growing vegetables including eggplant, pepper, melon, strawberry and herbs (Merle, 1991). In the present work, different sweet potato varieties were grown in water as well as in heavy metal containing solutions (figure 2.2).

Figure 2.2: Growth of the pre-rooted sweet potato vines in solutions containing a specific metal of interest.

2.6.1. Advantages of hydroponics culture

It involves high cleansing planting therefore giving maximum crop yield. It is used for crop production where no suitable soil exists and has freedom from the constraints of ambient temperature and seasonality. The minimal use of land area and is also suitable to mechanized production and diseases control (Massantini, 1976). It provides an excellent means for controlling the quantity and relative proportions of mineral salts given to plant in an experiment (Viets, 1994).

2.6.2. Disadvantages of Hydroponic Culture

It involves high cost of capital and energy inputs especially if the structure is artificially heated and cooled by fan and pad system (Merle, 1991).

2.6.3. Sources of Contamination in Hydroponic Culture

Rooting medium, reagents, container, water, cutting implements and dust and other particles from the atmosphere may be possible source of contamination in the culture.

2.6.4. Container for Hydroponic Culture

The best containers for use should be made of borosilicate glass or polythene. However, boron will be a source of contamination when borosilicate glass is used while molybdenum and cobalt contamination is possible when polythene containers are used. (Viets, 1944)

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study design

The study was carried at the University of Nairobi, Departments of Chemistry and Botany laboratories in College of Biological and Physical Sciences, Chiromo campus. Immersing sweet potato plant varieties in distilled water and the heavy metal containing solutions as well as monitoring of the plants growth took place at the green house at the Department of Botany. Acid digestion of water, plant and soil samples was carried out at the Department of Chemistry. Analysis of the heavy metals present in the digested samples using Atomic Absorption Spectroscopy (AAS) method was carried out at the Nairobi Water and Sewerage Services laboratory at Kabete, Nairobi.

3.2 Sweet potato varieties

Five different varieties namely UP-A, UP-B, UP-C, UP-D and UP-16 were obtained from the University of Nairobi, Chiromo gardens. Variety UP-A had thin stems, narrow leaves and a few thin long roots. The rest of the varieties produced long and thick hairy roots and broad leaves. However, varieties UP-B and UP-D developed more leaves than varieties UP-C and UP-16.

3.3 Field Sampling: Random sampling

Field sampling was carried out in the month of September 2007, in Western Kenya and Lake Victoria region. Sampling sites were as follows:

3.3.1 Kenya Agricultural Research Institute (KARI), Kakamega.

Soil samples:

Five samples were collected about 3 m distance from each other. Top layer soil and the sub soil dug about 30 cm deep were collected and placed in plastic paper bags.

Sweet potato vines and tubers

Five samples of sweet potato variety SPK 013 were collected from the same sampling points where the soil was collected from.

3.3.2 River Nzoia Bridge

The bridge is located along Mumias-Bungoma road. Sand harvesting is the economic activity that takes place at the site. The site is about 10 km from Mumias Sugar Factory downstream.

River sediment samples:

A set of three samples were collected at the river bank, another set 2m in the river and the third set of samples collected at about 30 m inside from the river bank.

Water samples:

The samples were collected at the same sampling points as the river sediment samples.

3.3.3 River Yala and Yala Swamp

Water and Sediment samples:

Sampling was done at a bridge along Bondo- Yala road. Samples were collected and stored in plastic containers.

Soil samples:

The samples were collected from KARI Yala swamp field trial site. Top layer soil and soil from 30 cm deep were collected from the same point. Five samples were collected from a distance of 3 m from each other.

Sweet potato vines and tubers:

Samples of variety Mugande vines and tubers were collected from KARI field trial site at the same sampling points where the soil samples were collected from.

3.3.4 River Nyando.

Sampling site was about 600m from Ahero Bridge along Nairobi- Kisumu highway.

Water and Sediment samples:

They were collected from three different sites about 3m from each other; 3m from the river banks and 3m inside the river.

3.3.5 Lake Victoria.

Water and Sediment samples:

Water and sediment samples were collected from Lake Victoria at its shores. Similar samples were collected about 50m inside the lake.

3.4 Apparatus and Equipments

The following apparatus were used during the study: Portable conductivity and pH meter model HI 991300 (Hanna Instruments): used to measure conductivity of μS/cm with a range of 0-3999, temperature in °C with a range of 0-60 and pH with a range of 0.00-14.00. Analytical balance model Sartorius 2463: used to weigh dry plant and soil samples for digestion. Atomic Absorption

Spectrometer model A 6300, Shimadzu: used for analysis of heavy metal ions in digested samples of water, soil and plants. Glass ware: Volumetric flasks, pipettes, measuring cylinders and beakers. Plastic containers: Used for holding distilled water and heavy metal containing solutions in which the sweet potato plant varieties were immersed during the monitoring period. Plastic containers of 1L volume were also used for storage of prepared stock solutions.

3.5 Chemicals

Both analytical and general purpose grade chemicals were used in the study as appropriate. The analytical grade chemicals were concentrated nitric acid, hydrochloric acid and perchloric acid. Standard solutions used in analysis of cadmium, zinc, lead and chromium ions using AAS were obtained from Spectrosol BDH chemicals ltd Poole England in 1000ppm stock solutions. Calibration solutions: fo r electrical conductivity measurements; 1413 µS/cm at 25°C solution obtained from Hanna Instrument. pH calibration; pH 7.01 buffer solution at 25°C was first used followed by pH 4.01 buffer solution at 25°C. The general purpose grade chemicals included cadmium nitrate tetra hydrate, zinc nitrate hexa hydrate, lead nitrate and potassium dichromate. These reagents were used to prepare Cd, Zn, Pb and Cr-containing solutions respectively, in which sweet potato plants were immersed.

3.6 Sample collection and storage

3.6.1 Field Samples

Plant and soil samples collected from the field sites in KARI farms in Kakamega and Yala swamp in western Kenya were stored in polythene bags. The samples were transported to the green house at the University of Nairobi. The plant leaves, roots and stem were separated and placed in paper bags for air drying. Water samples collected from sampling sites namely; rivers Nzoia, Yala, Nyando and Lake Victoria were stored in plastic containers and transported to the University of Nairobi, School of Biological Sciences (SBS) laboratory. A volume of 2ml concentrated nitric acid was added in every one liter of sample solution for preservation before digestion and analysis.

3.6.2 Sweet potato plant materials for experimental work.

The sweet potato plant cuttings used in the study were obtained from varieties grown in a garden at the University of Nairobi, College of Biological and Physical Sciences (CBPS). The cuttings were 15-20cm long (4 nodes). Leaves were removed and the cuttings placed in large plastic container with tap water (figure 3.1). They were left to pre-root for four weeks.

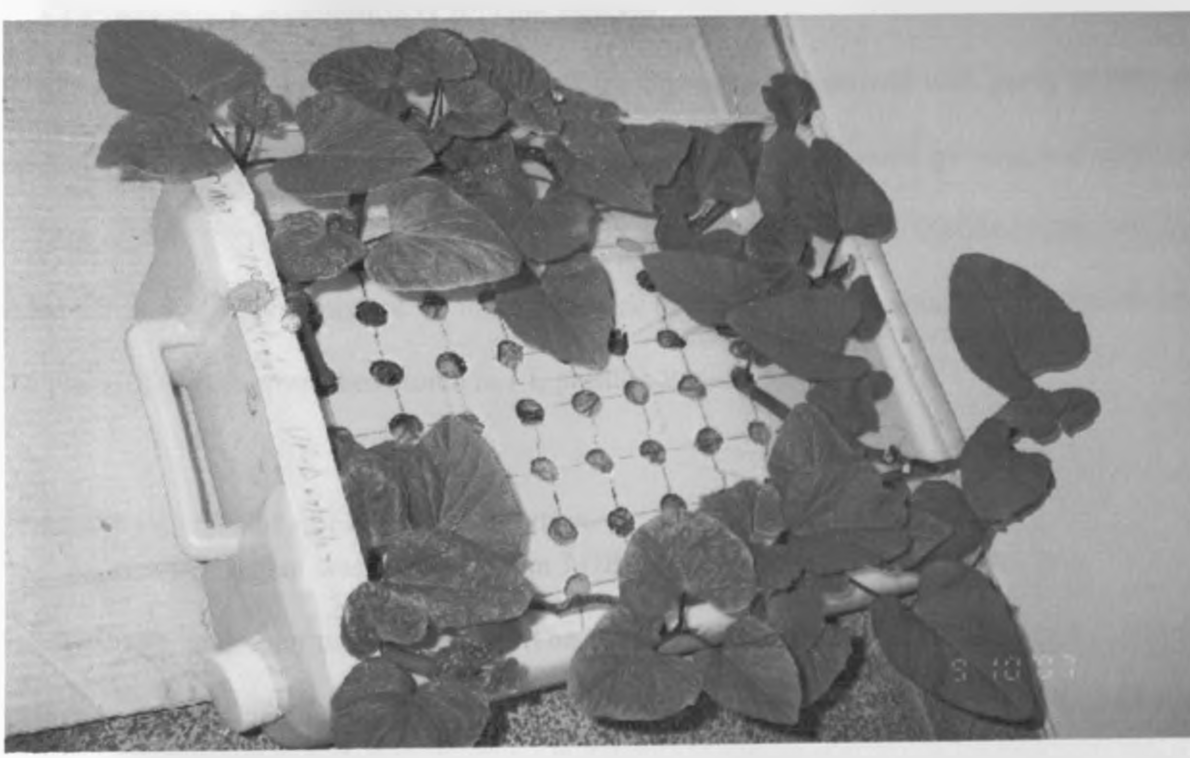

Figure 3.1: Pre-rooting of the sweet potato cuttings in an open plastic container containing tap water.

At the end of the pre rooting period, the plants had developed leaves and roots.

3.7 Laboratory preparation of heavy metal containing solutions

3.7.1 Stock solutions

The stock solutions of 1000ppm were prepared from cadmium nitrate tetra hydrate, zinc nitrate hexa hydrate, lead nitrate and potassium dichromate and stored in a 1L plastic container. Further dilutions of the stock solutions into working concentrations of 10ppm, 20ppm and 50ppm were later prepared. Preliminary work indicated that at heavy metal concentrations beyond 100ppm the sweet potato plants dried up after about three days. This was the basis of working with 10ppm, 20ppm and 50ppm solutions. Appropriate volumetric flasks and polypropylene or Teflon stoppers were used in the preparation. The procedure used in preparing the different heavy metal ion solutions is described in the subsequent subsections.

3.7.1.1 Preparation of cadmium (Cd^{2+}) ion solution.

$Cd(NO_3)_2.4H_2O$ reagent was obtained from Fluka Chemeka Switzerland with purity of 99% and molecular mass of 308.47. The cadmium ions stock solution was prepared by weighing accurately 2.7721g of $Cd(NO_3)_2.4H_2O$ and placing in a 1000ml volumetric flask. Distilled water was then added while shaking the mixture up to the 1L mark to make 1000ppm solution of cadmium ions. The prepared solution was then stored in 1 L plastic container.

3.7.1.2 Preparation of zinc (Zn^{2+}) ion solution

$Zn(NO_3)_2.6H_2O$ reagent was obtained from LOBA Chemie PVT LTD Mumbai, India. Its purity was 99% with molecular mass of 297.48. The zinc ions stock solution was prepared by weighing accurately 4.5960g of $Zn(NO_3)_2.6H_2O$ and placing in a 1000ml volumetric flask. Distilled water was then added while shaking the mixture up to the 1L mark to make 1000ppm solution of zinc ions. The prepared solution was then stored in 1 L plastic container.

3.7.1.3 Preparation of lead (Pb^{2+}) ion solution.

$Pb(NO_3)_2$ was obtained from LOBA Chemie PVT LTD Mumbai, India. Its purity was 99% with a molecular mass of 331.21. The lead ions stock solution was prepared by weighing accurately 1.6147g of $Pb(NO_3)_2$ and placing in a 1000ml volumetric flask. Distilled water was then added while shaking the mixture up to the 1L mark to make 1000ppm solution of lead ions. The prepared solution was then stored in 1 L plastic container.

3.7.1.4 Preparation of chromium (Cr^{6+}) ion solution.

$K_2Cr_2O_7$ was obtained from BDH chemicals Ltd Poole England. Its purity was 99.9% and the molecular mass was 294.18. The chromium ions stock solution was prepared by weighing accurately 2.8431g of $K_2Cr_2O_7$ and placing in a 1000ml volumetric flask. Distilled water was then added while shaking the mixture up to the 1L mark to make 1000ppm solution of chromium ions. The prepared solution was then stored in 1 L plastic container.

3.7.2 Preparation of working solutions.

To obtain the working solutions of heavy metal-containing solutions of 10ppm, 20ppm and 50ppm cadmium, zinc, lead and chromium, respective serial dilutions were carried out from 1000ppm stock solutions using the formulae;

$$C_1 V_1 = C_2 V_2$$

Where C_1 = Initial concentration

V_1 = Initial volume

C_2 = Final Concentration

V_2 = Final Volume

3.7.3 Experimental set up

The already pre-rooted plants were immersed in 200ml of the prepared heavy metal solutions in plastic containers. Each experimental set up was in triplicate. A 24h equilibration time was allowed before electrical conductivity, temperature and pH were measured. After this 24 h equilibration time the pre-rooted sweet potato plants were immersed except for the control experiments (one contained only distilled water and the other contained heavy metal ions). The plants in solutions were again allowed a 24h equilibration time before the measurements were taken. The measurements were taken after every 24h. The first day when electrical conductivity, temperature and pH of solutions were measured before immersing the plants in them was taken to be day 1 of the experiment (zero time). The plants were harvested after 14-21 days, depending on when the experiment was terminated. The experimental period was determined by tolerance of the plant variety towards the heavy metal ion in the solution.

3.7.4 Monitoring

Conductivity meter, Hanna Instrument model HI 991300, was used to measure electrical conductivity (μS/cm), temperature (^{0}C) and pH. Calibration of the instrument was done using pH buffer solutions of 4.01 and 7.01. Physical changes of plants leaves, roots and stem were observed and recorded. Measurements in electrical conductivity, pH and temperature were taken and recorded daily for a period between 14-21 days depending on the length of the period the plants survived in the test solutions.

3.7.5 Control Experiment
The set-ups used as control experiments consisted of the following:

(i) Distilled water without the sweet potato plant varieties

(ii) Heavy metal ion solutions containing zinc, lead, cadmium and chromium with varying concentrations of 10ppm, 20ppm and 50ppm without the plant varieties.

(iii) The pre-rooted sweet potato plant varieties placed in distilled water.

3.7.6 Harvesting

After 14 days, the sweet potato plant cuttings placed in cadmium ion solutions were harvested because they had dried up. Plant cuttings immersed in zinc and lead ion solutions survived for a period of 21 days. However, the plant cuttings in 50ppm chromium ion solution dried before the end of the two weeks and were therefore harvested after 14 days. Ten (10) ppm and 20ppm solutions of chromium ions were monitored for 21 days. The plants parts were separated by cutting, using clean stainless steel blades, into leaves, roots and stem during harvesting. The wet weights of the parts of the plants were then measured and stored in absorbent paper for one month for air drying.

3.8 Chemical Analysis

3.8.1 Digestion of water Samples
Water samples were obtained from field sampling, laboratory for pre-rooting plants (sweet potatoes vines) and after harvesting the plants. The procedure used for digestion was acid digestion as it suits preparation of surface and ground water samples for analysis by flame atomic absorption spectroscopy for the following metals, Al, Pb, Mg, Co, Cr, Ni, K, Zn, Ba, As and Cd (Maria & CSavia, 2004).

Procedure

Water samples of 50ml volume were placed in digestion tubes. Into each sample, 2ml of conc. nitric acid and 6ml of conc. hydrochloric acid were added and the samples placed in the digestion block and heated at 90^0C – 95 ^{0}C until the volume reduced to about 20ml. The samples were then removed from the hot plate and then allowed to cool. The tube walls were washed with water as they were filtered in 100ml volumetric flasks. Distilled water was added to the extract to adjust to final volume of 100ml. The samples were then stored for analysis.

3.8.2 Digestion of Plant Samples

Sweet potato plant samples were separated into leaves, roots and stem during harvesting. After air drying them in an absorbent paper for about one month at room temperature, they were oven dried at temperature of 105^0C for approximately six hours until the dried plants attained a constant weight. The plant samples were then ground into smaller particles after which the dry weights were measured using Sartorius model analytical weighing balance. Acid digestion method was used to digest the plant samples using the following procedures.

Procedure 1

The pre-weighed dried samples were placed in a glass beaker (50ml). Into each sample, 2ml of conc. nitric acid and 6ml of conc. hydrochloric acid were added. The beakers were then covered with a watch glass. They were then placed on a hot plate which was then set at temperatures between 90^0C – 95 ^{0}C and then heated. The samples were removed from the hot plate and then allowed to cool. The beaker walls were washed with distilled water. The solution samples were then filtered in 100ml volumetric flasks. Distilled water was added to the extract to adjust to final volume of 100ml. The samples were stored for analysis. This procedure was applied to all samples of cadmium and zinc samples.

Procedure 2

The dried samples were placed in a glass beaker (50ml). Ten ml conc. nitric acid was added to the sample and the beaker placed on a hot plate and covered with watch glass. The temperature was increased to about 100^0C to digest all organic matter until the solution turned clear yellow. The watch glass was removed and heating continued to reduce volume and concentrate the digest. However, care was taken not to dry the digest. The beaker was removed from hot plate and then 5ml 70% Perchloric acid ($HClO_4$) was added. The samples were then returned to the hot plate and digested at a temperature of $200\text{-}250^0C$ until solution became clear and white fumes were produced. The sample beakers were removed from hot plate and about 10ml of distilled water added to cool samples and stop fuming. The samples were then filtered into 100ml volumetric flask and allowed to cool at room temperature. The solution was then diluted by adding distilled water and made to 100ml mark and stored for metal analysis. This procedure was applied for samples of lead and chromium.

3.8.3. Digestion of soil samples

Soil samples were obtained from Chiromo gardens where the sweet potato plants under test were obtained from. They were also obtained from the field in Western and Nyanza provinces. They were then air dried for two months and later oven dried to constant weight at 105^0C for 24 h. They were then ground into finer size using motor and pestle after which the dry weights were measured using Sartorius model analytical weighing balance. Soil samples were digested using procedure 2.

3.8.4 Determination of heavy metal ions using AAS method

The determination of the heavy metal ions absorbed by the plant roots and translocated to the stems and leaves of the sweet potato plant varieties was done using Atomic Absorption Spectroscopy method following the procedure discussed in the subsequent subsections.

3.8.4.1. Determination of cadmium (Cd^{2+}) ion concentration.

The Cd^{2+} ion was quantified by atomic absorption spectroscopy (AAS).

Preparation of standard cadmium solution

A cadmium stock solution was obtained from Spectrosol BDH chemicals Ltd Poole England, in 1000ppm. Dilution of 100ppm was prepared by pipetting 10ml of stock solution and placed it in a volumetric flask and then adding distilled water to 100ml mark to make 100ppm intermediate stock solution. Six portions 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0ml ml of this intermediate stock solution were separately diluted by adding distilled water in 100ml volumetric flask and resultant solution diluted to the mark to give six standard solutions of cadmium as 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0ppm, respectively, lying within the optimum working range of the atomic absorption spectrometer.

Procedure

The cadmium hollow cathode lamp was placed in the operating position and the current adjusted to the recommended value and cadmium line selected at 228.8nm using the appropriate monochromatic slit width. The appropriate gas supplies were connected to the burner following detailed instructions for the instrument and the operating conditions were adjusted to give a fuel-lean acetylene-air flame. Starting with the least concentrated solution, standard cadmium solution was aspirated in turn into the flame and for each concentration three absorbance readings taken. Between each solution distilled water was aspirated into the burner. The average of the three absorbances were recorded and a calibration curve plotted and used to determine cadmium cation concentrations of acid-digested plant samples and water samples from their absorbance.

3.8.4.2. Determination of zinc (Zn^{2+}) ion concentration.

These concentrations were determined using atomic absorption spectroscopy after digesting the samples.

Preparation of standard zinc solution

Zinc nitrate standard solution was obtained from BDH chemicals Ltd Poole England (Spectrosol). Preparation of working standard solution followed the procedure used in section 3.8.4.1. A Wave length of 213.9 nm was selected. A zinc hollow cathode lamp was fixed and allowed time to stabilize. Calibration curve from the standard range was prepared and standards aspirated in turn. Between each solution distilled water was aspirated into the burner. The calibration curve was used to obtain zinc ppm in the unknown sample solution. The same procedure was used to determine blank concentrations.

3.8.4.3. Determination of lead (Pb^{2+}) ion concentration.

Lead ion concentrations were determined by atomic absorption spectroscopy, using an acetylene-air flame.

Preparation of standard lead solution

Lead nitrate standard solution used as standard was obtained from BDH chemicals Ltd Poole, England as 1000ppm stock solution. Preparation of working standard solution followed the procedure used in section 3.8.4.1. A wave length of 217.0 nm was selected and air adjusted; gas flows, slit width and other settings as recommended for the instrument. A lead hollow cathode fixed and allowed time to stabilize. Calibration curve from the standard range was

nd standards aspirated in turn. Between each solution distilled water was aspirated into

The calibration curve was used to obtain lead concentration in the unknown sample

he same procedure was used to determine blank concentrations.

etermination of total chromium ion concentration

nium ions in samples obtained from water and plants were determined by atomic

spectrometer (AAS).

on of standard total chromium solution

mium standard solution used was obtained from BDH chemicals Ltd Poole England as a tion of 1000ppm. Preparation of working standard solution followed the procedure used 3.8.4.1. A wave length of 357.9nm was selected and air, gas flows, slit width and other djusted as recommended for the instrument. A chromium hollow cathode lamp was fixed ed time to stabilize. Calibration curve was prepared using standards, which were n turn. Between each standard solution, distilled water was aspirated into the burner. The curve was used to obtain chromium concentration in the unknown sample solution. The edure was used to determine blank concentrations.

lts analysis

ysis for mean, standard deviation and plotting of trend graphs was carried out using Excel 2003.

ons

entration of heavy metals obtained from the calibration graph is in ppm, then for:

erials and soil extract,

$$\text{Metal } (\mu g/g) = \frac{\text{concentration (ppm)} \times \text{solution volume (ml)}}{\text{Sample weight (g)}}$$

The metal ion concentrations were obtained from the calibration graphs and the amount of each metal ion obtained as follows: If the value from the graph was for instance 0.5 ppm Zn and 1g of plant or soil sample had been digested initially in 20ml digestion mixture and then diluted to 100ml for atomization by AAS then;

0.5ppm = 0.5 μg of Zn per ml of sample

The amount of zinc in 100ml sample = 50 μg

Hence, concentration in μg/g = 50 μg Zn per 1g of plant or soil sample (50 μg/g)

The exact content of Zn in the sample based on the obtained dry weight of the sample is calculated by multiplying the sample dry weight in g with its concentration in μg/g.

For water samples, if AAS reading was 0.2ppm Pb and 100ml of water was digested and diluted to 100ml for atomization, then;

0.2ppm = 0.2 μg per ml of water sample

The amount of Pb in 100ml = 20 μg

The same calculations were used for all the other values and the results tabulated in the next chapter. The amount of the metals in the original solutions was calculated as follows:

For 10ppm solution is equivalent to 10μg/ml, meaning 10μg is contained in 1ml of solution. Therefore in 200ml of metal solution the amount of the metal is 2,000μg. Similarly, for 20ppm metal solution, the amount of the metal in 200ml is 4,000μg while 200ml 50ppm metal solution contained 10,000μg.

3.9.1. Instrumental methods

3.9.2. Atomic Absorption Spectroscopy

Introduction

Atomic Absorption Spectroscopy is one of the most common methods available for quantitative determination of trace amounts of solid, liquid and gaseous pollutants in environmental samples. If a solution containing a metallic salt (or some other metallic compound) is aspirated into a flame for instance acetylene burning in air, a vapor which contains atoms of the metal may be formed. Some of these gaseous metal atoms may be raised to an energy level which is sufficiently high to permit the emission of radiation which is characteristic of the metal.

Principle

However, a large number of the gaseous metal atoms will remain in an unexcited state, or the ground state. These ground state atoms are capable of absorbing radiant energy of their own specific resonance wavelength, which in general is the wavelength of the radiation that the atoms would emit if excited from the ground state. Hence if light of the resonance wavelength is passed through a flame containing the atoms in question, then parts of the light will be absorbed and the extent of absorption will be proportional to the number of ground- state atoms present in the flame.

Theory

Consider the simplified energy level diagram below, where E_0 present the ground state in which the electrons of a given atom are at their lowest energy level and E_1, E2 and E_3 represent higher or excited energy levels (Jeffery *et al*, 1989).

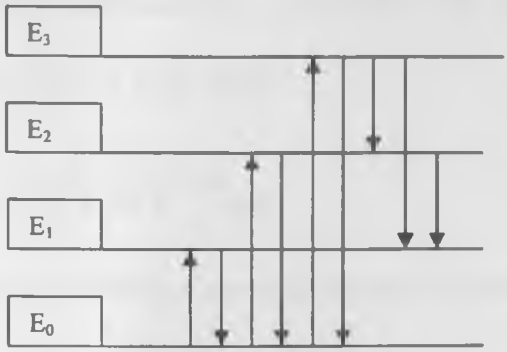

Figure3.2: Simplified energy level diagram.

Transitions between two quantized energy level say, from E_0 to E_1 correspond to the absorption of radiant energy and the amount of energy absorbed (ΔE) is determined by Bohr's equation (Jeffery *et al*, 1989).

$$\Delta E = E_1 - E_1 = h\upsilon = h^{C}/_{\lambda}$$

Where **c** - is the velocity of light

h = Planck's constant

υ = Frequency

λ = Wavelength of the radiation absorbed.

There are different excitation states associated with different elements since an atom of a given element gives rise to a definite, characteristic line spectrum.

In theory it is possible for absorption of radiation by already exited states to occur, for example E_1 to E_2, E_2 to E_3 But in practice, the ratio of excited to ground state atoms is extremely small. The relationship between the ground-state and excited-state populations is given by Boltzmann equation (Jeffery *et al*, 1989).

$$N_1/N_0 = (g_1/g_0)\, e^{-\Delta E/KT}$$

Where N_1 = number of atoms in the excited state

N_0 = number of ground state atoms.

g_1/g_0 =ratio of statistical weights for ground and excited states

ΔE= energy of excitation= hυ

K= the boltzmann constant

T= temperature in kelvin

The absorption spectra of most elements are simple in character as compared with the emission spectra hence atomic absorption spectroscopy is less prone to inter element interference than in flame emission spectroscopy. In atomic absorption spectroscopy, as with molecular absorption, the absorbance A is given by logarithmic ratio of the intensity of the incident light signal to that of transmitted light.

$$A= \log I_o/I_t = KLN_0$$

Where

N_0 = the concentration of atoms in the flame (no of atoms per ml)

L= is the path length through the flame (cm)

K= a constant related to the absorption coefficient (Jeffery *et al*, 1989).

Instrumentation

For atomic absorption spectroscopy, a resonance line source is required for each element to be determined. This source is placed in line with the detector.

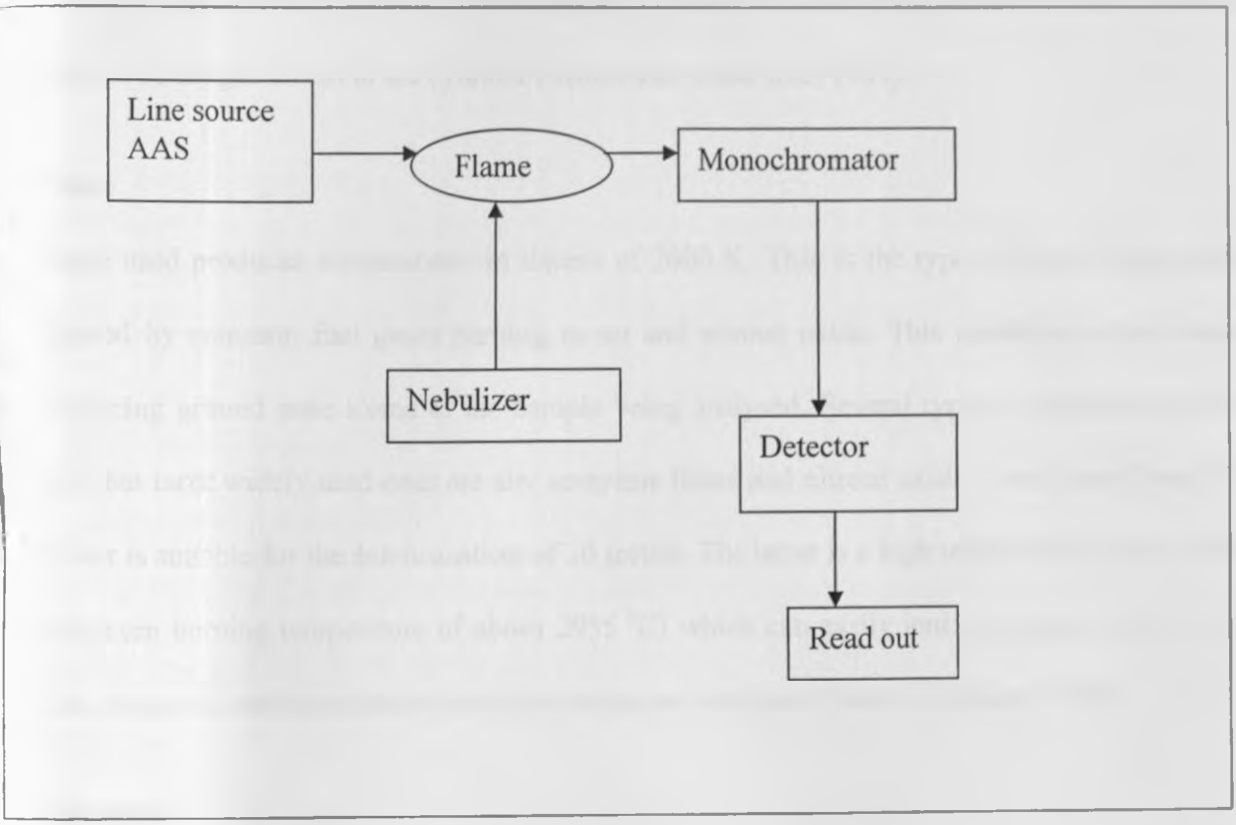

Figure 3.3: A schematic diagram showing essential components of AAS

Resonance Line Sources

For any given determination the hollow cathode lamp used has an emitting cathode of the same element as that tested in the flame. The cathode is in the form of cylinder and the electrodes are enclosed in a borosilicate of quartz envelop containing inert gases (neon or argon) at an appropriate pressure. Application of a high potential across the electrodes causes a discharge which create ions of the noble gas. The ions are accelerated to the cathode and on collision excite the cathode element to emission (Jeffery *et al*, 1989). The hollow cathode is made up of the specific element being determined and therefore the emitted radiation will only be specific to that element. The anode is most often made of tungsten. Both cathode and anode are sealed in a glass cylinder filled with either argon or neon with a window at its end for transmitting the emitted radiation. The electrical potential when applied between the anode and cathode causes ionization of some of the gas atoms in the cylinder (Milner and white side, 1984).

Flame

Flame used produces temperatures in excess of 2000 K. This is the type of flame temperatures attained by common fuel gases burning in air and nitrous oxide. This produces atomic vapors containing ground state atoms of the sample being analysed. Several types of flame are used in AAS but most widely used ones are air- acetylene flame and nitrous oxide – acetylene flame. The former is suitable for the determination of 30 metals. The latter is a high temperature flame (with a maximum burning temperature of about 2955 °C) which can easily ionize gaseous atoms. Lead, zinc, chromium and cadmium are analyzed using air- acetylene flame (Christian, 1980).

Nebuliser

This is used to convert the test solution to gaseous atoms. Nebuliser produces a mist or aerosol of the test solution drawn up by a capillary tube by the venturi action of a jet of air blowing across the top of the capillary at high pressure (Jeffery *et al*, 1989). The flow of the carrier and oxidant gas mixture generates a pressure differential at the end of the capillary tube connected to the sample and this draws the latter into the nebulizer. The sample then forms a fine mist with the fuel mixture in the spray chamber before reacting in the burner where combustion and atomization take place. Propane hydrogen, acetylene is among the fuel gases currently used. The oxidants are usually nitrous oxide and compressed air.

Nebulizers are either made from steel or corrosion resistant material such as inert plastic or platinum- rhodium alloy (Perkin-Elmer, 1978; Milner and Whiteside, 1984).

Monochromator or wavelength selector

This device is used to isolate the resonance line from all non- absorbed lines emitted by the radiation source. The resonance line corresponds to the electronic transitions from the ground state to the lowest excited state. This is often but not always, the most strongly absorbed line. Wavelength selection enables quantitative determination of a selected element in the presence of others (Milner and Whiteside, 1984).

Detector, amplifiers and read out system

The output from the detector is fed to a suitable read-out system and in this connection it must be borne in mind that the radiation received by detector originates from selected resonance line and possibly emission within the flame. The read out system available include meters, chart recorder and digital display (Jeffery *et al*, 1989). The electrical signal from the detector is further amplified and then conveyed to the read out system. The read out system comprise the electronic circuitry and a digital display. The amplified signal from the detector is directly proportional to the percentage transmittance of the sample and for this relationship to be more useful, the percentage transmittance must be converted to absorbance. This conversion and further processing of the signal up to the instrumental read out is affected by a microprocessor (Pye Unicam, 1985).

Interferences

These include:

a) spectral interferences

These are from overlap between the frequencies of a selected resonance line with lines emitted by some other elements, examples include aluminum which has wavelength of 308.216 nm and vanadium 308.211 nm, iron 271.903nm and platinum 271.904nm. Overall, spectral interferences limit the use of AAS, due to low resolution for the elements, which have very close absorption lines (Jeffery *et al*, 1989).

b) Chemical interferences

Production of ground–state gaseous atoms which is the basis of flame spectroscopy may be inhibited by two main forms of chemical interferences.

***Stable compound formation**

This leads to incomplete dissociation of substance to be analyzed when placed in the flame or from the association within the flame of refractory compounds which fail to dissociate into constituent atoms.

***Ionization**

Ionization of the ground–state gaseous atoms within a flame will reduce the intensity of the extent of absorption on the atomic absorption spectroscopy. It is therefore necessary to reduce to a minimum the possibility of ionization occurring. Hence, high temperature of an acetylene- air or acetylene- nitrous oxide flame may result in appreciable ionization of element for instance alkali metals, calcium and barium.

Other effects

- Matrix effects- physical factors which influence the amount of sample reaching the flame and are related to viscosity, density, surface tension and the volatility of the solvent and in preparation of test solution.
- Background absorption- arises from the presence in the flame of gaseous molecules, molecular fragment and in some instances where organic solvents are used. These are dealt with instrumentally by the incorporation of a background correction facility (Jeffery *et al*, 1989).

To Reduce Interferences in AAS

1. Ensure if possible standard and sample solutions are of similar bulk composition in order to eliminate matrix effects.
2. Alteration of flame or of flame temperature can be used to reduce the hitch hood of stable compound formation within the flame.
3. Selection of an alternative resonance line will overcome spectral interferences from other atoms/molecules fragment.
4. Occasionally, separation by solvent extraction or by ion exchange process may be necessary to remove an interfering element.
5. Use an appropriate background correction facility.

3.9.3. Electrolytic Conductivity.

It is defined as the ability of a substance to conduct electrical current. It is measured in siemens per cm and the more commonly used unit is micro siemens per cm (μS/cm). Conductivity is conductance as measured between opposite faces of a 1 cm tube of material.

Application of Conductivity

Conductivity is extensively used in the measurements of water supplies for municipal, commercial, hospital and industries.

Major Draw Back of Conductivity

Conductivity measurement are non- specific and therefore cannot distinguish between different types of ions, giving instead a reading that is proportional to all the ions present in the solution, with some ions for example sodium hydroxide and hydrochloric acid contributing far more than others.

Determination of conductivity of a solution

The essential items of equipment include a suitable cell containing metal electrodes between which the current to be measured passes and a means of measuring the electrical resistance between these electrodes. To avoid errors due to polarization it is essential that the current passing in the cell is alternating (Strouts *et al.*, 1955)

Effect of Polarization

When direct current voltage is applied across the electrodes of a conductivity cell, the ions present in the solution will be discharged on the electrodes and by surrendering or accepting electrons they change into molecular form. The flow of ion ceases within a short time and consequently current decreases to virtually zero. Therefore, alternating current voltage is used for conductivity measures. Polarization still takes place during a half cycle of one polarity, causing space charge build up around the electrodes resulting in a loss of current flow. In addition to polarization effects, conductivity cells with higher cell constants require long, narrow passages to obtain these constants, which make the electrode contacts more susceptible to coatings by oils, slurries or sludge commonly found in the streams of high conductivity.

Electrode cell constant

Simple conductivity sensors are constructed from an insulating material embedded with platinum, graphic stainless steel or other metallic pieces. The metal contacts serve as sensing element placed at a fixed distance apart to make contact with a solution where conductivity is to be determined. The length between the sensing element as well as the surface area of the metallic piece determines the cell constant.

$$\text{Cell Constant} = \frac{\text{Distance between electrodes}}{\text{The electrodes surface area}}$$ (Strouts *et al.*, 1955)

Effect of Temperature

Conductivity of aqueous solution is by means of ionic motion and invariably increases with increasing temperature, opposite to metals but similar to graphite.

Conductivity and Concentration

The number of charge carriers per unit volume of electrolyte usually increases with increase in electrolyte concentration; therefore solutions conductivity usually increases as electrolytes concentration increases (Levine, 2002).

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Trends in temperature and pH measurements in solutions containing various heavy metal ions in which different sweet potato plant varieties were immersed.

Experiments were performed to determine the possible influence of different sweet potato plant varieties on the temperature and pH of solutions containing varying concentrations of different heavy metal ions. The results of these series of experiments are described and discussed in the subsequent subsections.

4.1.1 Influence of sweet potato plant varieties immersed in Cadmium - containing solutions on temperature and pH

The influence of various sweet potato plant varieties immersed in Cd^{2+}-containing solutions on temperature and pH were determined and results provided below. Table 4.1 shows the temperature and pH range measurements taken for Cd^{2+}-containing solutions of varying concentrations. The sweet potato plant varieties are identified as UP-A, UP-B, UP-C, UP-D and UP-16. The control solution conditions contained no sweet potato plant varieties.

Table 4.1: The mean temperature and pH range of Cd^{2+}-containing solutions with immersed sweet potato plant varieties over a 14 day period.

Concentration of Cd^{2+} solution(ppm)	Variety	Mean temperature range * (°C)	Mean pH range *
0	Control (No plant)	21.77 -23.93	5.09 - 5.85
	UP-A	22.03 - 24.00	5.00 - 6.26
	UP-B	22.00 - 23.73	5.00 - 6.46
	UP-C	21.93- 23.90	5.09 - 6.44
	UP-D	21.93- 23.83	4.71 - 6.42
	UP-16	21.93-23.90	5.09 - 6.65
10	Control (No plant)	21.44 - 24.20	4.66 - 6.26
	UP-A	22.03 - 24.13	4.66 - 6.26
	UP-B	22.00 - 23.97	4.68 - 7.25
	UP-C	22.00 - 23.90	4.68 - 7.48
	UP-D	21.70 - 23.93	4.69 - 7.48
	UP-16	22.03 - 23.87	4.69 - 7.69
20	Control (No plant)	22.00 - 23.87	4.50 - 6.54
	UP-A	21.97 - 23.77	4.52 - 7.56
	UP-B	21.93 - 23.70	4.53 - 7.62
	UP-C	21.93 - 23.70	4.53 - 7.62
	UP-D	21.93 - 23.47	4.53 - 7.44
	UP-16	21.97 - 23.43	4.54 - 7.56

*The range given corresponds to the lowest and highest value obtained within 14 days.

Sweet potato plant varieties immersed in the solution did not affect the temperature as shown in table 4.1. The pH of the solutions with different plant varieties increased with increase in concentration of Cd^{2+}-containing solutions. Aqueous salts of cadmium are hydrolyzed.

$$Cd^{2+}_{(aq)} + 2H_2O \rightleftharpoons CdOH^{+}_{(aq)} + H_3O^{+}$$

The presence of H_3O^+ explains why pH at day one of the experiment was acidic. Preferential adsorption of H_3O^+ on the plant roots results into a slightly higher pH of the solution. The adsorption of the hydronium ion depended on the variety used, hence the variation of pH used (Cotton and Wilkinson, 1978).

Table 4.2 shows the physical changes observed on the sweet potato plant varieties immersed in distilled water and in different solutions containing different concentrations of cadmium (Cd^{2+}) over a 14 day period. Leaves were counted at the beginning of the experimental period. The sweet potato plant varieties immersed in Cd^{2+}-containing solutions showed different physical changes at different days within the range of days indicated in table 4.2.

Table 4.2: Observations on physical changes of sweet potato varieties immersed in solutions of varying concentrations of Cd^{2+} solutions over 14 days

Variety	Concentration of Cd^{2+} solution (ppm)	Day 0-4	Day 5-9	Day 10-14
UP-A	0	3 leaves and three long thin roots	new shoots formed from 6th day	Plants survived without drying on day 10
	10	3-5 leaves, fresh stem and long hairy roots	Stem and leaves changed color from green to yellow	Plants had dried up on day 11

Table 4.2 (*contd...*)

Variety	Concentration of Cd^{2+} solution (ppm)	Day 0-4	Day 5-9	Day 10-14
UP-A	20	3 leaves and long hairy thin roots	Stems changed from green color to yellow Leaves withered	Stems and leaves dried up on day 10
UP-B	0	two leaves and long thin roots	New leaves forming	Plants survived
	10	4-5 leaves, fresh stem and long hairy roots	Leaves wilted and then changed colour to yellow	Leaves and stem withered and dried up on day 12 but roots remained intact
	20	Leaves, long hairy roots and shoots developing	leaves and stems changed color from green to yellow	No change in roots but leaves and stem dried up
UP-C	0	Leaves about 4and long hairy roots	Size of roots and leaves growing well	Plants survived until harvesting.
	10	More than 3 leaves, hairy roots and fresh green stem	Leaves wilted and stem changed color from green to yellow, new roots forming	Stems withered and dried on up followed by leaves.
	20	3 leaves, long hairy roots and fresh green stem	Stems withered and begun drying up and new roots forming on day8	Plants stems and leaves dried up on the 11th day
UP-D	0	Leaves and roots well developed	New roots and leaves forming	All the plants survived with more roots and leaves
	10	4 leaves, long hairy roots and fresh stems	Leaves changed to yellow from green color	Stems changed from green to yellow and then dried.
	20	Leaves 5, fresh stems and hairy roots	Wilting of leaves and then turned yellow	Plants withered and dried up with stem first, then leaves.

Table 4.2 (*contd*...)

Variety	Concentration of Cd^{2+} solution (ppm)	Day 0-4	Day 5-9	Day 10-14
UP-16	0	1-3 broad leaves, new shoots and long roots	New leaves and roots forming.	None of the plants dried on 11th
	10	2 leaves, long hairy roots and fresh stem.	Leaves turned yellow from green. New roots formed.	Plant stems, leaves dried up. Root tips were black in color.
	20	3 leaves, long hairy roots and fresh stem.	Leaves and stem begun changing color from green to yellow after day 7	Plant stems, leaves dried up day10. Root tips were black in color.

The observations on the plants immersed in distilled water indicated that growth continued throughout the experimental period. However, the plants immersed in cadmium- containing solutions demonstrated wilting between the 5th and 9th day after which the plants withered and dried up. Therefore, the plants were harvested after two weeks. These observations indicated that the sweet potato plant varieties could not tolerate cadmium in solution. The changes in colour of the leaves from green to yellow (chlorosis) agree with observation made on the sunflower plants (Salt *et al*. 1995). Salt reported that Cd^{2+} preferentially accumulated in the leaves of the sunflower plants (*Helianthus annus*) and this might be the cause of chlorosis. This observation is further supported by Stobart *et.al* (1985) who reported that Cd^{2+} is a potent inhibitor of chlorophyll biosynthesis in barley leaves.

4.1.2 Influence of sweet potato plant varieties immersed in chromium- containing solutions on temperature and pH

The influence of various sweet potato plant varieties immersed in chromium - containing solutions on temperature and pH were determined and results provided below. Table 4.3 shows the temperature and pH range measurements taken for chromium-containing solutions of varying concentrations. The sweet potato plant varieties are identified as UP-A, UP-B, UP-C UP-D and UP-16. The control solution conditions contained no sweet potato plant varieties immersed.

Table 4.3: The mean temperature and pH range of chromium -containing solutions with immersed sweet potato plant varieties over a 14 and 21 day period.

Concentration of Cr^{6+} solution (ppm)	Variety	Mean temperature range *	Mean pH range *
0	Control (No plant)	17.83 -23.43	5.21 - 5.84
	UP-A	19.80 -23.07	5.09 - 6.20
	UP-B	19.70 -23.00	5.24 - 5.93
	UP-C	19.70 -23.00	5.24 - 5.93
	UP-D	17.77 -23.50	5.25 - 5.80
	UP-16	17.80 -23.63	5.33 - 6.22
10	Control (No plant)	17.83 - 23.83	5.04 - 5.23
	UP-A	17.80 - 23.77	5.05 - 7.28
	UP-B	17.83 - 23.87	5.06 - 7.23
	UP-C	17.83 - 23.87	5.06 - 7.23
	UP-D	18.00 - 23.77	5.06 - 7.02
	UP-16	18.00 - 23.77	5.06 - 7.02
20	Control (No plant)	17.87 - 23.63	4.91 - 5.14
	UP-A	17.93 - 23.57	4.94 - 6.83
	UP-B	17.97 - 23.40	4.92 - 7.30

Table 4.3 (*contd...*)

Concentration of Cr^{6+} solution (ppm)	Variety	Mean temperature range *	Mean pH range *
20	UP-C	17.97 - 23.40	4.92 - 7.30
	UP-D	18.00 - 23.23	4.92 - 7.38
	UP-16	17.97 - 23.63	5.15 - 7.42
50	Control (No plant)	21.83 - 24.27	4.91 - 5.06
	UP-A	21.60 - 24.17	4.82 - 6.74
	UP-B	21.77 - 24.20	6.13 - 7.27
	UP-C	21.77 - 24.20	6.13 - 7.27
	UP-D	21.57 - 24.30	4.81 - 7.12
	UP-16	21.77 - 24.27	4.82 - 7.39

* The range given corresponds to the lowest and highest value obtained within 14 and 21 days.

The plant varieties immersed in the chromium-containing solutions did not affect the temperature of the solutions. The 50ppm chromium-containing solution set up was set at different time and this justified the difference in temperature from the other set ups. It has been suggested that plants take up chromium as chromates CrO_4^{2-}. However, at the pH values and redox potentials prevailing in most soils, chromium (VI) is readily reduced to chromium (III) ion mainly occurring as the slightly soluble chromium (III) hydroxide (Bott and Bruggenwert, 1976). This may have attributed to increase in pH of the chromium-containing solution. The results in table 4.3 demonstrate that pH range of chromium- containing solutions increases with the chromium concentration in solution. The control experiment results show a slight change in the pH. Immersing the sweet potato plants in the chromium-containing solutions generally contributed to the solutions changing into neutral solution from slightly acidic as explained in the case of cadmium (page 56).

Table 4.4 shows the physical changes observed on the sweet potato plant varieties immersed in distilled water (0ppm) and different chromium (Cr) containing solutions for a period of 14 -21 days. Leaves were counted at the beginning of the experimental period. The sweet potato plant varieties immersed in Cr-containing solutions showed different physical changes at different days within the range of days indicated in table 4.4.

Table 4.4: Observations on physical changes of sweet potato varieties immersed in Cr-containing solutions for a period of 14-21 days

Variety	Concentration of Cr^{6+} solution (ppm)	Day 0-7	Day 8-14	Day 15-21
UP-A	0	Small leaves and long thin roots	New leaves and roots	Plant tissues did not dry
	10	3 leaves and long thin roots	Plant roots, leaves and stems survived	stems drying on day 14, leaves remained green and no change in roots
	20	Leaves, long thin roots and fresh stem. The plants wilted on day 3.	Stems immersed in the solution begun withering	Stems dried followed by leaves. No change in the roots.
	50	Fully developed leaves, roots and stems	Stems and leaves dried up but no change in roots.	
UP-B	0	3 leaves with long thin roots and fresh stems	New roots and leaves forming	Plant growth progressive until harvesting.
	10	2 leaves and short roots	New leaves but no change in the root and stem changed to yellow	stems and leaves completely dried up

Table 4.4 (*contd...*)

Variety	Concentration of Cr^{6+} solution (ppm)	Day 0-7	Day 8-14	Day 15-21
UP-B	20	3 leaves with long thin roots and fresh stems	New leaves were observed but no new roots	Plant did not show signs of drying up.
	50	4 leaves, long hairy roots and fresh stems	Leaves and stems turned yellow and then dried up.	
UP-C	0	4 leaves, long thin roots and fresh stems	New leaves forming but roots intact.	None of the plants dried up
	10	3 leaves, fresh stems and long thin roots	New leaves forming but no new roots.	Plant tissues survived.
	20	5 leaves and long hairy roots	New roots formed but leaves withered	Stems fresh, leaves withered there were no new roots formed
	50	Leaves begun withering, no new roots formed.	Stems dried up and no new roots developed.	
UP-D	0	3 to 4 leaves, fresh stems and long thin roots	New leaves and roots formed	Plant tissues showed continuous growth.
	10	4 leaves, fresh stems and long thin roots	New leaves forming but no new roots.	Plant tissues survived.
	20	4 leaves and long hairy roots	Leaves broadened and new leaves and roots formed.	Plants survived.
	50	Leaves and stems turned yellow. No new roots, wilting was observed.	Stems and leaves dried up from day 10	

Table 4.4 (*contd...*)

Variety	Concentration of Cr^{6+} solution(ppm)	Day 0-7	Day 8-14	Day 15-21
UP-16	0	Two leaves, short roots and fresh stem	New leaves and roots formed. Stem remained fresh	None of the plants dried up
	10	3 leaves, thin roots and fresh stem	Leaves broadened and roots grew longer	Plant tissues survived
UP-16	20	3 leaves, thin roots and fresh stem	New roots and leaves formed	Plants survived until harvesting day.
	50	Leaves and stem turned yellow. No new roots formed.	Stems withered and then dried up at the 10th day with leaves following	

The observations in table 4.4 indicate that the sweet potato plants immersed in distilled water, 10ppm and 20ppm chromium-containing solutions survived. However, the plants could not tolerate 50ppm chromium-containing solutions with most plants drying up after the first week. This can be attributed to toxicity of chromium to the plant tissues at 50ppm concentration level.

4.1.3 Influence of sweet potato plant varieties immersed in zinc-containing solutions on temperature and pH

The influence of various sweet potato plant varieties immersed in zinc -containing solutions on temperature and pH were determined and results provided below. Table 4.5 shows the temperature and pH range measurements taken for zinc - containing solutions of varying concentrations. The sweet potato plant varieties are identified as UP-A, UP-B, UP-C UP-D and UP-16. The control solution conditions contained no sweet potato plant varieties immersed.

Table 4.5: The mean temperature and pH range of zinc -containing solutions with immersed sweet potato plant varieties over a 21 day period.

Concentration of Zn^{2+} solution(ppm)	Variety	Mean temperature range *	Mean pH range *
0	Control (No plant)	18.80 -23.00	5.15 - 5.89
	UP-A	18.83 -23.27	5.30 - 5.92
	UP-B	18.77 -23.17	5.41 - 6.02
	UP-C	18.60 - 22.83	5.53 - 6.09
	UP-D	18.77 - 22.50	5.57 - 6.27
	UP-16	18.77 - 23.40	5.63 - 6.04
10	Control (No plant)	19.03 - 22.83	5.30 - 5.72
	UP-A	18.83 - 23.53	5.98 - 6.88
	UP-B	18.57 - 23.27	6.03 - 7.15
	UP-C	18.50 - 23.47	6.08 - 7.19
	UP-D	18.83 - 23.43	6.08 - 7.15
	UP-16	18.80 - 23.57	6.09 - 7.17
20	Control (No plant)	18.83 - 23.37	5.99 - 6.48
	UP-A	19.07 - 23.20	6.22 - 6.75
	UP-B	18.83 - 23.30	6.24 - 7.21
	UP-C	19.07 - 23.17	6.25 - 7.27
	UP-D	18.67 - 23.03	6.24 - 7.19
	UP-16	18.60 - 22.93	6.26 - 7.18
50	Control (No plant)	19.60 - 24.57	6.10 - 6.32
	UP-A	19.40 - 24.30	6.18 - 6.87
	UP-B	21.83 - 24.40	6.22 - 7.29

Table 4.5(*contd...*)

Concentration of Zn^{2+} solution(ppm)	**Variety**	**Mean temperature range ***	**Mean pH range ***
	UP-C	19.50 - 24.30	6.22 - 7.20
	UP-D	19.57 - 24.33	6.20 - 7.31
	UP-16	19.47 - 24.23	6.19 - 7.31

* The range given corresponds to the lowest and highest value obtained within 21 days.

The measured pH range in solutions containing zinc ions and sweet potato plant varieties were slightly higher than those obtained for cadmium and chromium- containing solutions which were more acidic than shown by zinc-containing solutions (table 4.5). Both cadmium and zinc ions form solutions that are acidic as reported by Liptrot (1971) and aqueous solution of cadmium are less acidic than those of zinc due to the large size of Cd^{2+} which cannot polarize water molecules as readily as smaller Zn^{2+}. The pH values of zinc solutions exhibit a different observation probably due to the influence of plant varieties immersed in the solutions containing zinc ions. The pH of the solutions with different plant varieties increased with increase in concentration of Zn^{2+}-containing solutions. Aqueous salts of zinc are hydrolyzed similar to that of cadmium.

$$Zn^{2+}_{(aq)} + 2H_2O \rightleftharpoons ZnOH^{+}_{(aq)} + H_3O^{+}$$

Table 4.6 shows the physical changes observed on the sweet potato plant varieties immersed in distilled water (0ppm) and varying concentrations of zinc (Zn^{2+}) solutions for 21 days. Leaves were counted at the beginning of the experimental period. The sweet potato plant varieties immersed in Zn^{2+}-containing solutions showed different physical changes at different days within the range of days indicated in table 4.6.

Table 4.6: Observations on physical changes of sweet potato varieties immersed in Zn^{2+}-containing solutions over 21days

Variety	Concentration of Zn^{2+} solution(ppm)	Day 0-7	Day 8-14	Day 15-21
UP-A	0	3 leaves, long thin roots and fresh stem	New roots and leaves forming	None of the plants dried up.
	10	2-3 leaves, long thin roots and fresh stem	Stem immersed in solution turning yellow	New leaves formed and root tips turned black
	20	3 leaves, long thin roots and fresh stem	New leaves formed but no new roots	Plants survived until harvesting day.
	50	3-5 leaves, long thin roots and fresh stem	Leaves and roots intact but stem drying	Leaves and stems dried up at the 17^{th} day.
UP-B	0	3 leaves, shoots fresh stems and long roots	New roots and stems forming	Plant growth continued until harvesting day.
	10	3 leaves, fresh stems and long hairy roots	Root tips turned black in color, leaves intact.	Plants survived
	20	4 leaves, fresh stems and long hairy roots	New leaves and roots formed	None of the plants dried.
	50	3 leaves, fresh stems and long hairy roots	New leaves formed but no new roots formed.	Plants survived in the solution.
UP-C	0	2 leaves, fresh stems and long hairy roots	New leaves and roots formed	None of the plants dried.
	10	3 leaves, fresh stems and long hairy roots	Stems turned yellow and new roots forming.	Plants survived to harvesting.

Table 4.6 (*contd...*)

Variety	Concentration of Zn^{2+} solution (ppm)	Day 0-7	Day 8-14	Day 15-21
UP-C	**20**	3 leaves, fresh stems and long hairy roots	New leaves and roots formed	Root tips turned black in color. The plants survived.
	50	4 leaves, fresh stems and long hairy roots	Leaves turned yellow from green and no new roots	Stem remained green but leaves dried up.
UP-D	**0**	3 leaves, shoots fresh stems and long roots	New roots and leaves formed	None of the plants dried.
	10	3 -4 leaves, shoots fresh stems and long roots	Root tips turned black, no change in leaves and roots	Plants survived until harvesting.
	20	3 leaves, shoots fresh stems and long roots	New roots and leaves formed	Plants survived until harvesting.
	50	3 leaves, shoots fresh stems and long roots	Leaves wilted and drying and no new roots formed.	Root tips turned black in color. Leaves dried up.
UP-16	**0**	5 leaves, fresh stems and long hairy roots	new leaves, roots forming and length of stem extending	None of the plants dried.
	10	4-5 leaves, fresh stems and long hairy roots	New leaves and roots formed	Plants survived until harvesting.
	20	3 leaves, fresh stems and long hairy roots	Roots turned black at the tips as new leaves formed.	No new roots were formed and the stem remained green.
	50	4 leaves, fresh stems and long hairy roots. Leaves wilted by day 3.	Leaves withered and turned yellow. No new roots formed	Leaves and stem dried up slowly toward the last day.

Generally, all the plants survived in the test solutions for the first week. New roots and leaves were observed in plants immersed in distilled water, 10ppm and in some cases 20ppm zinc solutions. This growth may be attributed to zinc being essential in plants for enzymes like dehydrogenase and peptidases (Underwood, 1977). However in 50ppm solutions, leaves withered and dried in the third week in all varieties except UP-B. It was also noted that the plants immersed in zinc solutions took more time to wither and dry up compared to similar varieties immersed in cadmium and chromium- containing solutions.

4.1.4 Influence of sweet potato plant varieties immersed in lead- containing solutions on temperature and pH

The influence of various sweet potato plant varieties immersed in lead-containing solutions on temperature and pH were determined and results provided below. Table 4.7 shows the temperature and pH range measurements taken for lead - containing solutions of varying concentrations. The sweet potato plant varieties are identified as UP-A, UP-B, UP-C UP-D and UP-16. The control solution conditions contained no sweet potato plant varieties immersed.

Table 4.7: The mean temperature and pH range of Pb^{2+}-containing solutions with immersed sweet potato plant varieties over a 21 day period.

Concentration of Pb^{2+} solution(ppm)	Variety	Mean temperature range *	Mean pH range *
0	Control (No plant)	19.13 - 25.97	5.27 - 5.73
	UP-A	19.20 - 26.80	5.23 - 6.68
	UP-B	19.07 - 25.40	5.24 - 6.77
	UP-C	19.07 - 25.37	5.21 - 6.27
	UP-D	19.03 - 26.10	5.20 - 6.30
	UP-16	19.17 - 26.03	5.28 - 6.31

Table 4.7 (*contd...*)

Concentration of Pb^{2+} solution(ppm)	Variety	Mean temperature range *	Mean pH range *
10	Control (No plant)	19.13 - 28.63	5.31 - 5.74
	UP-A	20.10 - 26.83	5.45 - 6.99
	UP-B	19.07 - 26.87	5.48 - 6.98
	UP-C	19.43 - 28.20	5.46 - 6.87
	UP-D	19.35 - 26.43	5.40 - 6.89
	UP-16	19.97 - 26.90	5.41 - 6.89
20	Control (No plant)	19.20 - 25.77	5.08 - 5.37
	UP-A	19.30 - 27.10	5.32 - 7.30
	UP-B	19.33 - 24.67	5.47 - 7.31
	UP-C	19.37 - 25.37	5.12 - 7.05
	UP-D	19.35 - 24.75	5.52 - 7.15
	UP-16	20.10 - 25.57	5.52 - 7.15
50	Control (No plant)	19.30 - 24.67	5.33 - 5.60
	UP-A	19.37 - 24.70	5.38 - 6.64
	UP-B	19.40 - 24.57	5.43 - 7.29
	UP-C	19.43 - 24.63	5.44 - 7.71
	UP-D	19.47 - 24.43	5.46 - 7.43
	UP-16	19.87 - 24.43	5.45 - 7.41

*The range given corresponds to the lowest and highest value obtained within 21 days.

The presence of sweet plant varieties in distilled water and lead-containing solutions did not influence the temperature of the solutions as is evident with the temperature in the control experiments without the plant varieties. The lead-containing solutions of 10ppm showed its pH range as being nearly equal to that of plant varieties immersed in distilled water. This then means the plant varieties immersed in 10ppm lead-containing solutions did not influence change in pH of the solution. However, for 20ppm and 50ppm lead-containing solutions the pH solutions turned from weakly acidic into neutral solutions. These results were similar to those obtained from cadmium, chromium and zinc-containing solutions. The plumbous ion is partially hydrolyzed in water.

$$Pb^{2+}_{(aq)} + 2H_2O \rightleftharpoons PbOH^{+}_{(aq)} + H_3O^{+}$$

Table 4.8 shows the physical changes observed on the sweet potato plant varieties immersed in distilled water (0ppm) and varying concentrations of lead (Pb^{2+}) solutions over 21 days. Leaves were counted at the beginning of the experimental period. The sweet potato plant varieties immersed in Pb^{2+}-containing solutions showed different physical changes at different days within the range of days indicated in table 4.8.

Table 4.8: Observations on physical changes of sweet potato varieties immersed in Pb^{2+}-containing solutions over 21days

Variety	**Concentration of Pb^{2+} solution(ppm)**	**Day 0-7**	**Day 8-14**	**Day 15-21**
UP-A	0	3 leaves were small in size, thin roots and stem.	New roots and leaves formed	Plants tissues increased in size.
	10	3 leaves, thin long roots and stem	New roots and leaves formed	Plants survived in the solution.
	20	3 leaves, thin long roots and fresh stem	new leaves and roots observed	Stems begun drying but leaves still green

Table 4.8 (*contd...*)

Variety	Concentration of Pb^{2+} solution(ppm	Day 0-7	Day 8-14	Day 15-21
UP-A	50	3-4 leaves, thin long roots and fresh stem	Stems begun withering with no new roots forming.	Plants dried up beginning with the stems.
UP-B	0	3 large leaves, fresh stem and long hairy roots.	New shoots, leaves and roots formed.	Plants growth continued until harvesting.
	10	2-3 leaves, fresh stem and long hairy roots.	New leaves and roots formed.	Plants survived in the solution.
	20	3 leaves, fresh stem and long hairy roots	New shoots, leaves and roots formed.	Plants growth continued until harvesting.
	50	3-4 leaves, fresh stem and long hairy roots	Leaves turned yellow and new roots developed.	No new roots and leaves formed
UP-C	0	3 leaves fresh stems and long hairy roots	New leaves and roots formed	None of the plants dried up.
	10	5 leaves fresh stems and long hairy roots	New roots formed but no new leaves were formed.	Leaves turned yellow but the stems remained intact.
	20	3 leaves fresh stems and long hairy roots	New leaves and roots formed	New roots developed rapidly.
	50	3-5 leaves fresh stems and long hairy roots	Leaves turned yellow in color and new roots forming	Leaves and stems dried up.
UP-D	0	4 leaves fresh stems and long hairy roots	New leaves and roots formed	Plants growth continued until harvesting.
	10	4 leaves fresh stems and long hairy roots	Leaves wilted, turned yellow and root turned brown	New long roots and leaves formed.

Table 4.8 (*contd*...)

Variety	Concentration of Pb^{2+} solution(ppm	Day 0-7	Day 8-14	Day 15-21
	20	3 leaves, fresh stems and long hairy roots. Wilting of leaves observed	Leaves wilted, turned yellow. New roots formed	The stem remained green but the leaves withered and dried up at the 18th day.
	50	3-4 leaves fresh stems and long roots	Leaves turned yellow as new roots were formed.	The stem remained green but the leaves dried up.
UP-16	0	4 leaves fresh stems and long roots	New roots and leaves formed	The plant tissues continued with growth.
	10	5 leaves fresh stems and long roots	Few leaves turned yellow but new leaves and roots formed	The stem remained green but the leaves dried up
	20	4 leaves fresh stems and long roots	New roots and leaves formed	The stem remained green but the leaves dried up
	50	4-5 leaves fresh stems and long roots. Leaves wilted by day 2.	Leaves wilted, turns yellow. New leaves formed.	The stem remained green but the leaves withered and then dried up after day 16.

A general observation made from the plants immersed in lead- containing solutions was growth of new roots within the first two weeks. Leaves were however drying in the third week for the plants immersed in 20ppm and 50ppm lead solution probably due to lead toxicity after a possible translocation of lead by the plant from the contaminated solutions in the course of the growth. However, variety UP-B did not dry up in 50ppm Pb^{2+}-containing solutions implying significant tolerance towards lead metal.

4.2 Mean electrical conductivity trends of heavy metal -containing solutions in which different sweet potato plant varieties are immersed.

The effects of various sweet potato plant varieties immersed in hydroponic solutions containing varying concentrations of heavy metal ions (Cd^{2+}, Pb^{2+}, Zn^{2+} and Cr ions) on electrical conductivity are discussed in this section. The electrical conductivity measurements are in µS/cm and were recorded over a period of between 14-21 days in the varying concentrations of heavy metal solutions ranging from 10ppm to 50ppm.

4.2.1 Mean electrical conductivity measurements of Cd^{2+}-containing solutions

The results of mean electrical conductivity of distilled water and cadmium- containing solutions of 10ppm and 20ppm without any sweet potato plant varieties immersed in them were chosen as control experiments are shown in figure 4.1. These electrical conductivity data from the blanks were always subtracted from the electrical conductivity data obtained with corresponding sweet potato plant immersed in cadmium- containing solutions.

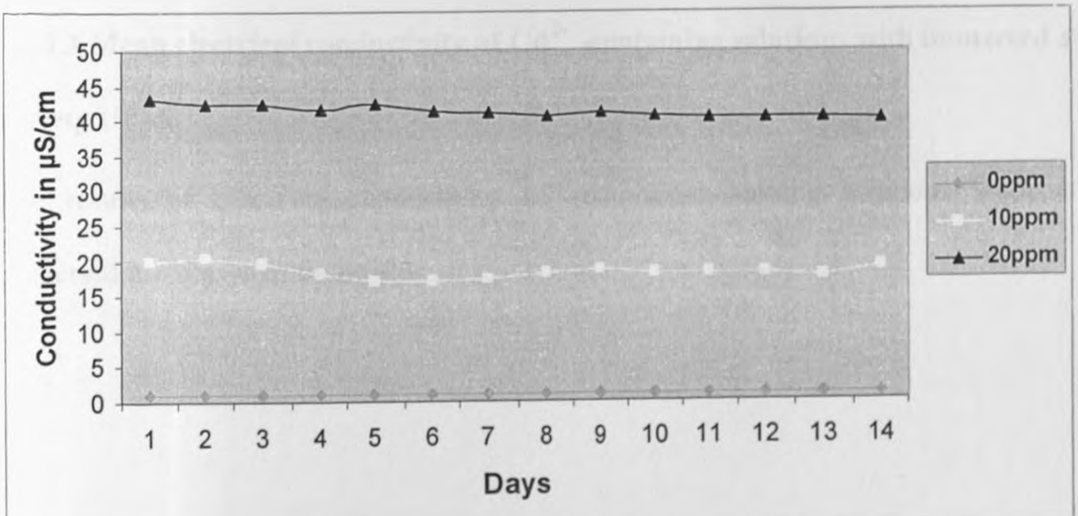

Figure 4.1: Mean electrical conductivity in µS/cm of cadmium-containing blank solutions without sweet potato plants.

stilled water showed a constant electrical conductivity of 1.00μS/cm throughout the perimental period. During the same period the electrical conductivity of the 10ppm cadmium-ntaining solution dropped from 20μS/cm in the first day to 17.00μS/cm on day 6 and then rose 19.00μS/cm in the last day. A similar trend was observed for the 20ppm cadmium-containing ution where the conductivity was 43.00μS/cm on the first day but dropped to 40.00μS/cm by last day. The electrical conductivity of the blank solutions remained relatively constant oughout the growing period. The results demonstrate that electrical conductivity of cadmium reases with increase in concentration of the control solutions with 20ppm cadmium solution gistering higher conductivity than 10ppm solution and distilled water respectively as expected.

nerally, electrical conductivity of cadmium-containing solutions with immersed sweet potato ant varieties increased in comparison with those obtained from their respective corresponding ntrol solutions (i.e. without the sweet potato plant varieties) as illustrated in the subsequent sub-ctions.

2.1.1 Mean electrical conductivity of Cd^{2+} -containing solutions with immersed sweet potato riety UP-A

ie results of electrical conductivity of cadmium-containing solutions with variety UP-A mersed are shown in figure 4.2.

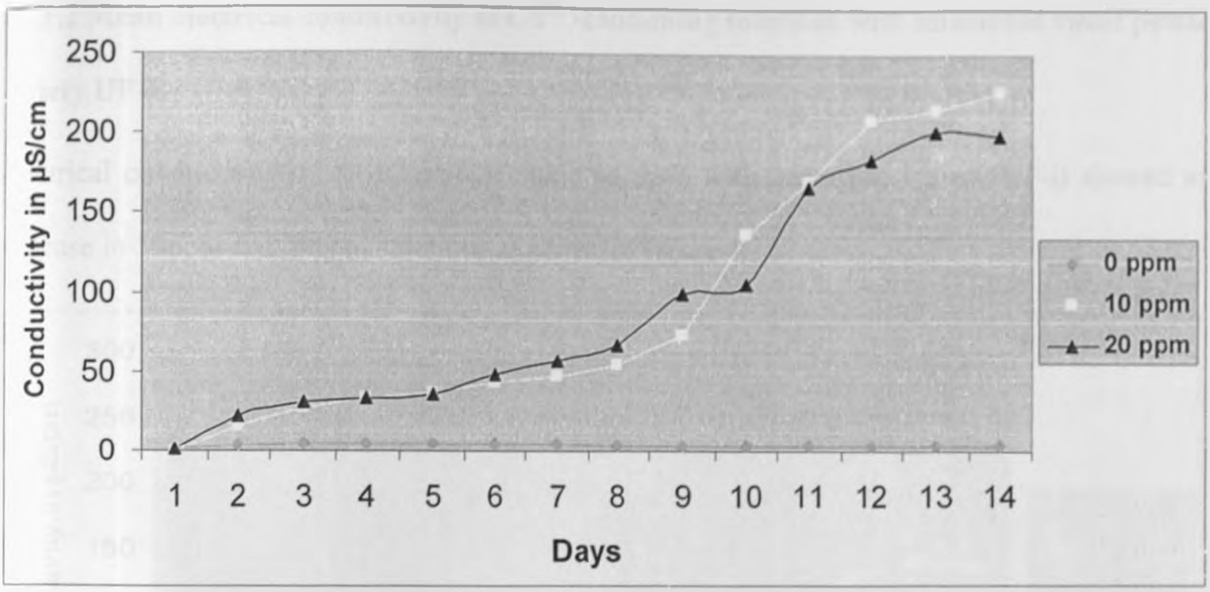

Figure 4.2: Mean electrical conductivity in µS/cm of cadmium- containing solutions with UP-A variety immersed.

The conductivity of the blank distilled water with variety UP-A had a constant electrical conductivity throughout the experimental period registering a range between 1.00µS/cm and 4.33µS/cm. However, there was increase in electrical conductivity for 10ppm and 20ppm cadmium-containing solutions with 10ppm solution showing higher conductivity after 9[th] day than 20ppm solution. The electrical conductivity increased from 1.00µS/cm to 226.33µS/cm during the experimental period for 10ppm Cd^{2+}-containing solution. On the other hand, the conductivity of 20ppm Cd^{2+}-containing solution rose from 1.00µS/cm to 198.67µS/cm over the same period. These results clearly illustrated that immersing the sweet potato plant variety UP-A in the cadmium-containing solution resulted into an increase in the electrical conductivity.

4.2.1.2 Mean electrical conductivity of Cd^{2+} -containing solutions with immersed sweet potato variety UP-B

Electrical conductivity of cadmium-containing solution with immersed variety UP-B showed an increase in 10ppm and 20ppm solutions as shown in figure 4.3.

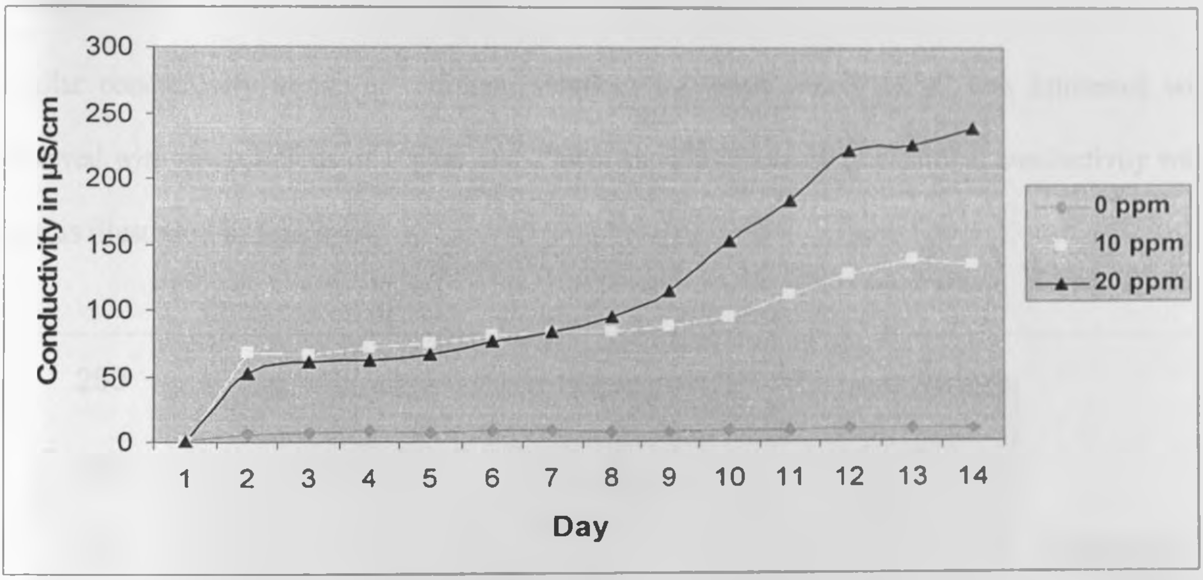

Figure 4.3.: Mean electrical conductivity in µS/cm of cadmium-containing solutions with immersed UP-B variety.

The electrical conductivity of distilled water containing variety UP-B increased from 1.00µS/cm on day 1 to 6.00µS/cm on day 2 and to 9.33µS/cm on days 12-14. For the 10ppm Cd^{2+}-containing solution, the conductivity rose from 1.00µS/cm to 134.33µS/cm, while that of 20ppm Cd^{2+}-containing solution increased from 1.33µS/cm to 238.67µS/cm by the 14th day. The results further showed that the electrical conductivity for 10ppm and 20ppm rose by the second day and remained almost constant for the first week before rising, with 20ppm showing higher conductivity than 10ppm as harvesting day approached. The rise in electrical conductivity of the solutions from day 8 coincided with drying up of the plant leaves of the variety. This behaviour was similar to that in solutions containing variety UP-A except that 20ppm solution had higher electrical conductivity than 10ppm cadmium containing solutions.

4.2.1.3 Mean electrical conductivity of Cd^{2+}-containing solutions with immersed sweet potato variety UP-C

Similar conductivity trends of cadmium solutions in which variety UP-C was immersed was observed with the solutions of 10ppm and 20ppm showing increase in electrical conductivity with time as illustrated in figure 4.4.

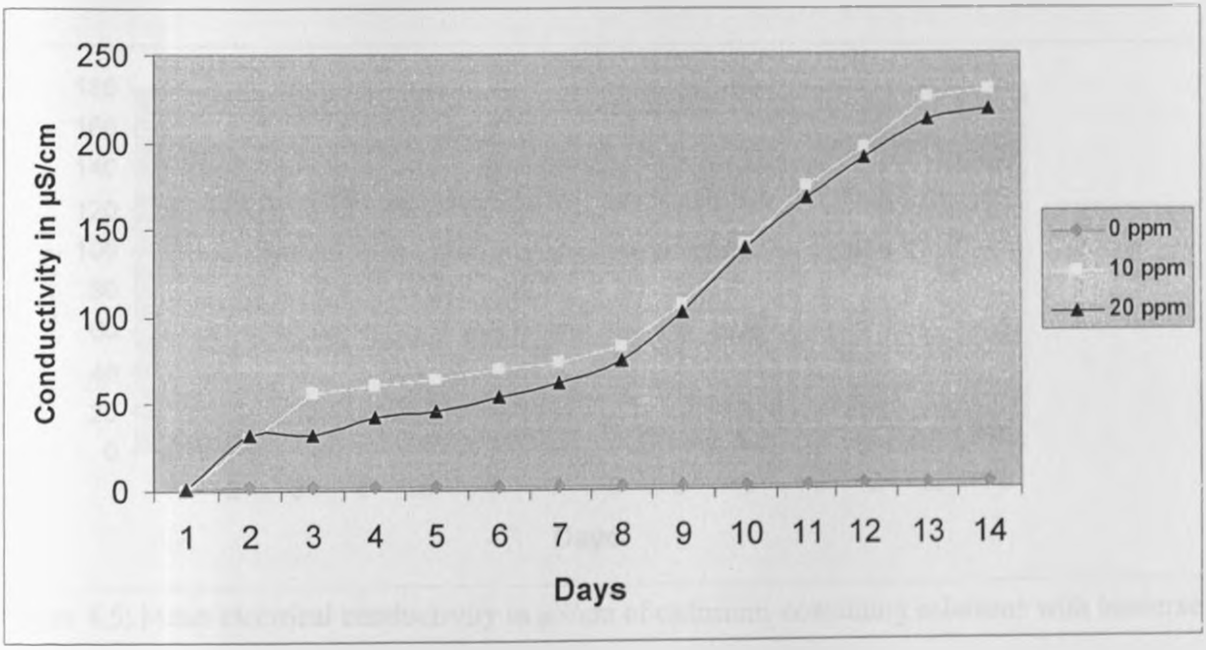

Figure 4.4: Mean electrical conductivity in µS/cm of cadmium-containing solutions with immersed UP-C variety.

Distilled water containing variety UP-C registered the mean electrical conductivity of 1.00µS/cm on the first day of the experimental period which then rose slightly to 3.00µS/cm by day 14. Both 10ppm and 20ppm cadmium-containing solutions showed their electrical conductivity increase with time until harvesting day with 10ppm solution having slightly higher electrical conductivity than 20ppm. The electrical conductivity of 10ppm Cd^{2+}-containing solution rose from 1.00µS/cm to 229.00µS/cm, while that in 20ppm Cd^{2+}-containing solution increased from 1.33µS/cm to 217.67µS/cm. For both solutions, a sharp increase in conductivity was observed after 8 days.

4.2.1.4 Mean electrical conductivity of Cd^{2+}-containing solutions with immersed sweet potato variety UP-D

In the same concentrations of cadmium-containing solutions with variety UP-D immersed, the electrical conductivity increased with time of immersion as indicated in figure 4.5

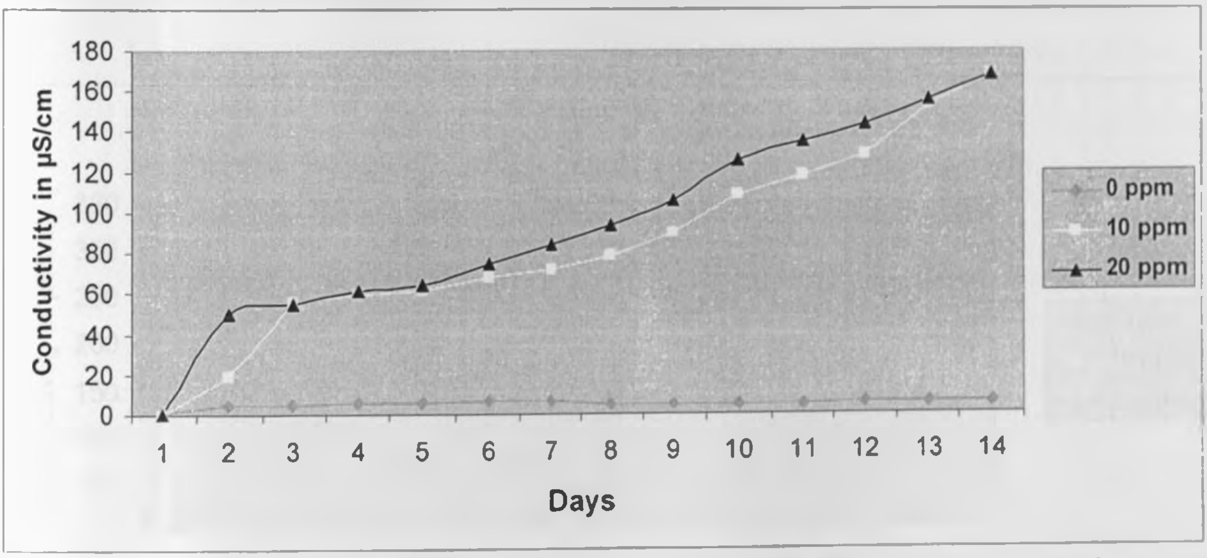

Figure 4.5: Mean electrical conductivity in µS/cm of cadmium-containing solutions with immersed UP-D variety.

Electrical conductivity of distilled water containing variety UP-D rose from 1.00µS/cm on day 1 to 6.00µS/cm on day 14 of the experimental period. This did not show a significant change. The above results demonstrated a sharp increase in the first two days for 20ppm solution and the increase continued for the rest of the days. Similar observation was made for the 10ppm cadmium-containing solution, but electrical conductivity trend was lower than that of 20ppm. The electrical conductivity of 10ppm Cd^{2+}-containing solution increased from 1.00µS/cm to 167.67µS/cm while that of 20ppm Cd^{2+} solution rose from 1.33µS/cm in the first day to 168.00µS/cm in day 14. The results demonstrate the increase in the electrical conductivity with the plant variety immersed in cadmium- containing solutions.

4.2.1.5 Mean electrical conductivity of Cd^{2+}-containing solutions with immersed sweet potato variety UP-16

The results of electrical conductivity of cadmium-containing solutions with variety UP-16 immersed showed 10ppm solution with higher conductivity than in 20ppm solution (figure 4.6).

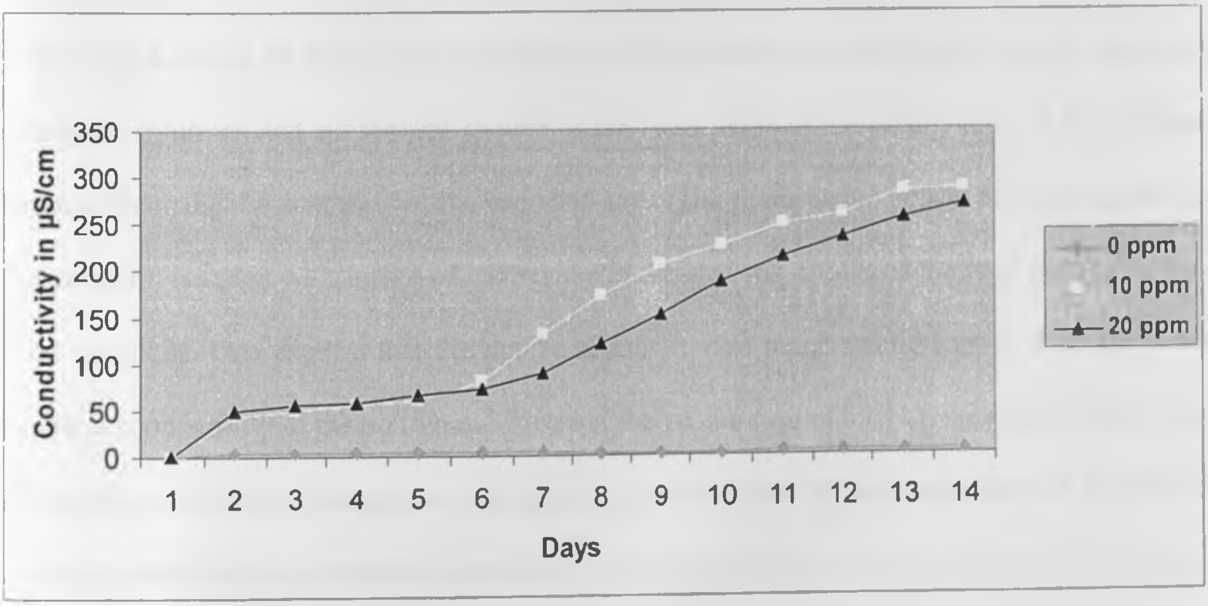

Figure 4.6: Mean electrical conductivity in µS/cm of cadmium-containing solutions with UP-16 variety.

Electrical conductivity of the blank did not however, show significant change throughout the experimental period. The range of electrical conductivity of the distilled water containing the variety was between 1.00μS/cm and 4.00μS/cm on day 14. The trend however changed for 10ppm Cd^{2+}-containing solution and 20ppm Cd^{2+} solution with the same variety. Both cadmium-containing solutions of 10ppm and 20ppm showed rise in electrical conductivity by the 2nd day. This was followed by slight increase for the next three days and then a sharp increase the rest of the days. The 10ppm Cd^{2+}-containing solution registered electrical conductivity of between 1.00μS/cm and 286.33μS/cm while that of 20ppm Cd^{2+}-containing solution increased from 1.67μS/cm to 270.00μS/cm.

Introduction of pre-rooted plants and their consequent growth in the metal solution with and without ions do not change the pH of the solution significantly (table 4.1). This suggests that the observed electrical conductivity of figures 4.2-4.6 is not due to the variation in H^+ concentration. A possible explanation for the observed behavior is that introduction of the plants into the cadmium-containing solutions and subsequent growth of the roots leads to the perturbation of the solution, thereby enhancing the solubility of the cadmium salts. The perturbation produced by the growth of root network, coupled with intake of cadmium and nitrate ions, increases the total number of ions in the solutions. One expects that the uptake of ions by the plants would lead to decrease in the electrical conductivity of the solutions. However, the production of ions brought about by the root perturbation seems to outweigh the ions taken up by the plant. Hence, the observed increase of electrical conductivity in cadmium-containing solutions with time as showed (figures 4.2-4.6). An argument that the formation of ions increases with increase in contact time between the dissolved salt, the plant and the water may be considered. However, this point is eliminated by the fact that the control experiment did not show increase in electrical conductivity with time (figure 4.1).

4.2.2 Mean electrical conductivity measurements of chromium -containing solutions

The results of mean electrical conductivity of distilled water and chromium - containing solutions of 10ppm, 20ppm and 50ppm without any sweet potato plant varieties immersed in them were chosen as control experiments are shown in figure 4.7. These electrical conductivity data from the blanks were always subtracted from the electrical conductivity data obtained with corresponding sweet potato plant immersed in chromium- containing solutions.

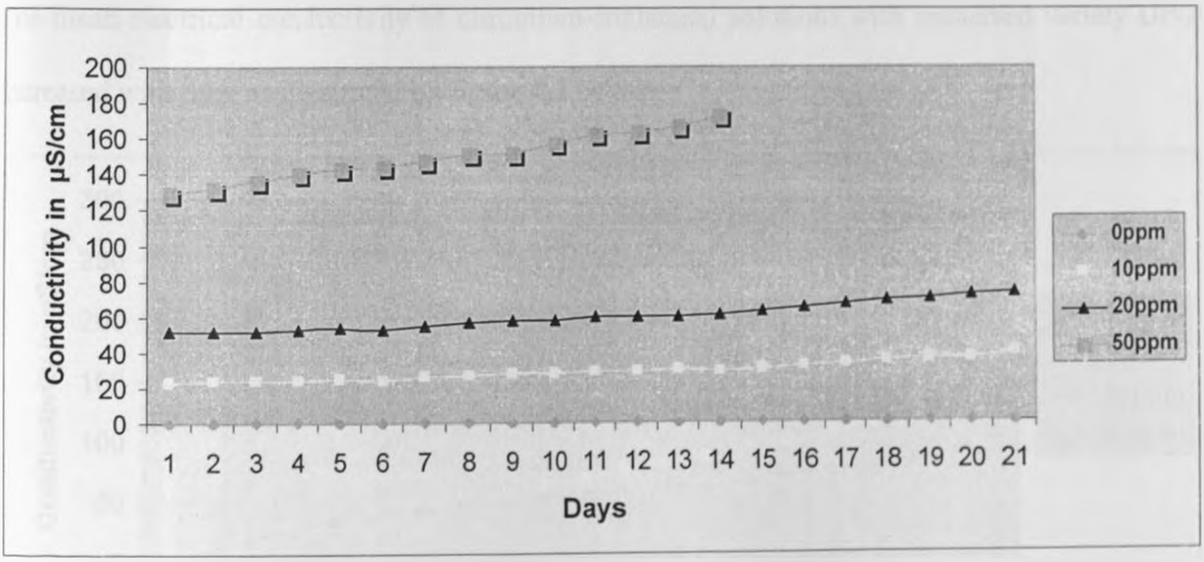

Figure 4.7: Mean electrical conductivity of µS/cm in chromium-containing blank solutions without sweet potato plants.

The results illustrated in figure 4.7 further demonstrated that electrical conductivity increased with increase of the concentration of the chromium in solution. For example, if chromium ion concentration is doubled or tripled, corresponding conductivity values nearly doubles or triples respectively (figure 4.7). This trend was similar to the conductivity of cadmium-containing solutions. Similar observations to the case of cadmium-containing solutions, the electrical conductivity of the solutions containing chromium ions with sweet potato plant varieties exhibited pronounced increase as shown in subsequent sections. Generally, electrical conductivity of chromium-containing solutions with immersed sweet potato plant varieties increased in comparison with those obtained from their respective corresponding control solutions (i.e. without the sweet potato plant varieties) as illustrated in the subsequent sub-sections.

4.2.2.1 Mean electrical conductivity of chromium -containing solutions with immersed sweet potato plant variety UP-A

The mean electrical conductivity of chromium-containing solutions with immersed variety UP-A increased with time as illustrated by figure 4.8 below.

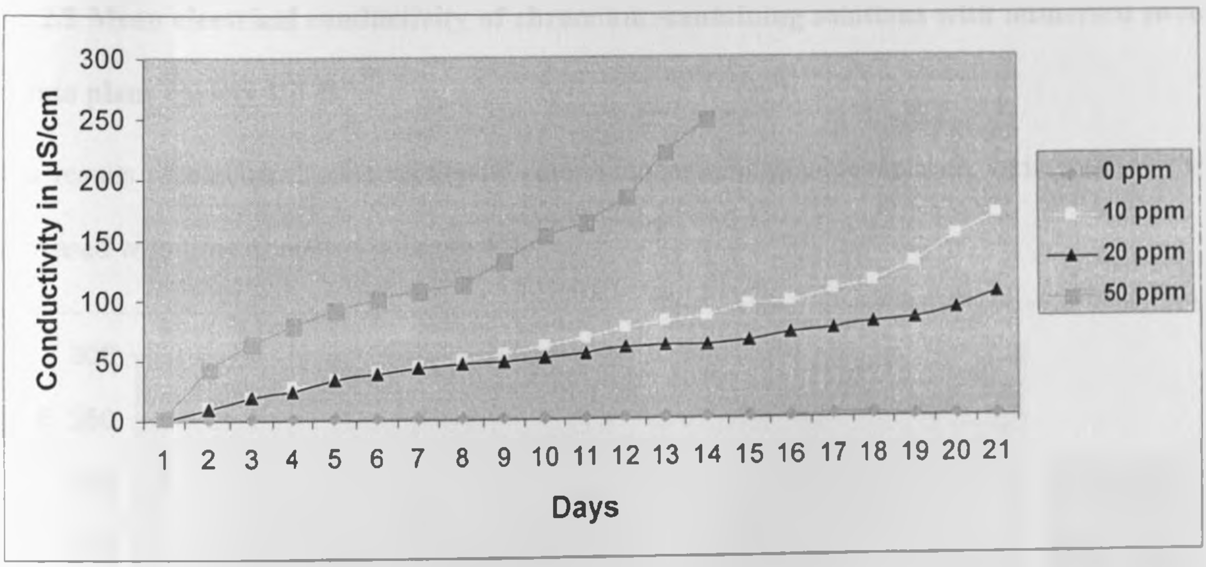

Figure 4.8: Mean electrical conductivity in µS/cm of chromium-containing solutions with immersed UP-A variety.

Electrical conductivity of distilled water slightly increased from 1.00µS/cm to 2.33µS/cm during the experimental period. Solution of 10ppm and 20ppm chromium ions showed a similar trend up to day 8 suggesting there was a definite time the ions begun having impact on the plants, after which 10ppm solution gave higher conductivity than 20ppm until the last day of experiment. Electrical conductivity of 10ppm solution increased from 1.00μS/cm to 167.0μS/cm while that of 20ppm chromium-containing solution rose from 1.00μS/cm to 102.67μS/cm during the immersion period. Similar trend was observed in electrical conductivity of 10ppm and 20ppm cadmium-containing solutions with the same variety. Conductivity of the 50ppm was much higher than the rest but the plant variety did not survive in the solution for long. It increased from 1.00μS/cm to 249.0μS/cm for the 14 days. The trends demonstrate that immersing the plant in the chromium-containing solution raises its electrical conductivity.

4.2.2.2 Mean electrical conductivity of chromium -containing solutions with immersed sweet potato plant variety UP-B

The results of electrical conductivity of chromium-containing solutions with variety UP-B also increased with time as shown in figure 4.9.

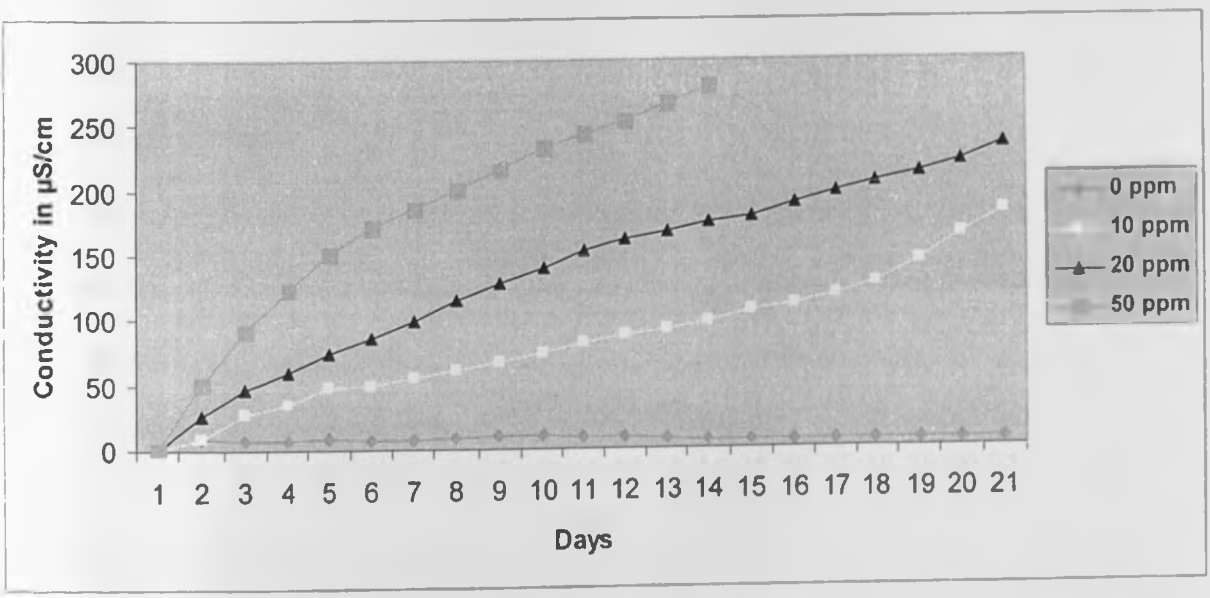

Figure 4.9: Mean electrical conductivity in μS/cm of chromium-containing solutions with immersed UP-B variety.

Electrical conductivity of distilled water with the variety rose from 1.00μS/cm to 10.67μS/cm on day 9 and then reduced to 6.33μS/cm by day 16 and then remained constant throughout the experimental period. All the other concentrations increased their electrical conductivity with 50ppm solution showing higher conductivity trend followed by 20ppm and then 10ppm. The electrical conductivity of 10ppm chromium-containing solution rose from 1.00μS/cm to 182.0μS/cm. Conductivity of 20ppm solution increased from 1.00μS/cm to 234.67μS/cm during the experimental period. The electrical conductivity of 50ppm also registered an increase of between 1.33μS/cm to 280μS/cm for the 14 days of immersion.

4.2.2.3 Mean electrical conductivity of chromium -containing solutions with immersed sweet potato plant variety UP-C

Chromium-containing solutions with variety UP-C had similar trend of electrical conductivity of those of chromium-containing solutions with variety UP-B (figure 4.10).

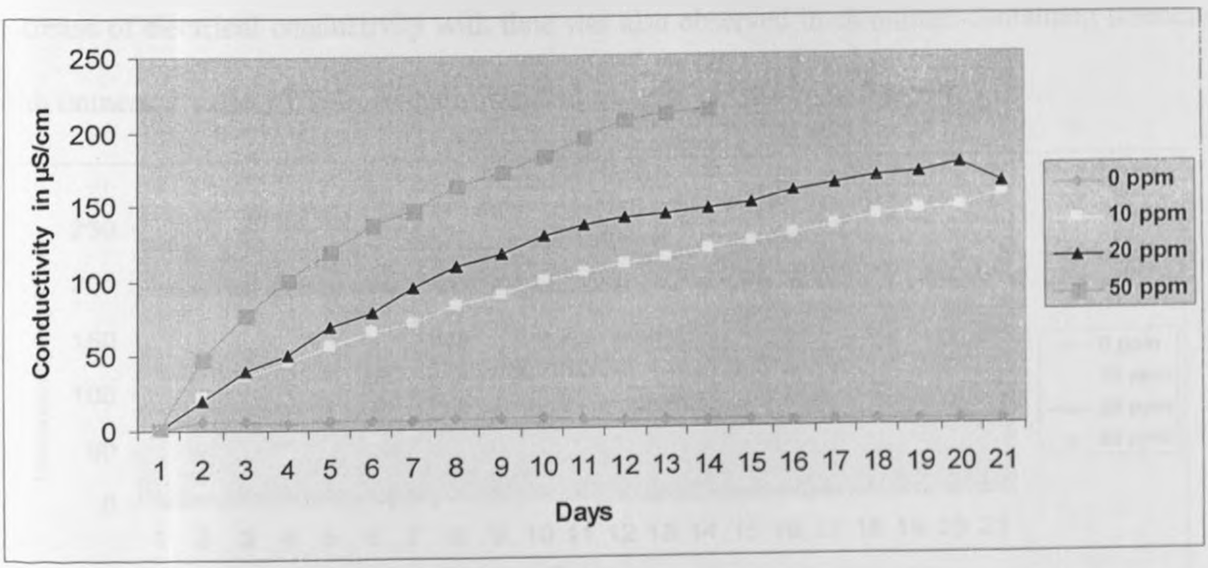

Figure 4.10: Mean electrical conductivity in μS/cm of chromium-containing solutions with UP-C variety.

Blank solution of distilled water with variety UP-C did not show any significant change in electrical conductivity during the growth period. Its electrical conductivity rose from 1.00µS/cm to 6.67µS/cm on 8th day and then reduced to 4.00µS/cm at day 16 and remained constant until the experiment was terminated on 21st day. The results demonstrated that the chromium-containing solutions of 10ppm, 20ppm and 50ppm chromium ions showed a general trend of increased conductivity with 50ppm giving higher values than 20ppm and 10ppm respectively. The electrical conductivity of 10ppm solution containing chromium increased from 1.00µS/cm to 155.66µS/cm while that in 20ppm solution rose from 1.00µS/cm to 176.0µS/cm over 20 days and then reduced to 162.67µS/cm on the 21st day. The electrical conductivity of 50ppm chromium-containing solution also increased from 1.67µS/cm to 214.0µS/cm by the 14th day.

4.2.2.4 Mean electrical conductivity of chromium -containing solutions with immersed sweet potato plant variety UP-D

Increase of electrical conductivity with time was also observed in chromium-containing solutions with immersed variety UP-D except in distilled water as illustrated in figure 4.11.

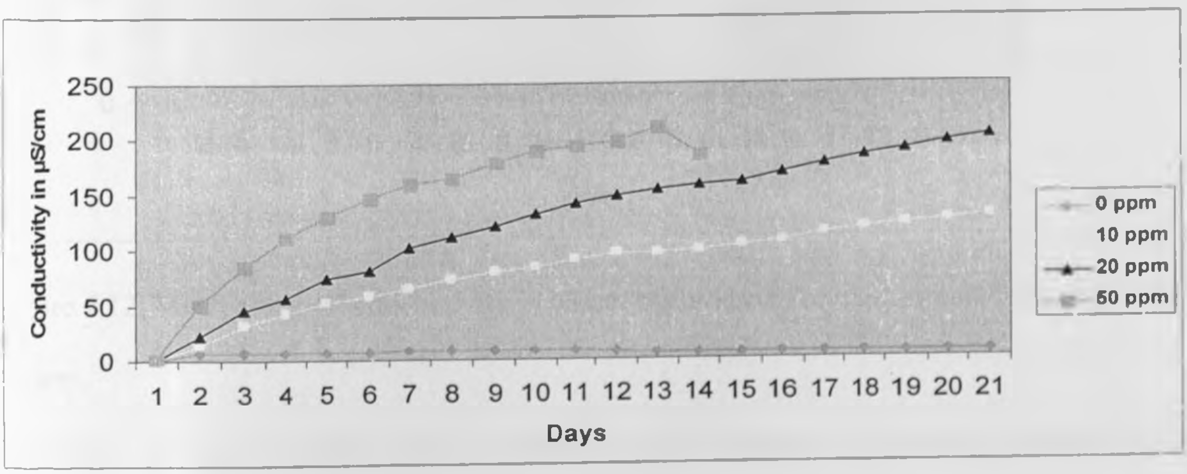

Figure 4.11: Mean electrical conductivity in µS/cm of chromium-containing solutions with immersed variety UP-D.

Electrical conductivity of distilled water rose from 1.00μS/cm to 8.67μS/cm on day 9 and then reduced to 5.67μS/cm. The conductivity of 10ppm and 20ppm chromium-containing solutions increased with time. The electrical conductivity of 10ppm solution rose from 1.00μS/cm to 129.0μS/cm while that in 20ppm solution also increased from 1.00μS/cm to 202.0μS/cm during the 21day experimental period. Conductivity of 50ppm however showed an increase from 1.00μS/cm to 209.67μS/cm until 13th day then reduced to 186.0μS/cm on the 14th day.

4.2.2.5 Mean electrical conductivity of chromium -containing solutions with immersed sweet potato plant variety UP-16

The chromium solutions containing variety UP-16 showed similar results to those of other varieties used for the study except variety UP-A as shown in figure 4.12

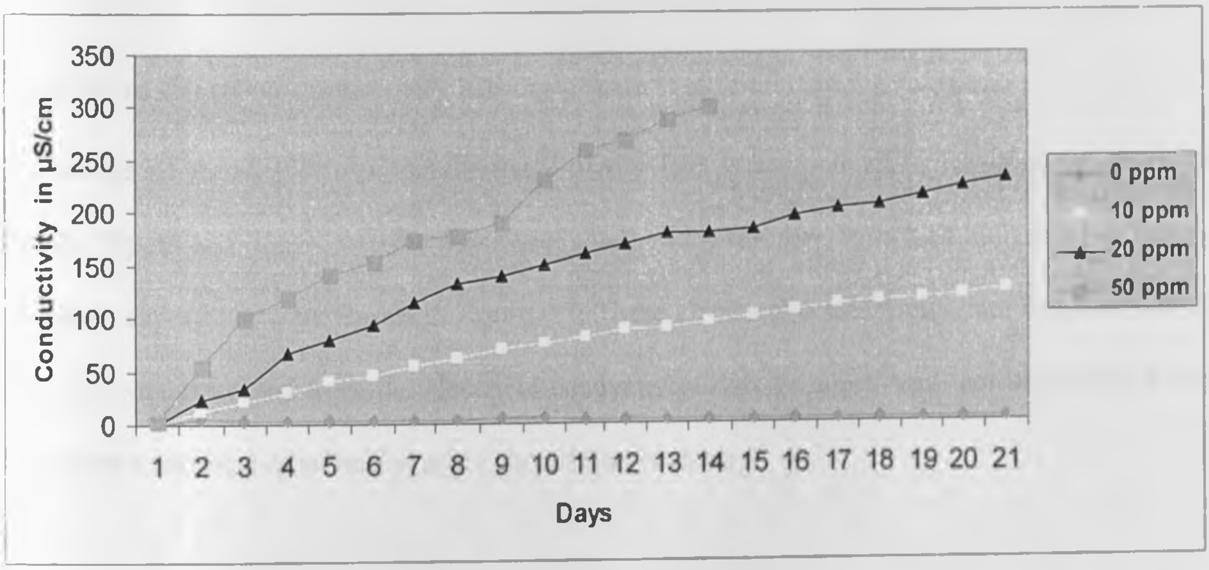

Figure 4.12: Mean electrical conductivity in μS/cm of chromium containing solutions with UP-16 variety.

The blank set up of distilled water showed a slight increase in electrical conductivity from 1.00μS/cm to 2.67μS/cm throughout the experimental period. However, the electrical conductivity of the chromium solutions containing variety UP-16 increased with time. The electrical conductivity of 10ppm chromium solution increased from 1.00μS/cm to 124.0μS/cm while that in 20ppm solution rose from 1.00μS/cm to 231.0μS/cm during the experimental period. Conductivity of chromium solution also registered an increase from 1.00μS/cm to 299.0μS/cm for the 14 days in which the plants were immersed.

Electrical conductivity of chromium ions solutions containing variety UP-16 was highest in 50ppm, followed by 20ppm and 10ppm respectively, similar to the trend of electrical conductivity of chromium solutions containing varieties UP-B, UP-C and UP-D. The increase in electrical conductivity with the growth rate of the plant can be attributed to perturbation of the chromium-containing solutions brought about by the production and growth of the roots with time, similar to the case of cadmium- containing solutions.

4.2.3 Mean electrical conductivity measurements of zinc-containing solutions

The results of mean electrical conductivity of distilled water and zinc-containing solutions of 10ppm, 20ppm and 50ppm without any sweet potato plant varieties immersed in them were chosen as control experiments are shown in figure 4.7. These electrical conductivity data from the blanks were always subtracted from the electrical conductivity data obtained with corresponding sweet potato plant varieties immersed in zinc- containing solutions.

The electrical conductivity behavior of zinc ions in solutions without the sweet plant varieties was similar to that observed in case of cadmium and chromium-containing solutions. The results of conductivity of the blank distilled water showed slight changes in electrical conductivity throughout the planting period as illustrated in figure 4.13.

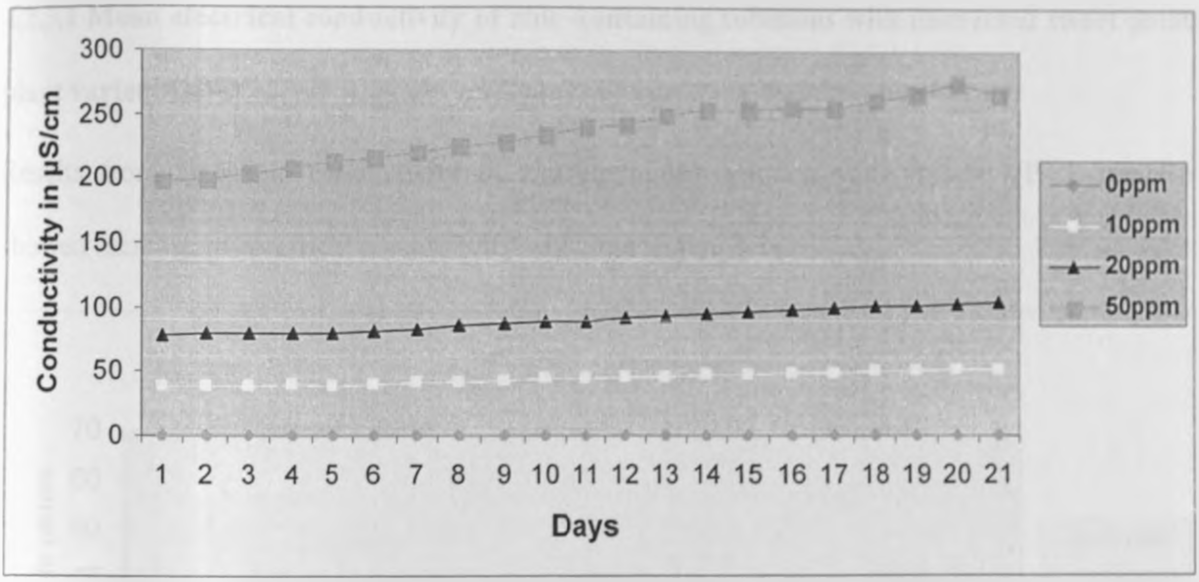

Figure 4.13: Mean electrical conductivity in µS/cm of the zinc-containing solutions without sweet potato plants.

The results in figure 4.13 further demonstrated that the electrical conductivity of 10ppm zinc-containing solution rose from 38.00µS/cm to 52.00µS/cm during the experimental period while in the 20ppm zinc ion solution it increased from 78.67µS/cm to 103.6µS/cm during similar period. Similarly, the conductivity of 50ppm zinc solution increased from 197.0µS/cm to 266.0µS/cm. the results clearly indicated that the electrical conductivity of the zinc-containing solutions increased with increase in solution concentration.

Generally, electrical conductivity of zinc-containing solutions with immersed sweet potato plant varieties increased in comparison with those obtained from their respective corresponding control solutions (i.e. without the sweet potato plant varieties) as illustrated in the subsequent sub-sections. The values of conductivity for zinc ions with this variety were lower compared to those of chromium and cadmium ions.

4.2.3.1 Mean electrical conductivity of zinc -containing solutions with immersed sweet potato plant variety UP-A

Results from electrical conductivity of zinc-containing solution with variety UP-A immersed showed increase in electrical conductivity with time (figure 4.14).

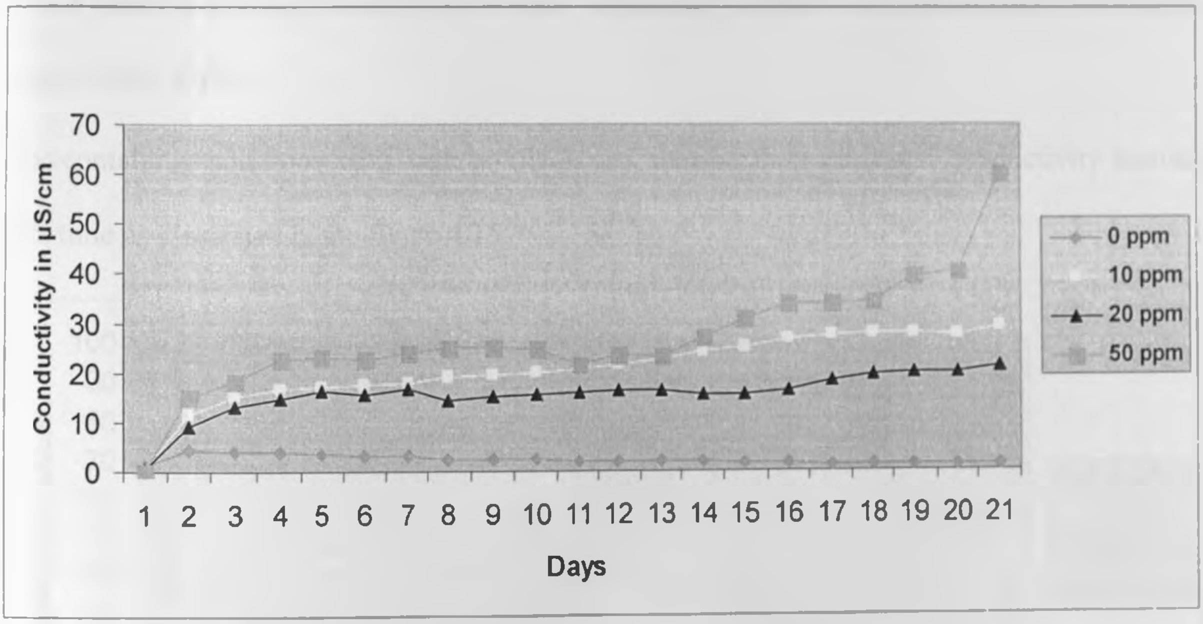

Figure 4.14: Mean electrical conductivity in µS/cm of zinc-containing solutions with immersed UP-A variety.

Electrical conductivity of distilled water containing the variety rose from 1.00µS/cm in the first day to 4.33µS/cm in the second day and then reduced to 1.33µS/cm in the 17th day and then remained constant until the end of experimental period. The trend curves for 10ppm and 20ppm did not show a sharp increase and for 50ppm solution the increase was sharp towards the last day of exposure. Electrical conductivity of 10ppm was higher than that of 20ppm zinc-containing solution with variety UP-A, results that were also observed in solutions of cadmium and chromium of similar concentration and variety. The 10ppm zinc-containing solution had the electrical conductivity rising from 1.33μS/cm to 29.0μS/cm, while that of 20ppm solution increased from 1.33μS/cm to 21.0μS/cm. The 50ppm zinc-containing solution also registered an increase from 1.00μS/cm to 60.0μS/cm for a similar experimental period.

4.2.3.2 Mean electrical conductivity of zinc -containing solutions with immersed sweet potato plant variety UP-B

Zinc-containing solutions with variety UP-B also showed their electrical conductivity increase with time as illustrated in the figure 4.15.

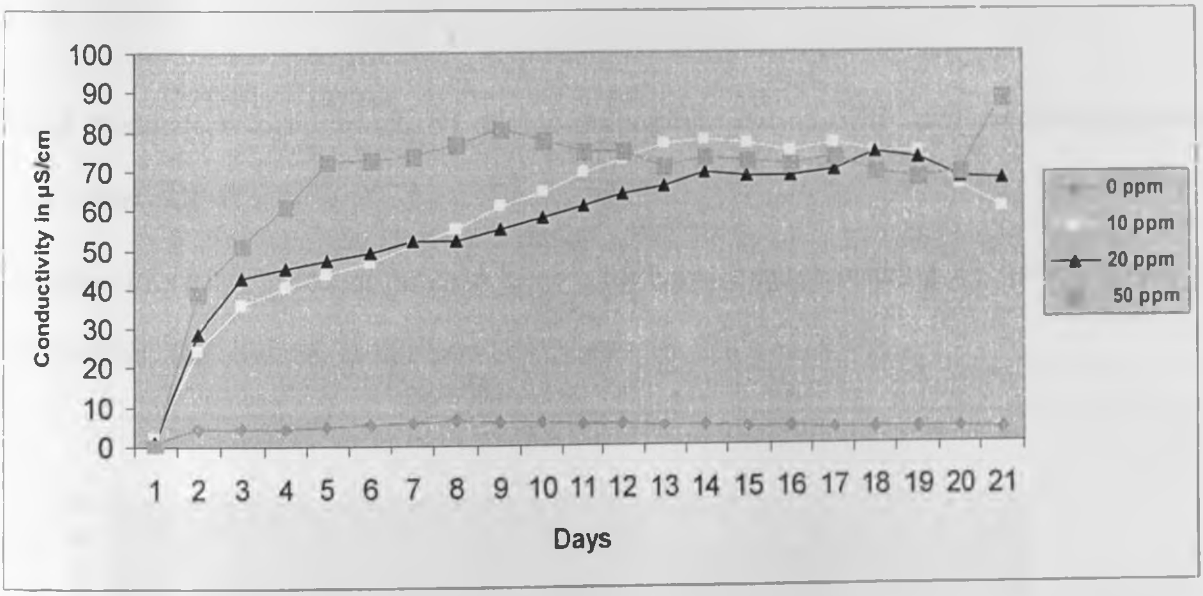

Figure 4.15: Mean electrical conductivity in μS/cm of zinc-containing solutions with immersed UP-B variety.

Electrical conductivity of distilled water rose from 1.00μS/cm to 6.5μS/cm in 8 days and then reduced to 3.5μS/cm at the end of 21 days. Sharp rise in electrical conductivity was however observed in the rest of the set ups with 50ppm having the highest electrical conductivity for the first twelve days. The results further show that during the first week, the electrical conductivity of

20ppm was higher than that of 10ppm, but this changed at the 8th day with conductivity of 10ppm solution rising above the 20ppm. At the 19th day, both had their conductivity reducing. The electrical conductivity of 10ppm zinc-containing solution rose from 2.00μS/cm to 77.66μS/cm in 14 days and then reduced to 60.33μS/cm by day 21. The electrical conductivity of 20ppm zinc-containing solution with the variety increased from 1.00μS/cm to 74.34μS/cm on the 18th day and then reduced to 67.66μS/cm by the last day of the experiment. The zinc-containing solution of 50ppm similarly showed an increase in electrical conductivity from 1.00μS/cm to 80.67μS/cm in 9 days and then reduced to 68.00μS/cm in the 19th day and finally rose to 88.33μS/cm in the final day 21.

4.2.3.3 Mean electrical conductivity of zinc-containing solutions with immersed sweet potato plant variety UP-C

The effect of variety UP-C on the electrical conductivity of zinc-containing solutions was similar to that of the other varieties as illustrated by figure 4.16.

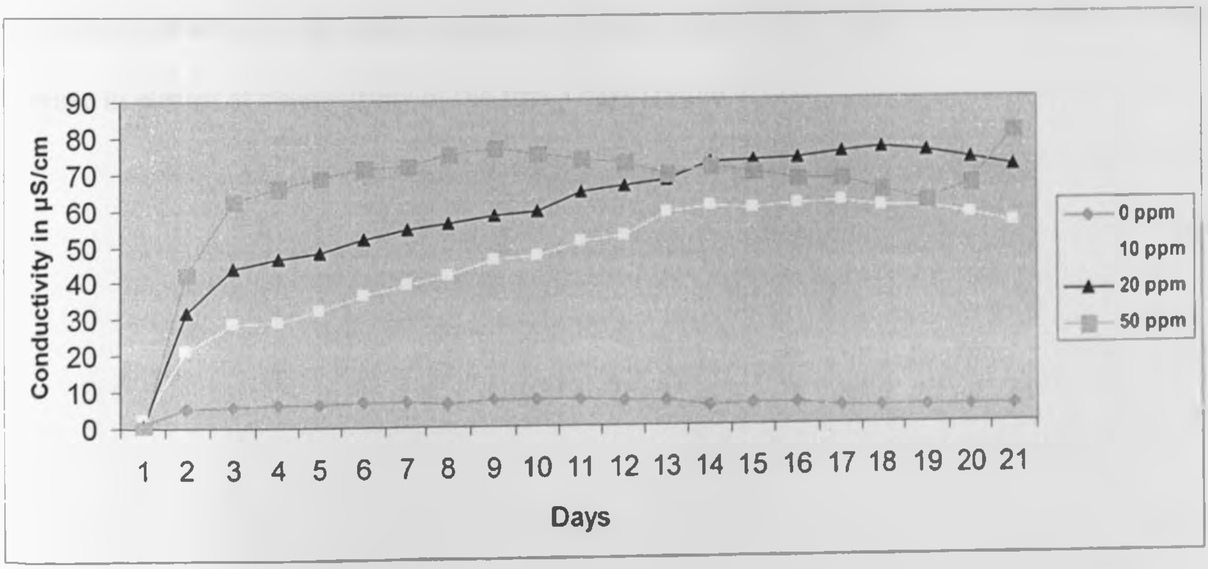

Figure 4.16: Mean electrical conductivity in μS/cm of zinc-containing solutions with immersed UP-C variety.

The electrical conductivity of the solutions increased with time of the experiment except in distilled water in which the conductivity remained relatively constant after rising from 1.00μS/cm to 7.33μS/cm by day 8 and then reducing to 4.67μS/cm by the last day of the experiment. Electrical conductivity of 20ppm zinc-containing solution was higher than that of 10ppm throughout the growth period. The conductivity of 10ppm zinc-containing solution rose from 2.00μS/cm to 61.67μS/cm on the 17th day and then slightly reduced to 55.00μS/cm on the last day. In the 20ppm solution, the electrical conductivity increased from 0.66μS/cm to 76.34μS/cm on day 18 and then reduced to 71.00μS/cm on day 21. However, 50ppm solution rose sharply for the first 9 days from 1.00μS/cm to 73.67μS/cm and then declined until 19th day with 61.33μS/cm but later rose up to 80.64μS/cm on the last day.

4.2.3.4 Mean electrical conductivity of zinc -containing solutions with immersed sweet potato plant variety UP-D

Electrical conductivity of zinc-containing solutions containing variety UP-D showed a sharp increase in electrical conductivity of the first 3 days (figure 4.17).

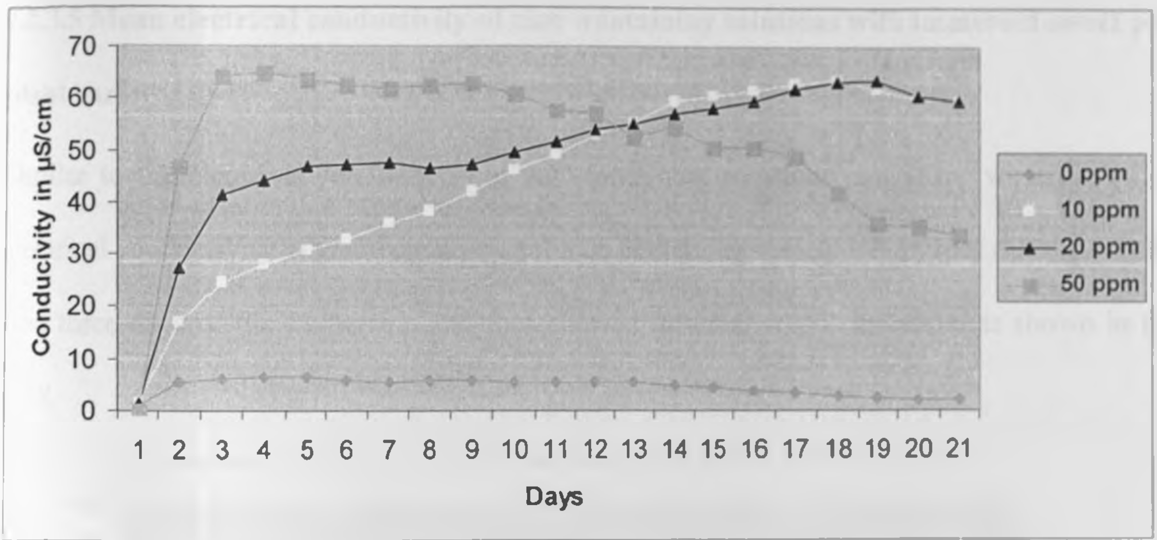

Figure 4.17: Mean electrical conductivity in µS/cm of zinc-containing solutions with UP-D variety.

Electrical conductivity of distilled water containing the variety UP-D initially rose from 1.00µS/cm to 6.33µS/cm by the 4th day and then reduced to 2.00µS/cm during the experimental period. Results showed that a sharp increase in electrical conductivity was observed zinc-containing solutions with 50ppm solution giving the highest followed by 20ppm and 10ppm respectively. After day 19, the electrical conductivity of 10ppm and 20ppm declined slightly. Electrical conductivity of 10ppm zinc-containing solution increased from 1.67µS/cm to 63.35µS/cm by the 18th day and then reduced to 59.34µS/cm on day 21. The 20ppm zinc-containing solution had the conductivity rising from 1.33µS/cm to 63.67µS/cm in the 19th day but then reduced to 59.32µS/cm on the last day of the experiment. For 50ppm zinc -containing solution, the rise was observed in the first 4 days from 1.00µS/cm to 65.0µS/cm after which the conductivity reduced considerably until the experiment was terminated in the 21st day where 33.33µS/cm was recorded. This could be attributed to the toxicity of 50ppm zinc containing solutions.

4.2.3.5 Mean electrical conductivity of zinc -containing solutions with immersed sweet potato plant variety UP-16

Similar to the electrical conductivity of zinc-containing solutions containing variety UP-D, the electrical conductivity of zinc-containing solution containing variety UP-16 rose sharply within the first three days of the immersion and then showed different trends thereafter as shown in figure 4.18.

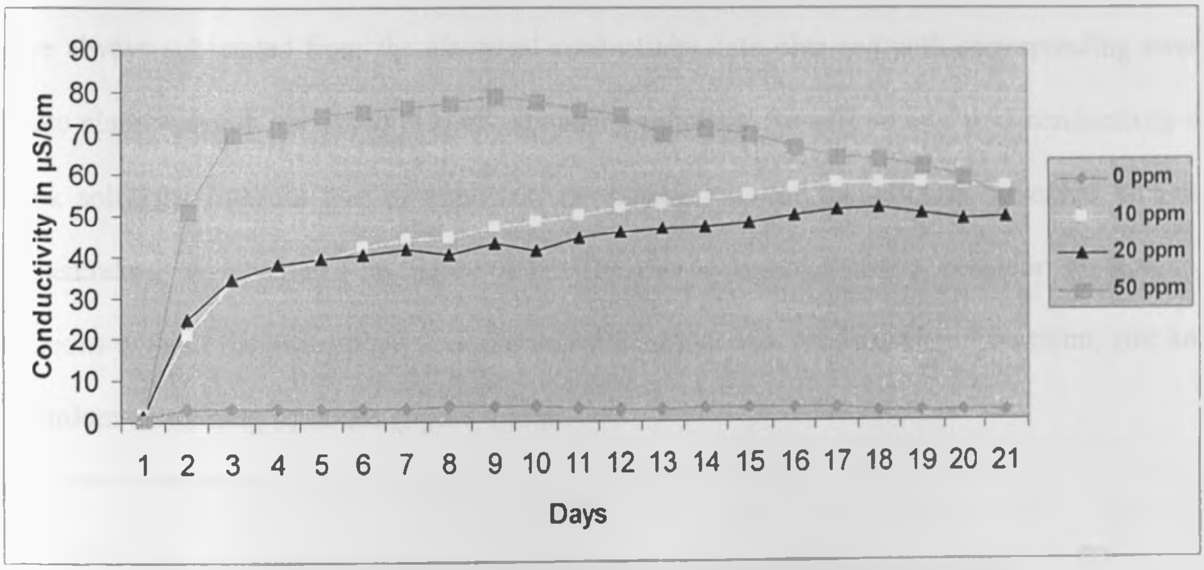

Figure 4.18: Mean electrical conductivity in µS/cm of zinc-containing solutions with immersed UP-16 variety.

The distilled water showed a constant electrical conductivity through the monitoring period. Both 10ppm and 20ppm solutions gave a rise in conductivity with 10ppm solution showing a higher trend than 20ppm solution. The electrical conductivity of 10ppm zinc-containing solution rose from 2.00µS/cm to 57.67µS/cm while that in the 20ppm solution increased from 1.33µS/cm to 49.66µS/cm during the 21 day period. The 50ppm zinc-containing solution on the other hand showed a sharp rise in electrical conductivity from 1.00µS/cm to 79.00µS/cm on the 9th day then gave a constant trend to the 12th day and then went down until final day of the experiment. The electrical conductivity of zinc-containing solutions with immersed different plant varieties except UP-A exhibited a sharp increase in the first three days. This observation could not be explained.

4.2.4. Mean electrical conductivity measurements of lead-containing solutions

The results of mean electrical conductivity of distilled water and lead-containing solutions of 10ppm, 20ppm and 50ppm without any sweet potato plant varieties immersed in them were chosen as control experiments are shown in figure 4.19. These electrical conductivity data from the blanks were always subtracted from the electrical conductivity data obtained with corresponding sweet potato plant varieties immersed in lead- containing solutions. Results on electrical conductivity of blank solutions indicate that as expected, the conductivity of the solution increased with its concentration as illustrated in figure 4.19. The electrical conductivity behavior of lead ion solutions without the sweet plant varieties was similar that observed in case of cadmium, zinc and chromium-containing solutions (figure 4.19).

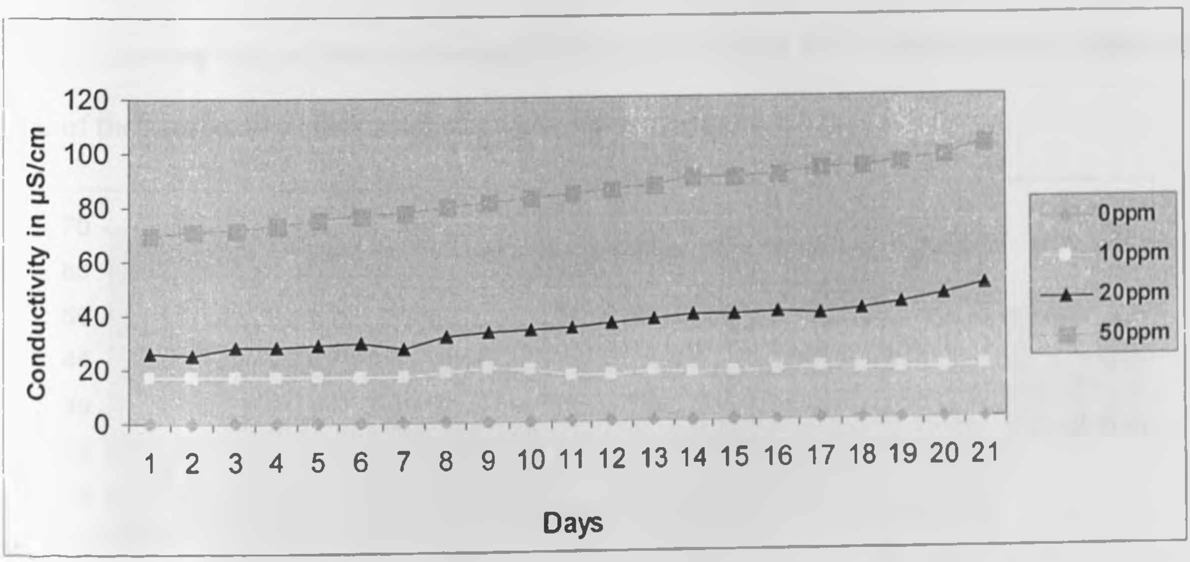

Figure 4.19: Mean electrical conductivity in µS/cm of control solutions of lead without plant varieties.

Electrical conductivity of distilled water remained constant throughout the period, while that of 20ppm and 50ppm slightly increased with time. The electrical conductivity of 10ppm lead-containing solution ranged from 17.0μS/cm and 19.33μS/cm throughout the experimental period. The electrical conductivity of 20ppm lead-containing solution rose from 25.0μS/cm to 49.33μS/cm while that in 50ppm increased from 70.0μS/cm to 102.0μS/cm. Generally, electrical conductivity of lead-containing solutions with immersed sweet potato plant varieties increased in comparison with those obtained from their respective corresponding control solutions (i.e. without the sweet potato plant varieties) as illustrated in the subsequent sub-sections. It was however noted that the trend changed for most of the lead containing solutions after about 9 to 11 days of exposure as the electrical conductivity was observed to decrease until the growth was terminated after 21 days.

4.2.4.1 Mean electrical conductivity of lead-containing solutions with immersed sweet potato plant variety UP-A

Electrical conductivity of lead-containing solutions with variety UP-A, was generally higher than those of their respective blank solutions used as control (figure 4.20).

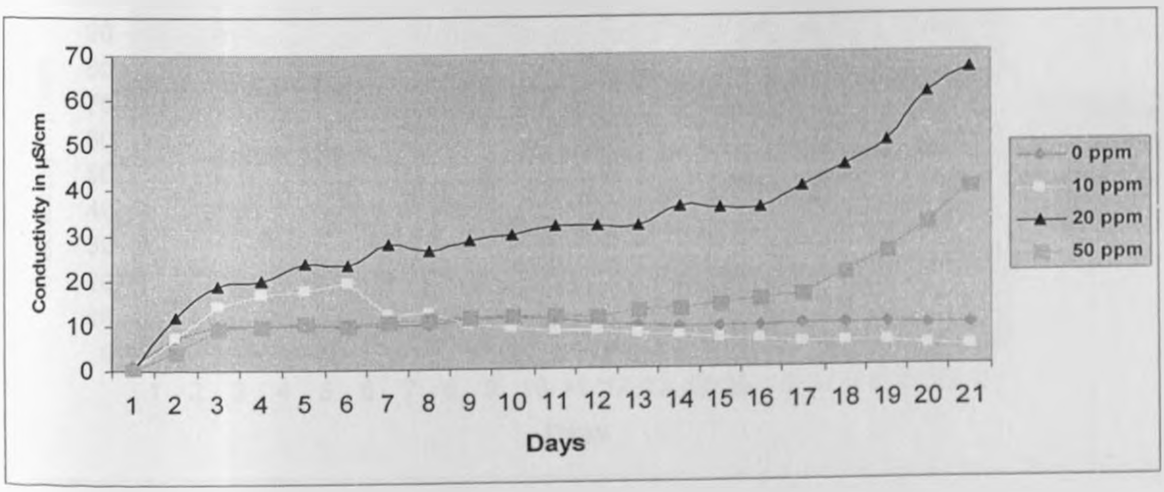

Figure 4.20: Mean electrical conductivity in μS/cm of lead-containing solutions with UP-A variety.

The mean electrical conductivity of the distilled water rose from 1.00μS/cm to 11.33μS/cm on the 10th day and then reduced to 9.00μS/cm by day 11. The results further show that electrical conductivity of 10ppm lead-containing solution increased for about 6 days from 1.00μS/cm to 12.67μS/cm after which it considerably reduced to 4.33μS/cm at the time the experiment was terminated. The 20ppm lead-containing solution also registered an increase in electrical conductivity from 1.00μS/cm to 66.0μS/cm during the experimental period. It also showed the highest trend compared to the rest of the concentrations. Lead-containing solution of 50ppm showed slight increase in electrical conductivity for 17 days from 1.00μS/cm to 16.0μS/cm and then increased to 39.67μS/cm at the last day.

4.2.4.2 Mean electrical conductivity of lead -containing solutions with immersed sweet potato plant variety UP-B

Electrical conductivity of lead -containing solutions with UP-B variety also showed increased electrical conductivity with time but later reduced (figure 4.21).

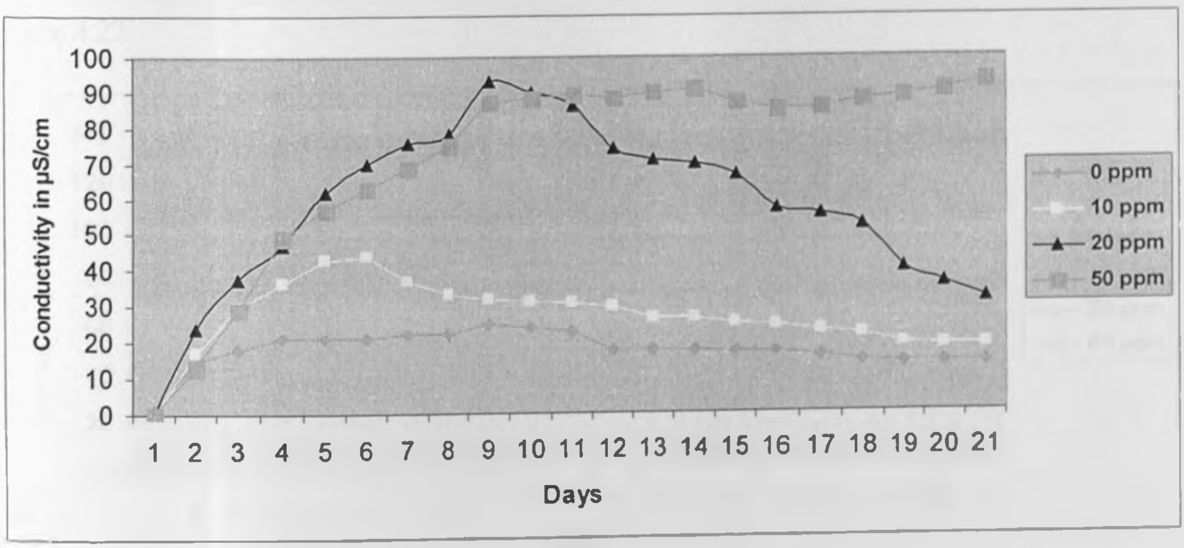

Figure 4.21: Mean electrical conductivity in μS/cm of lead-containing solutions with immersed UP-B variety.

Electrical conductivity of solutions of the distilled water (0ppm), 10ppm, 20ppm rose for a few days and then reduced as the experimental period progressed. The electrical conductivity of distilled water containing variety UP-B increased from 1.00μS/cm to 24.67μS/cm by the 9th day and then reduced to 13.67μS/cm on 19th day and remained constant until day 21. The conductivity of 10ppm lead-containing solution on the other hand, rose from 1.00μS/cm to 43.67μS/cm on day 6 and then reduced to 18.33μS/cm on the last day. A similar trend in conductivity was observed in 20ppm lead-containing solution which rose from 1.00μS/cm to 93.00μS/cm at the 9th day and then reduced to 32.00μS/cm at day 21. However, the electrical conductivity of 50ppm increased throughout the experimental period rising from 1.00μS/cm to 93.00μS/cm.

4.2.4.3 Mean electrical conductivity of lead -containing solutions with immersed sweet potato plant variety UP-C

Similar results to those of electrical conductivity of lead-containing solution containing variety UP-B were also observed in lead solutions with variety UP-C as shown in the trend curves in figure 4.22.

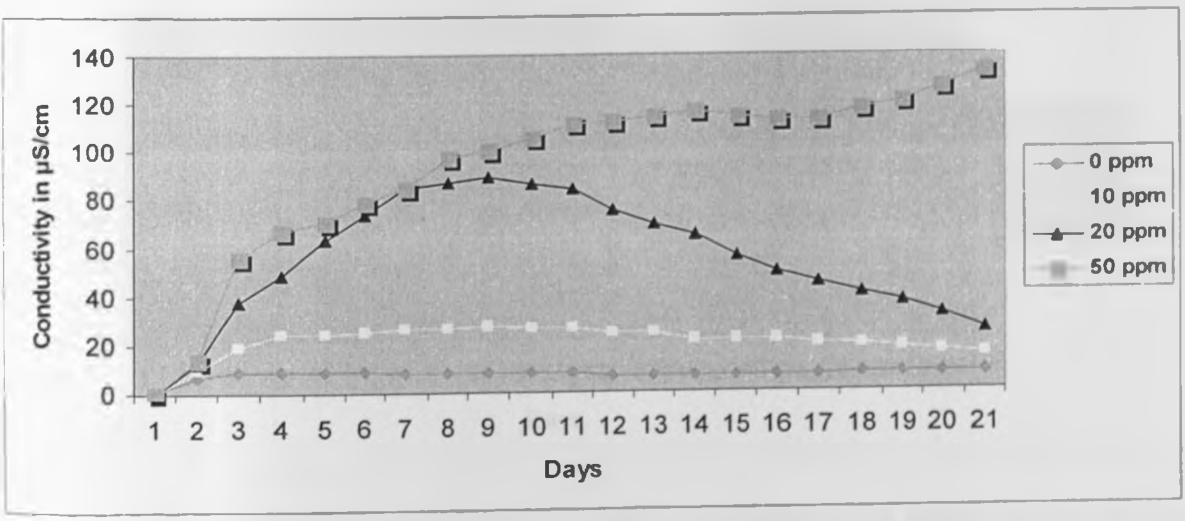

Figure 4.22: Mean electrical conductivity in μS/cm of lead-containing solutions with UP-C variety.

The available data shows that the electrical conductivity of both the distilled water and 10ppm lead-containing solution with variety UP-C, showed a slight increase then reduced. The electrical conductivity of distilled water slightly rose from 1.00μS/cm to 7.33μS/cm during the experimental period while that in 10ppm lead solution increased from 0.33μS/cm to 27.34μS/cm on the 9th day and then reduced to 14.67μS/cm on day 21. For 20ppm lead-containing solution, there was a rise in electrical conductivity for the first 9 days from 1.00μS/cm to 89.33μS/cm. This was however followed by a decline in electrical conductivity until the final day. The 50ppm lead-containing solution had no consistent trend but generally increased throughout the experimental period from 1.00μS/cm to 132.67μS/cm. Electrical conductivity of 50ppm lead-containing solution was the highest followed with 20ppm and 10ppm respectively.

4.2.4.4 Mean electrical conductivity of lead -containing solutions with immersed sweet potato plant variety UP-D

Electrical conductivity of lead-containing solutions containing variety UP-D showed an increase for about 9 days and then reduced for 10ppm and 20ppm lead-containing solution (figure 4.23).

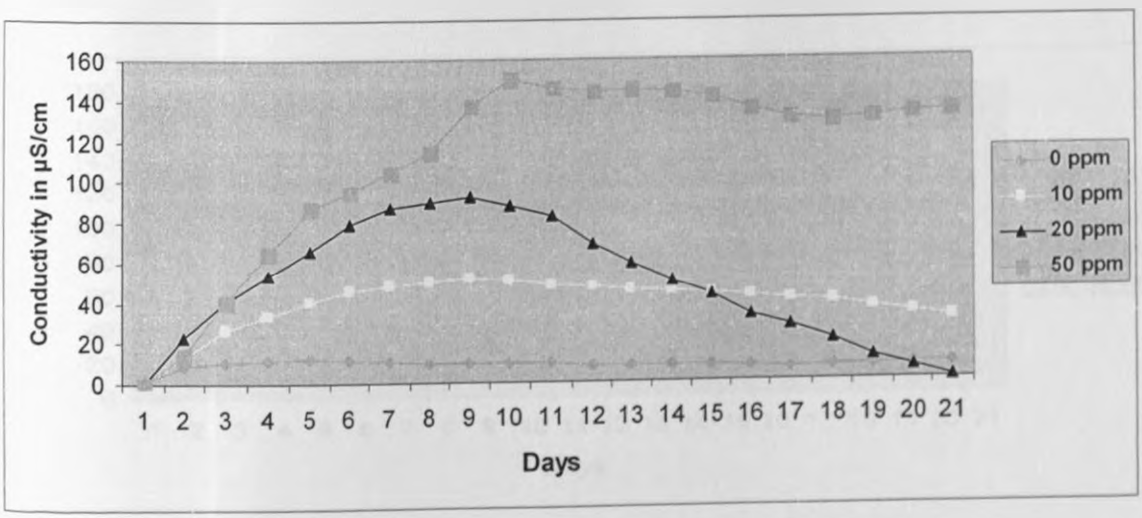

Figure 4.23: Mean electrical conductivity in μS/cm of lead-containing solutions with immersed UP-D variety.

Electrical conductivity of distilled water rose from 1.00µS/cm to 12.00µS/cm on the 5th day and then reduced to 7.33µS/cm at the 21st day. Results in figure 4.23 further demonstrated that electrical conductivity of 10ppm lead-containing solution showed a slight increase in the first week from 1.00µS/cm to 51.67µS/cm before gradually reducing to 31.00µS/cm on the final experimental day. The 20ppm solution showed a sharp rise in the electrical conductivity for the first nine days from 1.00µS/cm to 92.00µS/cm then sharply declined to 1.17µS/cm at the end of the experiment. For the first 10 days, the electrical conductivity of 50ppm increased from 1.00µS/cm to 145.66µS/cm and then declined gradually to 133.35µS/cm on the 21st day.

4.2.4.5 Mean electrical conductivity of lead -containing solutions with immersed sweet potato plant variety UP-16

Lead-containing solution with variety UP-16 showed electrical conductivity increasing continuously throughout the exposure period for 50ppm solution (figure 4.24). These results were similar to those of electrical conductivity of the same solution concentrations containing other varieties.

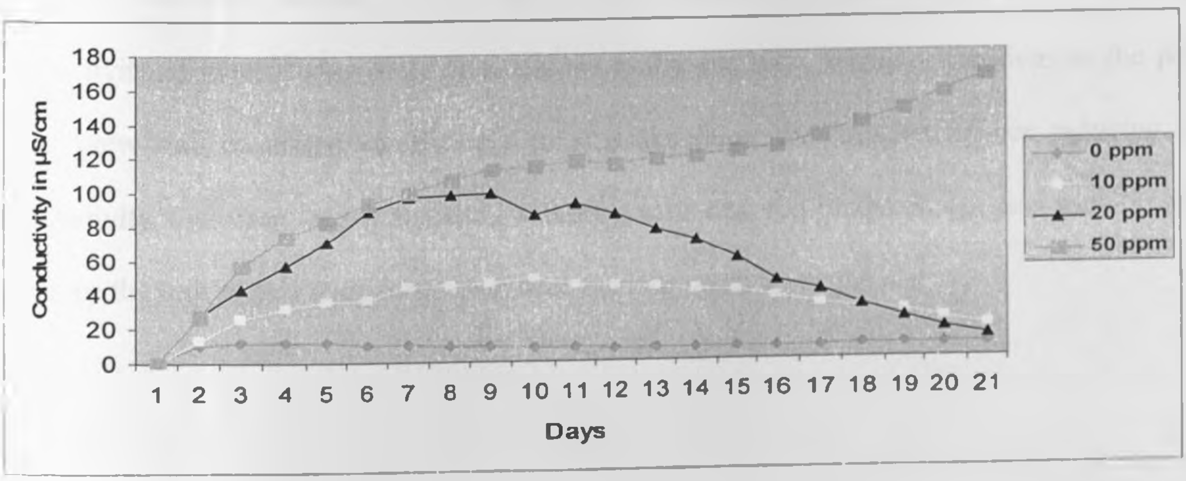

Figure 4.24: Mean electrical conductivity in µS/cm of lead-containing solutions with UP-16 variety.

Electrical conductivity of the distilled water with immersed variety UP-16 rose from1.00 μS/cm to 12.33μS/cm for the first five days and then reduced to 8.00μS/cm. Both 10ppm and 20ppm solutions showed similar trend where the conductivity first rose but then reduced as the experimental period progressed. The electrical conductivity of 10ppm lead solution rose from 1.00μS/cm to 48.67μS/cm on the 10^{th} day but then reduced to 18.33μS/cm by the 21^{st} day. The 20ppm lead solution also rose from 1.00μS/cm to 99.5 μS/cm for 9 days after which it declined to 12.67μS/cm by the time the experiment was terminated. However, for the electrical conductivity of 50ppm lead solution it increased throughout the experimental period from 1.00μS/cm to 165.00μS/cm.

The fact that the pH and the temperature remained relatively constant, as well as the solution being stagnant and under the same conditions as the control, suggested that the only variable would be due to the agitation of the solution brought about by the growth of the roots and the absorption of the ions by the roots. For the lead-containing solutions in which the plant varieties were immersed except in 50ppm, the electrical conductivity curves exhibited three phases: initial increase in the first five to six days, leveling off up to the 11^{th} day, followed by decrease. The slight decrease in conductivity of the 10^{th} day could be attributed to the excessive intake of lead ions as the plant roots grew and increased significantly in size absorbing the ions and hence reducing the conductivity. However, in 50ppm lead-containing solutions, the production of lead ions brought about by the root perturbation seems to exceed the ions taken up by the plant.

4.3 Comparison of mean electrical conductivity in 20ppm heavy metal ion-containing solutions with selected sweet potato varieties

The heavy metal solutions varied in electrical conductivity for varying concentrations. The figures 4.25 - 4.28 illustrate the variations in conductivity of 20ppm metal solutions with time. The figures compare the electrical conductivity of the heavy metal ion solutions containing cadmium, zinc, lead and chromium without the sweet potato plants and the electrical conductivity of the same solutions containing the plants.

4.3.1 Comparison of mean electrical conductivity in 20ppm heavy metal ion-containing solutions without sweet potato plants

For comparison purposes, 20ppm metal solutions containing varieties UP-A, UP-B and UP-D were selected. Figure 4.25 shows the electrical conductivity of different 20ppm metal solutions without the plants with time.

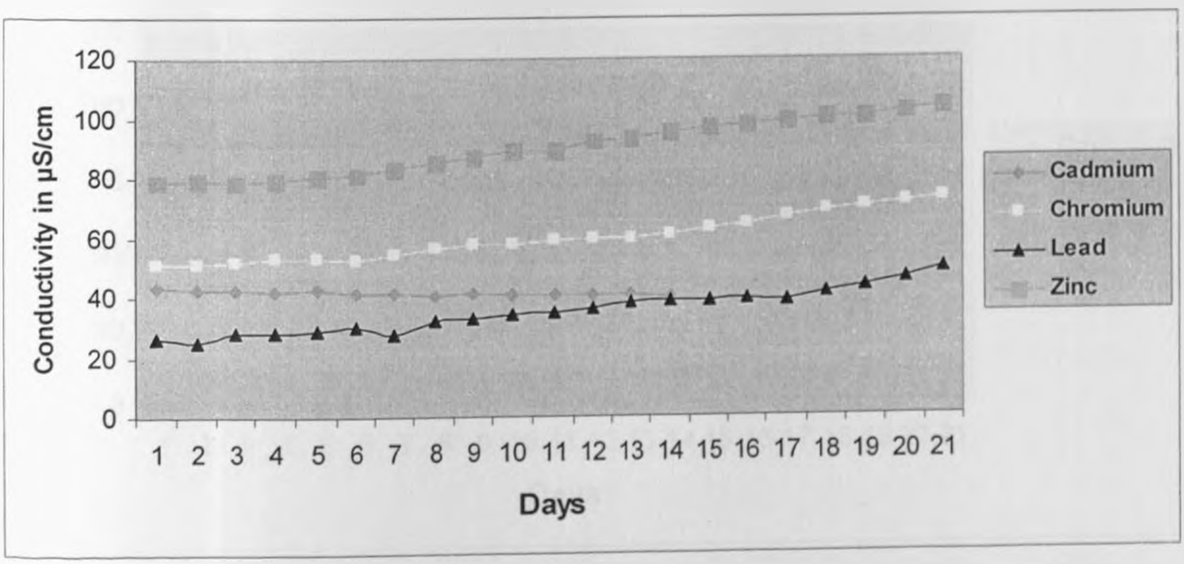

Figure 4.25: Comparison in mean electrical conductivity in µS/cm of 20ppm control solutions without plant varieties.

The results in figure 4.25 indicate that 20ppm zinc-containing solution had the highest conductivity followed by 20ppm chromium, cadmium and lead-containing solutions respectively. The electrical conductivity of 20ppm zinc-containing solution rose from 78.67µS/cm to 103.6µS/cm while that of chromium increased from 51.33µS/cm to 73.00µS/cm. Conductivity of 20ppm cadmium-containing solution on the other hand reduced from 43.00µS/cm on the first day to 40.00µS/cm on the last day. Lead-containing solution registered the lowest conductivity compared to other metal under test. It increased from 26.00µS/cm to 49.33µS/cm during the experimental period.

4.3.2 Comparison of mean electrical conductivity in 20ppm heavy metal ion-containing solutions with immersed sweet potato variety UP-A

Figure 4.26 illustrates the trend of conductivity of 20ppm metal ion-containing solutions with the sweet potato variety UP-A.

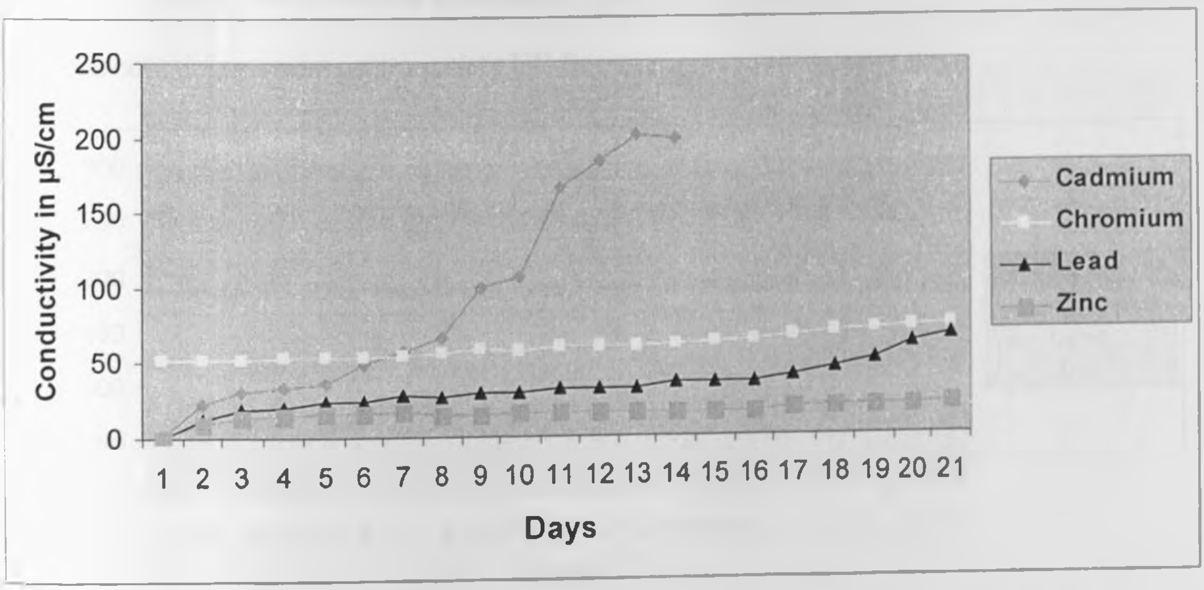

Figure 4.26: Comparison in mean electrical conductivity in µS/cm of heavy metal ions in 20ppm metal solutions containing variety UP-A.

Figure 4.26 shows that cadmium-containing solution containing variety UP-A had its electrical conductivity rise with time from 1.00μS/cm to 198.67μS/cm during the experimental period. The rise was sharp compared to the behavior of the other solutions. However, the electrical conductivity of 20ppm chromium and lead-containing solutions with the same varieties did not vary significantly. The electrical conductivity of 20ppm chromium-containing solution rose from 51.33μS/cm to 73.00μS/cm showing a slight increase compared to that of the cadmium-containing solution. Electrical conductivity of 20ppm zinc-containing solution also rose from 0.33μS/cm to 21.00μS/cm during the experimental period and was the lowest compared to other metal ion containing solutions under test. The 20ppm lead-containing solution containing the variety UP-A had its conductivity increase from 1.00μS/cm to 66.00μS/cm during 21 day period.

4.3.3 Comparison of mean electrical conductivity in 20ppm heavy metal ion-containing solutions with sweet potato variety UP-B

Figure 4.27 shows the electrical conductivity trend in 20ppm different metal ions -containing solutions containing sweet potato variety UP-B.

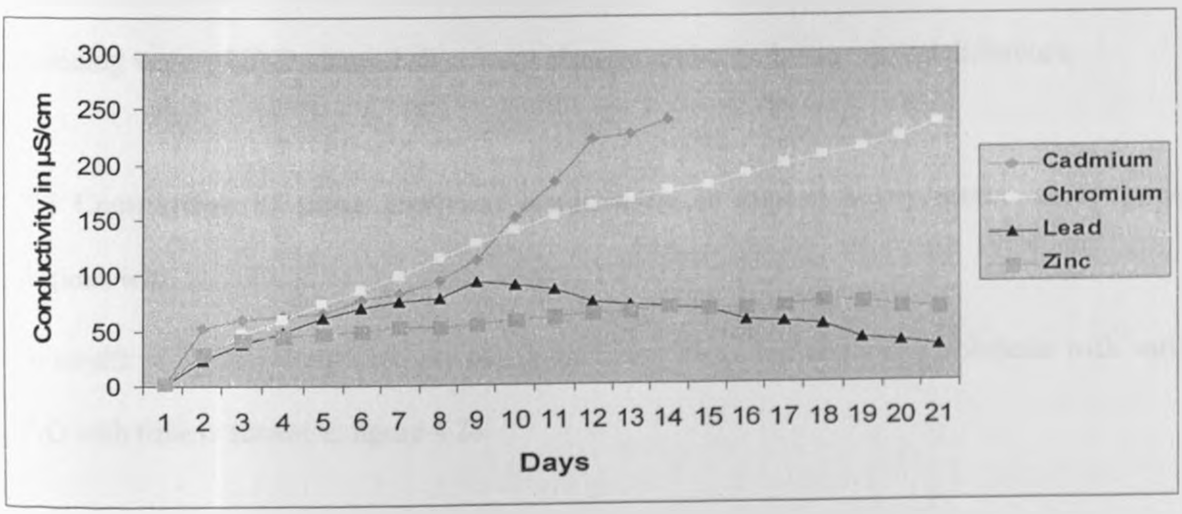

Figure 4.27: Comparison of mean electrical conductivity in μS/cm of heavy metal ions in 20ppm metal solutions with immersed variety UP-B.

Cadmium-containing solution showed highest electrical conductivity by the end of the experimental period which increased from 0.33μS/cm to 238.67μS/cm. Unlike the results obtained from solution containing variety UP-A, in variety UP-B the conductivity of chromium–containing solution increased significantly with time. The electrical conductivity of 20ppm chromium–containing solution rose from 1.00μS/cm to 234.67μS/cm while that of 20ppm zinc-containing solution also increased from 1.00μS/cm to 74.34μS/cm on the 18^{th} day and then reduced to 67.66μS/cm. However, 20ppm lead-containing solution increased for nine days from 1.00μS/cm to 93.00μS/cm and then reduced to 32.00μS/cm at the end of experimental period. The electrical conductivity of the zinc-containing solution showed the least electrical conductivity and remained constant with time. The sweet potato variety UP-B was different to UP-A in the root biomass. Variety UP-B had higher root density than variety UP-A. The electrical conductivity of the 20ppm solutions containing variety UP-B increased with time. Cadmium-containing solution registered highest electrical conductivity of the solution containing variety UP-B, followed by the 20ppm chromium, lead and zinc-containing solutions, respectively. Although these results were comparable to those obtained from the solutions containing variety UP-A, the trend for solutions containing variety UP-B showed significant changes probably due to varietal difference.

4.3.4 Comparison of mean electrical conductivity in 20ppm heavy metal ion-containing solutions with immersed sweet potato variety UP-D

The results of electrical conductivity of 20ppm heavy metal ion-containing solutions with variety UP-D with time is shown in figure 4.28

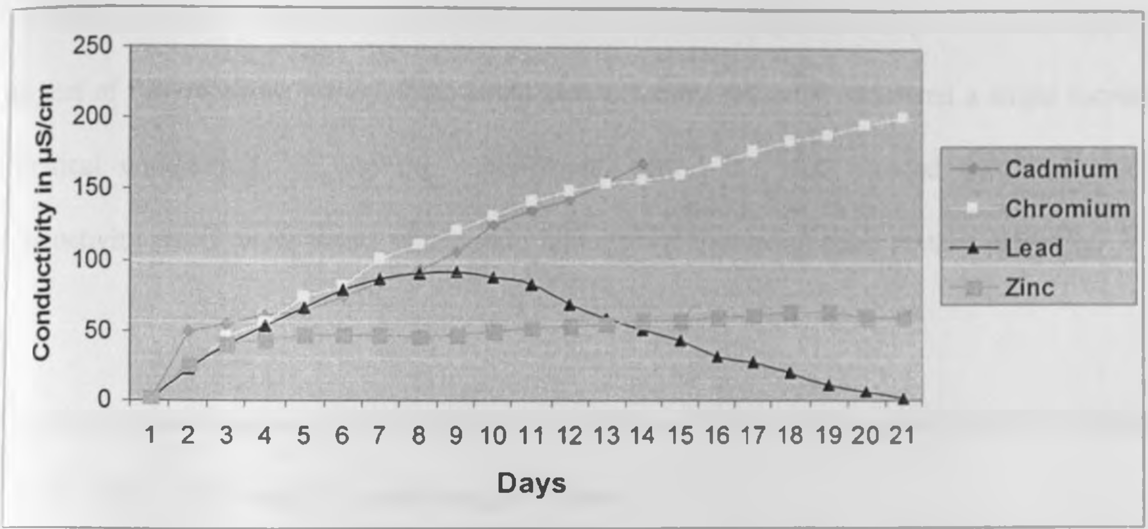

Figure 4.28: Comparison of mean electrical conductivity in µS/cm of heavy metals in 20ppm metal solutions containing variety UP-D.

The electrical conductivity of 20ppm heavy metal ion-containing solutions containing variety UP-D registered an increase in the first five days after which the trends changed differently. Chromium-containing solution had the highest electrical conductivity when variety UP-D was immersed in it. The conductivity increased from 1.00µS/cm to 202µS/cm. However, the 20ppm cadmium-containing solution with the same variety also registered an increase from 0.33µS/cm to 168µS/cm although the experimental period was 14 days. Similar trend in electrical conductivity of 20ppm lead-containing solution with variety UP-B was observed in 20ppm lead-containing solution with immersed variety UP-D. The electrical conductivity increased in the first nine days from 1.00µS/cm to 92.00µS/cm and then reduced to 1.17µS/cm by the 21st day. Zinc-containing solution of 20ppm rose from 1.33µS/cm to 59.32µS/cm during the experimental period. Generally, the electrical conductivity of 20ppm cadmium-containing solution was the highest while 20ppm chromium-containing solutions followed closely in solutions containing sweet potato varieties. The solutions of cadmium and chromium increased considerably with time. The conductivity of lead-containing solutions containing metal varieties increased for about nine days and then reduced for the rest of the exposure period. Zinc-containing solutions not only registered a slight increase in electrical conductivity during the experimental period but also showed the least electrical conductivity when sweet potato plants were immersed compared to other metals under test.

4.4. Heavy metal uptake and distribution in tissues of sweet potato plant varieties immersed in Cd^{2+}, Zn^{2+}, Pb^{2+} and Cr- containing solutions.

Experiments were performed to determine the uptake and distribution of cadmium, zinc, lead and chromium in the roots, stems and leaves of different sweet potato plant varieties from their respective heavy metal-ion containing solutions with varying concentrations. The results of these series of experiments are described and discussed in the subsequent subsections.

4.4.1 Cadmium uptake and distribution in the roots, stems and leaves of sweet potato plant varieties immersed in 10mg/l cadmium-containing solution.

The results of cadmium concentration in µg/g and content in µg of sweet potato varieties immersed in 10mg/l cadmium ion solutions for two weeks demonstrated that cadmium was accumulated into the roots and then translocated to the stem and the leaves as shown in table 4.9.

Table 4.9: Cadmium uptake and distribution by sweet potato plant varieties immersed in 10mg/l cadmium-containing solution over14 days

Variety	Plant part	Dry weight (g) A	Cadmium concentration (μg /g) B	Cadmium content (μg of dry weight in column A) C	Percentage cadmium content D
UP-A	Leaves	0.12	296.17 ± 149.30	35.54 ± 17.68	1.78
	Roots	0.03	11624.40 ± 724.11	348.72 ± 20.28	17.44
	Stem	0.81	478.10 ± 27.40	387.26 ± 22.23	19.36
	Total	0.96		771.52	38.58
UP-B	Leaves	0.43	ND	ND	0
	Roots	0.05	7997.00 ± 426.81	399.85 ± 23.18	19.99
	Stem	1.66	173.09 ± 16.56	287.33 ± 27.68	14.37
	Total	2.15		687.17	34.36
UP-C	Leaves	0.29	4.56 ± 1.40	1.32 ± 0.42	0.07
	Roots	0.05	8778.40 ± 1008.50	438.92 ± 37.72	21.95
	Stem	1.34	159.15± 33.3	213.26 ±44.55	10.66
	Total	1.68		653.51	32.68
UP-D	Leaves	0.27	11.10 ± 0.39	2.97 ± 0.12	0.15
	Roots	0.04	9333.25 ± 0.88	373.33 ± 33.53	18.67
	Stem	1.49	194.46 ± 1.73	289.75 ± 2.46	14.49
	Total	1.80		666.08	33.31
UP-16	Leaves	0.21	7.76 ± 0.01	1.63 ± 0.19	0.08
	Roots	0.05	8506.6 ± 654.33	425.33 ± 31.87	21.27
	Stem	1.18	252.79 ± 24.44	298.29 ± 28.67	14.91
	Total	1.44		725.26	36.26

KEY: ND- Not Detected

Column A (g) X column B (μg/g) = column C

$$\text{Column D} = \frac{\text{column C} \times 100}{2{,}000\mu g \text{ (Total Cd in 200ml solution)}}$$

n =3 replicates

The roots in all the plant varieties under test accumulated highest cadmium content in all the varieties except UP-A which had more cadmium content in the stem than in the roots. In all the varieties, leaves had the least cadmium content (table 4.9). Plant variety UP-C had the highest cadmium content accumulated in the roots (21.95% of the cadmium dissolved in the initial solution). Results of cadmium content in the plant stems showed variety UP- A (19.36%) with the highest cadmium accumulation while variety UP- C showed the least cadmium content present (10.66%). More cadmium content was translocated into leaves of variety UP-A (1.78%), while variety UP-C had the least cadmium content in the leaves (0.07%). Variety UP-B however, did not take up cadmium in the leaves.

The results of total cadmium taken up by the varieties indicated that the plant varieties immersed in the 10mg/l cadmium-containing solution showed cadmium accumulation above 600 μg. More cadmium content was recovered from variety UP-A (38.58% of initial cadmium content in solution) followed by varieties UP-16 (36.26%), UP-B (34.36%), UP-D (33.31%) and UP-C (32.68%) respe ctively. These results as shown in indicated that all the varieties took up the cadmium almost equally. The fact that there was significant amount of Cd in the leaves signifies that truly the Cd was absorbed by the plant and translocated into the leaves. The cadmium concentration in μg/g was highest in the roots in all the plant varieties probably due to the exposure of the plant to the solution throughout the experimental period.

Stems accumulated less cadmium than the roots while the leaves accumulated least cadmium showing slow translocation of the metal in the leaves tissue. For 10 ppm Cd-containing solutions the order of distribution of Cd in the plant parts was as follows:

Leaves<Roots<Stems for UP-A variety.

Leaves<Stems<Roots for UP-B, UP-C, UP-D and UP-16 varieties.

The lower uptake of cadmium in the roots of plant variety UP-A may be attributed to a low root biomass in the variety compared with the other varieties used in the experiment.

4.4.2. Cadmium uptake and distribution in the roots, stems and leaves of sweet potato plant varieties immersed in 20mg/l cadmium-containing solution

Table 4.10 shows results of cadmium concentration and content in plants immersed in 20mg/l cadmium-containing solutions. The results indicate that the dry weights of the stem were highest followed by the leaves and the roots in that order (column A).

Table 4.10: Cadmium uptake and distribution by sweet potato plant varieties immersed in 20mg/l cadmium-containing solution over14 days

Variety	Plant part	Dry weight (g) A	Cadmium concentration (μg /g) B	Cadmium content (μg of dry weight in column A) C	Percentage cadmium content D
UP-A	Leaves	0.18	800.94 ± 106.10	144.17 ± 19.28	3.60
	Roots	0.04	10764.49 ± 881.28	430.58 ± 32.08	10.76
	Stem	1.05	436.14 ± 38.40	457.95 ± 40.35	11.45
	Total	1.27		1032.7	25.81
UP-B	Leaves	0.30	14.10 ± 2.21	4.23 ± 6.68	0.11
	Roots	0.06	7537.17 ±188.19	452.23 ± 10.53	11.30
	Stem	1.53	303.08 ± 9.12	463.72 ± 13.90	11.59
	Total	1.89		920.18	23.00
UP-C	Leaves	0.31	ND	ND	0
	Roots	0.06	8110.17 ± 145.89	486.61 ± 9.15	12.17
	Stem	1.42	316.17 ± 13.00	448.96 ± 1.85	11.22
	Total	1.79		935.58	23.39
UP-D	Leaves	0.28	3.61 ± 0.35	1.01 ± 0.97	0.03
	Roots	0.04	12114.75 ± 438.70	484.59± 19.30	12.11
	Stem	1.15	407.97 ± 10.18	469.17 ± 11.72	11.73
	Total	1.47		954.78	23.87
UP-16	Leaves	0.25	17.84 ± 10.30	4.46 ±2.60	0.12
	Roots	0.08	5876.88 ± 640.46	470.15 ± 49.13	11.75
	Stem	1.33	367.28 ± 66.30	488.48 ± 8.70	12.21
	Total	1.66		963.09	24.08

KEY: ND- Not Detected

Column A (g) X column B (μg/g) = column C

$$\text{Column D} = \frac{\text{column C} \times 100}{4{,}000\ \mu g\ (\text{Total Cd in 200ml solution})}$$

n =3 replicates

Cadmium concentration was highest in the roots in all the plant varieties, an observation similar to that of the same varieties immersed in 10mg/l cadmium-containing solutions. More concentration of cadmium was present in the stems than the leaves in all the plant varieties except UP-A which had higher cadmium presence in the leaves than the stem.

Results of cadmium content in the plant varieties showed an almost equal distribution of cadmium in the stem and the roots. Variety UP-A which accumulated highest cadmium content among the varieties, had 10.76% cadmium content in the roots and 11.45% cadmium content in the stem while variety UP-B which accumulated least cadmium content had 11.30% cadmium content in the roots and 11.59% cadmium content in the stem. Variety UP -A had highest cadmium content in the leaves (3.60%) with variety UP-C showing no cadmium content in the leaves. Variety UP-A, UP-B and UP-16 had higher cadmium content accumulated in the stems followed by the roots then the leaves, while variety UP-C and UP-D had higher cadmium content in the roots followed by the stems and the leaves. The ratio of accumulation of cadmium content in Roots: Stem is 1:1. Low accumulation levels were recovered in leaves in all varieties except variety UP-A (3.60% of the cadmium in the initial solution). The low cadmium recoveries in the leaves can be attributed to slow translocation of the cadmium in the plant as it did not survive in the solution as expected.

The total cadmium content was higher in the plants immersed in 20mg/l solution than from the same varieties immersed in 10mg/l cadmium-containing solution.

The plant varieties absorbed cadmium almost equally, with variety UP-A showing the highest recovery of 25.81% of the initial cadmium content in the solution while variety UP-B showed least recovery of 23.00% cadmium. Other varieties included UP-16 (24.08%), UP-D (23.87%) and UP-C (23.39%). This indicated that all the varieties accumulated cadmium almost equally during the experimental period.

The percentage uptake of cadmium content in 20mg/l Cd-containing solution with immersed plants was lower compared to that present in plant varieties immersed in 10mg/l solution. This may be attributed to increased cadmium toxicity of the 20mg/l cadmium-containing solution which may have inhibited plant growth and therefore reducing cadmium uptake from the solution. For 20 ppm Cd-containing solutions the order of distribution of Cd in the plant parts was as follows:

Leaves<Roots<Stems for UP-A, UP-B and UP-16 varieties.

Leaves<Stems<Roots for, UP-C and UP-D varieties.

4.4.3 Comparison of cadmium levels in different sweet potato plant varieties immersed in varying concentrations of Cd^{2+}-containing solutions.

The results obtained above for the absorption of cadmium and translocation into the sweet potato plant varieties correlate well with what was reported earlier for absorption of Cd by *helianthus annus* seedlings in soils (Di Cagno *et al.*, 1999). Evidence that cadmium ions are readily transported and accumulated in the shoots of several plant species has also been reported by Salt *et al.*, (1995).

In all the plant varieties the mass of dry weight was highest in the stems, followed by the leaves then the roots. However, it was observed that variety UP-A had lower root dry weight compared with the other plant varieties tested and this was probably the reason why in 10mg/l and 20mg/l cadmium-containing solutions the accumulation of cadmium in the stem was higher than the roots in the variety.

Comparing cadmium content in plant varieties immersed in both 10mg/l and 20mg/l cadmium-containing solutions, all varieties accumulated higher cadmium from 20mg/l solutions than in 10mg/l solutions in which they were immersed. To illustrate this, figure 4.29 shows the comparison of distribution of cadmium in different parts of the plant varieties immersed in 10mg/l and 20mg/l cadmium-containing solutions.

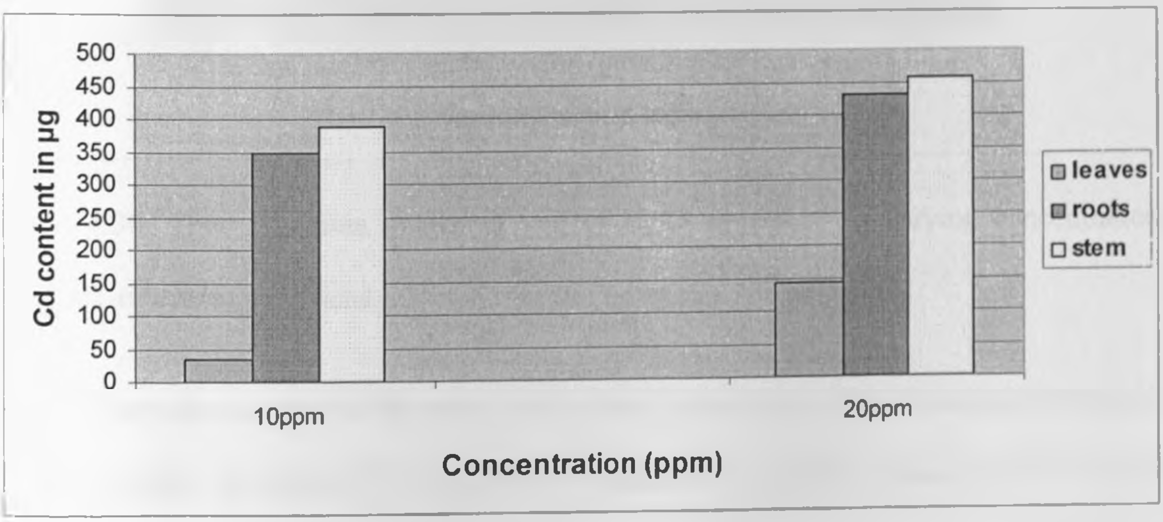

Figure 4.29: Comparison in cadmium content uptake and distribution in variety UP-A immersed in varying concentrations of Cd^{2+}-containing solutions.

Cadmium content was highest in UP-A in both set up of plants immersed in 10mg /l and 20 mg /l cadmium-containing solutions. Stems accumulated higher cadmium in both concentrations followed by the roots and the leaves. This showed low translocation of cadmium to the leaves as they turned yellow by the 5th day and completely dried up by the 10th day.

The total cadmium content in the plant varieties also increased with the increase in the concentration of the cadmium-containing solution in which the plants were immersed (figure 4.30) illustrates this observation using immersed sweet potato plant variety UP-A.

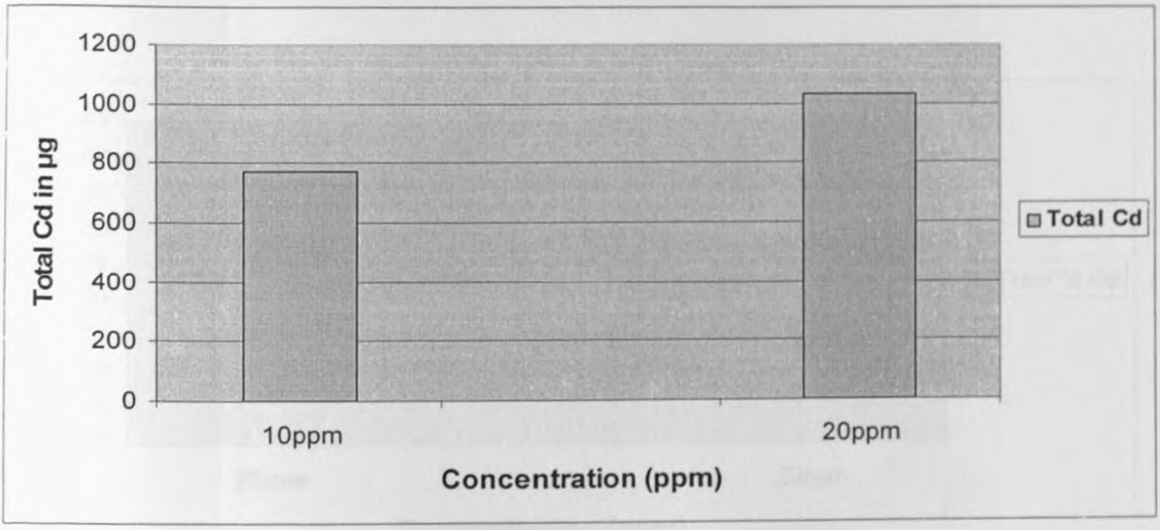

Figure 4.30: Total cadmium uptake in variety UP-A immersed in varying concentrations of cadmium-containing solutions.

The total cadmium content in the sweet potato plants immersed in 10mg/l ranged between 653.51 µg of dry weight for variety UP-C (32.68% of cadmium in the initial solution) and 771.52µg per g of dry weight for variety UP-A (38.58%). The plant varieties immersed in 20mg/l cadmium-containing solution showed a range of the total cadmium content was between 920.18µg per g of dry weight for variety UP-B (23.00% of cadmium content in the initial solution) and 1032.70µg per g of total dry weight for variety UP-A (25.81%). The results further demonstrate that variety UP-A accumulated highest cadmium content in both 10 mg/l and 20mg/l cadmium-containing solutions in which they were immersed. Cadmium concentration µg/g was highest in plant roots in all varieties immersed in both 10mg/l and 20mg/l cadmium solutions followed by the stems and then leaves. Further, the results demonstrated that the percentage uptake of cadmium content reduced with increase in concentration of cadmium solution. Cadmium content percentages in 20mg/l cadmium-containing solution immersed plants were lower than those obtained from 10mg/l cadmium-containing solution. This is illustrated using the percentages cadmium uptake in variety UP-A in figure 4.31.

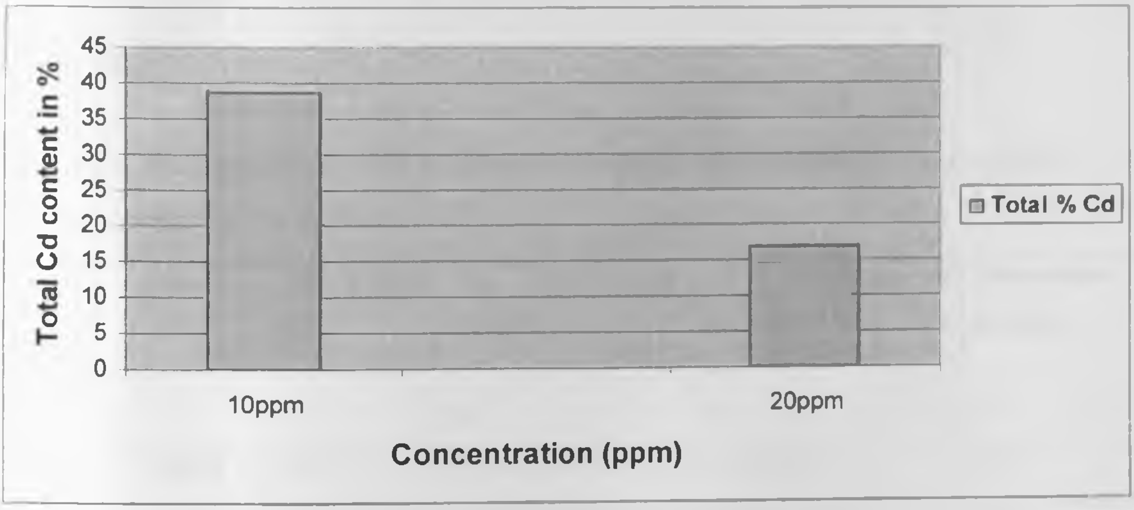

Figure 4.31: Total % Cadmium uptake in variety UP-A immersed in different concentrations of cadmium-containing solutions.

The reduction of the percentage uptake of cadmium in 20mg/l could be attributed to increased toxicity of cadmium in the solution compared to the 10mg/l cadmium-containing solution. The plant varieties immersed in the 20mg/l cadmium solution dried within a shorter time and therefore could not take up much cadmium from the solution. A possible explanation for this observation is that as the amount of non essential Cd ions is increased, the toxicity increases, implying that there might be inhibition of further uptake. Furthermore, the adsorption of the cadmium ion on the surface of the roots inhibits the normal uptake of nitrate nutrients. Among the heavy metals, the most effective inhibitor of the nitrate absorption in higher plants is cadmium (Hernandez *et al*., 1998). This explains the observation of drying plant varieties immersed in cadmium-containing solution.

4.4.4 Zinc uptake and distribution in the roots, stems and leaves of sweet potato plant varieties immersed in 10mg/l Zn^{2+}-containing solutions

The results of zinc concentration and content in the sweet potato plant varieties in 10mg/l zinc-containing solution are shown in table 4.11.

Table 4.11: Zinc uptake and distribution by sweet potato plants immersed in 10mg/l zinc-containing solutions for 21 days.

Variety	Plant part	Dry weight (g) A	Zinc concentration (µg/g) B	Zinc content (µg of dry weight in column A) C	Percentage zinc content D
UP-A	Leaves	0.08	13.75± 2.20	1.10 ± 0.18	0.06
	Roots	0.01	8579.00 ± 570.94	85.79 ± 26.41	4.29
	Stem	1.03	273.66 ± 1.66	281.87 ± 1.68	14.09
	Total	1.12		368.76	18.44
UP-B	Leaves	0.24	15.46 ± 2.10	3.71 ± 0.50	0.19
	Roots	0.04	5375.25 ± 916.60	215.01 ± 36.64	10.75
	Stem	1.42	175.85 ± 2.60	249.70± 3.69	12.49
	Total	1.70		468.42	23.43
UP-C	Leaves	0.17	214.45 ± 7.71	4.29 ± 1.33	0.21
	Roots	0.03	8585.33 ± 1249.68	257.56 ± 36.74	12.88
	Stem	1.53	155.52 ± 15.58	237.94 ± 34.98	11.90
	Total	1.73		499.79	24.99

Table 4.11 (*contd...*)

Variety	Plant part	Dry weight (g) A	Zinc concentration (µg/g) B	Zinc content (µg of dry weight in column A) C	Percentage zinc content D
UP-D	**Leaves**	0.14	28.36 ± 13.50	3.97 ± 1.90	0.20
	Roots	0.02	6510.00 ± 547.10	130.20 ± 11.05	6.51
	Stem	1.26	180.33 ± 27.56	227.21 ± 34.77	11.36
	Total	1.42		361.38	18.07
UP-16	**Leaves**	0.10	25.70 ± 4.23	2.57 ± 0.45	0.13
	Roots	0.01	8421.06 ± 740.70	84.21 ± 8.74	4.21
	Stem	1.05	307.95 ± 32.70	323.35 ± 34.38	16.17
	Total	1.16		410.13	20.51

Column A (g) X column B (µg/g) = column C

Column D = column C X 100 / 2,000 µg (Total Zn in 200ml solution)

n =3 replicates

Zinc content translocated in stem was highest in all varieties except in variety UP- C which had more zinc content in the roots, stems and the leaves. Variety UP-16 had the highest zinc content recovered from the stem (16.17% of zinc content in the initial solution) compared to the other varieties. Variety UP-C on the other hand accumulated more zinc content in its roots (12.88%) while varieties UP-A and UP-16 accumulated least zinc in their roots (4.29%) and (4.21%) respectively. The UP-C variety had 0.21% zinc content in the leaves being the highest accumulation among the varieties. Translocation of zinc in the leaves was minimal in all the plant varieties with all the percentages being below 0.3% zinc content. Distribution of zinc content in the roots, the stems and the leaves tissues of the sweet potato varieties immersed in 10mg/l zinc solution showed zinc was present in all the parts of the plant. Zinc concentration in µg/g was highest in the plant roots for all varieties with variety UP-A showing the highest concentration in the roots.

Comparing the results of zinc uptake in all the varieties, variety UP-C absorbed highest total zinc content (24.99% of zinc content in the initial solution) while variety UP- D had least total zinc content (18.07%). Others were, UP-B (23.43%), UP-16 (20.51%) and UP-A (18.44%) total zinc content accumulation. The results from variety UP-D and UP-A could be attributed to low presence of zinc in the plant roots compared to the other plants. For 10ppm zinc solutions the order of distribution of Zn in the plant parts was as follows:

Leaves<Roots<Stems for UP-A, UP-B, UP-D and UP-16 varieties

Leaves<Stems<Roots for UP-C variety

4.4.5 Zinc uptake and distribution in the roots, stems and leaves of sweet potato plant varieties immersed in 20mg/l Zn^{2+}-containing solutions

Table 4.12 shows the uptake and distribution of zinc concentration and content in sweet potato varieties immersed in 20mg/l zinc solutions.

Table 4.12: Zinc uptake and distribution by sweet potato plants immersed in 20mg/l zinc-containing solutions over 21 days

Variety	Plant part	Dry weight (g) A	Zinc concentration (μg/g) B	Zinc content (μg of dry weight in column A) C	Percentage zinc content D
UP-A	Leaves	0.08	732.88 ± 38.62	58.63 ± 3.01	1.47
	Roots	0.01	15937.04 ± 1832.58	159.37 ± 7.88	3.98
	Stem	1.16	280.84 ± 26.63	325.77 ± 30.81	8.14
	Total	1.25		543.77	13.59
UP-B	Leaves	0.24	116.04 ± 24.11	27.85 ± 5.75	0.70
	Roots	0.02	14113.50 ± 1390.33	282.27 ± 30.45	7.06
	Stem	1.30	224.27 ± 17.26	291.55 ± 22.45	7.29
	Total	1.56		601.67	15.05
UP-C	Leaves	0.17	318.82 ± 158.55	54.20 ± 26.19	1.36
	Roots	0.02	10703.00 ± 2498.51	214.06 ± 41.23	5.35
	Stem	1.47	184.77 ± 24.20	271.61 ± 35.48	6.79
	Total	1.66		539.87	13.50
UP-D	Leaves	0.13	19.38 ± 4.91	2.52 ± 0.64	0.06
	Roots	0.02	12080.32 ± 1145.80	241.60 ± 30.65	6.05
	Stem	1.03	253.71 ± 45.20	261.32 ± 46.67	6.53
	Total	1.18		505.44	12.64
UP-16	Leaves	0.10	48.00 ± 10.30	4.80 ± 0.98	0.12
	Roots	0.02	11703.03 ± 2744.76	234.06 ± 44.47	5.85
	Stem	1.26	245.36 ±17.10	309.15 ± 21.51	7.73
	Total	1.38		548.01	13.70

KEY:

Column A (g) X column B (µg/g) = column C

$$\text{Column D} = \frac{\text{column C}}{4{,}000\ \mu g\ (\text{Total Zn in 200ml solution})} \times 100$$

n=3 replicates

The concentration of zinc in the 20mg/l zinc-containing solution was still highest in the roots in all the varieties probably due to the continuous exposure of the roots in the solution. However, the actual zinc content in µg was highest in stem followed by the roots and the leaves for all the varieties. The content of zinc in the stems was highest in variety UP-A (8.14% of zinc content in the initial solution) compared to the rest of the varieties. Variety UP-B (7.06%) had the highest zinc content in the roots while variety UP-A (3.98%) showed the least zinc in the roots. Zinc accumulation in the leaves was low in all varieties showing slow translocation of the metal in the plants. Variety UP-A had more zinc in the leaves (1.47%) while variety UP-D had the least zinc present in the leaves (0.06%).

The total zinc content recovered from plant varieties immersed in 20mg/l zinc-containing solution was higher than those immersed in 10mg/l zinc-containing solution. However, the percentage accumulation of zinc content from the 20mg/l solution was lower than that of 10mg/l. Variety UP-B had the highest total zinc content which was 15.05% of the initial zinc content in the solution, while variety UP- D had the least zinc content of 12.64%. Other varieties had almost equal total zinc accumulation with UP-16 (13.70%), UP-A (13.59%) and UP-C (13.50%) showing a nearly equal uptake. For 20ppm zinc-containing solutions the order of distribution of Zn in the plant parts was as follows: Leaves<Roots<Stems for UP-A, UP-B, UP-C, UP-D and UP-16 varieties

4.4.6 Zinc uptake and distribution in the roots, stems and leaves of sweet potato plants immersed in 50mg/l Zn^{2+}-containing solution

The plant varieties immersed in 50mg/l zinc-containing solution showed zinc accumulation and distribution in the plant tissues as shown in the results in table 4.13.

Table 4.13: Zinc uptake and distribution by sweet potato plants immersed in 50mg/l zinc-containing solution for 21 days

Variety	Plant part	Dry weight (g) A	Zinc concentration (µg /g) B	Zinc content (µg of dry weight in column A) C	Percentage zinc content D
UP-A	Leaves	0.13	123.85 ± 11.80	16.10 ± 1.48	0.16
	Roots	0.01	12370.10 ± 822.33	123.70 ± 9.87	1.24
	Stem	1.64	102.95 ± 7.70	168.83 ± 12.61	1.69
	Total	1.78		308.63	3.09
UP-B	Leaves	0.26	130.31 ±8.52	33.88 ± 2.26	0.34
	Roots	0.10	1717.10 ± 75.70	171.71 ± 7.50	1.72
	Stem	1.64	100.51 ± 6.55	164.83 ± 10.69	1.65
	Total	2.00		370.42	3.71
UP-C	Leaves	0.20	42.25 ± 3.90	8.45± 0.44	0.08
	Roots	0.06	2675.67 ± 153.33	160.54 ± 9.66	1.61
	Stem	1.74	90.69 ± 4.72	157.80 ± 8.09	1.58
	Total	2.00		326.79	3.27
UP-D	Leaves	0.19	59.11 ± 11.20	11.23 ± 2.08	0.11
	Roots	0.06	2783.17 ± 153.35	166.99 ± 9.63	1.67
	Stem	1.34	120.41 ± 7.70	161.35 ± 10.3	1.62
	Total	1.59		339.56	3.40

Table 4.13 (*contd...*)

Variety	Plant part	Dry weight (g) A	Zinc concentration (μg /g) B	Zinc content (μg of dry weight in column A) C	Percentage zinc content D
UP-16	Leaves	0.22	62.68 ± 5.52	13.79 ± 1.24	0.14
	Roots	0.08	2062.50 ± 50.71	165.00 ± 3.78	1.65
	Stem	1.39	115.76 ± 5.20	160.90 ± 7.22	1.61
	Total	1.69		339.69	3.40

KEY:

Column A (g) X column B (μg/g) = column C

Column D = column C X 100 / 10,000 μg (Total Zn in 200ml solution)

n =3 replicates

The results of zinc uptake and distribution in the different plant parts of the sweet potato varieties immersed in 50ppm zinc solutions show the presence of zinc in the plant tissues. The zinc concentration in the roots was highest in all the plant varieties (table 4.13). The results of zinc content distribution in varieties UP-B, UP-C, UP-D and UP-16 showed higher zinc content in the roots, followed by the stem and the leaves. However, varieties UP –A showed higher zinc content present in the stem followed by the roots and then leaves. This may be attributed to a small root biomass in the variety compared to the other varieties. The ratio of the zinc content in the roots to the zinc content in stem was1:1 in all varieties. For instance, variety UP-C had zinc content in the roots as 1.61% while the content in the stem was 1.58%. Similarly, the zinc content in the roots of variety UP-16 was 1.65% while in the stem it was 1.61% of the zinc in the solution. Variety UP-B on the other hand, gave highest zinc content in the leaves (0.34% of zinc in the initial solution) compared to the other varieties. Generally, translocation of zinc at this concentration was low in the leaves, an observation similar to those of other zinc-containing solutions. The zinc content present in the plant tissues of the plant varieties immersed in 50mg/l zinc-containing was lower compared to those in the solutions of 20mg/l and 10mg/l respectively.

Table 4.13 showed the percentage of zinc content accumulated by the plant varieties. These results indicated that the zinc percentage reduced compared to percentage results obtained from 20mg/l and 10mg/l zinc-containing solutions. The zinc content and concentration was also observed to be lower than those obtained from the same plant varieties immersed in 20mg/l and 10mg/l zinc-containing solutions. This observation may be attributed to the excessive amount of Zn adsorbed on the surface of the roots, which could not be taken up by the plant. This explanation is further supported by the fact that in all the four heavy metals studied in this work the percentage metal content decreases as their original concentration increases.

The results further demonstrated that the plant varieties accumulated zinc almost equally. Variety UP-B had highest total zinc content present which represented 3.71% of the amount of zinc dissolved in 200ml solution while the variety UP-A had least zinc content representing 3.09% of total zinc in the solution. Other varieties were UP-D and UP-16 (3.40% each) and UP-C (3.27%).

For 50ppm zinc solutions the order of distribution of Zn in the plant parts was as follows:

Leaves<Roots<Stems for UP-A variety.

Leaves<Stems<Roots for UP-B, UP-C, UP-D and UP-16 varieties.

4.4.7 Comparison of zinc levels in different sweet potato plant varieties immersed in varying concentrations of Zn^{2+}-containing solutions.

The uptake and trans-location of zinc into the sweet potato plant can be related to previous work, which indicate that zinc accumulated in *Arabidopsis halleri* (Bert *et al*., 2000). The dry weight mass in the stems were higher than those of leaves and the roots in all the set ups. However, there was no correlation between changes in mass of dry weight with increase in concentration of zinc solutions. The content of zinc in all the sweet potato varieties under test increased with increase concentration of solutions of zinc in which they were immersed except in 50mg/l which showed lower zinc content. Figure 4.32 illustrates zinc uptake and distribution in different parts of the plant UP-B variety immersed in different concentrations of zinc solution.

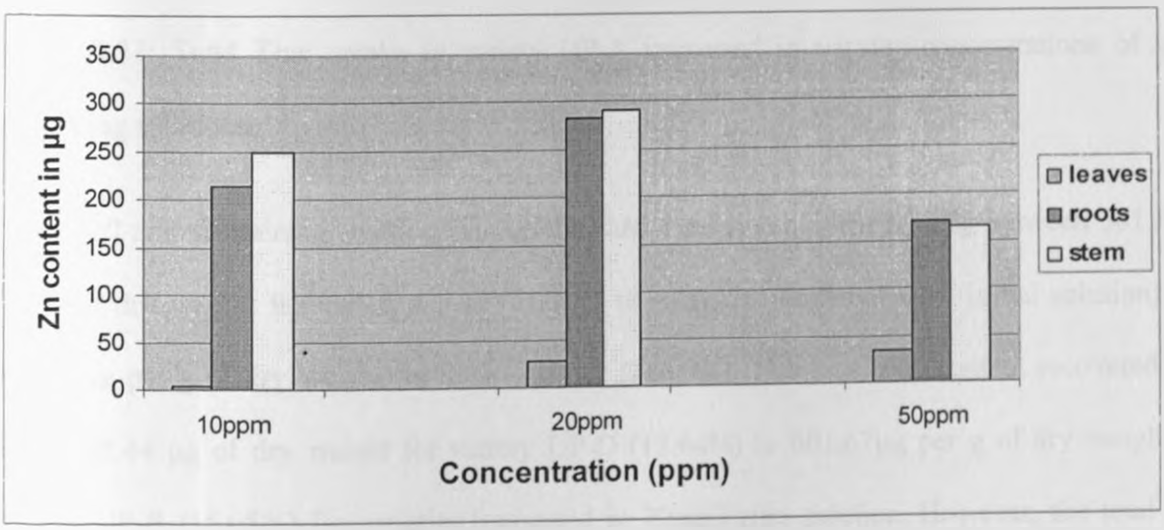

Figure 4.32: Comparison of zinc content uptake and distribution in variety UP-B immersed in varying concentrations of zinc-containing solutions.

The results in figure 4.32 demonstrate that for variety UP-B, higher zinc content was recovered from the stems then the roots and the leaves respectively. It was also observed that the distribution of zinc content in the roots and the stem was almost equal. Leaves showed very low zinc presence probably due to low zinc translocation from the roots through the stem to the leaves.

A similar trend was observed for total zinc absorbed by the plant varieties immersed in zinc solutions. Figure 4.33 illustrates this similarity for variety UP-A.

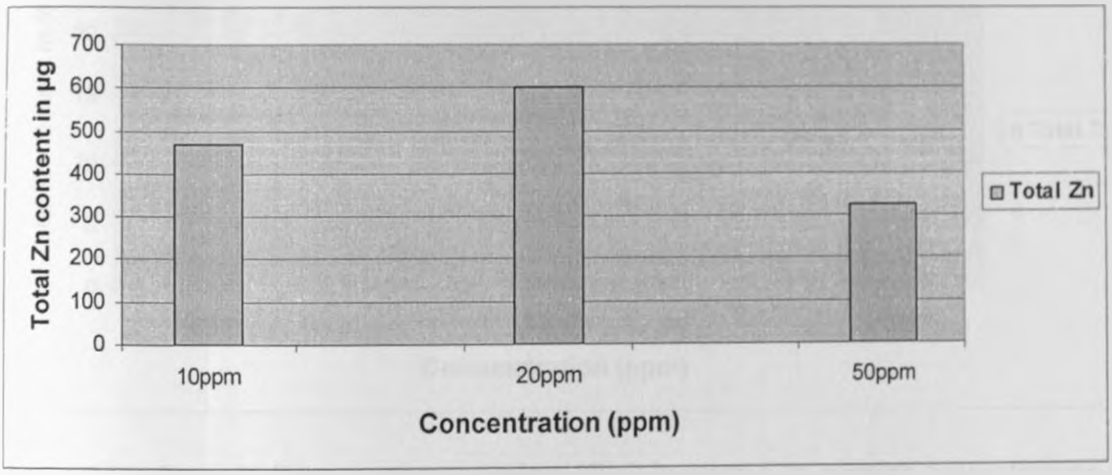

Figure 4.33: Total Zinc uptake in variety UP-A immersed in varying concentrations of zinc-containing solutions.

In 10mg/l zinc containing solution the varieties had total zinc content ranging between 361.38µg per g of dry weight for variety UP-D (11.36% of total zinc content in the initial solution) and 499.79µg per g of dry weight for variety UP-C (24.99%). The total zinc content recovered was from 505.44 µg of dry weight for variety UP-D (12.64%) to 601.67µg per g of dry weight for variety UP-B (15.05%) for varieties immersed in 20mg/l zinc solution. However, the total zinc content ranged from 308.63 µg of dry weight for variety UP-A (3.09%) to 370.42 µg of dry weight for variety UP-B (3.71%). Variety UP-A was the highest total zinc concentration accumulator in all the set up of the zinc contaminated solutions.

The percentage zinc content accumulated in the plant varieties compared to zinc dissolved in the initial solutions but decreased with increase in the concentrations. Figure 4.34 illustrates this trend for variety UP-B.

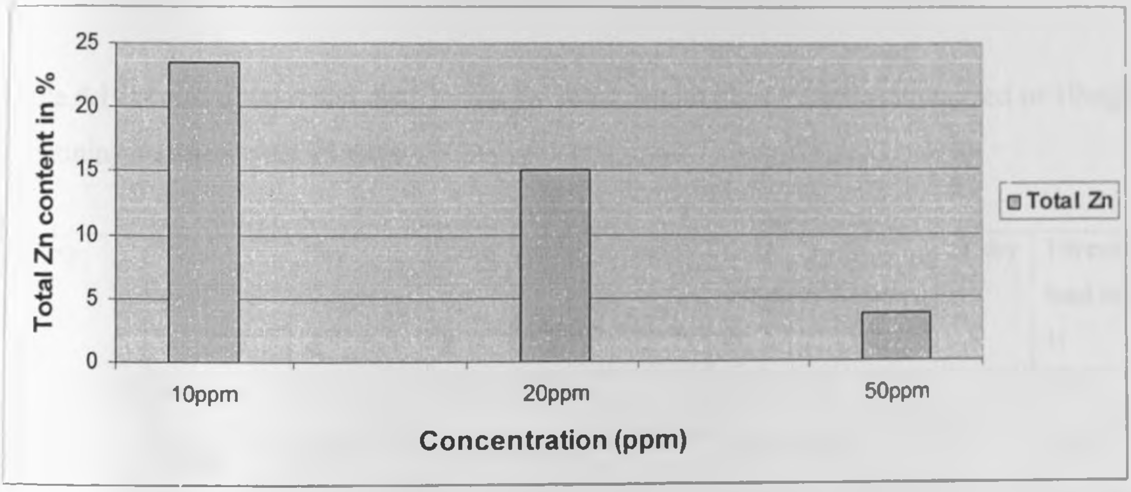

Figure 4.34: Total % Zinc content in variety UP-B immersed in varying concentrations of zinc-containing solutions.

The reduction in percentage uptake as the concentrations of zinc solutions increases could be attributed to increase of toxicity of zinc in the solutions. The plants did not tolerate higher zinc concentrations and therefore the zinc uptake was lower as the concentration of solutions increase. The toxicity of zinc in plants has been reported to be caused by interactions with other elements like phosphorus and iron. Toxicity arising from excess zinc is seen in chlorosis of leaves and produces stunted growth (Dowdy, 1975). This observation agrees with the observations made on the leaves of varieties UP-C, UP-D and UP-16 immersed in 50ppm zinc-containing solutions showing evidence of toxicity in plants. Sweet potato plant varieties however, showed tolerance in 10ppm and 20ppm zinc-containing solutions.

4.4.8 Lead uptake and distribution in the roots, stems and leaves of sweet potato plant varieties immersed in 10mg/l Pb^{2+}-containing solutions

In the 10mg/l lead-containing solution, the sweet potato plant varieties immersed accumulated lead and distributed in its roots, stems and leaves as the results in table 4.14 indicate.

Table 4.14: Lead uptake and distribution by sweet potato plant varieties immersed in 10mg/l lead-containing solution over 21 days

Variety	Plant part	Dry weight (g) A	Lead concentration(µg /g) B	Lead content (µg of dry weight in column A) C	Percentage lead content D
UP-A	Leaves	0.14	30.79 ± 18.60	4.31± 2.64	0.22
	Roots	0.02	222.50 ± 63.5	4.45 ± 1.56	0.22
	Stem	0.81	1.21 ± 1.07	0.98 ± 0.17	0.05
	Total	0.97		9.74	0.49
UP-B	Leaves	0.27	20.41 ± 2.40	5.51 ± 0.66	0.28
	Roots	0.10	15.60 ± 0.14	1.56 ± 0.01	0.08
	Stem	1.18	103.26 ± 11.50	121.85 ± 17.89	6.09
	Total	1.55		128.92	6.45
UP-C	Leaves	0.14	23.71± 5.80	3.32 ± 0.84	0.17
	Roots	0.09	15.22 ± 0.10	1.37 ± 8.92	0.07
	Stem	1.03	87.69 ± 0.01	90.32 ± 0.32	4.52
	Total	1.26		95.01	4.76
UP-D	Leaves	0.41	4.61	1.89	0.09
	Roots	0.10	15.50 ± 0.39	1.55 ± 0.04	0.08
	Stem	1.23	122.51 ± 23.50	150.69 ± 28.63	7.53
	Total	1.74		154.13	7.70

Table 4.14 (*contd...*)

Variety	Plant part	Dry weight (g) A	Lead concentration(μg /g) B	Lead content (μg of dry weight in column A) C	Percentage lead content D
UP-16	Leaves	0.20	ND	ND	0
	Roots	0.11	13.91 ± 2.04	1.53 ± 0.02	0.08
	Stem	1.36	118.10 ± 4.59	160.62 ± 60.80	8.03
	Total	1.67		162.15	8.11

KEY: ND- Not Detected

Column A (g) X column B (μg/g) = column C

Column D = <u>column C X 100</u>

2,000 μg (Total Pb in 200ml solution)

n =3 replicates

Lead content was absorbed from 10mg/l lead-containing solution and absorbed in the roots, then translocated into the stem and leaves of the sweet potato plant varieties used in the study (table 4.14). The results demonstrated that except for variety UP-A, the rest had more lead content in the stems followed by the leaves and then roots. Variety UP -A had more lead in roots than leaves. UP-B had the highest lead content in the leaves (0.28% of the lead dissolved in the initial solution) compared to the rest of the plants. However, variety UP-16 did not show any presence of lead in its leaves. Variety UP-D and UP-16 had more lead content in the stem (7.53% and 8.03% of the lead dissolved in the initial solution) respectively. Lead concentration in μg/g in the stems was highest for varieties UP-B, UP-C, UP-D and UP-16 while in UP-A was highest in the roots.

The results of total lead content in the plant varieties showed variety UP-16 accumulated more lead content than the rest of the varieties which was 8.11% of the lead dissolved in 200ml solution. Variety UP-D was closely second with 7.70% total lead from same concentration. The variety that accumulated the least lead content was UP-A with 0.49% with variety UP-B (6.45%) and variety UP-C (4.76%).

For 10ppm lead-containing solutions the order of distribution of Pb content in the plant parts was as follows:

Roots<Stems for UP-16 variety

Stems<Leaves<Roots for UP-A variety

Roots<Leaves<Stems for UP-B, UP-C and UP-D varieties.

4.4.9 Lead uptake and distribution in the roots, stems and leaves of sweet potato plant varieties immersed in 20mg/l Pb^{2+}-containing solutions

The plants showed accumulation and distribution of lead in the different tissues of the plants as illustrated in the table 4.15.

Table 4.15: Lead uptake and distribution by sweet potato plant varieties immersed in 20mg/l lead-containing solution over 21 days

Variety	Plant part	Dry weight (g) A	Lead concentration (µg /g) B	Lead content (µg) of dry weight in column A) C	Percentage lead content D
UP-A	Leaves	0.04	65.75 ± 5.83	2.63 ± 2.39	0.07
	Roots	0.01	87892.00 ± 6368.10	878.92 ± 9.06	21.97
	Stem	0.95	715.45 ± 62.12	679.67 ± 58.95	16.99
	Total	1.00		1561.22	39.03

Table 4.15 (*contd...*)

Variety	Plant part	Dry weight (g) A	Lead concentration (µg /g) B	Lead content (µg) of dry weight in column A) C	Percentage lead content D
UP-B	Leaves	0.25	2.96 ± 1.50	0.74 ± 0.36	0.02
	Roots	0.14	12516.93 ± 9857	1752.37 ± 135.83	43.81
	Stem	1.43	146.17 ± 14.50	209.02 ± 20.64	5.23
	Total	1.82		1962.13	49.06
UP-C	Leaves	0.23	8.22	1.89	0.05
	Roots	0.09	17159.30 ± 1455.9	1544.31 ± 132.05	38.61
	Stem	1.67	221.81 ± 15.70	370.42 ± 26.08	9.26
	Total	1.99		1916.62	47.92
UP-D	Leaves	0.18	5.28	0.95	0.03
	Roots	0.11	13122.06 ± 286.22	1443.42 ± 31.28	36.09
	Stem	1.54	176.46 ± 2.75	271.75 ± 4.42	6.79
	Total	1.83		1716.12	42.91
UP-16	Leaves	0.19	8.32	1.58	0.04
	Roots	0.07	16259.29 ± 675.41	1138.15 ± 45.38	28.46
	Stem	1.15	217.10 ± 5.10	249.67 ± 5.88	6.24
	Total	1.41		1389.40	34.74

KEY:

Column A (g) X column B (µg/g) = column C

Column D = column C X 100 / 4,000 µg (Total Pb in 200ml solution)

n =3 replicates

The lead concentration in μg/g in the roots was highest in all the plant varieties immersed in the 20mg/l lead-containing solutions followed by the stems and the leaves. The results of lead content in the roots were similar as it was highest in the roots for all the varieties under test. This is probably due to the growth of new roots in the plants as observed during the experimental period. The results further showed an increase in the lead content in the plant tissues immersed in the solution as compared to the plant varieties immersed in 10mg/l lead-containing solution. Variety UP-B had the highest lead absorbed in the roots (43.81% of lead dissolved in the solution). Variety UP-A on the other hand accumulated the highest content of lead in the stems (16.99%). In comparison with the content of lead in the roots and the stem, the lead content translocated to the leaves was very low. Variety UP-A had more lead translocated in the leaves than the rest of the varieties and this was 0.07% of the total lead content in the solution. This showed slow translocation rate of lead to the leaves.

The results of lead content in the plant varieties are shown in column C of table 4.15. These results showed an increase in the lead content recovered from the plants immersed in 20mg/l solution compared to the same varieties in 10mg/l lead-containing solution. Variety UP- B had the highest total lead content (49.06% of lead in 200ml solution) and was the highest accumulation of all the metals used in the study. Variety UP- 16 had the least total lead content (34.74%). The lead content was beyond 1mg recovery in all the varieties compared to any other metal under investigation. As observed in cadmium and zinc percentage accumulation, the lead accumulation percentage reduced with increase in concentration of lead-containing solutions. For 20ppm lead-containing solutions the order of distribution of Pb in the plant parts was as follows: Leaves<Stems<Roots for UP-A, UP-B, UP-C, UP-D and UP-16 varieties

4.4.10 Lead uptake and distribution in the roots, stems and leaves of sweet potato plant varieties immersed in 50mg/l Pb^{2+}-containing solutions

Table 4.16 shows the results of uptake of lead in the sweet potato varieties immersed in 50mg/l lead-containing solution.

Table 4.16: Lead uptake and distribution by sweet potato plant varieties immersed in 50mg/l lead-containing solution over 21 days

Variety	Plant part	Dry weight (g) A	Lead concentration (µg /g) B	Lead content (µg of dry weight in column A) C	Percentage lead content D
UP-A	Leaves	0.08	3.75 ± 4.32	0.30 ± 0.40	0.003
	Roots	0.01	93060 ± 1745.98	930.6 ± 22.30	9.31
	Stem	1.05	1781.37 ± 63.28	1870.44 ± 662.90	18.70
	Total	1.15		2801.34	28.01
UP-B	Leaves	0.26	53.08 ± 9.80	13.8 ± 2.6	0.14
	Roots	0.08	34082.50 ± 1109.80	2726.60 ± 90.0	27.27
	Stem	1.65	398.67 ± 92.00	657.81 ± 15.22	6.58
	Total	1.99		3398.21	33.99
UP-C	Leaves	0.13	95.38 ± 14.30	12.40 ± 1.97	0.12
	Roots	0.07	40483.90 ± 2087.80	2833.81 ± 140.90	28.34
	Stem	0.68	712.25 ± 15.55	484.33 ± 10.62	4.84
	Total	0.88		3330.54	33.30
UP-D	Leaves	0.24	7.92 ± 2.60	1.90 ± 0.61	0.02
	Roots	0.14	19794.29 ± 851.88	2771.2 ± 115.11	27.71
	Stem	1.41	299.04 ± 10.70	421.64 ± 15.00	4.22
	Total	1.79		3194.74	31.95

Table 4.16 (*contd...*)

Variety	Plant part	Dry weight (g) A	Lead concentration (μg /g) B	Lead content (μg of dry weight in column A) C	Percentage lead content D
UP-16	Leaves	0.24	2.50	0.60	0.01
	Roots	0.07	41917.14 ± 1029.00	2934.20 ± 76.77	29.34
	Stem	1.24	512.58 ± 260.23	635.50 ± 32.10	6.36
	Total	1.55		3570.3	35.70

KEY:

Column A (g) X column B (μg/g) = column C

$$\text{Column D} = \frac{\text{column C} \times 100}{10{,}000\ \mu g\ (\text{Total Pb in 200ml solution})}$$

n=3 replicates

The results of concentration in μg/g of lead in the plant tissues in 50mg/l lead-containing solutions registered highest concentrations in the roots in all the varieties. These results are similar to those obtained from the plants immersed in 20mg/l solutions. Lead content absorbed in different parts was observed with lead content in the roots being highest in all varieties except UP-A. The high accumulation of lead in the roots may be attributed to the new root growth observed in the varieties during the experimental period. However, variety UP-A did not have new roots growing therefore the low content in the roots is justified. Variety UP-A had the highest lead absorbed in the stem (18.70% of the total lead in 200ml solution). Varieties UP-B and UP-C accumulated high lead content in the leaves (0.14%) and (0.12% of lead in the solution) respectively showing the low content of lead translocated in the leaves. Lead content in the leaves were very low compared to those in the roots and stem in all the varieties. These results were similar to those of plants immersed in 10mg/l and 20mg/l lead-containing solutions. It has been demonstrated that Pb is rapidly accumulated in the roots if Pb is bioavailable in the plant growth media; however, only a small proportion of absorbed Pb is translocated to the shoots (Huang and Cunningham, 1996).

The total lead content accumulated by the varieties immersed in 50mg/l lead solution was higher than the contents recovered from the same varieties immersed in 20mg/l and 10mg/l lead solutions. The high amounts were attributed to the high accumulations in the roots of the plant. Generally, lead uptake was almost equal in all the varieties. Variety UP-16 accumulated highest total lead (35.70% of the lead amount in the 200ml solution); variety UP-B (33.99%), UP-C (33.30%), UP-D (31.95%) and the least was UP-A (28.01%) total lead. The results also indicated that the percentage content uptake in the plants was lower compared to the percentage uptake in the same varieties immersed in 20mg/l and 10mg/l lead-containing solutions. This suggested that there was excessive adsorption of lead ions on the surface of the roots inhibits further uptake and trans-location of lead ions in the plant. For 50ppm lead-containing solutions the order of distribution of Pb in the plant parts was as follows:

Leaves<Roots <Stems for UP-A variety.

Leaves<Stems<Roots for UP-B, UP-C, UP-D and UP-16 varieties.

4.4.11 Comparison of lead level in different sweet potato plant varieties immersed in different lead-containing solutions.

Significant lead uptake and translocation in corn was earlier reported by Huang and Cunningham (1996). These results compares favorably with the current work, which show that lead uptake by sweet potato plant varieties is higher compared to that of other metals used in the study.

The lead concentration and content increased with increase in concentration of lead in which the plants varieties were immersed for 21days. It was observed that the dry weight of the stems were higher than the leaves and the roots in that order. The uptake of lead was however not dependent on the dry weight of the plant tissue. Figure 4.35 shows the distribution of lead in the different parts of the variety UP-B.

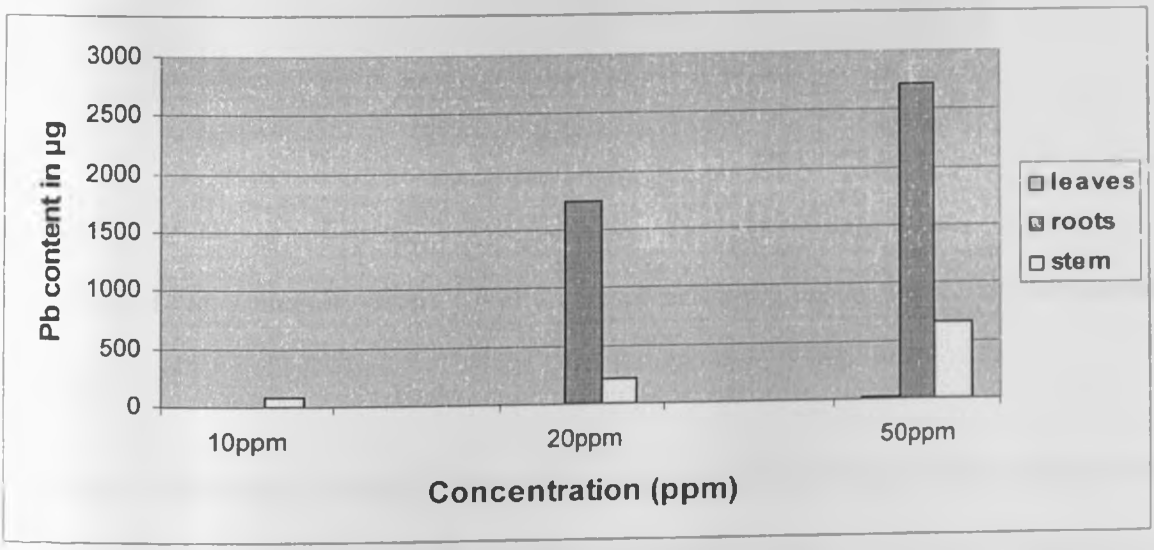

Figure 4.35: Variation in lead uptake content in variety UP-B immersed in varying concentrations of lead-containing solutions.

The results in figure 4.35 illustrates that accumulation of lead was highest in the roots than in the stem as concentration of the solutions increased. This was attributed to the vigorous growth of new roots in the lead immersed solutions for all varieties except UP-A. The total lead taken up by plant varieties immersed in 10ppm and 20ppm lead containing solutions were highest in content compared to those of other metals. Leaves accumulated least lead content.

The total lead uptake content in all the plant varieties also increased with increase in lead concentrations in which the plants were immersed. The results of variety UP-B were used to illustrate this as shown in figure 4.36.

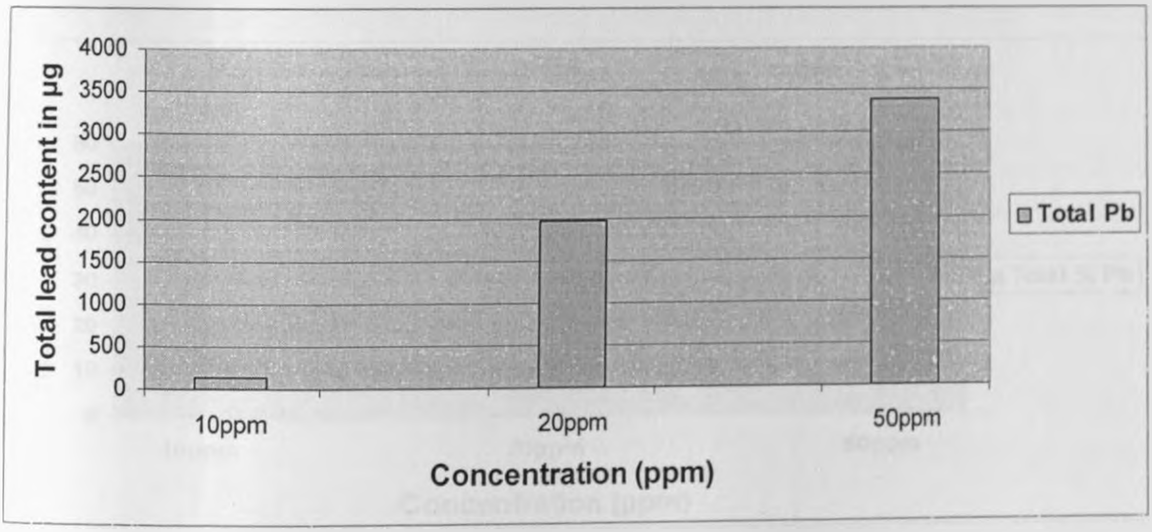

Figure 4.36: Lead content in variety UP-B immersed in varying concentrations of lead-containing solutions.

The content of lead was between 9.74 µg of dry weight for variety UP-A (0.49% of lead content in the initial solution) and 162.15µg per g of dry weights for variety UP-16 (8.11%) immersed in 10mg/l solution of lead. For plant varieties immersed in 20mg/l, the recovery results showed the range in total lead content as1389.41µg per g of dry weight for variety UP-16 (34.74%) and 1962.13µg per g of dry weight for variety UP-B (49.06%). In 50mg/l lead-containing solution, the plant varieties immersed showed total lead content ranged between 2801.34µg per g of dry weight for variety UP-A (28.01%) to 3570.30μg per g of dry weight for variety UP-16 (35.70%). Variety UP-16 accumulated highest total lead content in 10mg/l and 50mg/l lead containing solution while variety UP-B accumulated highest total lead content in 20mg/l solution.

The results of percentage accumulation of lead showed an increase in accumulation from plants immersed in 10mg/l to 20mg/l lead-containing solutions and then a decrease as the lead solution concentration increases to 50mg/l. This trend is illustrated in figure 4.37 in which the percentage accumulation of lead content is shown.

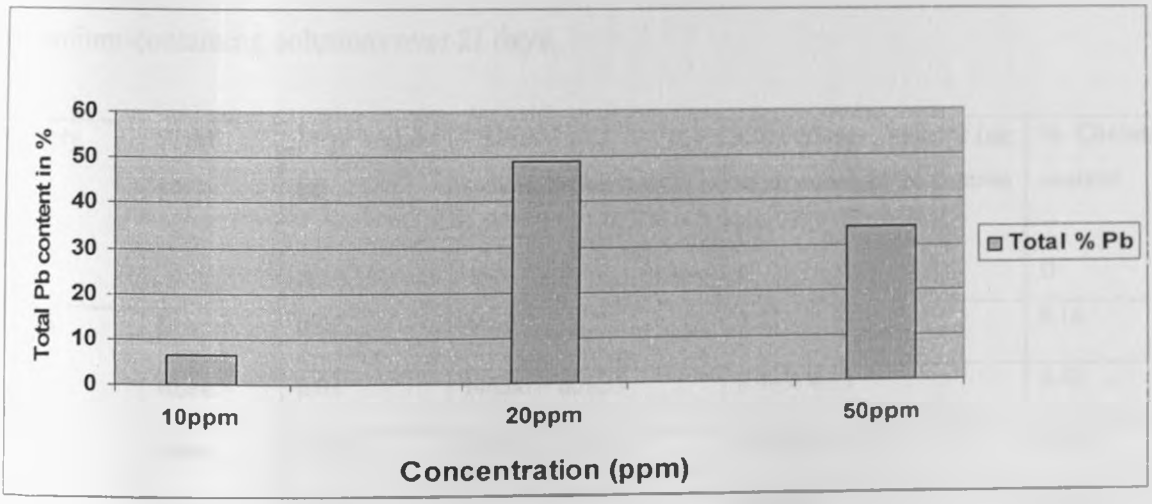

Figure 4.37: Total % lead content uptake in variety UP-B immersed in varying concentrations of lead-containing solutions.

The results indicate that lead percentage uptake for plants immersed in 20ppm and 50ppm lead solutions was higher compared to the uptake of other heavy metal of the same concentrations used in this study. The behaviour of the plant varieties immersed in 10ppm Pb^{2+}-containing solutions could not be explained. Maina (1984) reported that lead was taken up in very low concentration by cowpeas, tomatoes, sugar loaf and spinach planted in Kariobangi sewage works soils. However, results of available data indicate that lead is absorbed and translocated in sweet potato plants. A possible explanation of this behaviour is that lead uptake is increased by calcium deficiency. High calcium intake inhibits lead absorption (Goyer, 1977).

4.4.12 Chromium uptake and distribution in the roots, stems and leaves of sweet potato plant varieties immersed in 10mg/l chromium-containing solutions.

Table 4.17 shows the accumulation of total chromium in different parts of the sweet potato plant immersed in 10mg/l chromium-containing solution.

Table 4.17: Chromium uptake and distribution by sweet potato plant varieties immersed in 10mg/l chromium-containing solutions over 21 days.

Variety	Plant part	Dry weight (g) A	Chromium concentration (μg/g) B	Chromium content (μg of dry weight in column A) C	% Chromium content D
UP-A	Leaves	0.02	162.5	3.25	0.16
	Roots	0.01	946.00 ± 601.33	9.46 ± 4.33	0.47
	Stem	0.88	168.06 ± 13.33	147.89 ± 11.74	7.40
	Total	0.91		160.60	8.03
UP-B	Leaves	0.18	31.38 ± 11.20	5.65 ± 2.01	0.28
	Roots	0.08	973.00 ± 104.82	77.84 ± 8.56	3.89
	Stem	1.22	33.39 ± 4.20	40.73± 5.06	2.04
	Total	1.48		124.22	6.21
UP-C	Leaves	0.21	13.38 ± 12.20	2.81 ± 0.81	0.14
	Roots	0.09	1012.68 ± 104.30	91.08 ± 9.83	4.55
	Stem	1.39	20.85 ± 4.4	28.98 ± 6.16	1.45
	Total	1.70		122.87	6.14

Table 4.16 (*contd...*)

Variety	Plant part	Dry weight (g) A	Chromium concentration (µg/g) B	Chromium content (µg of dry weight in column A) C	% Chromium content D
UP-D	**Leaves**	0.21	60.24 ± 13.40	12.65 ± 2.81	0.63
	Roots	0.11	1041.18 ± 100.00	114.53 ± 11.28	5.73
	Stem	1.52	24.64 ± 7.70	37.46 ± 11.72	1.87
	Total	1.84		164.64	8.23
UP-16	**Leaves**	0.15	79.87 ± 21.67	11.98 ± 3.26	0.60
	Roots	0.04	901.75 ± 342.00	36.07 ± 13.95	1.80
	Stem	1.19	51.41 ± 10.32	61.18 ± 12.23	3.06
	Total	1.38		109.23	5.46

KEY:

Column A (g) X column B (µg/g) = column C

$$\text{Column D} = \frac{\text{column C} \times 100}{2{,}000\ \mu g\ \text{(Total Cr in 200ml solution)}}$$

n=3 replicates

The results on table 4.17 demonstrate that all the parts of the sweet potato plants absorbed chromium. The concentration of chromium in µg/g was highest in the roots in all the varieties used for the experiment. Varieties UP-A and UP -16 had the highest chromium content in the stems, 7.40% and 3.06% respectively followed by the roots and the leaves. The remaining varieties had the roots showing highest chromium content present. Variety UP-D had the highest total chromium content in the roots (5.73%). Leaves in variety UP-D accumulated highest chromium content (0.63% of total chromium in the initial solution) followed closely by variety UP-16 (0.60%).

Total chromium content of plant varieties immersed in 10mg/l total chromium solution showed that all the varieties absorbed chromium (table 4.17). The results further show that variety UP- D had the highest total chromium content which was 8.23% of total chromium content in the initial solution followed closely by UP- A (8.03%). Variety UP- 16 (5.46%) had least total chromium content. The chromium content in the remaining varieties was UP-B (6.21%) and UP-C (6.14%).

For 10 ppm Chromium solutions the order of distribution of Cr in the plant parts was as follows:

Leaves<Roots<Stem for UP-A and UP-16 varieties.

Leaves<Stem<Roots for UP-B, UP-C and UP-D varieties.

4.4.13 Chromium uptake and distribution in the roots, stems and leaves of sweet potato plant varieties immersed in 20mg/l chromium-containing solutions.

Results of the uptake and distribution of total chromium in the varieties as shown in table 4.18 indicate that total chromium was detected in the plants.

Table 4.18: Chromium uptake and distribution by sweet potato plant varieties immersed in 20mg/l chromium-containing solutions over 21 days.

Variety	Plant part	Dry weight (g) A	Chromium concentration (μg/g) B	Chromium content (μg of dry weight in column A) C	% Chromium content D
UP-A	Leaves	0.03	249.33 ± 117.22	7.48 ± 3.73	0.19
	Roots	0.01	4619.00 ± 1132.40	46.19 ± 16.19	1.15
	Stem	0.91	115.89 ± 26.43	105.46 ± 24.16	2.64
	Total	0.95		159.13	3.98
UP-B	Leaves	0.26	171.31 ± 49.03	44.54 ± 12.59	1.11
	Roots	0.07	1780.86 ± 185.00	124.66 ± 13.76	3.12

	Stem	2.02	30.38 ± 6.34	61.36 ± 12.72	1.53
	Total	2.35		230.56	5.76
UP-C	Leaves	0.19	97.63 ± 38.05	18.55 ± 7.16	0.46
	Roots	0.06	1522.33 ± 264.35	91.34 ± 14.60	2.28
	Stem	1.24	58.11 ± 10.46	72.06 ± 13.08	1.80
	Total	1.49		181.95	4.54
UP-D	Leaves	0.19	58.16 ± 32.11	11.05 ± 5.97	0.28
	Roots	0.08	1787.00 ± 266.45	142.96 ± 21.08	3.57
	Stem	1.29	67.25 ± 7.68	86.75 ± 9.90	2.17
	Total	1.55		240.76	6.02
UP-16	Leaves	0.20	98.44 ± 64.31	19.68 ± 12.68	0.49
	Roots	0.07	1948.43 ± 308.67	136.39 ± 22.04	3.41
	Stem	0.51	61.22 ± 22.20	31.22 ± 11.27	0.78
	Total	0.78		187.29	4.68

KEY

Column A (g) X column B (μg/g) = column C

$$\text{Column D} = \frac{\text{column C} \times 100}{4{,}000\ \mu g\ (\text{Total Cr in 200ml solution})}$$

n =3 replicates

Results from table 4.18 shows that the total chromium concentration was highest in the roots of all the varieties. Chromium content absorbed in the roots in all varieties except UP-A were highest followed by the stems and then the leaves. In the UP- A variety, more chromium content was present in the stems than in the roots and the leaves. The variety UP-A took up highest chromium content in the stem, (2.64% of the chromium in the initial solution) compared to the other plant varieties. The results obtained from variety UP-A were similar in distribution of total chromium in the plant as the results of the same variety immersed in 10mg/l total chromium-containing solution. Root density in variety UP-A is low compared to the other varieties and this may have contributed to a low accumulation in its roots. Generally, all the varieties had low total chromium content in the leaves. Variety UP-B had the highest content of total chromium in the leaves which was 1.11% of total chromium in the solution.

The total chromium content in the varieties immersed in 20mg/l solution were more than those obtained from the same varieties immersed in 10mg/l solution except for variety UP-A which gave a slight deviation. The total chromium content accumulation shows variety UP-D with the highest (6.02% of the total chromium in the initial solution). Other varieties showed the cadmium accumulation as follows; UP- B (5.76%), UP- 16 (4.68%), UP- C (4.54%) and finally UP- A (3.98%), respectively. The percentage total chromium in this concentration however, was lower than that of uptake in 10mg/l chromium-containing solution. For 20ppm chromium-containing solutions the order of distribution of Cr in the plant parts was as follows:

Leaves<Roots <Stems for UP-A variety.

Leaves<Stems<Roots for UP-B, UP-C, UP-D and UP-16 varieties.

4.4.14 Chromium uptake and distribution in the roots, stems and leaves of sweet potato plant varieties immersed in 50mg/l chromium-containing solutions.

The results on table 4.19 show the uptake of chromium in the plants.

Table 4.19: Chromium uptake and distribution by sweet potato plant varieties immersed in 50mg/l chromium-containing solutions over 14 days.

Variety	Plant part	Dry weight (g) A	Chromium concentration (μg/g) B	Chromium content (μg of dry weight in column A) C	% Chromium content D
UP-A	Leaves	0.13	774.08 ± 137.33	100.63 ± 18.38	1.01
	Roots	0.04	4136.50 ± 798.28	165.46 ± 29.14	1.65
	Stem	0.90	405.86 ± 62.78	365.27 ± 56.52	3.65
	Total	1.07		631.36	6.31
UP-B	Leaves	0.24	104.08 ± 45.11	24.98 ± 10.96	0.25
	Roots	0.13	2226.46 ± 408.30	289.44 ± 54.79	2.90
	Stem	1.85	138.48 ± 24.55	256.18 ± 45.57	2.56
	Total	2.22		570.60	5.71
UP-C	Leaves	0.21	201.95 ± 62.00	42.41 ± 13.27	0.42
	Roots	0.09	2723.67 ± 584.46	245.13 ± 54.00	2.45
	Stem	2.19	101.39 ± 19.57	222.04 ± 43.66	2.22
	Total	2.49		509.58	5.09
UP-D	Leaves	0.21	94.90 ± 51.00	19.93 ± 10.48	0.20
	Roots	0.08	2418.88 ± 493.77	193.51± 41.28	1.94
	Stem	1.03	124.31 ± 87.33	128.04 ± 89.43	1.28
	Total	1.32		341.48	3.42
UP-16	Leaves	0.17	234.53 ± 34.18	39.87 ± 5.97	0.40
	Roots	0.08	2127.88 ± 420.42	170.23 ± 31.78	1.70
	Stem	1.17	406.49 ± 62.08	475.59 ± 72.58	4.76
	Total	1.42		685.69	6.86

KEY:

Column A (g) X column B (μg/g) = column C

$$\text{Column D} = \frac{\text{column C} \times 100}{10{,}000\ \mu g\ (\text{Total Cr in 200ml solution})}$$

n=3 replicates

Chromium was recovered in the roots, stem and the leaves of all the varieties used. The amount accumulated in the plant tissues was higher than those recovered from the same varieties immersed in 20mg/l and 10mg/l chromium-containing solutions (table 4.19). Varieties UP- B (2.90% of the total chromium in the initial solution), UP-C (2.45%) and UP- D (1.94%) showed higher chromium content in the roots followed by the stems then leaves. Varieties UP- 16 (4.76%) and UP-A (3.65%) had higher chromium content in the stems followed by the roots and then the leaves. The trend of distribution of total chromium in variety UP-A in 50mg/l solution was similar to that of the same variety immersed in 20mg/l and 10mg/l total chromium-containing solution. Compared to the absorption of total chromium in the roots and the stem, the translocation to the leaves is lower probably due to slower translocation of the chromium through the plant tissues.

The total chromium content obtained from plants immersed in 50mg/l chromium-containing solutions was higher than those recovered from the plants immersed in 20mg/l and 10mg/l chromium-containing solutions over a period of three weeks exposure. This means that the accumulation of total chromium was not dependent on the time of exposure. However, variety UP-16 (6.86% of the total chromium in the initial solution) showed the highest total chromium content followed by variety UP- A (6.31%), UP-B (5.71%), UP-C (5.09%) while UP- D with (3.42%) had the least total chromium content. For 50ppm chromium solutions the order of distribution of Cr in the plant parts was as follows:

Leaves<Roots <Stems for UP-A and UP-16 varieties.

Leaves<Stems<Roots for UP-B, UP-C and UP-D varieties.

4.4.15 Comparison of chromium levels in different sweet potato plant varieties immersed in varying concentrations of chromium-containing solutions.

The chromium concentration and content increased with increase in the concentration of initial chromium solutions into which they were immersed. The mass of dry weight was higher in the stems followed by the leaves and the roots for all varieties tested. However, variety UP-A had lower root dry weight compared to the other varieties. Generally, the chromium content increased with increase in concentration of chromium-containing solutions, results similar to those obtained from other metals used in this research work. The distribution and accumulation of chromium in the plants is illustrated in figure 4.38 showing the translocation of total chromium in variety UP-C.

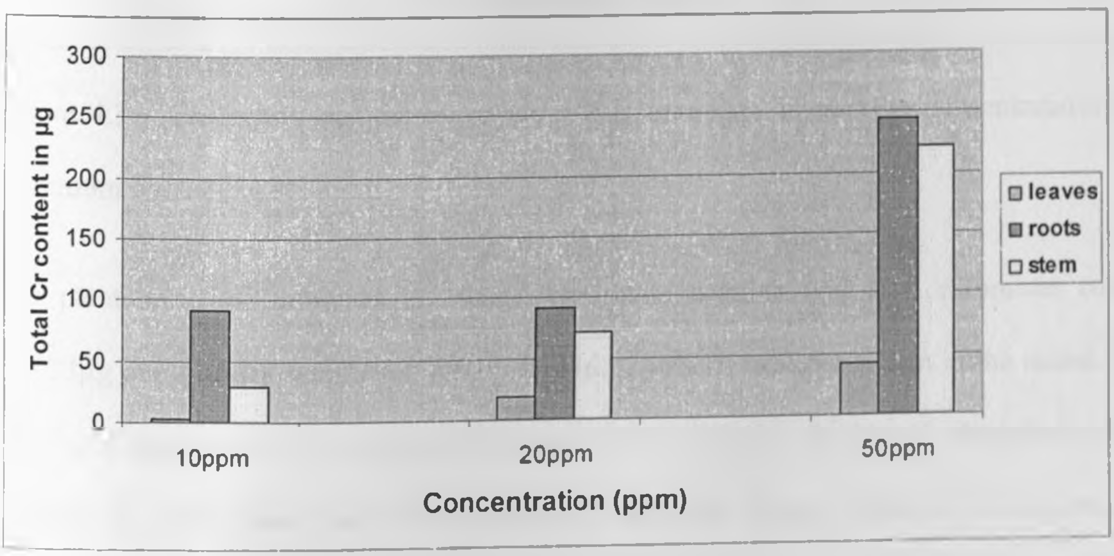

Figure 4.38: Comparison of chromium content in variety UP-C immersed in varying concentrations of chromium-containing solutions.

The roots uptake of chromium was almost equal for the variety immersed in 10mg/l and 20mg/l solutions. However, it was clear that the chromium content in the leaves and the stems increased with increase in chromium concentration in the solutions (figure 4.38). The total chromium content in plants immersed in 50mg/l solutions was higher than those immersed in the rest of the solutions despite the shorter period of exposure in the solution. This is illustrated in figure 4.39 using results from variety UP-D.

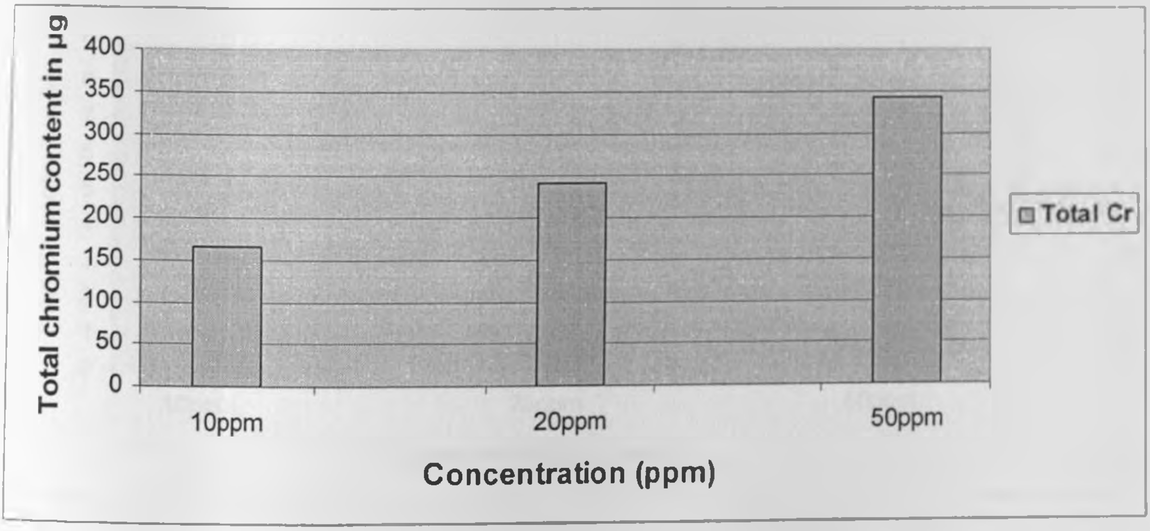

Figure 4.39: Chromium content in variety UP-D immersed in varying concentrations of total chromium-containing solutions.

The plant varieties immersed in 10mg/l chromium solution had total chromium content of 109.23µg per g of dry weight for variety UP-16 (5.46% of total chromium in the initial solution) and 164.64µg per g of dry weight for variety UP-D (8.23%). In 20mg/l chromium-containing solution the sweet potato plant varieties had total chromium content between159.13µg per g of dry weight for variety UP-A (3.98%) and 240.76µg per dry weight for variety UP-D (6.02%). The total concentration and content of chromium was even higher for the plant varieties immersed in 50mg/l solution. The total chromium content ranged between 341.48µg per g of dry weight for variety UP-

D (3.42%) and 685.69µg per g of dry weight for variety UP-16 (6.86% of total chromium content in the initial chromium solution). Similar to results obtained in percentage uptake of cadmium and zinc metals, for most varieties immersed in chromium solution, the percentage uptake of chromium in plants reduced as the concentration of chromium solutions increased. This is shown in figure 4.40 using total chromium uptake in variety UP-D compared to the initial chromium in the solutions of different concentrations.

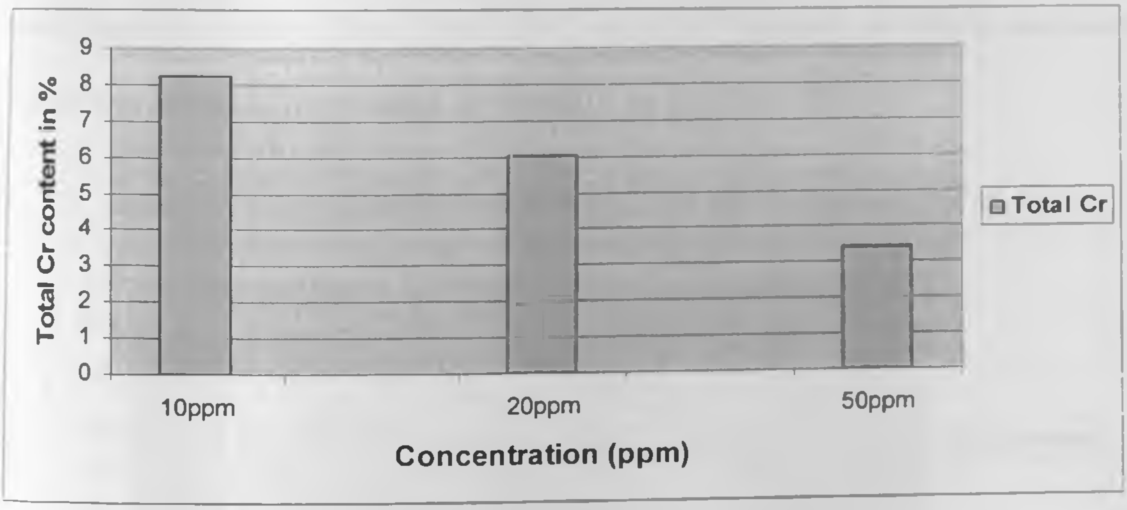

Figure 4.40: %chromium content uptake in variety UP-D immersed in varying concentrations of chromium-containing solutions.

The plant varieties immersed in 50mg/l chromium solutions gave the lowest percentage chromium content compared to the rest of the solutions (figure 4.40). This was attributed to increase of toxicity of chromium in more concentrated solutions which could have inhibited chromium uptake by the plant. Chromium has not been shown to be essential for plant growth and phytotoxicity is due to high concentration in soils has been reported (Bott and Bruggenwert, 1976).

4.5 Comparison of heavy metal ion uptake in different sweet potato plant varieties immersed in heavy metal ion-containing solutions

In this section, selected sweet potato varieties immersed in different concentrations of cadmium, zinc, lead and chromium-containing solutions are compared and the differences in their metal uptake illustrated. Results of total heavy metal uptake in different sweet potato varieties immersed in the same metal concentrations were compared. Figure 4.41 shows the comparison of total heavy metal uptake in variety UP-A, UP-B, UP-C and UP-D immersed in 10ppm metal-containing solutions of cadmium, zinc lead and chromium.

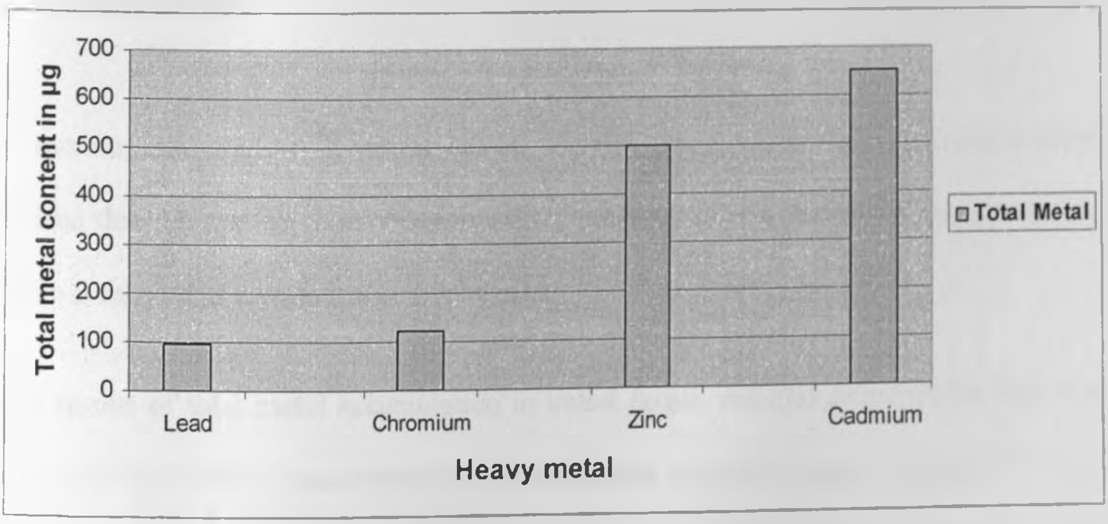

Figure 4.41: Total heavy metal uptake in variety UP-C immersed in 10ppm heavy metal-containing solutions.

Lead content accumulation in variety UP-C was least compared to the other metals followed by chromium and zinc while cadmium showed highest accumulation in the same variety immersed in 10ppm metal solutions. Similar trend was observed from variety UP-16 immersed in 10ppm solutions containing cadmium, zinc, lead and chromium as illustrated in figure 4.42.

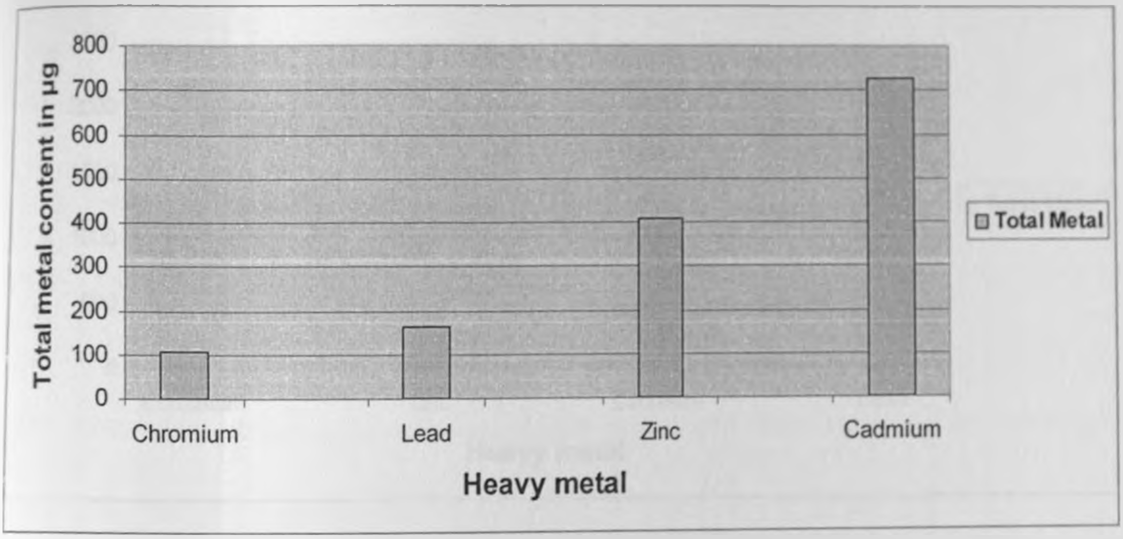

Figure 4.42: Total heavy metal uptake in variety UP-16 immersed in 10ppm heavy metal-containing solutions.

Chromium total content in variety UP-16 was the lowest, while cadmium accumulation was the highest through out the time of immersion of plant varieties in cadmium solution was two weeks while for the other metals it was three weeks.

The results of total metal accumulation in sweet potato varieties immersed in 20ppm cadmium, zinc, lead and chromium-containing solutions were compared using varieties UP-B and UP-D. Figure 4.43 shows the variation in heavy metal uptake in variety UP-B immersed in 20ppm metal solutions.

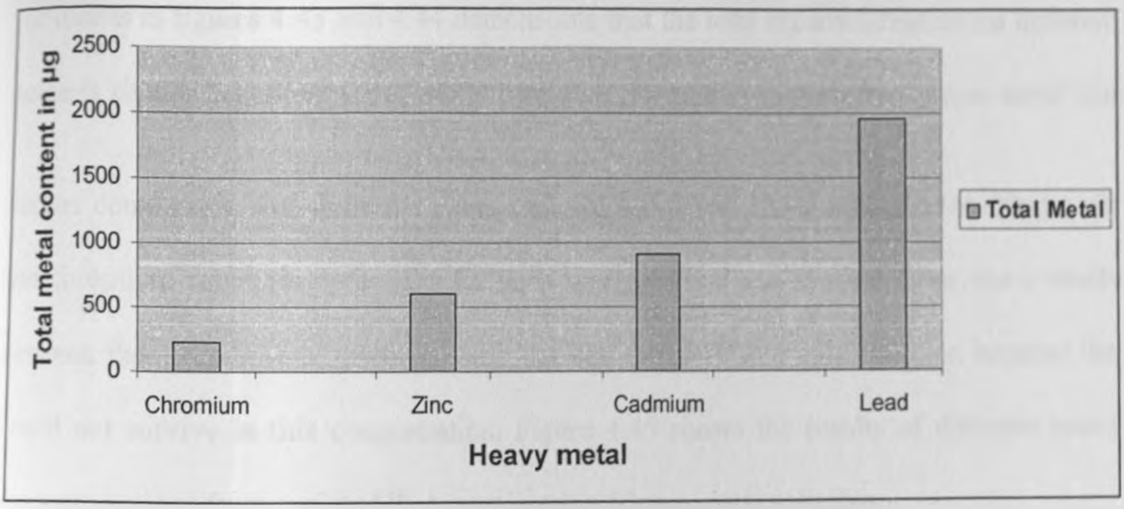

Figure 4.43: Total heavy metal uptake in variety UP-B immersed in 20ppm heavy metal-containing solutions.

In the 20ppm metal-containing solutions, lead showed highest content accumulated in variety UP-B followed by cadmium and zinc while chromium had the least content in the same variety. Similar results were obtained from variety UP-D immersed in 20ppm solutions of cadmium, zinc, lead and chromium as shown in figure 4.44.

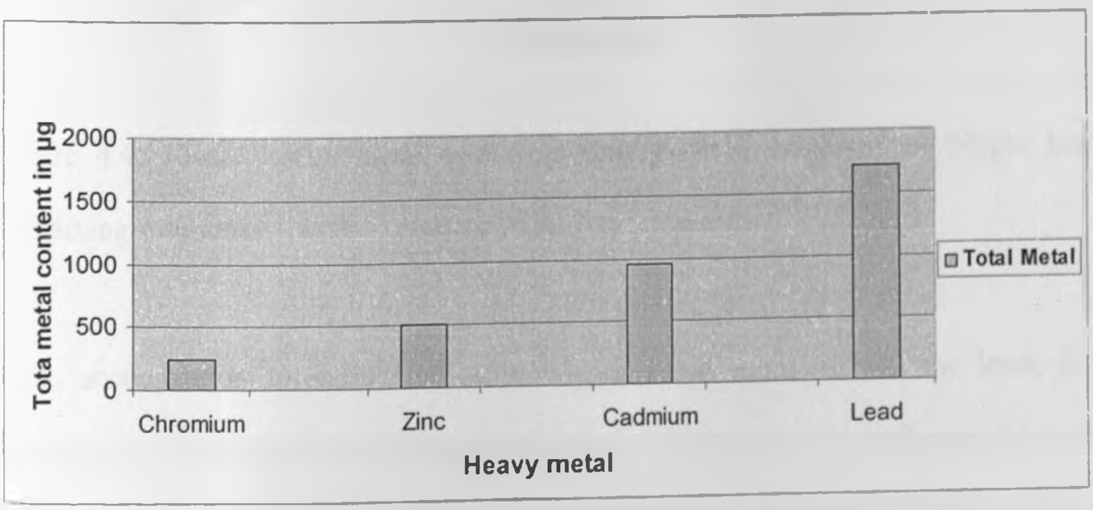

Figure 4.44: Total heavy metal uptake in variety UP-D immersed in 20ppm heavy metal-containing solutions.

The results in figures 4.43 and 4.44 demonstrate that the total accumulation of the different heavy metals is similar in content for all sweet potato plant varieties immersed in 20ppm metal solutions.

Further comparison was done for sweet varieties UP-A and UP-D immersed in 50ppm zinc, lead and chromium-containing solutions for three weeks to find out whether there was a similar trend between them. Cadmium solutions were not set up for 50ppm concentration because the plants could not survive in this concentration. Figure 4.45 shows the results of different heavy metal content obtained from variety UP-A immersed in 50ppm metal solutions.

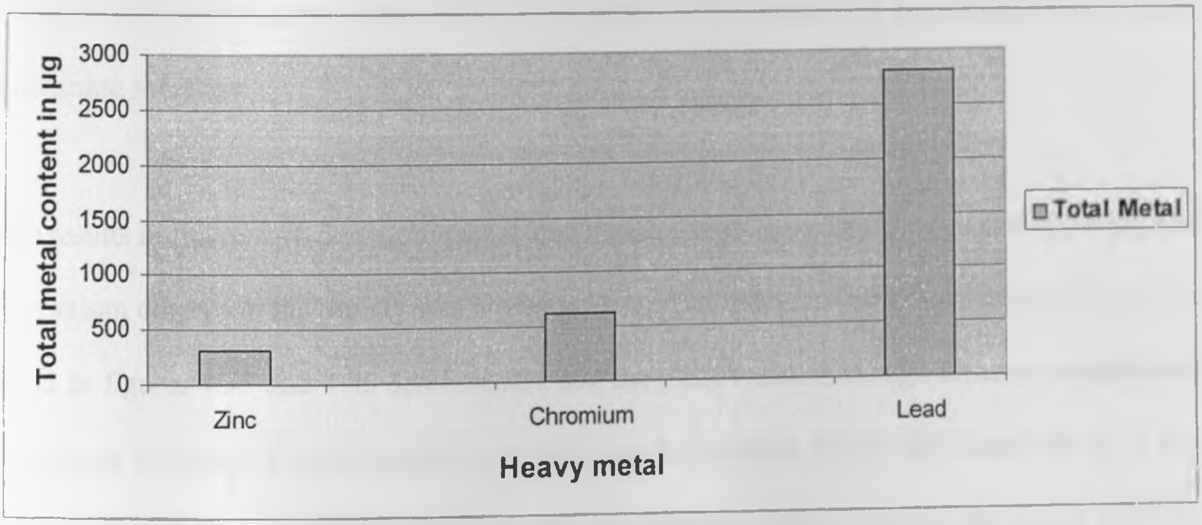

Figure 4.45: Total heavy metal uptake in variety UP-A immersed in 50ppm heavy metal-containing solutions.

Zinc accumulation in variety UP-A in 50ppm metal solutions was the least, followed by chromium, while lead showed highest total content in the variety. A similar trend was observed in variety UP-D immersed in a similarly concentrated solution as illustrated in figure 4.46.

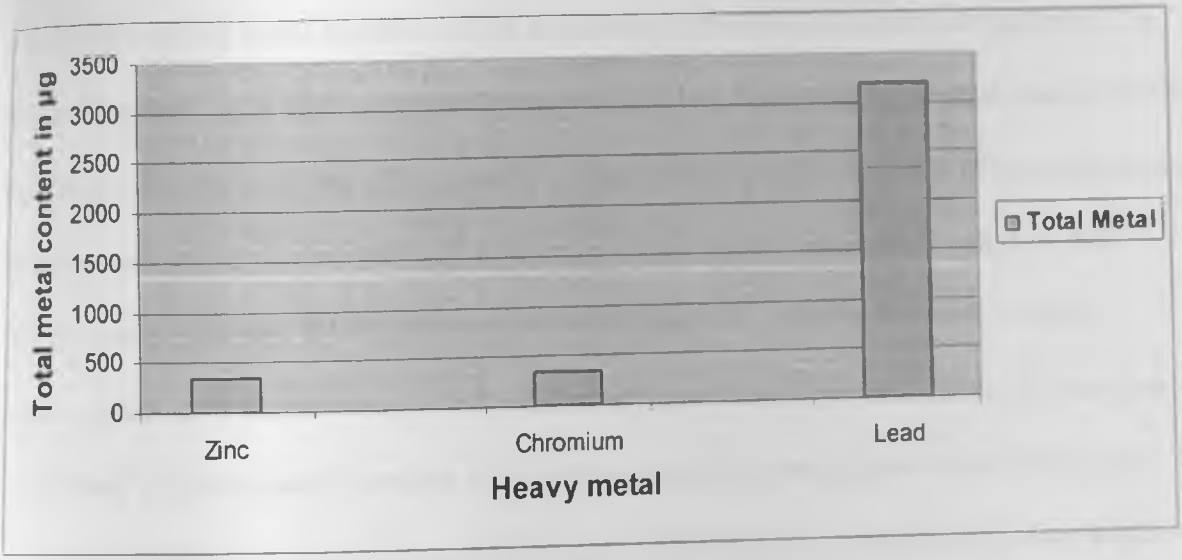

Figure 4.46: Total heavy metal uptake in variety UP-D immersed in 50ppm heavy metal-containing solutions.

The results in figure 4.46 demonstrate that lead accumulation in variety UP-D was still the highest. Chromium content in the variety was however lower than that recovered from variety UP-A. The trend in figures 4.45 and 4.46 demonstrates that the plant varieties though different accumulated the metals similarly. The above trend was also true for varieties UP-B, UP-C and UP-16. It was also noted that in case of chromium and zinc the amount of each found in the leaves of sweet potato plant varieties was a bit higher that those obtained in case of lead and cadmium. This similarity in the behavior of Cr and Zn can be attributed to their positions (first row of transition elements) in the periodic table.

4.6. Chemistry of the heavy metals absorbed by the sweet potato plant varieties

The chemistry of zinc and cadmium is very similar. The two elements are in the same group of transition elements and can readily form complexes. Since there is no ligand field stabilization effect in Zn^{2+} and Cd^{2+} ions because of their completed d shells, their stereochemistry is determined solely by considerations of size, electrostatic forces and covalent bonding forces. The effect of size is to make Cd^{2+} ions more likely than Zn^{2+} ions to assume coordination number of six explaining why cadmium was taken up more readily than zinc. Most chromium (III) complexes on the other hand are hexa coordinates. Their principal characteristic in aqueous solutions is their relative kinetic inertness. It is largely because of this kinetic inertness that so many complex species persist for relatively long periods in solution (Cotton and Wilkinson, 1978). This may have contributed to high residue chromium in the residue solutions as well as low uptake in the plant varieties compared to the rest of the metals under test. Lead (II) ion is hydrolyzed in water and at higher degrees of hydrolysis and at high concentrations it is polymerized and becomes more tightly bound as the pH rises (Bartlett, 1976; Cotton and Wilkinson, 1978).

4.7. Results of concentration of cadmium, zinc, lead and chromium residue in the residue solution volume after harvesting sweet potato varieties from heavy metal containing solutions.

In this section, the results of mean volume of residue solutions obtained after harvesting the sweet potato plants are discussed. The residue volume concentrations were calculated in μg/ml. Generally, the residue volume of solutions in which the plants were exposed depended on the temperature of the environment where the experiment was carried out, the root density of the plants, the surface area of the plant leaves and the period of exposure of the plant varieties in the solution.

4.7.1. Residue concentration and volume of cadmium in varying concentrations of Cd^{2+}-containing solutions.

The results of concentration and volume of residue solutions of 10 mg/l Cd^{2+}-containing solutions after harvesting the sweet potato plant varieties immersed in them are shown in table 4.20.

Table 4.20: Concentration and volume of 10mg/l Cd^{2+}-containing residue solution after 14days

Variety in solution	Volume of residue solution (ml)	Volume of residue solution (%)	Concentration of Cd^{2+}-containing solution (µg/ml)	Concentration of Cd^{2+}-containing solution (%)
Control	150.00 ± 2.00	75.00	187.21 ± 2.45	9.36
UP-A	145.00	72.50	43.52 ± 7.56	2.18
UP-B	136.00 ± 1.73	68.00	47.17 ± 2.58	2.36
UP-C	137.67 ± 2.52	68.33	39.38 ± 3.10	1.97
UP-D	144.33 ± 4.04	72.17	47.38± 0.69	2.37
UP-16	143.33 ± 2.89	71.67	23.01± 5.67	1.15

The residue volume of 10ppm Cd^{2+}-containing solution in which variety UP-A was immersed was highest with variety UP- B immersed solution showing the least volume of residue. The solution in which variety UP-D was immersed had the highest concentration per volume of residue while solution containing variety UP- 16 had the least concentration per residue volume.

The results of concentration and volume of residue solutions of control and 20mg/l Cd^{2+}-containing solution after harvesting the sweet potato plant varieties immersed in them are shown in table 4.21.

Table 4.21: Concentration and volume of 20 mg/l Cd^{2+}-containing residue solution after 14days

Variety in solution	Volume of residue solution (ml)	Volume of residue solution (%)	Concentration of Cd^{2+}-containing solution (μg/ml)	Concentration of Cd^{2+}-containing solution (%)
Control	151.67 ± 2.89	75.84	422.38 ± 84.03	10.56
UP-A	142.00 ± 1.73	71.00	39.23 ± 26.39	0.98
UP-B	145.33 ± 9.29	72.67	21.92 ± 6.49	0.55
UP-C	137.67 ± 2.52	68.84	37.92 ± 4.08	0.95
UP-D	142.00 ± 5.29	71.00	8.54± 4.95	0.21
UP-16	144.00 ± 6.08	72.00	32.46 ± 7.82	0.81

The Cd^{2+}-containing solution with immersed variety UP-B showed least evapo -transpiration rate as it showed the highest residual volume. However, more cadmium remained in variety UP-A immersed solution while the solution containing variety UP- D showed least cadmium residue. Comparing the residue solutions in 10mg/l and 20mg/l Cd^{2+}-containing solution after plant exposure for two weeks the volume of residue solution ranged from 136.00ml -145.00ml with the range residue concentration in 10mg/l cadmium solution 23.00μg/ml-47.38μg/ml of residue. The concentration of residue solution in 20mg/l Cd^{2+}-containing solution however decreased with a range of 8.54μg in 142.00ml to 39.23μg in 142.00ml of Cd^{2+}-containing solution

4.7.2. Residue concentration and volume of zinc in varying concentrations of Zn^{2+}-containing solutions.

The results of concentration and volume of residue solutions of 10mg/l Zn^{2+}-containing solution after harvesting the sweet potato plant varieties immersed in them are shown in table 4.22.

Table 4.22: Concentration and volume of 10 mg/l Zn^{2+}-containing solution after 21days

Variety in solution	Volume of residue solution (ml)	Volume of residue solution (%)	Concentration of Zn^{2+}-containing solution (µg/ml)	Concentration of Zn^{2+}-containing solution (%)
Control	148.33 ± 2.89	74.17	617.99 ± 24.49	30.90
UP-A	118.67 ± 18.88	59.34	163.31 ± 27.76	8.17
UP-B	111.67 ± 2.89	55.84	25.19 ± 3.33	1.26
UP-C	126.67 ± 2.89	63.34	34.31 ± 8.41	1.72
UP-D	130.00 ± 7.00	65.00	70.12 ± 16.36	3.51
UP-16	130.00 ± 5.00	65.00	57.44 ± 9.03	2.87

Higher concentration of zinc residue per volume of residue solution was recovered in variety UP-A immersed Zn^{2+}-containing solution and the least concentration in UP- B variety immersed residue solution. The results of concentration and volume of residue solutions of 20mg/l Zn^{2+}-containing solution after harvesting the sweet potato plant varieties immersed in them are shown in table 4.23.

Table 4.23: Concentration and volume of 20 mg/l Zn^{2+}-containing residue solution after 21days

Variety in solution	Volume of residue solution (ml)	Volume of residue solution (%)	Concentration of Zn^{2+}-containing solution (µg/ml)	Concentration of Zn^{2+}-containing solution (%)
Control	147.67 ± 2.52	73.84	947.96±13.23	23.70
UP-A	139.33 ± 1.15	69.67	667.22 ±103.66	16.68
UP-B	130.33 ± 2.52	65.17	218.21 ± 23.90	5.46
UP-C	137.00 ± 3.61	68.50	128.49 ± 26.07	3.21
UP-D	136.67 ± 2.89	68.34	444.36 ± 49.20	11.11
UP-16	137.67 ± 4.62	68.84	246.79± 54.61	6.17

In 20mg/l Zn^{2+}-containing solution in which five varieties were immersed, the solution containing UP-A variety had higher residue level of zinc in 139.33ml of solution that remained while 137.00 ml Zn^{2+}-containing solution containing variety UP-C had least zinc.

The results of concentration and volume of residue solutions of 50mg/l Zn^{2+}-containing solution after harvesting the sweet potato plant varieties immersed in them are shown in table 4.24.

Table 4.24: Concentration and volume of 50 mg/l Zn^{2+}-containing residue solution after 21days

Variety in solution	Volume of residue solution (ml)	Volume of residue solution (%)	Concentration of Zn^{2+}-containing solution (µg/ml)	Concentration of Zn^{2+}-containing solution (%)
Control	124.00 ± 8.72	62.00	1201.49 ±77.09	12.04
UP-A	122.00 ± 2.00	61.00	1018.07 ±156.91	10.18
UP-B	109.00 ± 15.52	54.50	126.26 ± 34.25	1.26
UP-C	107.00 ± 12.71	53.50	808.87 ± 50.03	8.09
UP-D	111.67 ± 3.51	55.84	737.17± 51.43	7.37
UP-16	108.67 ± 8.08	54.34	860.01 ± 109.67	8.60

Similar results as those obtained in 20mg/l Zn^{2+}-containing residue solution with immersed variety UP-A, showed the solution containing variety UP-A with the highest zinc residue in 122.00ml solution. However, variety UP-B immersed solution had the least zinc residue concentration in 109.00ml solution. Generally, the residue volumes of 50mg/l concentration are lower than those of 20mg/l and 10mg /l Zn^{2+}-containing solution Comparing the results of the Zn^{2+}-containing residue solution volume and their concentrations, it can be concluded that the concentration of zinc in residual solution that remained after plants were removed increased with increase in initial concentration. There was higher volume of zinc residue solution in variety UP-A in all concentrations probably because of its small root biomass compared to the other varieties.

4.7.3. Residue concentration and volume of lead in varying concentrations of Pb^{2+}-containing solutions.

The results of concentration and volume of residue solutions of 20mg/l Pb^{2+}-containing solution after harvesting the sweet potato plant varieties immersed in them are shown in table 4.25.

Table 4.25: Concentration and volume of 20 mg/l Pb^{2+}-containing residue solution after 21days

Variety in solution	Volume of residue solution (ml)	Volume of residue solution (%)	Concentration of Pb^{2+}-containing residue solution (μg/ml)	Concentration of Pb^{2+}-containing solution (%)
Control	94.67 ± 4.16	47.34	932.29±115.28	23.31
UP-A	106.00 ± 20.07	53.00	161.03± 51.32	4.03
UP-B	68.67 ± 29.01	34.34	311.05±132.24	7.78
UP-C	83.67 ± 16.01	41.34	268.33 ±110.94	6.71
UP-D	87.33 ± 26.10	43.67	133.85± 53.45	3.35
UP-16	90.00 ± 48.22	45.00	64.97± 18.83	1.62

Generally there was low Pb^{2+}-containing residue solution volumes compared to the initial volume of 200ml. In the control experiment no plant varieties were immersed to the solution and this justifies the high lead concentration residue. Pb^{2+}-containing residue solution containing variety UP-B had the lowest volume of lead residue but the highest residue concentration. Solution containing immersed variety UP-A had the highest volume of residue solution while Pb^{2+}-containing residue solution with UP-16 had the least lead concentration per residue volume.

The results of concentration and volume of residue solutions of 50mg/l Pb^{2+}-containing solution after harvesting the sweet potato plant varieties immersed in them are shown in table 4.26.

Table 4.26: Concentration and volume of 50 mg/l Pb^{2+}-containing residue solution after 21days

Variety in solution	Volume of residue solution (ml)	Volume of residue solution (%)	Concentration of Pb^{2+}-containing residue solution (µg/ml)	Concentration of Pb^{2+}-containing solution (%)
Control	132.00 ± 2.00	66.00	5506.98 ±183.21	55.07
UP-A	115.33 ± 1.15	57.67	235.22 ± 67.80	2.35
UP-B	96.00 ± 20.00	48.00	196.48 ± 72.32	1.96
UP-C	101.33 ± 12.86	50.67	367.13 ± 44.57	3.67
UP-D	87.33 ± 13.32	43.67	395.67 ± 79.96	3.96
UP-16	87.33 ± 30.55	43.67	72.16 ± 16.72	0.72

Pb^{2+}-containing residue solution volumes in which varieties UP-D and UP-16 were immersed were equal and the least. The solution containing variety UP-16 also showed least residue of lead concentration with variety UP-D immersed solution showing highest lead residue concentration per residue volume. The results obtained from UP-16 variety containing residue solution were similar for that of 20mg/l Pb^{2+}-containing residue solution in that the concentration was the least.

The volume of residue solution in 20mg/l and 50mg/l Pb^{2+}-containing residue solution did not show significant differences. However concentration of lead residue in the 50mg/l solution was higher than that of 20mg/l Pb^{2+}-containing residue solution in which plant varieties were immersed. This was expected given that the percentage of lead absorbed by the plants reduced with increase in concentration of Pb^{2+}-containing solution in which they were immersed (page 139).

4.7.4. Residue concentration and volume of chromium in varying concentrations of Cr-containing residue solutions.

The results of concentration and volume of residue solutions of 10mg/l Cr-containing solution after harvesting the sweet potato plant varieties immersed in them are shown in table 4.27.

Table 4.27: Concentration and volume of 10mg/l Cr-containing residue solutions after 21days

Variety in solution	Volume of residue solution (ml)	Volume of residue solution (%)	Concentration of Cr-containing residue solution (µg/ml)	Concentration of Cr-containing solution (%)
Control	138.67 ± 2.31	69.34	1433.71 ± 33.00	71.69
UP-A	132.67 ± 2.31	66.34	1304.76 ± 104.91	65.24
UP-B	112.00 ± 3.46	56.00	1315.44 ± 49.60	65.77
UP-C	109.33 ± 1.15	54.67	1381.56 ± 74.62	69.08
UP-D	108.00 ± 10.09	54.00	1326.12 ± 71.33	66.31
UP-16	109.67 ± 0.58	54.84	1351.50 ± 51.70	67.58

The concentration of residue chromium in the solutions was generally higher than in other metals .In all varieties of sweet potato immersed in 10mg/l Cr-containing solutions, the levels of concentration of residue was almost equal. However more volume of solution containing UP-A variety was observed to be higher than in the rest of the set-ups. The results of concentration and volume of residue solutions of 20mg/l Cr-containing solution after harvesting the sweet potato plant varieties immersed in them are shown in table 4.28.

Table 4.28: Concentration and volume of 20mg/l Cr-containing residue solutions after 21days

Variety in solution	Volume of residue solution (ml)	Volume of residue solution (%)	Concentration of Cr-containing residue solution (µg/ml)	Concentration of Cr-containing solution (%)
Control	135.00 ± 8.19	67.50	2726.66 ± 111.99	68.17
UP-A	136.67 ± 1.15	68.34	2608.87 ± 30.90	65.22
UP-B	112.33 ± 2.89	56.17	2317.11 ± 30.33	57.93
UP-C	114.33 ± 0.58	57.17	2380.92 ± 32.96	59.52
UP-D	121.33 ± 9.87	60.67	2312.42± 57.91	57.81
UP-16	112.00 ± 4.00	56.00	2141.66 ± 155.53	53.54

Higher residue volumes were observed in 20mg/l Cr-containing residue solutions containing the varieties than it was in 10mg/l Cr-containing residue solutions.

The results of concentration and volume of residue solutions of 50mg/l Cr-containing solution after harvesting the sweet potato plant varieties immersed in them are shown in table 4.29.

Table 4.29: Concentration and volume of 50mg/l Cr-containing residue solutions after 14days

Variety in solution	Volume of residue solution (ml)	Volume of residue solution (%)	Concentration of Cr-containing solution (µg/ml)	Concentration of Cr-containing solution (%)
Control	140.33 ± 8.50	70.17	5493.88 ± 251.62	54.94
UP-A	137.33 ± 11.02	68.67	4671.72 ± 426.53	46.72
UP-B	133.67 ± 2.31	66.84	4331.85 ± 334.30	43.32
UP-C	134.00 ± 2.65	67.00	4559.26 ± 145.77	45.59
UP-D	137.33 ± 3.06	68.67	4599.81 ± 96.80	46.00
UP-16	133.33 ± 3.06	66.67	4488.67 ± 240.15	44.89

Similar results to those obtained from 20mg/l and 10mg/l Cr-containing residue solutions. The volumes of residue chromium solutions were higher in 50mg/l than in 20mg/l and 10mg/l Cr-containing residue solutions respectively.

Comparing the residue concentrations in different concentrations in Cr-containing residue solutions, it can be observed that the concentration of chromium in residue volume of solution increased with increase in concentration of initial solutions in which the plant varieties were immersed. The volume of residual solution also increased with increase in concentration of initial solutions. It was observed that chromium concentration in the chromium-containing residue solutions after plant varieties were immersed were highest compared to that of cadmium, lead and zinc. The concentration of chromium residue in the solutions is justified. This is because compared to the other metals used in this study; chromium was least absorbed and translocated by the sweet potato plant varieties (pages 151 and 152).

4.8 Contamination levels of some heavy metals in soil, water and plant samples collected from the field.

Soil, water and plant sampling was done randomly and the samples digested for analysis of heavy metals. The results of heavy metal presence in the samples have been described and discussed in the subsequent sections.

4.8.1. Soil samples

Table 4.30 shows the results obtained from the analysis of soils and sediment samples from field sampling.

Table 4.30: Heavy metal concentration in μg/g obtained from field soil samples.

Site description	Cadmium (μg/g of dry weight)	Zinc (μg/g of dry weight)	Lead (μg/g of dry weight)	Chromium (μg/g of dry weight)
KARI Kakamega (Top soil)	ND	53.02 ± 1.33	ND	74.50 ± 8.09
KARI Kakamega (soil 30 cm deep)	ND	41.67 ± 12.37	ND	49.97 ± 29.07
Yala swamp (Top soil)	ND	60.69 ± 6.57	ND	14.17 ± 8.42
Yala swamp (soil 30 cm deep)	ND	60.79 ± 2.53	ND	23.01 ± 5.69
River Nzoia sediment	ND	15.25 ± 5.96	ND	ND
Lake Victoria sediment	ND	44.89 ± 22.19	ND	ND
River Yala sediment	ND	42.26 ± 22.33	ND	ND
River Nyando sediment	ND	69.62 ± 0.70	ND	ND

KEY: ND – Not Detected

Cadmium and lead were not detected from the soil samples obtained from the field. Samples of soil obtained from the sites showed presence of zinc and total chromium with varying concentrations. The presence of chromium and zinc in the soil samples explains why sweet potato plants harvested from the sites accumulated the metals.

Table 4.31 shows the results obtained after the analysis of soil samples obtained from the Chiromo gardens.

Table 4.31: Heavy metal concentration obtained from Chiromo garden soil samples.

Site description	Cadmium (µg/g of dry weight)	Zinc (µg/g of dry weight)	Lead (µg/g of dry weight)	Chromium (µg/g of dry weight)
UP-A garden	ND	126.48 ± 65.86	ND	ND
UP-B garden	ND	115.92 ± 11.79	ND	ND
UP-C garden	ND	113.46 ± 19.87	ND	ND
UP-D garden	ND	92.62 ± 6.02	ND	ND
UP-16 garden	ND	153.13 ± 18.96	ND	ND

KEY: ND–Not Detected

The results of soil analysis for the metals from the same site where the sweet potato varieties was obtained did not show any traces of cadmium, lead and chromium. Only zinc was detected from soil samples analyzed from the University of Nairobi gardens.

4.8.2. Plant samples

The plant samples obtained from KARI Kakamega was SPK 013 while the variety obtained from Yala swamp was Mugande.

Table 4.32: Heavy metal uptake and distribution in sweet potato plant SPK 013 variety, obtained from KARI, Kakamega.

Heavy metal	Plant parts	Dry weight in g A	Metal concentration (μg/g of dry weight) B	Metal content (μg of dry weight in column A) C
Cadmium	**Leaves**	0.86	ND	ND
	Stem	2.15	ND	ND
	Tuber	3.13	ND	ND
Zinc	**Leaves**	0.86	17.21 ± 3.69	14.80 ± 2.04
	Stem	2.15	13.37 ± 2.51	28.75 ± 7.79
	Tuber	3.13	5.42 ± 4.49	16.96 ± 12.80
Lead	**Leaves**	0.86	ND	ND
	Stem	2.15	ND	ND
	Tuber	3.13	ND	ND
Chromium	**Leaves**	0.86	22.33 ± 14.70	19.20 ± 12.69
	Stem	2.15	6.36 ± 2.58	13.67 ± 2.73
	Tuber	3.13	4.95 ± 1.58	15.49 ± 4.34

KEY: ND – Not Detected

Column A (g) X column B (μg/g) = column C

Results from the variety SPK 013 from Kakamega demonstrated that zinc and total chromium were taken by the plant variety. However, cadmium and lead were not detected from the samples. Zinc content was accumulated more in the stems, then the tubers and the leaves. It was noted that the metals accumulated in the tubers of the sweet potato plants. Chromium content on the other hand was distributed in the plant tissues and was found to be more in the leaves than in the tubers and the stems. It was also observed that chromium was almost equally distributed in the plant variety.

Table 4.33: Heavy metal uptake and distribution from sweet potato plant Mugande variety, obtained from Yala swamp.

Heavy metal	Plant parts	Dry weight in g A	Metal concentration (µg/g of dry weight) B	Metal content (µg of dry weight in column A) C
Cadmium	Leaves	0.95	ND	ND
	Stem	1.90	ND	ND
	Tuber	3.10	ND	ND
Zinc	Leaves	0.95	16.97 ± 5.81	16.12 ± 8.51
	Stem	1.90	42.16 ± 8.73	80.10 ± 5.43
	Tuber	3.10	5.92 ± 1.58	18.35 ± 5.52
Lead	Leaves	0.95	ND	ND
	Stem	1.90	ND	ND
	Tuber	3.10	ND	ND
Chromium	Leaves	0.95	1.78 ± 1.55	1.69 ± 0.08
	Stem	1.90	8.54 ± 7.90	16.23 ± 12.72
	Tuber	3.10	8.27 ± 6.11	25.64 ± 19.87

KEY: ND – Not Detected

Column A (g) X column B (µg/g) = column C

The Mugande variety from Yala swamp showed uptake of zinc and chromium in all plant parts but no detection of lead and cadmium was observed from this variety. The results were similar to those obtained from SPK 013 variety. Zinc content was highest in the stem tissue of Mugande variety. The tubers in the same variety accumulated the highest chromium content compared to the leaves and the stem.

4.8.3. Water samples

Acid digested water samples collected from River Nzoia, River Yala, River Nyando and Lake Victoria were analysed for cadmium, zinc, lead and chromium. Results obtained demonstrated that the water samples from all the sites did not show presence of cadmium, zinc and chromium. However, water samples from River Nzoia showed traces of lead. The mean lead concentration in the samples was 0.2815mg/l. This was above the recommended WHO levels of 0.01mg/l. the lead may have been as a result of contamination of water from a sugar factory not far from the sampling site. The water samples from other sites did not show any lead.

CHAPTER FIVE

5.1 CONCLUSIONS

5.1.1 Heavy metal uptake

The results demonstrated that the sweet potato plant varieties used for this work absorbed and translocated significant amounts of cadmium, zinc, lead and chromium in their roots stems and leaves. The heavy metal content absorbed by the sweet potato plant variety depended on the initial concentration of the metal, originally present in the heavy metal-containing solutions.

Three main steps involved in uptake can be regarded as involving adsorption on the surface of roots and the part of the stem immersed in the solution, absorption by the roots and eventual trans-location into the stems and the leaves. This suggestion is supported by the fact that increased metal solutions concentration resulted into an increase in metal content taken up in different plant variety tissues. In most of the plant varieties immersed in different concentrations of metal-containing solutions, the leaves had the least amount of metal ions. The highest contents of metal ions were recorded in either the roots or the stems. Only in the case of varieties UP-B, UP-C and UP-D at 10ppm lead-containing solution where the leaves had more lead content than the stem. Considering the different distribution of the metal content in different parts of the plant, it is clear that metal contents in solutions are absorbed and translocated in different parts of the plants.

For the five varieties considered, lead exhibited the highest accumulation in roots, stem and leaves. In most of these varieties, highest accumulation of the heavy metals was recovered in the roots followed by the stems and then the leaves. The high accumulation of lead in the roots was possibly due to growth of new roots in the sweet potato varieties immersed in the lead-containing solutions.

The metal uptake was however neither dependent on the pH and the temperature of the metal-containing solution nor the dry weight of the plant parts.

In the current r esearch work, it was observed that for all the plants immersed in the metal solutions, the percentage uptake of metals in the plants decreased with increase in the initial concentration in which the plant varieties were immersed. A possible explanation for this observation is that as the amount of the metal ions in the solutions increased, the toxicity increases, implying that there might be inhibition of further heavy metal uptake.

5.1.2 Electrical conductivity, pH and temperature of metal solutions

This research work demonstrated ability to use electrochemical method to monitor the growth of the sweet potato plant varieties grown in metal-containing solutions without the nutrients. The electrical conductivity remained nearly constant for the control experiments metal solutions without the plant varieties over the experimental period of 14-21 days. However, immersion of sweet potato plant varieties into the heavy metal-containing solutions led to pronounced increase in electrical conductivity. This could be attributed to perturbation of solution as a result of growth of new and existing roots as well as increased ions mobility in the metal containing solutions. The uptake and translocation of the metal ions is envisaged to decrease the conductivity, but this is outweighed by the enhanced solubility of the metal salt. Solutions containing lead ions exhibited decrease in conductivity of the tenth day, suggesting high uptake in metal ions by the improved growth rate of the sweet potato plant roots. These results showed probable relationship between decrease in electrical conductivity of lead- containing solutions with the high levels of lead recovered from the plants. It was observed that the extent of increase in conductivity with time depended on the type of variety being studied. The pronounced growth of large network of roots possibly enhanced solubility of the metal salts, thereby producing increased amount of ions, which were responsible for the increased conductivity. Generally, the electrical conductivity of cadmium-containing solutions containing sweet potato plants was higher compared to those of lead, zinc and chromium-containing solutions.

The pH of all the solutions ranged between 4.50 and 7.50 which implied that the heavy metal-containing solutions were initially weakly acidic before immersing the sweet potato plant varieties. This was attributed to hydrolysis of the metal ions in solutions in their aqueous form. This however changed on immersing the plant varieties in the solutions which turned neutral. The absorption into the plant varieties and adsorption of hydronium ion at the surface of the roots may have reduced the acidity of solution. The temperatures of the solutions were not regulated and were similar to those in the green house in which the experiments were carried out and immersion of sweet potato plant varieties did not change in temperature.

5.1.3 Tolerance

The sweet potato varieties used for this work were able to tolerate zinc and lead throughout the exposure period of 21 days. Plants immersed in the lead-containing solutions showed vigorous growth of new roots more than in any other metal-containing solution, a probable reason why the uptake of this metal was higher than the rest. The plants immersed in the cadmium-containing solutions dried within ten days and were therefore harvested by the end of two weeks. Plants in total chromium solution survived for 21 days in 10ppm and 20ppm chromium-containing solutions. However, for 50ppm solution containing chromium, the plants dried after one week and harvesting was therefore done after two weeks. It was however not possible to monitor the exact period when the plant growth stopped as well as the time when the plants begun the actual uptake of the heavy metals. The conclusions were therefore made out of physical observations of the plant during the experimental period.

5.1.4. Limitations of the study

Only five varieties were used in phytoremediation experiments out of about hundred of varieties known and which are grown in the country. The experiment was conducted *in vitro* conditions; the plants were immersed in heavy metal ion-containing solutions placed in a stone wall green house covered with translucent roof which allowed sunlight into the room. Distilled water was used to dissolve the heavy metal containing salts and no nutrients were added into the solutions. This growth environment is different from the actual field conditions. The effect of the nitrates of the soluble heavy metal salts used in preparing the hydroponics was largely ignored.

The plastic containers used during the growth period could have adsorbed heavy metal ions on the walls, therefore reducing the actual concentration of heavy metal ions in the solutions. These containers may have also hindered free growth of the plant roots. The probe of the conductivity meter used for measuring electrical conductivity, temperature and pH could also have adsorbed heavy metal ions during monitoring process. There was no advance study done on the physiology of the different plant varieties used in this research so as to determine their varietal differences.

5.2 Recommendations

Based on the conclusion of the current research work, the following areas should be considered for more research work:

i. The use of sweet potato plant varieties as a possible method of removing cadmium, chromium, lead and zinc from contaminated environment is possible and should be tried on large scale. Although the results obtained from heavy metal ion containing solutions experiments are useful, they are difficult to extrapolate to field conditions. A detailed study of adsorption of the heavy metal ions on the surface of the roots and the stem of the sweet potato plants should be carried out to provide the relevant data.

ii. The data obtained from the experiment could be used to warn consumers who grow sweet potato plants in heavy metal contaminated areas against consuming their leaves. Sweet potato plants could also be used as bio-indicators of heavy metal contamination whereby they dry in highly contaminated areas.

iii. A study of the absorption and translocation paths of the metals in the plant tissues should also be carried out. This study may help in explaining the transport path ways of different metal ions in the sweet potato plant tissues.

iv. The actual tolerance concentration of the heavy metals could not be established because of the wide range of the working concentration that was used for the work. More research work is therefore recommended where lower levels of concentration will be applied to determine the actual tolerance levels.

iv. The study did not cover the accumulation of the heavy metals in sweet potato tubers which is common food among many people. Further studies of the extent of accumulation of these metals in the sweet potato tubers obtained from contaminated sites are recommended. This will help the consumers of the tubers against consuming sweet potato tubers and leaves obtained from heavy metals contaminated sites.

v. After the use of the sweet potato plant in phytoremediation process, the next challenge is to find out the safest way of disposing the vines in order to avoid more contamination. A study to this effect is therefore recommended.

vi. Further research on the cost of using sweet potato plants in the environmental remediation compared to the existing methods is important.

vii. This study need to be extended to cover other known toxic heavy metal pollutants such as mercury and silver. The study should also include organic pollutants such as trichloroethylene (TCE).

viii. Detailed studies of soil and sediment where sweet potato plants accumulated zinc and chromium should be carried out to establish the source and levels of chromium and zinc in the soil and sediments.

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Appendices

Appendix I: The Mean conductivity, pH and temperature of control experiments for chromium solutions setup.

	Parameter/ Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Control 0 ppm	Mean Cond µS/cm	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Mean Temp °C	19.40	19.57 ±0.21	18.57 ±0.06	17.83 ±0.06	19.83 ±0.15	19.17 ±0.06	20.63 ±0.15	22.10 ±0.20	23.57 ±0.15	22.93 ±0.06	22.20 ±0.10	22.40 ±0.61	20.63 ±0.06	20.30	21.10 ±0.52	22.30 ±0.10	22.10 ±0.70	23.43 ±0.12	23.07 ±0.06	22.97 ±0.06	21.80 ±0.10
	Mean pH	5.21± 0.05	5.23± 0.03	5.31± 0.02	5.21± 0.03	5.30± 0.02	5.27± 0.13	5.29± 0.05	5.45± 0.02	5.35± 0.11	5.36± 0.10	5.36± 0.09	5.61± 0.06	5.66± 0.06	5.81± 0.06	5.82± 0.06	5.77± 0.02	5.80± 0.08	5.84± 0.13	5.73± 0.06	5.78± 0.10	5.79± 0.10
	Mean Temp °C	19.40	19.57 ±0.21	18.57 ±0.06	17.83 ±0.06	19.87 ±0.12	19.17 ±0.06	20.63 ±0.15	22.30 ±0.61	23.57 ±0.15	22.93 ±0.06	22.20 ±0.10	22.75 ±0.07	20.65 ±0.07	20.30	22.00 ±0.28	21.95 ±0.49	22.20 ±0.85	23.40 ±0.14	23.05 ±0.07	22.95 ±0.07	21.80 ±0.14
Control 10 ppm	Mean Cond µS/cm	23.33 ±1.15	23.67 ±0.58	24.00 ±1.00	24.33 ±0.58	25.33 ±0.58	24.00	26.00	27.00	27.67 ±0.58	27.67 ±0.58	29.00 ±2.00	28.67 ±1.15	30.00 ±2.00	29.33 ±1.15	30.00 ±2.00	31.67 ±1.53	33.00 ±1.73	34.33 ±0.58	35.33 ±2.31	36.00 ±2.00	38.67 ±1.15
	Mean Temp °C	19.40	19.43 ±0.06	18.67 ±0.12	17.83 ±0.06	20.17 ±0.15	19.40 ±0.10	20.93 ±0.15	22.37 ±0.15	23.83 ±0.15	23.07 ±0.06	22.50 ±0.10	23.20 ±0.10	20.57 ±0.06	20.27 ±0.06	21.77 ±0.06	22.30 ±0.10	22.80 ±0.10	23.80 ±0.10	23.50 ±0.10	23.37 ±0.15	21.93 ±0.06
	Mean pH	5.04± 0.01	5.07± 0.01	5.12± 0.06	5.07± 0.06	5.12± 0.06	5.12± 0.05	5.10± 0.07	5.22± 0.06	5.15± 0.05	5.09± 0.07	5.12± 0.05	5.33± 0.08	5.17± 0.08	5.23± 0.06	5.23± 0.08	5.20± 0.08	5.20± 0.10	5.21± 0.09	5.16± 0.08	5.21± 0.07	5.20± 0.06
	Mean Temp °C	19.40	19.43 ±0.06	18.57 ±0.06	17.83 ±0.06	20.10 ±0.17	19.40 ±0.10	20.93 ±0.15	22.37 ±0.15	23.83 ±0.15	23.03 ±0.06	22.50 ±0.10	23.20 ±0.10	20.57 ±0.06	20.27 ±0.06	21.67 ±0.06	22.27 ±0.12	22.80 ±0.10	23.80 ±0.10	23.50 ±0.10	23.03 ±0.72	21.93 ±0.06
Control 20 ppm	Mean Cond µS/cm	51.33 ±0.58	51.33 ±0.58	51.67 ±0.58	53.00	53.33 ±0.58	52.67 ±0.58	54.33 ±0.58	56.33 ±0.58	58.00 ±1.00	57.67 ±1.15	59.33 ±1.15	60.00	60.00 ±1.00	60.67 ±1.15	63.00 ±1.00	64.33 ±1.53	66.67 ±1.15	69.00 ±1.00	70.00 ±1.73	71.33 ±0.58	73.00 ±1.73
	Mean Temp °C	19.30	19.40 ±0.10	18.57 ±0.12	17.87 ±0.12	20.13 ±0.23	19.53 ±0.15	20.77 ±0.06	22.63 ±0.51	23.53 ±0.12	22.90 ±0.10	22.27 ±0.15	23.27 ±0.15	20.53 ±0.06	20.17 ±0.06	21.80	22.70 ±0.52	22.60 ±0.44	23.63 ±0.15	23.57 ±0.29	23.30 ±0.10	21.83 ±0.15
	Mean pH	4.91± 0.01	4.94± 0.02	4.97± 0.01	4.95± 0.03	4.99± 0.01	4.98± 0.01	4.97± 0.04	5.09± 0.01	5.04± 0.07	5.01± 0.06	5.05± 0.03	5.12± 0.02	5.10± 0.08	5.10± 0.09	5.12± 0.08	5.13± 0.09	5.13± 0.08	5.14± 0.08	5.07± 0.06	5.13± 0.03	5.12± 0.05
	Mean Temp °C	19.30	19.40 ±0.10	18.57 ±0.12	17.87 ±0.12	20.23 ±0.15	19.53 ±0.15	20.57 ±0.40	22.30 ±0.17	23.53 ±0.12	22.90 ±0.10	22.23 ±0.15	23.27 ±0.15	20.53 ±0.06	20.17 ±0.06	21.77 ±0.06	22.33 ±0.06	22.80 ±0.10	23.67 ±0.12	23.57 ±0.29	23.30 ±0.10	21.83 ±0.15
Control 50 ppm	Mean Cond µS/cm	129.67±0.58	132.00±1.00	136.33±0.58	140.33±0.58	143.33±0.58	144.67±0.58	147.67±0.58	151.67±1.15	155.00±1.00	157.67±0.58	162.67±0.58	163.67±1.15	166.33±2.08	172.00±2.65							
	Mean Temp °C	22.10	21.83 ±0.06	23.37 ±0.15	24.27 ±0.06	23.50 ±0.10	22.60 ±0.10	23.47 ±0.15	23.73 ±0.06	24.10 ±0.10	24.07 ±0.12	23.43 ±0.06	21.20 ±0.10	23.83 ±0.06	23.97 ±0.15							
	Mean pH	4.91± 0.02	4.91± 0.07	4.87± 0.03	4.90± 0.01	4.94± 0.02	4.97± 0.03	4.99± 0.02	5.01± 0.04	5.00± 0.03	5.01± 0.03	5.03± 0.04	4.73± 0.56	5.06± 0.03	5.06± 0.05							
	Mean Temp °C	22.10	21.67 ±0.32	23.37 ±0.15	24.27 ±0.12	23.50 ±0.10	23.07 ±0.64	23.70 ±0.44	23.87 ±0.29	23.87 ±0.32	23.07 ±1.62	23.53 ±0.32	22.13 ±1.70	23.75 ±0.07	23.95 ±0.07							

Appendix II: The Mean conductivity, pH and temperature of chromium solutions in which variety UP-A was immersed

Variety	Parameter/ Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Variety UP-A 0 ppm	Mean Cond μS/cm	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.33±0.58	2.00	2.00	2.00	1.67±0.58	1.67±0.58	1.67±1.15	1.67±1.15	2.00±1.73	2.67±2.89	2.67±2.89	2.33±2.31	2.33±2.31	2.33±2.31
	Mean Temp °C	19.33 ±0.06	19.47 ±0.06	18.50	17.80	19.87 ±0.06	19.20 ±0.10	20.67 ±0.06	22.17 ±0.06	23.60 ±0.10	22.83 ±0.15	22.23 ±0.06	22.73 ±0.25	20.60 ±0.10	20.23 ±0.12	21.80	22.37 ±0.06	22.73 ±0.15	28.43 ±8.72	23.07 ±0.06	22.93 ±0.15	21.80 ±0.10
	Mean PH	5.25±0.04	5.66±0.16	5.79±0.18	5.69±0.17	5.86±0.20	5.98±0.35	5.85±0.27	5.97±0.32	5.91±0.30	5.87±0.29	5.90±0.30	6.08±0.24	6.04±0.21	6.11±0.22	6.11±0.24	6.11±0.18	6.12±0.24	6.16±0.23	6.08±0.25	6.17±0.27	6.20±0.27
	Mean Temp °C	19.33 ±0.06	19.47 ±0.06	18.50	17.80	19.90	19.17 ±0.06	20.67 ±0.06	22.17 ±0.06	23.60 ±0.10	22.83 ±0.15	22.20 ±0.10	22.73 ±0.25	20.60 ±0.10	20.23 ±0.12	21.77 ±0.06	22.33 ±0.06	22.70 ±0.10	23.43 ±0.06	23.07 ±0.06	22.93 ±0.15	21.73 ±0.15
Variety UP-A 10 ppm	Mean Cond μS/cm	22.33 ±0.58	35.67 ±6.43	44.00 ±14.18	51.33 ±16.44	59.00 ±21.93	64.00 ±23.30	71.33 ±27.39	76.33 ±30.01	82.33 ±34.27	88.33 ±39.53	97.00 ±45.51	104.67±50.20	110.33±55.87	115.00±60.23	124.67±66.29	129.00±67.27	138.67±72.76	146.67±76.92	164.33±76.85	188.00±70.00	205.67±78.68
	Mean Temp °C	19.40	19.47 ±0.06	18.73 ±0.15	17.80	20.27 ±0.06	19.47 ±0.12	20.93 ±0.15	22.53 ±0.21	23.77 ±0.25	22.97 ±0.06	22.43 ±0.15	23.23 ±0.25	20.53 ±0.06	20.97 ±1.07	21.77 ±0.06	22.30 ±0.10	22.80 ±0.10	23.90 ±0.20	23.70 ±0.20	23.40 ±0.20	21.97 ±0.12
	Mean pH	5.05±0.01	5.73±0.14	5.89±0.24	5.93±0.25	6.13±0.23	6.21±0.24	6.28±0.29	6.47±0.25	6.45±0.25	6.48±0.21	6.56±0.23	6.73±0.21	6.81±0.26	6.89±0.24	6.89±0.28	6.94±0.29	7.00±0.35	7.07±0.44	7.12±0.38	5.28±3.78	7.20±0.37
	Mean Temp °C	19.40	19.50 ±0.10	18.73 ±0.15	17.80	20.27 ±0.06	19.47 ±0.12	22.60 ±3.03	22.53 ±0.21	23.73 ±0.31	22.97 ±0.06	22.43 ±0.15	23.23 ±0.25	20.60 ±0.20	20.30 ±0.10	21.70 ±0.10	22.30 ±0.10	22.80 ±0.10	23.90 ±0.20	23.70 ±0.20	23.40 ±0.20	21.97 ±0.12
Variety UP-A 20 ppm	Mean Cond μS/cm	51.00	60.33 ±1.15	70.33 ±2.89	78.00 ±5.20	86.67 ±4.93	90.67 ±5.86	98.67 ±6.11	102.67±7.09	106.33±6.03	110.00±7.21	114.67±7.77	119.00±10.58	121.67±11.15	122.67±10.97	127.00±13.08	134.33±15.53	140.67±17.90	147.67±20.03	153.00±20.88	162.33±24.54	175.67±33.08
	Mean Temp °C	19.30	19.47 ±0.06	18.60	17.93 ±0.12	20.20 ±0.10	19.53 ±0.06	20.77 ±0.15	22.30 ±0.20	23.23 ±0.81	22.83 ±0.12	22.97 ±1.25	23.20 ±0.20	20.47 ±0.06	20.07 ±0.06	21.80	22.40	22.80 ±0.10	23.57 ±0.15	23.53 ±0.15	23.20 ±0.20	21.90 ±0.10
	Mean PH	4.94±0.02	5.62±0.03	5.83±0.08	5.90	6.14±0.06	6.12±0.09	6.19±0.11	6.35±0.13	6.25±0.13	6.30±0.12	6.29±0.13	6.47±0.14	6.56±0.21	6.65±0.22	6.67±0.26	6.70±0.25	6.75±0.25	6.77±0.25	6.71±0.23	6.83±0.27	6.83±0.28
	Mean Temp °C	19.30	19.47 ±0.06	18.60	17.93 ±0.12	20.20 ±0.10	19.63 ±0.15	20.77 ±0.15	22.30 ±0.20	23.53 ±0.21	22.83 ±0.12	22.30 ±0.17	23.40 ±0.20	20.47 ±0.06	20.10	21.77 ±0.06	22.40	22.77 ±0.15	23.57 ±0.15	23.53 ±0.15	23.20 ±0.20	21.90 ±0.10
Variety UP-A 50 ppm	Mean Cond μS/cm	130.67±1.15	175.67±6.43	200.33±9.71	218.67±12.42	235.33±14.74	246.00±16.52	255.33±19.73	264.00±19.92	287.67±23.18	311.67±45.01	326.00±51.03	348.33±58.82	386.67±60.87	421.67±67.00							
	Mean Temp °C	22.13 ±0.06	21.60 ±0.46	23.53 ±0.31	24.20 ±0.10	23.50 ±0.36	22.67 ±0.25	23.53 ±0.12	23.80 ±0.30	24.10 ±0.40	24.03 ±0.15	23.40 ±0.30	21.23 ±0.12	23.80 ±0.10	24.00 ±0.36							
	Mean pH	4.82±0.03	5.85±0.03	6.01±0.06	6.07±0.05	6.12±0.06	6.22±0.07	6.27±0.05	6.32±0.05	6.27±0.07	6.33±0.06	6.38±0.07	6.42±0.07	6.56±0.10	6.74±0.17							
	Mean Temp °C	22.10	21.60 ±0.46	23.53 ±0.31	24.17 ±0.15	23.50 ±0.36	22.67 ±0.25	23.47 ±0.15	23.80 ±0.30	24.10 ±0.30	24.10 ±0.10	23.37 ±0.35	21.20 ±0.10	23.80 ±0.10	23.97 ±0.38							

Appendix III: The Mean conductivity, pH and temperature of chromium solutions in which variety UP-B was immersed

	Parameter/ Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Variety UP-B 0 ppm	Mean Cond µS/cm	1.00	8.67±4.51	7.67±3.21	7.67±3.21	8.67±1.53	8.00±1.73	8.00±1.73	9.33±0.58	10.67±2.52	10.00±1.73	9.33±2.08	8.67±2.31	7.00±2.65	6.00±1.73	6.00±1.73	6.33±2.08	6.33±2.08	6.33±2.08	6.33±2.08	6.33±2.08	6.33±2.08
	Mean Temp °C	19.30	19.40±0.10	18.57±0.06	17.70	19.93±0.12	19.23±0.06	20.63±0.06	22.07±0.15	23.53±0.15	22.67±0.12	22.67±0.72	22.70±0.10	20.47±0.15	19.30	19.40±0.10	18.57±0.06	17.70	19.93±0.12	19.23±0.06	20.63±0.06	22.07±0.15
	Mean pH	5.24±0.06	5.58±0.11	5.67±0.09	5.52±0.13	5.65±0.10	5.68±0.08	5.65±0.06	5.82±0.04	5.76±0.04	5.75±0.05	5.76±0.05	5.93±0.07	5.74±0.11	5.78±0.13	5.80±0.14	5.79±0.09	5.74±0.13	5.76±0.16	5.72±0.23	5.78±0.16	5.77±0.15
	Mean Temp °C	19.30	19.43±0.06	18.57±0.06	17.70	19.93±0.12	19.23±0.06	20.67±0.06	22.00±0.26	23.53±0.15	22.67±0.12	22.23±0.06	22.73±0.06	20.47±0.15	20.17±0.12	21.73±0.06	22.97±1.16	22.83±0.06	23.23±0.15	23.00±0.10	23.00	21.80±0.10
Variety U PB10ppm	Mean Cond µS/cm	22.67±0.58	33.00±9.17	51.00±15.59	59.00±17.35	73.33±26.65	74.00±25.16	82.00±30.35	88.00±32.97	95.33±36.83	102.00±41.22	110.00±46.36	116.67±51.03	122.00±55.97	127.00±59.63	136.33±64.69	141.67±65.16	151.67±69.00	160.67±72.51	179.33±68.70	200.00±59.43	220.67±61.08
	Mean Temp °C	19.37±0.06	19.47±0.06	18.63±0.06	17.83±0.06	20.23±0.06	19.47±0.12	20.93±0.15	22.57±0.15	23.80±0.20	22.97±0.06	22.40±0.20	23.27±0.21	20.57±0.06	20.27±0.15	21.80	22.33±0.06	24.17±2.28	23.90±0.20	23.70±0.20	23.40±0.20	22.00±0.10
	Mean pH	5.06±0.01	5.79±0.12	5.66±0.58	6.01±0.20	6.19±0.20	6.29±0.20	6.32±0.26	6.51±0.23	6.50±0.22	6.51±0.21	6.51±0.22	6.72±0.20	6.77±0.24	6.84±0.20	6.84±0.24	6.91±0.26	6.98±0.34	7.04±0.43	7.07±0.38	7.23±0.35	7.19±0.37
	Mean Temp °C	19.37±0.06	19.50±0.10	18.60±0.00	17.83±0.06	20.20±0.10	19.47±0.12	20.93±0.15	22.57±0.15	23.73±0.25	22.97±0.06	23.07±1.17	23.23±0.23	20.60	20.80±0.87	21.80	22.07±0.58	22.83±0.06	23.87±0.21	23.67±0.21	23.40±0.20	21.97±0.15
Variety UP-B 20ppm	Mean Cond µS/cm	51.00	78.00±2.65	98.33±2.31	112.00±2.65	128.33±4.73	138.33±5.03	152.67±6.43	171.00±8.54	186.33±8.08	198.00±13.23	212.00±14.73	221.33±15.31	227.33±17.10	235.00±20.88	242.67±17.62	254.00±17.58	265.00±21.00	274.67±23.07	282.67±25.72	293.00±26.91	307.67±41.43
	Mean Temp °C	19.27±0.06	19.37±0.06	18.57±0.06	17.97±0.06	20.17±0.12	19.47±0.15	20.67±0.15	22.17±0.21	23.43±0.45	22.70±0.10	22.27±0.25	23.03±0.21	20.43±0.06	20.00±0.10	21.73±0.06	22.30±0.10	22.77±0.15	23.40±0.20	23.37±0.15	23.10±0.26	21.80±0.10
	Mean pH	4.92±0.01	5.91±0.06	6.01±0.02	6.03±0.07	6.23±0.07	6.31±0.08	6.34±0.04	6.53±0.05	6.51±0.07	6.56±0.10	6.52±0.07	6.82±0.06	6.96±0.06	7.04±0.06	7.06±0.06	7.13±0.05	7.16±0.03	7.19±0.02	7.18±0.02	7.30±0.01	7.27±0.02
	Mean Temp °C	19.30	19.40	18.57±0.06	17.97±0.06	20.17±0.12	19.47±0.15	20.67±0.15	22.20±0.26	23.40±0.30	22.70±0.10	22.27±0.25	23.03±0.21	20.43±0.06	20.00±0.10	21.70±0.10	22.23±0.21	22.73±0.15	23.40±0.20	23.37±0.15	23.10±0.26	21.80±0.10
Variety UP-B 50ppm	Mean Cond µS/cm	130.67±1.15	182.67±7.02	228.67±9.87	264.33±7.57	295.00±17.58	316.33±17.04	334.67±19.14	353.00±22.34	372.33±24.13	391.00±27.62	405.33±28.38	417.00±28.58	433.00±30.05	452.33±28.31							
	Mean Temp °C	21.97±0.06	21.77±0.12	23.20±0.20	24.20±0.10	23.27±0.21	22.40	23.63±0.15	23.63±0.15	23.90±0.20	24.00±0.20	23.30±0.17	21.17±0.06	23.80±0.20	23.83±0.15							
	Mean pH	6.13±2.31	5.96±0.02	6.14±0.01	6.36±0.09	6.50±0.03	6.56±0.20	6.71±0.02	6.78±0.02	6.84±0.05	6.98±0.02	7.07±0.04	7.10±0.04	7.17±0.04	7.27±0.05							
	Mean Temp °C	22.03±0.06	21.77±0.12	23.20±0.20	24.20±0.10	23.27±0.21	23.73±1.15	23.60±0.10	24.27±1.33	23.90±0.20	24.03±0.15	23.30±0.17	21.20±0.00	23.77±0.15	23.83±0.15							

Appendix IV: The Mean conductivity, pH and temperature of chromium solutions in which variety UP-C was immersed

Variety	Parameter/ Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Variety UP-C 0 ppm	Mean Cond µS/cm	1.00	5.67±0.58	5.33±1.15	5.00±1.73	5.33±2.08	5.33±2.08	5.67±1.53	6.67±0.58	6.67±0.58	7.00	5.33±0.58	5.00	4.33±0.58	4.33±0.58	4.33±0.58	4.00	4.00	4.00	4.00	4.00	4.00
	Mean Temp °C	19.30	19.37±0.06	18.63±0.15	17.63±0.06	19.97±0.06	19.27±0.06	20.70±0.10	22.10±0.10	23.13±0.74	22.60	21.37±1.18	22.63±0.06	20.33±0.06	19.90	21.77±0.06	22.33±0.12	22.80±0.10	23.33±0.12	22.90	23.00	21.87±0.06
	Mean pH	5.27±0.02	5.73±0.09	5.71±0.06	5.60±0.08	5.75±0.14	5.75±0.10	5.73±0.07	5.87±0.06	5.78±0.09	5.74±0.13	5.76±0.10	5.94±0.15	5.77±0.09	5.75±0.14	5.77±0.14	5.73±0.14	5.71±0.06	5.76±0.09	5.78±0.18	5.85±0.15	5.96±0.07
	Mean Temp °C	19.30	19.37±0.06	18.53±0.06	17.70±0.10	20.00±0.10	19.27±0.06	20.70±0.10	22.10±0.10	23.07±0.67	22.60	22.07±0.12	22.67±0.06	20.30	19.93±0.06	21.73±0.06	22.27±0.06	22.13±1.07	23.33±0.12	22.90	23.00	21.83±0.06
Variety 1UP –C 0 ppm	Mean Cond µS/cm	22.00	45.67±4.16	60.67±5.77	69.67±7.51	81.67±9.02	89.33±6.51	98.00±5.20	109.67±7.51	118.33±7.23	127.00±6.93	133.33±8.96	139.33±10.79	144.00±12.29	149.33±11.55	154.67±13.65	161.00±16.64	168.33±17.67	175.33±19.35	179.33±19.40	182.67±17.62	194.33±22.14
	Mean Temp °C	19.33±0.06	19.40±0.10	18.60±0.10	17.90±0.10	20.37±0.21	19.47±0.21	20.93±0.21	22.43±0.21	23.70±0.10	23.03±0.12	22.33±0.21	23.30±0.10	20.57±0.06	20.17±0.21	21.73±0.12	22.30±0.10	22.83±0.12	23.77±0.15	23.60±0.30	23.27±0.25	21.87±0.06
	Mean pH	5.05±0.01	5.89±0.05	5.77±0.61	5.78±0.64	6.27±0.03	6.33±0.05	6.38±0.06	6.57±0.12	6.64±0.01	6.68±0.02	6.66±0.04	6.87±0.08	6.89±0.08	7.02±0.06	7.06±0.06	7.12±0.05	7.18±0.02	7.23±0.03	7.21±0.05	7.37±0.06	7.34±0.05
	Mean Temp °C	19.33±0.06	19.40±0.10	18.93±0.49	17.90±0.10	20.37±0.21	19.47±0.21	20.63±0.50	22.43±0.21	23.70±0.10	23.03±0.12	22.33±0.21	22.97±0.59	20.57±0.06	20.17±0.21	21.37±0.49	22.30±0.10	22.80±0.10	23.77±0.15	23.60±0.30	23.23±0.25	21.87±0.06
Variety UP –C 20 ppm	Mean Cond µS/cm	51.00	71.00±3.46	91.33±6.43	103.00±5.57	122.33±7.23	131.67±5.77	149.67±8.50	166.00±8.89	175.67±11.06	186.33±11.02	195.33±11.59	200.33±12.22	203.33±12.42	207.33±11.59	213.00±10.44	222.00±12.29	230.00±16.64	236.67±14.74	240.67±15.37	247.33±17.47	235.67±25.03
	Mean Temp °C	19.20	19.37±0.06	18.93±0.58	17.97±0.06	20.03±0.21	19.40±0.17	20.67±0.15	21.87±0.12	23.23±0.15	22.60±0.10	22.03±0.06	23.00±0.17	20.37±0.06	20.00±0.10	21.70±0.10	22.33±0.12	22.80±0.10	23.33±0.12	23.37±0.12	23.13±0.23	21.83±0.06
	Mean pH	4.91±0.01	5.82±0.05	6.04±0.03	6.12±0.03	6.32±0.01	6.47±0.02	6.54±0.02	6.71±0.04	6.81±0.08	6.87±0.10	6.86±0.07	7.05±0.11	7.11±0.12	7.11±0.11	7.12±0.12	7.23±0.11	7.29±0.08	7.33±0.06	7.32±0.04	7.40±0.07	7.38±0.05
	Mean Temp °C	19.23±0.06	19.37±0.06	18.60	17.97±0.06	20.03±0.21	19.40±0.17	20.67±0.15	21.90±0.10	23.23±0.15	22.60±0.10	22.03±0.06	23.00±0.17	20.37±0.06	20.09±0.03	21.70±0.10	22.60±0.26	22.93±0.42	23.60±0.53	23.80±0.87	23.73±1.27	21.83±0.06
Variety UP – C 50 ppm	Mean Cond µS/cm	131.33±1.15	180.33±3.79	213.67±11.06	241.67±13.32	262.67±18.61	281.67±22.81	294.67±29.14	314.67±31.34	328.67±32.62	340.67±32.32	358.00±38.63	370.33±38.53	377.67±40.15	386.00±42.93							
	Mean Temp °C	21.93±0.06	21.70±0.10	23.07±0.21	24.23±0.06	23.20±0.20	22.33±0.15	23.50±0.30	23.37±0.21	23.63±0.15	23.93±0.12	23.17±0.06	21.17±0.06	23.70±0.10	23.67±0.15							
	Mean pH	4.81±0.02	5.97±0.06	6.10±0.05	6.25±0.08	6.41±0.05	6.59±0.08	6.63±0.08	6.67±0.09	6.75±0.14	6.81±0.16	6.92±0.15	6.96±0.15	7.03±0.13	7.29±0.38							
	Mean Temp °C	21.97±0.06	21.70±0.10	23.07±0.21	24.20±0.10	23.20±0.20	22.33±0.15	23.47±0.15	23.37±0.21	23.67±0.15	23.90±0.20	23.17±0.06	21.17±0.06	23.70±0.10	23.67±0.15							

Appendix V: The Mean conductivity, pH and temperature of chromium solutions in which variety UP-D was immersed

Variety	Parameter/ Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Variety UP-D 0 ppm	Mean Cond µS/cm	1.00	7.00±3.00	7.33±2.89	6.33±2.08	6.67±2.52	6.33±2.52	7.67±2.08	7.67±2.08	8.67±2.08	8.00±1.73	8.00±1.73	6.67±1.53	6.00±1.00	5.33±1.53	5.33±1.53	5.33±1.53	5.33±1.53	5.33±1.53	6.00±1.73	5.67±1.15	5.67±1.15
	Mean Temp °C	19.33±0.06	19.40	18.50	17.77±0.06	20.07±0.06	19.30	20.77±0.06	22.23±0.12	23.50	22.70±0.10	22.20±0.10	22.80±0.10	20.40	19.93±0.06	21.77±0.06	22.33±0.06	22.83±0.06	23.30±0.10	22.97±0.06	22.90±0.10	21.87±0.06
	Mean pH	5.25±0.05	5.80±0.12	5.65±0.01	5.60±0.05	5.69±0.08	5.71±0.15	5.67±0.09	5.82±0.09	5.70±0.04	5.65±0.10	5.75±0.15	5.74±0.07	5.64±0.19	5.69±0.14	5.68±0.12	5.68±0.11	5.69±0.11	5.63±0.11	5.62±0.21	5.69±0.18	5.58±0.12
	Mean Temp °C	19.33±0.06	19.40	18.50	17.77±0.06	20.03±0.06	19.27±0.06	20.77±0.06	22.23±0.12	23.50	22.63±0.12	22.17±0.15	22.77±0.12	20.40	19.93±0.06	21.73±0.06	22.33±0.06	22.80±0.10	23.30±0.10	22.97±0.06	22.93±0.06	21.47±
Variety UP-D 10 ppm	Mean Cond µS/cm	22.00	43.00±6.93	56.00±9.17	66.33±10.97	77.00±14.00	81.33±14.74	90.33±16.92	99.67±19.14	106.67±19.55	112.00±21.07	119.00±23.00	124.33±24.11	126.33±23.54	128.67±23.18	132.67±23.46	139.33±25.32	146.67±26.41	153.00±28.16	157.00±31.22	161.33±29.30	167.67±32.15
	Mean Temp °C	19.33±0.06	19.43±0.06	18.60	18.00	20.37±0.15	19.60±0.10	20.93±0.12	22.47±0.15	23.77±0.15	22.97±0.15	22.40±0.20	23.27±0.35	20.60±0.10	20.27±0.15	21.77±0.06	22.30±0.10	22.20±0.61	23.73±0.12	23.63±0.29	23.40±0.26	21.90±0.30
	Mean pH	5.06	5.82±0.04	6.08±0.01	6.06±0.08	6.21±0.08	6.23±0.08	6.23±0.12	6.44±0.12	6.45±0.17	6.45±0.09	6.53±0.08	6.63±0.06	6.68±0.05	6.79±0.03	6.80±0.03	6.89±0.02	6.94±0.04	6.97±0.06	6.96±0.05	7.10±0.02	7.02±0.05
	Mean Temp °C	19.33±0.06	19.43±0.06	18.60	18.00	20.37±0.15	19.57±0.12	20.93±0.12	22.47±0.15	23.77±0.15	22.97±0.15	22.40±0.20	23.27±0.35	20.60±0.10	20.30±0.10	21.73±0.12	22.30±0.10	22.17±0.64	23.73±0.12	23.63±0.29	23.40±0.26	22.00±0.17
Variety UP-D 20 ppm	Mean Cond µS/cm	51.00	72.67±1.53	97.00±8.72	109.33±8.39	127.00±12.29	134.00±10.15	155.33±17.50	167.00±19.67	179.00±19.00	189.33±22.55	200.67±25.17	209.00±27.51	214.00±27.51	218.00±30.05	223.67±30.02	233.33±26.58	244.00±29.51	253.67±32.08	259.33±33.56	268.00±33.60	275.00±36.51
	Mean Temp °C	19.20	19.33±0.06	18.50	18.00	19.97±0.15	19.40±0.10	20.43±0.12	21.97±0.15	23.10±0.10	22.43±0.15	21.93±0.15	22.80±0.26	20.37±0.06	18.27±2.92	21.77±0.06	22.30±0.10	24.30±2.26	23.23±0.06	23.33±0.15	23.00±0.17	21.83±0.12
	Mean pH	4.92±0.01	5.80±0.04	6.02±0.04	6.10±0.04	6.30±0.06	6.40±0.07	6.46±0.09	6.67±0.10	6.60±0.14	6.71±0.12	6.73±0.11	6.93±0.15	7.01±0.15	7.08±0.16	7.10±0.17	7.12±0.11	7.19±0.11	7.23±0.10	7.22±0.10	7.25±0.11	7.38±0.08
	Mean Temp °C	19.20	19.33±0.06	18.38±0.20	18.00	19.97±0.15	19.40±0.10	20.53±0.25	21.97±0.15	23.10±0.10	22.43±0.15	21.93±0.15	22.80±0.26	20.37±0.06	18.27±2.92	21.73±0.12	22.30±0.10	22.80±0.10	23.23±0.06	23.33±0.15	23.00±0.17	21.83±0.12
Variety UP-D 50 ppm	Mean Cond µS/cm	130.67±0.58	183.00±11.36	222.00±7.81	251.33±10.02	274.00±7.00	291.33±10.41	307.00±14.18	317.00±16.46	334.00±17.58	347.00±20.07	356.67±22.94	361.67±23.86	376.00±20.22	358.00±63.17							
	Mean Temp °C	21.90±0.10	21.57±0.12	22.87±0.15	24.30±0.10	22.97±0.12	22.50±0.69	23.57±0.36	23.23±0.06	23.60±0.17	23.87±0.06	23.03±0.06	21.20±0.10	23.57±0.12	23.53±0.06							
	Mean pH	4.81±0.01	5.95±0.03	6.12±0.04	6.26±0.04	6.46±0.03	6.55±0.10	6.62±0.05	6.64±0.06	6.52±0.39	6.81±0.12	6.89±0.13	6.93±0.13	7.05±0.10	7.12±0.10							
	Mean Temp °C	21.90±0.10	21.57±0.12	22.50±0.78	24.30±0.10	22.93±0.15	23.13±1.06	23.03±0.60	23.23±0.06	23.57±0.21	23.83±0.15	22.37±1.10	21.23±0.06	23.53±0.15	0.06							

Appendix VI: The Mean conductivity, pH and temperature of chromium solutions in which variety UP-16 was immersed

Variety	Parameter/ Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Variety UP-16 0 ppm	Mean Cond µS/cm	1.00	4.67±1.15	4.33±0.58	3.67±0.58	4.00±1.00	4.33±1.53	4.33±1.53	4.33±1.53	4.67±1.15	4.67±1.15	4.00±1.00	3.67±1.15	3.00±1.00	3.00±1.00	3.00±1.00	3.00±1.00	2.67±1.53	2.67±1.53	2.67±1.53	2.67±1.53	2.67±1.53
	Mean Temp °C	19.40	19.40±0.10	18.57±0.06	17.80	20.20±0.10	19.30	20.83±0.15	22.40±0.10	23.63±0.12	22.83±0.15	22.30±0.10	23.13±0.15	20.50±0.10	20.10±0.10	21.77±0.06	22.57±0.29	22.77±0.15	23.60	23.50±0.10	23.10±0.10	21.67±0.49
	Mean pH	5.33±0.06	5.88±0.05	5.85±0.08	5.79±0.10	5.61±0.51	5.98±0.18	6.00±0.19	6.22±0.23	6.08±0.27	6.07±0.29	6.07±0.28	6.23±0.32	6.12±0.40	6.43±0.20	6.08±0.37	6.09±0.32	6.08±0.33	6.06±0.33	6.05±0.32	5.93±0.68	6.11±0.34
	Mean Temp °C	19.40	19.40±0.10	18.90±0.52	17.80	20.20±0.10	19.30	20.83±0.15	22.40±0.10	23.77±0.06	22.83±0.15	22.30±0.10	23.13±0.15	20.47±0.06	20.40±0.62	21.70±0.10	22.30±0.10	22.70±0.10	23.60	23.50±0.10	23.07±0.06	22.00±0.10
Variety UP-16 10 ppm	Mean Cond µS/cm	22.33±0.58	36.00±2.65	45.67±4.16	54.00±4.58	65.67±6.11	69.33±7.02	80.00±7.21	88.33±9.45	97.33±11.85	104.33±13.58	110.67±15.95	116.00±18.25	119.00±19.97	124.00±20.81	130.67±24.54	137.00±25.12	143.33±25.74	148.33±25.74	152.00±24.33	156.33±26.63	162.67±27.30
	Mean Temp °C	19.33±0.06	19.47±0.06	18.93±0.58	17.97±0.06	20.37±0.06	19.60	20.93±0.06	22.50±0.10	23.63±0.15	22.97±0.12	22.43±0.15	23.27±0.21	20.57±0.06	20.20±0.10	21.77±0.06	21.53±0.99	22.80±0.10	23.63±0.15	23.57±0.12	23.37±0.25	21.97±0.06
	Mean pH	5.15±0.17	5.76±0.04	6.01±0.03	6.05±0.06	6.25±0.08	6.28±0.08	6.33±0.11	6.59±0.13	6.60±0.13	6.62±0.13	6.62±0.13	6.83±0.12	6.89±0.14	6.99±0.16	7.03±0.10	7.04±0.14	8.07±1.59	7.08±0.11	7.42±0.41	7.38±0.28	7.19±0.10
	Mean Temp °C	19.33±0.06	19.47±0.06	18.60	17.97±0.06	20.33±0.12	19.57±0.06	20.93±0.06	22.50±0.10	23.67±0.12	22.97±0.12	22.43±0.15	23.27±0.21	20.57±0.06	20.20±0.10	21.79±0.16	22.23±0.15	22.77±0.15	23.73±0.12	23.57±0.12	23.37±0.25	22.00±0.10
Variety UP-16 20 ppm	Mean Cond µS/cm	51.00	74.33±4.62	84.67±24.85	120.67±20.01	131.67±12.58	146.33±14.19	168.67±21.13	188.00±16.82	197.00±18.52	207.33±21.59	219.00±24.06	228.33±26.03	239.00±30.00	239.67±27.15	246.00±27.84	259.33±32.25	268.33±35.08	274.00±32.60	284.00±39.00	294.00±40.51	304.00±42.04
	Mean Temp °C	19.17±0.06	19.37±0.12	18.53±0.06	18.37±0.55	19.80±0.17	19.43±0.06	20.43±0.12	21.80±0.17	23.00±0.10	22.47±0.21	21.80±0.10	22.67±0.15	20.47±0.06	19.83±0.06	21.77±0.06	22.33±0.12	22.80±0.10	23.07±0.15	23.37±0.15	22.30±1.30	21.80±0.10
	Mean pH	4.95±0.02	5.81±0.03	6.06±0.02	6.29±0.29	6.34±0.07	6.45±0.09	6.50±0.04	6.71±0.07	6.76±0.10	6.55±0.29	6.64±0.31	6.99±0.09	7.09±0.07	7.13±0.06	7.15±0.05	7.17±0.09	7.16±0.07	7.27±0.11	7.26±0.13	7.38±0.11	7.35±0.12
	Mean Temp °C	19.20	19.27±0.06	18.53±0.06	18.00	19.80±0.17	19.40±0.10	20.43±0.12	21.80±0.17	23.00±0.10	22.43±0.15	21.80±0.10	22.67±0.15	20.47±0.06	19.83±0.06	21.70±0.10	22.30±0.10	22.83±0.06	23.07±0.15	23.37±0.15	22.93±0.15	21.83±0.12
Variety UP-16 50 ppm	Mean Cond µS/cm	130.67±0.58	187.33±10.69	236.00±32.51	260.00±41.15	283.67±47.00	297.00±46.51	321.67±41.48	329.33±49.03	325.00±77.09	387.67±31.37	420.67±46.09	431.00±51.86	453.00±47.29	471.33±50.64							
	Mean Temp °C	21.77±0.06	21.93±0.67	22.80±0.10	24.27±0.06	22.90±0.17	22.27±0.38	23.57±0.21	23.10±0.17	23.37±0.15	24.03±0.15	22.87±0.12	21.10±0.10	23.47±0.15	23.37±0.15							
	Mean pH	4.82±0.01	6.00±0.02	6.16±0.07	6.28±0.06	6.44±0.12	6.54±0.11	6.61±0.12	6.59±0.16	6.67±0.14	6.90±0.16	6.92±0.35	7.15±0.08	7.25±0.05	7.39±0.04							
	Mean Temp °C	21.77±0.06	21.70±0.10	22.83±0.15	24.20±0.10	22.87±0.21	22.27±0.38	23.47±0.15	23.10±0.17	23.37±0.15	24.00±0.20	22.87±0.12	21.13±0.06	23.13±0.57	23.37±0.15							

Appendix VII: The Mean conductivity, pH and temperature of control experiment for zinc solutions setup.

	Parameter / Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Blank 0 ppm	Mean cond. µS/cm	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Mean Temp. °C	19.30	19.63±0.15	19.13±0.06	18.80	18.97±0.06	19.90±0.10	19.90±0.10	20.23±0.15	21.60±0.26	21.10±0.10	20.90±0.10	22.20±0.20	20.39±0.26	23.00±0.52	22.10	20.23±0.06	20.83±0.06	21.83±0.15	21.53±0.58	21.40±0.10	22.10±0.20
	Mean pH	5.28±0.01	5.28±0.06	5.15±0.05	5.31±0.04	5.22±0.03	5.36±0.01	5.50±0.03	5.68±0.05	5.46±0.04	5.39±0.06	5.43±0.05	5.48±0.02	5.46±0.03	5.53±0.04	5.67±0.09	5.73±0.16	5.86±0.04	5.90±0.02	5.89±0.02	5.88±0.04	5.85±0.03
	Mean Temp. °C	19.30	19.63±0.15	19.13±0.06	18.80	18.97±0.06	19.90±0.10	19.90±0.10	20.23±0.15	21.60±0.20	21.10±0.10	20.63±0.47	22.20±0.20	20.57±0.12	23.00±0.52	22.13±0.06	20.23±0.06	20.83±0.12	21.87±0.15	21.43±0.59	21.77±0.55	22.10±0.20
Blank 10 ppm	Mean cond. µS/cm	38.00	38.33±0.58	38.67±0.58	39.33±0.58	39.00	39.67±0.58	41.00	42.00	43.00	44.00	44.33±0.58	45.33±0.58	46.00	47.67±0.58	48.00	48.33±0.58	49.33±0.58	51.00	51.00	51.33±0.58	52.00
	Mean Temp. °C	19.73±0.06	20.03±0.15	19.13±0.06	19.07±0.55	19.03±0.06	19.90±0.10	20.00±0.10	20.33±0.06	21.67±0.21	21.30±0.10	21.03±0.06	22.33±0.15	20.87±0.21	23.60	22.83±0.06	20.23±0.06	22.00±0.10	22.10±0.20	22.20	21.60±0.10	22.17±0.15
	Mean pH	5.91±0.05	5.30±0.46	5.59±0.12	5.57±0.12	5.50±0.13	5.55±0.14	5.58±0.12	5.56±0.23	5.69±0.10	5.64±0.13	5.57±0.09	5.56±0.17	5.57±0.13	5.56±0.20	5.58±0.19	5.60±0.21	5.61±0.14	5.65±0.16	5.69±0.21	5.72±0.19	5.65±0.23
	Mean Temp. °C	19.73±0.06	20.03±0.15	19.13±0.06	18.73±0.06	19.03±0.06	19.63±0.47	20.00±0.10	20.33±0.06	21.67±0.21	21.33±0.12	21.50±0.87	21.83±0.72	21.50±1.85	23.30±0.44	21.93±1.42	20.80±1.04	22.07±0.12	21.77±0.61	22.20±0.10	21.60±0.10	22.23±0.06
Blank 20 ppm	Mean cond. µS/cm	78.67±0.58	79.33±1.15	79.00±1.00	79.67±0.58	80.33±0.58	81.33±0.58	83.00	85.33±0.58	87.00±1.00	89.00	89.00	92.33±0.58	93.33±0.58	95.33±0.58	97.00±1.00	97.67±0.58	99.00±1.00	100.33±0.58	100.67±0.58	102.33±1.15	103.67±0.58
	Mean Temp. °C	19.87±0.06	20.10±0.10	19.1±70.06	18.80±0.10	19.13±0.06	19.87±0.15	20.00±0.10	22.77±4.53	21.47±0.21	21.23±0.12	21.03±0.12	22.10±0.20	21.07±0.21	23.37±0.06	22.49±0.37	20.50±0.53	20.50 ±	21.60±0.46	22.00	21.43±0.06	21.67±0.49
	Mean pH	6.13±0.04	6.33±0.03	5..99±0.99	6.01±0.01	6.16±0.58	6.12±0.04	6.11±0.04	6.20±0.06	6.21±0.05	6.21±0.02	6.18±0.05	6.31±0.04	6.33±0.05	6.38±0.07	6.38±0.06	6.38±0.05	6.39±0.05	6.42±0.05	6.45±0.05	6.48±0.06	6.45±0.09
	Mean Temp. °C	19.87±0.06	20.10±0.10	19.17±0.06	18.83±0.12	19.10±0.10	19.87±0.15	20.00±0.10	20.10±0.10	21.17±0.40	21.27±0.15	21.07±0.15	22.10±0.20	21.10±0.20	23.37±0.06	22.70	20.20±0.10	20.35±0.26	21.93±0.21	22.03±0.06	21.60±0.35	22.00±0.10
Blank 50 ppm	Mean cond. µS/cm	197.00±1.73	198.33±1.53	203.67±0.58	207.67±0.58	213.00±1.00	216.00±1.73	220.33±2.52	224.67±1.53	228.00±4.36	233.67±2.31	239.33±1.53	241.67±1.53	250.00±.100	253.67±2.08	254.67±2.89	255.67±2.89	256.00±2.65	262.33±2.52	267.00±2.65	275.67±2.89	266.00±2858
	Mean Temp. °C	22.20±0.10	21.87±0.06	23.47±0.15	24.30±0.10	23.60±0.10	22.70	23.50±0.10	23.47±0.10	23.40±1.04	24.03±0.15	23.57±0.06	21.07±0.06	23.90±0.10	24.33±0.15	22.17±0.06	20.90±0.10	19.60±0.26	21.97±0.12	22.93±0.12	24.10±0.10	24.57±0.12
	Mean pH	6.11±0.03	6.13±0.07	6.10±0.07	6.14±0.08	6.19±0.08	6.30±0.03	6.31±0.04	6.32±0.05	6.21±0.03	6.19±0.07	6.20±0.09	6.19±0.08	6.24±0.09	6.29±0.10	6.30±0.09	6.32±0.09	6.18±0.08	6.20±0.11	6.15±0.07	6.18±0.09	6.26±1.66
	Mean Temp. °C	22.20±0.10	21.87±0.06	23.47±0.15	24.30±0.10	23.60±0.10	22.70±0.10	23.50±0.10	23.80±0.20	24.07±0.15	24.03±0.15	23.57±0.06	21.10	23.87±0.15	24.33±0.15	22.13±0.06	20.90±0.10	19.60±0.26	21.93±0.12	22.90±0.17	24.10±0.10	24.57±0.12

Appendix VIII: The Mean conductivity, pH and temperature of zinc solutions in which variety UP-A was immersed

Variety	Parameter / Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Variety UP-A 0 ppm	Mean cond. µS/cm	1.00	4.33±2.89	4.00±3.00	4.00±3.00	3.67±3.06	3.33±3.21	3.00±2.65	2.33±2.31	2.33±2.31	2.33±2.31	2.00±1.73	2.00±1.73	2.00±1.73	2.00±1.73	1.67±1.15	1.67±1.15	1.33±0.58	1.33±0.58	1.33±0.58	1.33±0.58	1.33±0.58
	Mean Temp. °C	19.50	19.83±0.21	19.13±0.06	18.83±0.06	18.97±0.21	19.57±0.61	19.97±0.15	20.30±0.20	21.70±0.10	21.20±0.20	20.93±0.15	22.20	20.60	23.27±0.21	22.83±0.06	20.13±0.06	20.10	22.27±0.55	21.40±1.22	21.40±0.17	21.93±0.21
	Mean pH	5.30±0.01	6.24±0.07	5.70±0.44	5.97±0.05	5.79±0.05	5.83±0.07	5.84±0.09	5.92±0.15	5.75±0.12	5.75±0.10	5.75±0.06	5.74±0.11	5.74±0.12	5.65±0.10	5.64±0.06	5.69±0.06	5.72±0.05	5.72±0.07	5.50±0.30	5.56±0.10	5.57±0.08
	Mean Temp. °C	19.60±0.17	19.83±0.21	19.13±0.06	19.20±0.53	18.97±0.21	19.90±0.20	20.00±0.20	20.30±0.20	21.73±0.15	21.23±0.25	20.93±0.15	22.20	20.60	23.27±0.21	22.77±0.06	0.06	20.10	21.97±0.06	22.03±0.06	21.40±0.17	22.03±0.15
Variety UP-A 10ppm	Mean cond. µS/cm	38.33±0.58	49.67±0.58	53.67±1.53	56.00±2.00	56.00±2.00	57.33±3.06	60.00±3.00	61.00±2.65	62.67±2.31	64.00±2.65	65.00±3.46	67.00±2.65	68.67±2.52	72.00±1.73	73.00±2.00	75.00±1.73	76.67±2.31	78.67±2.31	78.33±3.79	78.67±4.51	81.00±4.58
	Mean Temp. °C	19.90	20.10±0.10	19.20	19.13±0.49	19.10±0.10	20.00±0.10	20.07±0.12	20.43±0.15	21.90±0.10	21.43±0.15	21.10±0.10	22.53±0.06	20.73±0.55	23.50±0.10	22.67±0.06	20.27±0.06	21.93±0.06	22.20±0.20	22.10	21.57±0.12	22.27±0.12
	Mean pH	5.98±0.02	6.40±0.07	6.39±0.04	6.47±0.09	6.39±0.08	6.50±0.09	6.55±0.07	6.59±0.07	6.59±0.08	6.65±0.15	6.55±0.07	6.57±0.09	6.59±0.09	6.69±0.10	6.72±0.11	6.66±0.07	6.82±0.10	6.85±0.10	6.86±0.10	6.88±0.11	6.86±0.10
	Mean Temp. °C	19.90	20.10±0.10	19.20	18.83±0.15	19.10±0.10	20.00±0.10	20.07±0.12	20.43±0.15	21.90±0.10	21.43±0.15	21.47±0.64	22.53±0.06	21.07±0.06	23.53±0.15	22.70±0.10	20.27±0.06	21.87±0.06	22.20±0.20	21.77±0.49	21.60±0.10	22.27±0.12
Variety UP-A 20ppm	Mean cond. µS/cm	79.00	88.67±2.31	92.00±3.00	94.33±3.06	96.67±2.31	97.00±2.65	99.67±2.31	99.67±1.53	102.00±2.65	104.33±1.15	105.00±2.00	108.33±2.89	109.67±4.51	111.00±3.61	112.33±4.04	114.00±6.08	117.33±5.86	119.67±5.69	120.67±6.43	122.33±8.50	124.67±8.14
	Mean Temp. °C	19.70±0.10	20.17±0.06	19.20±0.10	19.07±0.55	19.37±0.47	19.87±0.06	19.±0.15	20.17±0.06	21.53±0.21	20.81±0.70	20.70±0.61	22.13±0.06	21.10±0.10	23.30±0.10	22.60±0.35	20.20	21.60	21.87±0.96	22.00±0.10	21.60±0.66	22.00 0.10
	Mean pH	6.22±0.03	6.33±0.03	6.29±0.09	6.45±0.10	6.36±0.09	6.49±0.07	6.52±0.08	6.54±0.08	6.54±0.09	6.53±0.09	6.51±0.09	6.57±0.06	6.55±0.07	6.62±0.08	6.70±0.14	6.66±0.07	6.68±0.07	6.72±0.08	6.73±0.10	6.64±0.11	6.75±0.12
	Mean Temp. °C	19.70±0.10	20.17±0.06	19.20±0.10	19.07±0.55	19.37±0.47	19.87±0.06	19.93±0.15	20.17±0.06	21.53±0.21	20.81±0.70	20.70±0.61	22.13±0.06	21.10±0.10	23.30±0.10	22.80	20.20	21.60	21.57±0.51	21.97±0.06	21.60±0.66	22.00±0.10
Variety UP-A 50ppm	Mean cond. µS/cm	196.67±0.58	213.33±6.03	222.00±5.57	230.33±7.23	236.00±6.24	238.67±6.81	244.33±7.23	249.67±8.39	253.00±10.44	258.33±10.02	261.00±7.55	265.00±6.56	273.00±9.64	280.67±12.42	285.33±14.01	289.33±17.39	290.00±19.97	296.67±20.60	306.33±23.12	316.00±23.43	326.00±21.66
	Mean Temp. °C	22.67±0.81	21.87±0.12	23.47±0.21	24.23±0.06	23.63±0.15	22.70±0.17	23.37±0.32	24.23±0.06	24.23±0.06	24.03±0.15	23.37±0.32	21.40±0.61	23.63±0.55	24.37±0.21	22.20±0.10	20.90±0.10	19.40	21.93±0.06	22.80±0.17	24.07±0.12	24.30
	Mean pH	6.18±0.02	6.25±0.03	6.42±0.07	6.46±0.08	6.57±0.03	6.46±0.17	6.68±0.06	6.71±0.09	6.58±0.05	6.61±0.04	6.64±0.03	6.58±0.06	6.66±0.10	6.73±0.06	6.73±0.08	6.74±0.09	6.69±0.08	6.68±0.14	6.71±0.18	6.72±0.20	6.87±0.16
	Mean Temp. °C	22.63±0.84	21.87±0.12	23.37±0.35	24.23±0.06	23.63±0.15	24.00±2.17	23.37±0.32	24.23±0.06	24.23±0.06	24.07±0.12	23.37±0.32	21.40±0.61	23.57±0.51	23.73±1.25	22.20±0.10	20.90±0.10	19.40	21.90±0.10	22.80±0.17	24.07±0.12	24.30

Appendix IX: The Mean conductivity, pH and temperature of zinc solutions in which variety UP-B was immersed

Variety	Parameter / Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Variety UP-B 0 ppm	Mean cond. µS/cm	1.00	6.00±2.65	5.33±2.08	5.00±1.73	5.33±1.15	6.00±1.73	6.33±2.08	6.67±2.52	6.33±2.08	6.33±2.08	6.00±1.73	5.67±1.53	5.33±1.15	5.33±1.15	5.00±1.00	4.67±0.58	4.67±1.15	4.33±0.58	4.33±0.58	4.33±0.58	4.00±1.00
	Mean Temp. °C	19.60	19.83±0.15	19.33±0.49	18.77±0.06	19.23±0.58	19.87±0.15	19.93±0.12	20.23±0.12	21.53±0.40	21.07±0.06	20.87±0.06	22.30±0.17	20.67±0.06	23.17±0.15	22.83±0.06	20.10	21.87±0.06	20.27±0.06	20.23±0.21	21.20±0.14	22.05±0.07
	Mean pH	5.41±0.06	6.02±0.07	5.62±0.02	5.75±0.05	5.69±0.08	5.80±0.09	5.90±0.07	5.97±0.10	5.89±0.08	5.87±0.05	5.88±0.08	5.77±0.05	5.79±0.04	5.75±0.04	5.79±0.04	5.90±0.08	5.97±0.10	5.98±0.10	5.87±0.14	5.85±1.67	5.86±0.15
	Mean Temp. °C	19.60	19.83±0.15	19.33±0.49	18.77±0.06	18.87±0.06	19.87±0.15	19.97±0.15	20.23±0.12	21.67±0.15	21.07±0.06	20.90±0.10	22.33±0.12	20.67±0.06	23.20±0.17	22.80	20.10	21.87±0.06	20.23±0.06	20.33±0.06	21.23±0.12	22.10±0.17
Variety UP-B 10ppm	Mean cond. µS/cm	40.00±1.00	62.67±4.62	74.67±7.64	79.67±7.02	82.67±8.74	86.67±9.45	92.00±12.29	97.33±14.15	104.33±16.86	108.67±18.15	113.67±20.53	118.33±20.74	123.00±26.00	125.33±26.58	124.67±25.54	113.33±10.60	126.33±25.17	126.33±25.17	125.33±28.71	117.00±21.66	113.33±19.60
	Mean Temp. °C	19.77±0.12	20.13±0.06	19.23±0.06	19.50±0.61	19.10	20.03±0.06	20.13±0.15	20.43±0.12	21.90±0.20	21.47±0.15	21.60±0.61	22.03±0.90	21.87±1.24	23.10±0.46	21.60±1.25	20.27±0.12	20.83±0.92	22.13±0.15	21.87±0.40	21.03±0.90	21.27±1.07
	Mean pH	6.03±0.01	6.49±0.08	6.50±0.06	6.69±0.08	6.64±0.09	6.76±0.08	6.78±0.03	6.85±0.06	6.88±0.06	6.89±0.09	6.90±0.10	6.89±0.15	6.93±0.13	6.98±0.11	7.10±0.26	7.04±0.11	7.04±0.07	7.13±0.09	7.14±0.08	7.16±0.06	7.15±0.05
	Mean Temp. °C	19.80±0.10	20.13±0.06	19.23±0.06	18.57±0.49	19.10	20.13±0.15	20.10±0.17	20.30±0.30	21.63±0.50	21.50±0.17	21.23±0.15	22.47±0.15	21.10±0.10	23.27±0.25	22.70	20.27±0.12	20.23±0.06	22.13±0.15	22.07±0.06	21.50±0.10	22.30±0.17
Variety 20 ppm	Mean cond. µS/cm	79.67±0.58	108.00±3.46	121.67±3.06	125.00±2.65	127.33±3.06	130.67±4.16	135.33±5.51	137.67±4.93	142.00±6.93	147.33±4.62	150.00±5.29	156.33±7.02	169.33±24.21	164.67±10.02	165.67±10.79	166.33±11.93	169.00±11.36	174.67±18.50	173.67±20.23	170.33±16.17	171.33±17.90
	Mean Temp. °C	19.67±0.06	20.07±0.06	19.17±0.06	18.83±0.85	19.33±0.32	19.80±0.10	19.97±0.12	20.17±0.12	21.53±0.06	21.20±0.17	21.03±0.06	22.10±0.10	21.10±0.10	23.30±0.10	22.73±0.12	20.13±0.12	21.13±0.75	21.77±0.12	22.10	21.30±0.10	21.67±
	Mean pH	6.24	6.44±0.03	6.52±0.02	6.72±0.05	6.69±0.04	6.74±0.04	6.77±0.06	6.79±0.05	6.84±0.01	6.82±0.02	6.83±0.02	6.88±0.04	6.86±0.02	6.96±0.08	7.07±0.10	7.12±0.10	7.14±0.06	7.14±0.08	7.16±0.08	7.19±0.09	7.21±0.10
	Mean Temp. °C	19.67±0.06	20.07±0.06	19.17±0.06	18.83±0.85	19.33±0.32	19.80±0.10	19.97±0.12	20.17±0.12	21.53±0.06	21.20±0.17	21.03±0.06	22.10±0.10	21.10±0.10	23.30±0.10	22.73±0.12	20.13±0.12	21.13±0.75	21.77±0.12	22.10	21.30±0.10	21.67±0.49
Variety 50 ppm	Mean cond. µS/cm	196.67±0.58	237.00±26.66	254.67±23.76	268.67±24.68	285.33±27.14	289.00±26.89	294.33±29.74	301.67±33.50	308.67±37.90	311.67±39.70	314.33±44.07	316.33±44.12	321.67±47.88	327.00±53.11	327.33±54.45	327.00±55.02	329.33±55.64	331.67±59.41	335.00±64.37	345.33±68.38	354.3 376.4 2
	Mean Temp. °C	21.93±0.55	21.83±0.06	23.50±0.36	24.23±0.06	23.67±0.21	22.50±0.44	23.60	23.90±0.20	23.53±0.12	24.03±0.15	23.53±0.12	21.27±0.12	23.83±0.15	24.40±0.36	22.10±0.10	21.03±0.06	19.47±0.06	21.87±0.15	22.90±0.17	24.07±0.15	24.30±0.20
	Mean pH	6.22±0.02	6.55±0.14	6.70±0.10	6.81±0.11	6.75±0.47	6.83±0.48	6.85±0.48	7.07±0.15	7.00±0.12	7.04±0.13	7.09±0.13	7.06±0.11	7.13±0.12	7.20±0.14	7.22±0.16	7.24±0.16	7.10±0.17	7.14±0.16	7.21±0.18	7.21±0.18	7.29±0.22
	Mean Temp. °C	22.23±0.06	21.80±0.10	23.50±0.36	24.20±0.10	23.67±0.21	22.70±0.10	23.53±0.12	23.90±0.20	23.53±0.12	23.97±0.21	23.60	21.23±0.15	23.83±0.15	24.30±0.26	22.03±0.15	21.03±0.06	19.43±0.06	21.83±0.15	22.90±0.17	24.03±0.15	24.30±0.20

Appendix X: The Mean conductivity, pH and temperature of zinc solutions in which variety UP-C was immersed

	Parameter / Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Variety UP-C 0 ppm	**Mean cond. µS/cm**	1.00	5.33±1.53	5.67±1.53	6.33±0.58	6.33±0.58	6.67±0.58	7.00±1.00	6.33±1.53	7.33±1.53	7.33±2.31	7.33±2.31	6.67±2.08	6.67±2.08	5.33±1.53	5.67±1.53	5.67±1.53	5.00±1.00	4.67±0.58	4.67±0.58	5.00±1.00	4.67±0.58
	Mean Temp. °C	19.47±0.06	19.93±0.12	19.20±0.26	19.17±0.72	18.60±0.44	19.47±0.59	19.67±0.67	20.57±0.86	20.97±0.91	20.57±0.67	21.67±0.61	21.47±0.83	21.63±1.27	22.83±0.55	21.20±1.44	20.20±0.10	20.83±0.92	21.73±0.21	22.03±0.06	21.30	22.10±0.20
	Mean pH	5.53±0.06	6.09±0.03	5.90±0.57	5.68±0.07	5.61±0.08	5.72±0.06	5.78±0.01	5.88±0.02	5.80±0.04	5.61±0.26	5.72±0.10	5.74±0.08	5.71±0.12	5.73±0.08	5.75±0.08	5.80±0.09	5.69±0.35	6.01±0.08	5.89±0.07	5.80±0.05	5.85±0.07
	Mean Temp. °C	19.50±0.10	19.97±0.06	19.07±0.06	18.77±0.06	18.57±0.49	19.47±0.59	19.93±0.12	20.30±0.17	21.43±0.40	20.57±0.67	20.97±0.06	22.30±0.10	20.53±0.46	23.43±0.35	22.77±0.06	20.10±0.10	20.30	21.90	22.03±0.06	21.27±0.06	22.07±0.25
Variety UP-C 10ppm	**Mean cond. µS/cm**	40.00	59.33±3.06	67.00±2.65	68.67±3.06	71.33±3.21	76.00±3.46	80.33±4.16	83.67±4.73	89.00±5.29	91.33±5.86	95.33±5.86	98.00±4.24	104.67±10.26	108.00±9.64	108.00±7.94	109.33±8.39	111.00±8.66	80.67±61.72	110.67±9.87	109.00±7.81	107.00±7.81
	Mean Temp. °C	19.77±0.06	20.13±0.15	19.23±0.06	18.50±0.44	19.13±0.12	20.03±0.15	20.10±0.20	20.40±0.20	21.77±0.15	21.37±0.15	21.13±0.15	22.40±0.20	21.07±0.21	23.30±0.30	22.77±0.06	20.27±0.06	20.20	22.00±0.17	22.07±0.06	21.53±0.15	22.30±0.20
	Mean pH	6.08±0.02	6.53±0.10	6.50±0.04	6.66±0.03	6.57±0.02	6.72±0.04	6.77±0.03	6.86±0.03	6.91±0.02	6.95±0.02	6.96±0.04	6.99±0.02	6.99±0.06	7.06±0.06	7.09±0.08	7.33±0.35	7.17±0.08	7.17±5.76	7.19±0.06	7.19±0.05	7.15±0.05
	Mean Temp. °C	19.80	20.13±0.15	18.90±0.61	18.80±0.10	19.13±0.12	20.03±0.15	20.10 0.20±	20.40±0.20	21.77±0.15	21.37±0.15	21.13±0.15	22.40±0.20	21.07±0.21	23.47 0.15	22.80	20.27±0.06	20.20	22.10±0.30	22.03±0.06	21.53±0.15	22.30±0.20
Variety UP-C 20ppm	**Mean cond. µS/cm**	79.33±0.58	111.00±3.61	123.00±3.46	126.00±1.73	128.33±1.53	133.33±3.51	137.33±4.16	138.67±5.51	145.00±6.56	148.33±9.07	153.33±12.50	158.33±17.62	161.33±19.04	168.00±20.07	170.00±20.52	171.33±20.50	174.00±22.52	176.67±23.01	175.67±22.01	175.33±21.50	174.67±21.01
	Mean Temp. °C	19.57±0.06	19.90±0.17	19.17±0.06	18.67±0.06	19.03±0.06	19.70±0.10	19.87±0.12	20.00±0.17	21.37±0.21	21.10±0.10	20.60±0.52	22.03±0.12	21.07±0.06	23.13±0.15	22.83±0.06	20.17±0.06	20.67±0.06	21.60±0.17	22.10	21.30±0.20	21.83±0.15
	Mean pH	6.25±0.01	6.49±0.10	6.59±0.04	6.80±0.05	6.69±0.02	6.79±0.01	6.81±0.04	6.85±0.10	6.90±0.04	6.98±0.02	6.85±0.06	7.00±0.04	6.98±0.07	7.07±0.08	7.11±0.05	7.17±0.01	7.20±0.01	7.26±0.06	7.25±0.06	7.26±0.05	7.27±0.07
	Mean Temp. °C	19.67±0.12	19.90±0.17	19.17±0.06	19.00±0.61	19.07±0.06	19.73±0.15	19.87±0.12	19.97±0.21	21.37±0.21	21.10±0.10	20.67±0.58	22.07±0.06	21.03±0.06	23.17±0.21	22.77±0.06	20.17±0.06	20.47±0.23	21.63±0.23	22.07±0.06	21.30±0.20	21.87±0.15
Variety UP-C 50ppm	**Mean cond. µS/cm**	196.33±0.58	240.67±21.08	266.33±25.74	273.67±24.79	282.00±23.81	287.67±24.79	292.33±25.93	299.67±25.72	305.67±24.58	308.67±23.76	313.00±22.54	314.33±21.36	319.67±21.08	325.33±23.12	324.33±23.12	323.67±22.81	324.00±22.52	326.67±22.81	328.33±23.97	342.00±31.18	346.67±34.20
	Mean Temp. °C	22.20	21.90±0.10	23.40±0.30	24.17±0.15	23.43±0.35	22.53±0.47	23.57±0.06	23.83±0.25	24.10±0.30	23.77±0.59	23.53±0.15	21.20±0.10	23.87±0.12	24.20±0.20	22.17±0.15	21.07±0.12	19.50	21.80±0.10	22.73±0.15	24.00±0.20	24.30±0.20
	Mean pH	6.22±0.01	6.41±0.06	6.69±0.05	6.83±0.13	6.95±0.11	7.04±0.15	7.06±0.09	7.07±0.09	6.98±0.10	7.02±0.08	7.05±0.09	7.01±0.08	7.10±0.08	7.13±0.04	7.19±0.10	7.20±0.10	7.04±0.12	7.10±0.17	7.09±0.14	7.10±0.15	7.16±0.18
	Mean Temp. °C	22.20	21.90±0.10	23.40±0.30	24.17±0.15	23.60±0.20	22.43±0.38	23.47±0.15	23.50±0.36	24.10±0.26	23.77±0.59	23.53±0.15	21.17±0.12	23.90±0.10	24.23±0.21	22.13±0.15	21.07±0.12	19.50	21.77±0.12	22.73±0.15	24.00±0.20	24.30±0.20

Appendix XI: The Mean conductivity, pH and temperature of zinc solutions in which variety UP-D was immersed

	Parameter / Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Variety UP-D 0 ppm	Mean cond. µS/cm	1.00	5.33±4.16	6.00±4.00	6.33±3.06	6.33±3.06	5.67±2.31	5.33±2.08	5.67±1.53	5.67±1.53	5.33±1.15	5.33±1.15	5.33±1.15	5.33±1.15	4.67±0.58	4.33±0.58	3.67±0.58	3.33±0.58	2.67±0.58	2.33±0.58	2.00	2.00
	Mean Temp. °C	19.57±0.06	20.03±0.12	19.07±0.06	18.77±0.06	18.93±0.15	19.97±0.15	20.00±0.20	20.40±0.20	21.83±0.25	21.20±0.17	21.10±0.20	22.37±0.15	20.77±0.06	23.50±0.20	22.10	20.20±0.10	21.77±0.12	22.13±0.15	21.03±0.96	21.53±0.06	22.20±0.20
	Mean pH	5.57±0.03	6.27±0.13	5.80±0.19	5.64±0.36	5.74±0.10	5.79±0.10	5.80±0.12	5.85±0.08	5.71±0.08	5.65±0.12	5.64±0.08	5.65±0.07	5.67±0.07	5.69±0.05	5.74±0.06	5.83±0.04	5.91±0.09	6.02±0.09	5.93±0.15	5.83±0.08	5.80±0.05
	Mean Temp. °C	19.57±0.06	20.03±0.12	19.07±0.06	18.77±0.06	18.93±0.15	19.97±0.15	20.00±0.20	20.40±0.20	21.80±0.20	21.40±0.17	21.10±0.20	22.20±0.20	20.77±0.06	23.50±0.20	22.10	20.20±0.10	21.73±0.06	22.13±0.15	21.66±0.41	21.53±0.06	22.23±0.25
Variety UP-D10ppm	Mean cond. µS/cm	39.67±0.58	55.33±4.16	63.33±7.51	67.33±8.08	69.67±11.24	72.33±12.66	77.00±14.11	80.33±16.62	85.00±19.97	90.00±22.61	93.67±25.66	98.33±29.40	101.33±32.04	107.00±36.51	108.33±38.76	109.67±39.12	112.00±39.69	114.33±41.02	112.67±39.72	110.67±37.23	111.67±36.14
	Mean Temp. °C	19.73±0.06	20.23±0.06	19.23±0.06	19.17±0.55	18.83±0.72	20.03±0.15	20.10±0.20	20.40±0.20	21.17±1.02	21.37±0.15	21.17±0.12	22.37±0.15	21.13±0.06	23.43±0.21	22.80	20.30	20.20	22.07±0.25	22.10	21.47±0.12	22.30±0.10
	Mean pH	6.08±0.01	6.48±0.07	6.45±0.11	6.62±0.08	6.53±0.09	6.68±0.11	6.71±0.10	6.73±0.14	6.79±0.14	6.81±0.13	6.82±0.12	6.88±0.12	6.86±0.12	6.93±0.13	6.96±0.10	7.00±0.09	7.07±0.09	7.08±0.11	7.15±0.22	7.10±0.12	7.08±0.09
	Mean Temp. °C	19.73±0.06	20.23±0.06	19.23±0.06	18.83±0.06	19.17±0.15	20.07±0.12	20.43±0.42	20.40±0.20	20.97±0.95	21.37±0.15	21.17±0.12	22.37±0.15	21.17±0.06	23.43±0.21	22.77±0.06	20.30	20.20	22.07±0.25	22.10	21.50±0.10	22.30±0.10
Variety UP-D 20ppm	Mean cond. µS/cm	80.00	106.67±13.61	120.33±15.28	123.67±16.80	127.00±18.33	128.33±17.90	130.33±17.90	131.67±19.43	134.00±20.95	138.67±22.50	140.67±24.42	146.33±25.79	148.33±27.47	152.33±28.18	155.00±28.58	157.00±28.35	160.67±29.48	163.67±31.18	163.00±30.05	162.67±29.48	163.00±29.31
	Mean Temp. °C	19.47±0.06	19.83±0.06	19.07±0.06	18.63±0.06	18.97±0.06	19.63±0.06	19.80±0.10	19.90±0.10	21.17±0.06	20.97±0.23	20.80±0.10	21.80±0.10	21.00±0.10	23.03±0.15	22.80	20.17±0.06	21.60	21.57±0.15	22.00	21.20±0.10	21.77±0.15
	Mean pH	6.24±0.01	6.49±0.21	6.59±0.09	6.87±0.07	6.80±0.12	6.85±0.11	6.92±0.13	6.80±0.13	6.89±0.12	6.92±0.12	7.15±0.67	6.89±0.10	6.87±0.11	6.88±0.18	6.95±0.16	6.98±0.16	7.03±0.17	7.11±0.14	7.14±0.13	7.18±0.11	7.19±0.14
	Mean Temp. °C	19.47±0.06	19.83±0.06	19.07±0.06	18.67±0.06	18.97±0.06	19.63±0.06	19.80±0.10	19.93±0.12	21.17±0.06	20.97±0.23	20.80±0.10	21.80±0.10	20.70±0.53	23.03±0.15	22.77±0.06	20.17±0.06	21.57±0.06	21.57±0.15	21.97±0.06	21.20±0.10	21.77±0.15
Variety UP-D 50ppm	Mean cond. µS/cm	197.00	245.00±19.00	268.00±25.00	272.67±23.50	276.67±22.03	278.33±22.05	282.00±20.30	287.00±19.67	291.67±17.90	294.33±16.80	297.00±16.09	299.00±12.77	302.67±12.06	308.00±12.00	306.33±14.29	306.33±15.28	305.00±16.09	304.00±13.00	303.00±14.73	311.00±17.06	332.67±38.08
	Mean Temp. °C	22.10±0.10	21.97±0.12	23.47±0.29	24.17±0.15	23.57±0.21	22.73±0.15	23.70±0.10	23.83±0.35	24.13±0.25	24.00±0.10	23.53±0.15	21.10±0.10	23.77±0.15	24.23±0.25	21.73±0.64	21.00±0.10	19.57±0.12	21.83±0.15	22.77±0.21	24.07±0.21	24.33±0.21
	Mean pH	6.20±0.01	6.44±0.15	6.75±0.08	6.92±0.06	6.69±0.57	7.09±0.05	7.12±0.06	7.15±0.07	7.07±0.06	7.12±0.05	7.15±0.07	7.09±0.07	7.17±0.07	7.25±0.09	7.28±0.10	7.31±0.11	7.14±0.10	7.17±0.14	7.20±0.18	7.19±0.16	7.30±0.23
	Mean Temp. °C	22.10±0.10	21.97±0.12	23.47±0.29	24.17±0.15	23.57±0.21	22.73±0.15	23.77±0.06	23.83±0.35	24.13±0.25	24.07±0.15	23.53±0.15	21.10±0.10	23.80±0.10	24.23±0.25	21.80±0.70	21.00±0.10	19.57±0.12	21.87±0.15	22.77±0.21	24.03±0.15	24.33±0.21

Appendix XII: The Mean conductivity, pH and temperature of zinc solutions in which variety UP-16 was immersed

	Parameter / Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Variety UP-16 0 ppm	Mean cond. µS/cm	1.00	3.00±1.00	3.00	3.00	3.33±1.15	3.33±1.15	3.33±1.15	3.67±0.58	3.67±1.15	3.67±1.15	3.33±1.53	2.67±1.53	2.67±1.53	3.33±1.15	3.33±0.58	3.33±0.58	3.00	2.33±0.58	2.33±1.53	2.33±1.53	2.33±1.53
	Mean Temp. °C	19.57±0.06	20.03±0.12	19.13±0.06	18.77±0.06	18.97±0.06	19.93±0.12	20.33±0.67	20.43±0.12	21.90±0.17	21.30±0.10	21.03±0.12	22.50±0.10	20.83±0.06	23.40±0.10	20.27±0.06	20.20±0.10	21.50	22.10±0.10	22.07±0.06	21.50±0.10	21.50±0.10
	Mean pH	5.63±0.05	5.89±0.58	5.65±0.05	5.72±0.10	5.68±0.10	5.81±0.12	5.87±0.16	6.00±0.17	5.89±0.18	5.89±0.19	5.83±0.17	5.78±0.12	5.84±0.17	5.76±0.20	5.84±0.19	5.82±0.14	5.91±0.06	6.04±0.13	5.98±0.09	5.89±0.02	5.89±0.10
	Mean Temp. °C	19.57±0.06	20.03±0.12	19.17±0.06	18.77±0.06	18.97±0.06	19.93±0.12	20.33±0.67	20.53±0.25	21.87±0.15	21.33±0.12	21.03±0.12	22.50±0.10	20.83±0.06	23.40±0.10	20.20±0.10	20.20±0.10	21.50±0.10	22.10±0.10	22.10	21.50±0.10	21.50±0.10
Variety UP16 10ppm	Mean cond. µS/cm	40.00	59.67±0.58	72.00±3.00	76.00±2.00	78.00±2.65	82.00±2.00	85.00±2.65	86.67±2.31	90.33±1.53	92.67±2.08	94.33±1.53	97.00±2.00	98.67±2.08	102.00±2.65	103.33±4.04	105.00±3.46	107.33±5.77	108.67±4.62	108.67±5.51	108.67±5.51	109.00±5.29
	Mean Temp. °C	19.73±0.06	20.20±0.10	19.23±0.06	18.80	19.13±0.06	19.93±0.06	20.07±0.12	20.30±0.10	21.67±0.12	21.33±0.15	21.13±0.15	22.33±0.15	21.20±0.10	23.53±0.21	22.67±0.23	20.30	20.10	22.03±0.15	22.07±0.06	21.53±0.12	22.57±0.72
	Mean pH	6.09±0.01	6.40±0.28	6.60±0.04	6.82±0.04	6.65±0.06	6.83±0.03	6.87±0.02	6.87±0.01	6.88±0.01	6.88±0.03	6.89±0.08	6.96±0.03	6.95±0.04	6.97±0.03	7.03±0.05	7.05±0.10	7.10±0.06	7.11±0.06	7.15±0.05	7.17±0.05	7.17±0.04
	Mean Temp. °C	19.73±0.06	20.20±0.10	19.23±0.06	18.80	19.13±0.06	19.93±0.06	20.10±0.10	20.33±0.12	21.70±0.17	21.33±0.15	21.17±0.12	22.33±0.15	21.20±0.10	23.57±0.23	22.63±0.21	20.33±0.06	20.10	22.07±0.12	21.77±0.58	21.53±0.12	22.57±0.72
Variety UP-1620ppm	Mean cond. µS/cm	80.00	104.00±1.73	113.33±5.86	117.67±9.07	120.00±8.72	121.67±9.87	124.67±9.87	125.67±9.87	130.33±10.97	130.33±12.86	133.33±13.65	138.33±14.01	140.33±14.74	142.67±17.95	145.33±18.58	147.67±20.82	150.33±19.30	151.67±19.66	151.33±19.09	151.67±18.18	153.33±18.58
	Mean Temp. °C	19.40	19.83±0.06	19.03±0.06	18.60	18.93±0.06	19.60±0.10	19.70±0.10	19.83±0.06	20.97±0.06	21.00±0.10	20.73±0.06	21.70±0.10	20.97±0.06	22.93±0.15	22.80	20.13±0.06	20.70	21.47±0.06	22.00	21.13±0.06	21.73±0.06
	Mean pH	6.26±0.01	6.50±0.11	6.59±0.04	6.79±0.03	6.70±0.06	6.81±0.05	6.80±0.05	6.78±0.01	6.82±0.02	6.89±0.03	6.80±0.04	6.90±0.07	6.91±0.61	6.93±0.11	6.98±0.09	7.00±0.08	7.05±0.08	7.10±0.11	7.11±0.11	7.15±0.11	7.18±0.14
	Mean Temp. °C	19.37±0.06	19.83±0.06	19.03±0.06	18.60	18.93±0.06	19.63±0.06	19.70±0.10	19.83±0.06	20.93±0.12	21.00±0.10	20.80±0.10	21.70±0.10	21.00±0.10	22.93±0.15	22.73±0.06	20.13±0.06	20.70	21.47±0.06	21.93±0.06	21.13±0.06	21.70±0.10
Variety UP-1650ppm	Mean cond. µS/cm	197.00±1.00	249.67±20.43	273.33±22.68	279.00±23.81	287.33±23.63	291.33±26.27	296.33±27.02	302.00±28.69	307.00±31.58	311.33±31.09	315.00±30.41	316.00±32.36	320.00±31.24	324.00±31.18	324.33±30.09	322.33±30.89	325.33±33.50	325.67±35.02	329.00±33.87	335.00±36.10	340.00±41.80
	Mean Temp. °C	22.07±0.06	21.90±0.10	23.47±0.21	24.30±0.10	23.57±0.21	22.70±0.20	23.67±0.15	23.83±0.25	24.17±0.21	24.10±0.10	23.43±0.15	21.27±0.06	23.80±0.10	24.27±0.21	22.03±0.15	21.00±0.10	19.47±0.06	21.77±0.15	22.77±0.12	24.10±0.20	24.23±0.15
	Mean pH	6.19±0.02	6.59±0.09	6.81±0.05	6.94±0.09	7.04±0.04	7.16±0.10	7.18±0.11	7.21±0.13	7.14±0.14	7.18±0.14	7.21±0.15	7.14±0.13	7.22±0.15	7.31±0.17	7.35±0.17	7.39±0.20	7.24±0.16	7.26±0.20	7.27±0.25	7.27±0.22	7.27±0.24
	Mean Temp. °C	22.03±0.06	21.90±0.10	23.47±0.21	24.30±0.10	23.57±0.21	22.73±0.15	23.63±0.15	23.83±0.25	24.13±0.23	24.10±0.20	23.40±0.20	21.30	23.80±0.10	24.23±0.25	22.03±0.15	21.00±0.10	19.47±0.06	21.77±0.15	22.77±0.12	24.07±0.15	24.20±0.10

Appendix XIII: The Mean conductivity, pH and temperature of control experiment for lead solutions setup.

	Paramete r/ Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Control 0 ppm	Mean Cond. µS/cm	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Mean Temp. °C	22.43 ±2.10	21.53 ±0.64	24.83 ±0.15	24.23 ±0.06	23.97 ±0.15	22.77 ±0.06	23.57 ±0.06	24.30 ±0.10	25.40 ±0.10	24.17 ±0.06	23.60 ±0.44	20.93 ±0.06	23.77 ±0.06	25.97 ±0.06	22.20 ±0.10	20.83 ±0.06	19.13 ±0.06	21.47 ±0.59	23.07 ±0.06	24.63 ±0.06	24.90
	Mean pH	5.27± 0.04	5.20± 0.06	5.29± 0.03	5.34± 0.04	5.39± 0.07	5.45± 0.12	5.45± 0.04	5.48± 0.03	5.41± 0.02	5.42± 0.05	5.40± 0.06	5.42± 0.06	5.43± 0.08	5.46± 0.07	5.54± 0.14	5.73± 0.06	5.51± 0.16	5.53± 0.14	5.51± 0.08	5.55± 0.11	5.72± 0.03
	Mean Temp °C	22.43 ±2.10	21.53 ±0.64	24.83 ±0.15	24.20 ±0.10	23.97 ±0.15	22.77 ±0.06	23.50 ±0.10	24.27 ±0.15	25.40 ±0.10	24.17 ±0.06	23.60 ±0.44	20.90	23.80 ±0.10	25.97 ±0.06	22.22 ±0.10	20.83 ±0.08	19.13 ±0.06	21.43 ±0.57	23.08 ±0.06	24.63 ±0.06	24.90
Control 10 ppm	Mean Cond. µS/cm	17.00 ±1.73	17.33 ±1.53	17.67 ±2.89	20.67 ±3.79	23.33 ±3.21	26.67 ±2.08	33.00 ±1.00	40.00 ±1.73	52.67 ±12.9 0	56.00 ±11.7 9	63.00 ±13.0 0	69.00 ±13.4 5	68.33 ±14.2 9	72.67 ±13.5 8	73.67 ±11.6 7	76.33 ±16.3 4	79.00 ±13.3 3	81.33 ±16.6 7	83.47 ±11.6 7	86.33 ±15.0 0	90.33 ±11.3 3
	Mean Temp.°C	22.33 ±0.06	25.93 ±0.45	25.60 ±0.40	27.30 ±0.56	26.20 ±0.50	25.67 ±0.31	26.43 ±0.55	28.90 ±1.21	28.63 ±0.15	26.57 ±0.51	26.13 ±0.47	23.37 ±0.15	23.77 ±0.45	25.23 ±0.46	22.20 ±0.10	20.83 ±0.06	19.13 ±0.06	21.47 ±0.59	23.07 ±0.06	24.63 ±0.06	24.90
	Mean pH	5.31± 0.07	5.47± 0.05	5.43± 0.09	5.52± 0.05	5.19± 0.50	5.45± 0.05	5.56± 0.11	5.41± 0.02	5.48± 0.02	5.65± 0.31	5.75± 0.40	5.74± 0.19	5.62± 31.29	5.86± 0.16	5.45± 0.05	5.56± 0.11	5.41± 0.03	5.48± 0.12	5.65± 0.31	5.75± 0.40	5.74± 0.19
	Mean Temp.°C	22.30 ±0.10	25.93 ±0.51	25.60 ±0.40	27.20 ±0.56	26.17 ±0.45	25.67 ±0.31	26.40 ±0.50	28.24 ±1.70	28.63 ±0.15	26.57 ±0.55	26.07 ±0.45	23.37 ±0.15	23.83 ±0.45	25.10 ±0.35	22.20 ±0.10	20.83 ±0.06	19.13 ±0.06	21.47 ±0.59	23.07 ±0.06	24.63 ±0.06	24.90
Control 20 ppm	Mean Cond. µS/cm	26.00	25.00	28.33 ±0.58	28.00	28.67 ±0.58	30.00	27.67 ±5.77	32.00	33.00	34.00	34.67 ±0.58	36.00	38.00	39.00	39.00	39.67 ±0.58	39.00	41.00	43.00	46.00	49.33 ±0.58
	Mean Temp.°C	24.60	22.07 ±0.06	24.80	24.03 ±0.06	24.20 ±0.10	23.00 ±0.10	23.50 ±0.10	24.50 ±0.20	25.80 ±0.17	24.17 ±0.15	24.30 ±0.17	21.13 ±0.06	23.70 0.10±	25.47 ±3.35	21.90 ±0.10	21.23 ±0.06	19.20	21.73 ±0.06	23.77 ±0.15	25.33 ±0.40	25.33 ±0.06
	Mean pH	5.08± 0.08	5.18± 0.10	5.22± 0.10	5.29± 0.14	5.35± 0.16	5.28± 0.17	5.33± 0.15	5.37± 0.16	5.31± 0.13	5.33± 0.13	5.35± 0.16	5.28± 0.14	5.28± 0.14	5.32± 0.17	5.32± 0.20	5.32± 0.27	5.26± 0.19	5.28± 0.19	5.31± 0.22	5.33± 0.24	5.34± 0.23
	Mean. Temp.°C	24.60	22.07 ±0.06	24.80	24.00 ±0.10	24.20 ±0.10	23.00 ±0.10	23.47 ±0.15	24.50 ±0.20	25.77 ±0.21	24.17 ±0.15	24.30 ±0.17	21.13 ±0.06	23.70 ±0.10	25.47 ±3.35	21.93 ±0.15	21.23 ±0.06	19.20	21.70 ±0.10	23.73 ±0.12	25.63 ±0.21	25.30
Control 50 ppm	Mean Cond. µS/cm	70.00	71.33 1.15±	72.00 ±	73.33 ±1.15	75.33 ±1.15	76.67 ±0.58	78.00 ±1.00	79.67 ±1.15	81.67 ±1.53	83.33 ±1.15	84.67 ±0.58	85.67 ±1.15	87.33 ±0.58	90.33 ±0.58	90.67 ±0.58	91.00	93.67 ±47.3 4	94.00	95.33 ±57.7 4	98.00	102.0 0
	Mean Temp.°C	22.13 ±0.06	21.90 ±0.10	23.23 ±0.12	24.20 ±0.10	23.50 ±0.10	22.53 ±0.15	23.57 ±0.15	23.57 ±0.15	24.17 ±0.15	24.33 ±0.15	23.53 ±0.12	21.13 ±0.06	23.60 ±0.44	24.17 ±0.15	22.23 ±0.15	20.83 ±0.12	19.30 ±0.10	21.80 ±0.10	22.87 ±0.15	24.03 ±0.15	24.67 ±0.15
	Mean pH	5.33± 0.03	5.34± 0.06	5.36± 0.05	5.40± 0.04	5.41± 0.03	5.39± 0.06	5.44± 0.05	5.51± 0.05	5.49± 0.06	5.52± 0.05	5.53± 0.05	5.46± 0.06	5.59± 0.10	5.60± 0.07	5.62± 0.09	5.64± 0.10	5.57± 0.02	5.50± 0.09	5.48± 0.09	5.57± 0.09	5.60± 0.10
	Mean Temp.°C	22.10 ±0.10	21.90 ±0.10	23.23 ±0.12	24.20 ±0.10	23.50 ±0.10	22.57 ±0.15	23.57 ±0.15	23.57 ±0.15	24.17 ±0.15	24.27 ±0.15	23.53 ±0.12	21.13 ±0.06	23.60 ±0.44	24.17 ±0.15	22.23 ±0.06	20.83 ±0.12	19.30 ±0.10	21.80 ±0.10	22.90 ±0.10	24.03 ±0.15	24.67 ±0.15

Appendix XIV: The Mean conductivity, pH and temperature of lead solutions in which variety UP-A was immersed

Variety	Parameter/ Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Variety UP-A 0 ppm	Mean Cond. µS/cm	0.00	7.33±0.58	10.00±1.73	10.00±1.73	10.00±1.73	9.67±1.53	10.00±1.73	10.00±1.73	11.00±1.73	11.33±1.53	11.00±2.65	10.00±3.00	9.67±3.51	9.33±4.04	9.00±4.58	9.00±4.58	9.67±5.51	9.67±5.51	9.67±5.51	9.33±5.51	9.00±5.57
	Mean Temp.°C	24.90±0.10	21.93±0.06	25.27±0.25	24.27±0.06	24.00±0.10	22.63±0.21	23.43±0.21	24.57±0.25	25.23±0.55	24.20±0.10	23.60±1.04	20.93±0.06	23.70±0.10	26.83±0.12	22.23±0.06	20.87±0.06	19.20	21.80±0.10	23.23±0.12	24.73±0.23	24.97±0.12
	Mean pH	5.23±0.02	6.26±0.12	6.45±0.16	6.53±0.14	6.59±0.15	6.56±0.17	6.58±0.13	6.55±0.07	6.50±0.04	6.42±0.08	6.30±0.10	6.26±0.14	6.21±0.19	6.14±0.29	6.36±0.33	6.44±0.35	6.25±0.42	6.24±0.48	6.56±5.91	6.27±0.54	6.68±0.36
	MEAN. Temp.°C	24.90±0.10	21.93±0.06	25.27±0.25	24.23±0.06	24.00±0.10	22.63±0.21	23.40±0.20	24.57±0.25	25.23±0.55	24.17±0.06	23.60±1.04	20.93±0.06	23.70±0.10	26.80±0.10	22.20±0.10	20.83±0.06	19.20	21.77±0.15	23.23±0.12	24.73±0.23	24.97±0.12
Variety UP-A 10 ppm	Mean Cond. µS/cm	15.33±0.58	24.67±3.06	31.67±5.51	37.33±4.93	41.00±5.29	42.67±6.66	45.33±7.09	52.67±8.08	55.67±12.22	63.00±11.27	77.00±15.13	68.67±11.72	69.33±10.97	68.33±10.97	67.67±10.88	67.67±10.88	68.33±11.00	68.33±11.00	68.33±11.00	68.33±10.97	67.67±10.88
	Mean Temp.°C	22.33±0.06	26.00±0.56	25.53±0.35	26.90±0.40	26.43±0.35	25.97±0.21	26.50±0.30	26.43±0.25	26.43±0.25	26.60±0.36	26.03±0.31	23.40±0.17	24.00±0.17	25.40	22.2±0.22	20.85±0.06	20.10±0.52	21.85±0.15	23.25±0.23	24.7±0.22	25.00±0.11
	Mean pH	5.45±0.01	6.07±0.13	6.29±0.20	6.51±0.19	6.57±0.19	6.64±0.24	6.69±0.17	6.89±0.09	6.95±0.15	6.98±0.20	6.98±0.16	6.85±0.15	6.99±0.09	6.95±0.13	6.68±0.05	6.95±0.11	6.88±0.03	6.67±0.13	6.87±0.01	6.63±0.13	6.90±0.20
	Mean. Temp.°C	22.67±0.55	25.87±0.40	25.50±0.30	26.83±0.35	26.30±0.30	25.97±0.21	26.43±0.25	26.43±0.25	26.03±4.53	26.57±0.40	25.93±0.31	23.33±0.15	23.87±0.38	25.17±0.32	22.2±0.22	20.85±0.06	20.10±0.52	21.85±0.15	23.25±0.23	24.7±0.22	25.00±0.11
Variety UP-A 20ppm	Mean Cond. µS/cm	26.00	37.33±5.51	47.00±2.65	48.00±9.64	52.33±10.79	53.33±10.02	55.67±9.45	58.33±8.33	61.67±5.86	63.67±3.21	66.33±2.31	67.67±4.16	69.67±7.77	75.00±15.52	74.67±21.13	75.33±30.73	79.33±38.89	85.67±51.19	93.00±61.99	107.00±81.47	115.33±88.46
	Mean Temp.°C	23.60±0.10	22.07±0.06	24.40±0.10	24.10±0.10	24.13±0.15	22.97±0.15	23.50±0.10	24.27±0.15	25.20±0.56	24.23±0.06	24.20±0.17	21.17±0.06	23.87±0.06	27.07±0.42	22.13±0.15	21.20±0.10	19.33±0.06	21.80±0.10	23.67±0.32	25.70±0.17	24.70±1.05
	Mean pH	5.32±0.04	5.99±0.15	6.20±0.32	6.21±0.64	6.53±0.35	6.58±0.30	6.67±0.32	6.73±0.34	6.71±0.35	6.73±0.32	6.75±0.27	6.74±0.25	6.72±0.06	6.85±0.14	6.94±0.16	6.98±0.27	6.98±0.25	7.06±0.27	7.18±0.20	7.16±0.17	7.30±0.18
	Mean Temp.°C	23.63±0.06	22.10	24.40±0.10	24.10±0.10	24.13±0.15	22.97±0.15	23.80±0.44	24.27±0.15	25.20±0.56	24.27±0.06	24.23±0.21	21.20	23.87±0.06	27.10±0.36	22.10±0.10	21.17±0.06	19.30	21.80±0.20	23.63±0.31	25.70±0.17	24.70±1.05
Variety UP-A 50 ppm	Mean Cond. µS/cm	70.00	75.67±2.89	81.00±4.36	83.33±4.51	85.67±5.13	86.67±5.13	88.67±4.51	90.67±4.04	93.00±5.00	95.00±5.57	96.67±6.11	97.33±3.79	100.33±4.04	103.67±5.51	105.00±5.57	106.33±6.11	107.00±7.21	113.00±7.81	119.67±11.93	129.67±13.05	141.67±18.82
	Mean Temp.°C	22.07±0.06	21.93±0.06	23.33±0.25	24.20±0.10	23.57±0.15	22.57±0.15	23.53±0.12	23.60±0.10	24.23±0.15	24.13±0.15	23.23±0.64	21.20	23.80±0.10	24.27±0.25	22.07±0.21	20.83±0.12	19.37±0.06	21.87±0.15	22.87±0.12	24.00±0.10	24.70±0.10
	Mean pH	5.38±0.02	5.71±0.10	5.73±0.08	5.87±0.10	5.71±0.31	6.00±0.13	6.28±0.54	5.94±0.34	6.07±0.15	6.09±0.16	6.11±0.19	6.10±0.14	6.15±0.16	6.23±0.15	6.26±0.14	6.31±0.16	6.24±0.17	6.35±0.20	6.40±0.25	6.41±0.25	6.64±0.28
	Mean Temp.°C	22.07±0.06	21.93±0.06	23.33±0.25	24.13±0.12	23.57±0.15	22.57±0.15	23.53±0.12	23.60±0.10	24.23±0.15	24.13±0.15	23.23±0.64	21.20	23.80±0.10	24.27±0.25	22.03±0.21	20.80±0.10	19.37±0.06	21.83±0.15	22.87±0.12	24.00±0.10	24.70±0.10

Appendix XV: The Mean conductivity, pH and temperature of lead solutions in which variety UP-B was immersed

Variety	Parameter/ Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Variety UP-B 0 ppm	Mean Cond. µS/cm	0.00	15.00 ±3.61	18.00 ±3.46	21.00 ±6.24	21.00 ±7.81	22.00 ±9.64	22.00 ±9.64	22.33 ±10.02	24.67 ±11.15	23.67 ±10.41	22.67 ±9.45	17.67 ±6.51	17.67 ±6.51	17.67 ±6.51	17.00 ±6.56	17.67 ±6.51	15.67 ±4.51	10.00 ±8.54	14.7.00±229.52	13.67 ±3.79	14.00 ±3.61
	Mean Temp.°C	24.93 ±0.15	22.00 ±0.10	25.13 ±0.35	23.07 ±1.24	24.17 ±0.35	22.77 ±0.25	23.40 ±0.10	24.27 ±0.25	25.40 ±0.26	24.13 ±0.12	23.87 ±0.21	20.97 ±0.12	23.50 ±0.44	25.30 ±2.69	22.23 ±0.15	21.03 ±0.15	19.07 ±0.06	21.83 ±0.15	23.60	25.17 ±0.25	25.10 ±0.10
	Mean pH	5.24± 0.05	6.26± 0.11	6.37± 0.08	6.41± 0.04	6.450. 04±	6.58± 0.06	6.51± 0.05	6.48± 0.08	6.77± 5.72	6.40± 0.17	6.36± 0.21	6.29± 0.17	6.29± 0.17	6.28± 0.19	6.41± 0.20	6.56± 0.22	6.26± 0.20	6.29± 0.18	6.32± 0.17	6.31± 0.19	6.43± 22.95
	Mean Temp.°C	24.90 ±0.20	22.00 ±0.10	25.13 ±0.35	23.03 ±1.27	24.17 ±0.35	22.77 ±0.25	23.37 ±0.15	24.27 ±0.25	25.40 ±0.26	24.13 ±0.21	23.87 ±0.21	20.97 ±0.12	23.50 ±0.44	25.37 ±2.66	22.17 ±0.15	21.03 ±0.15	19.07 ±0.06	21.80 ±0.10	23.63 ±0.06	25.20 ±0.20	25.13 ±0.06
Variety UP-B 10 ppm	Mean Cond. µS/cm	15.67 ±0.58	34.00 ±2.00	47.33 ±1.53	57.33 ±1.53	67.33 ±4.04	73.33 ±4.51	76.67 ±8.33	77.00 ±15.72	72.67 ±17.79	63.00 ±22.72	58.00 ±18.73	49.67 ±22.81	44.33 ±19.66	40.00 ±19.47	42.67 ±22.37	42.33 ±18.33	36.67 ±14.33	35.00 ±12.67	33.67 ±11.66	31.53 ±9.67	31.53 ±9.67
	Mean Temp.°C	22.33 ±0.06	25.83 ±0.59	25.40 ±0.36	26.90 ±0.46	26.70 ±0.50	26.10 ±0.30	26.70 ±0.72	28.57 ±1.26	28.73 ±0.12	26.30 ±0.30	25.83 ±0.35	23.20 ±0.10	23.70 ±0.26	25.13 ±0.25	22.23 ±0.15	21.03 ±0.15	19.07 ±0.06	21.83 ±0.15	23.60	25.17 ±0.25	25.10 ±0.10
	Mean pH	5.48± 0.02	6.39± 0.01	6.69± 0.02	6.94± 0.07	6.98± 0.11	6.97± 0.16	6.94± 0.18	6.92± 0.17	6.94± 0.16	6.67± 0.20	6.64± 0.18	6.66± 0.17	6.67± 0.27	6.65± 0.20	6.69± 0.21	6.68± 0.16	6.69± 0.03	6.58± 0.24	6.67± 0.16	6.69± 0.18	6.72± 0.21
	Mean Temp.°C	22.27 ±0.15	25.77 ±0.55	25.40 ±0.36	26.87 ±0.40	26.67 ±0.45	26.10 ±0.30	26.67 ±0.76	28.50 ±1.25	28.73 ±0.12	26.27 ±0.35	25.77 ±0.35	23.20 ±0.10	23.77 ±0.31	25.00 ±0.26	22.23 ±0.15	21.03 ±0.15	19.07 ±0.06	21.83 ±0.15	23.60	25.17 ±0.25	25.10 ±0.10
Variety UP-B 20 ppm	Mean Cond. µS/cm	25.33 ±0.58	49.00 ±2.65	65.67 ±6.66	75.67 ±4.73	90.33 ±3.51	100.00±1.73	103.33±0.58	110.33±9.29	126.00±20.30	124.00±24.76	121.00±29.60	110.00±30.35	109.00±35.68	109.00±41.87	105.67±42.10	96.67 ±47.37	94.67 ±51.54	93.33 ±52.58	83.00 ±37.27	92.00 ±55.43	90.33 ±56.87
	Mean Temp.°C	22.97 ±0.06	22.00	23.97 ±0.15	24.10 ±0.10	23.90 ±0.10	22.80 ±0.10	23.63 ±0.12	24.07 ±0.15	24.67 ±0.61	24.30 0	23.83 ±0.15	21.17 ±0.06	23.80 ±0.10	25.80 ±0.36	22.50 ±0.70	21.03 ±0.06	19.33 ±0.06	21.90 ±0.10	22.97 ±0.12	23.37 ±1.54	25.30 ±0.10
	Mean pH	5.47± 0.04	6.32± 0.11	6.51± 0.27	6.82± 0.19	7.00± 0.12	7.00± 0.09	6.77± 0.50	7.07± 0.05	7.03± 0.06	7.02± 0.06	7.01± 0.06	6.97± 0.11	6.93± 0.13	6.90± 0.21	7.13± 0.13	7.31± 0.22	7.14± 0.08	7.24± 0.08	7.22± 0.07	7.24± 0.05	7.26± 0.14
	Mean Temp.°C	22.97 ±0.06	22.00	23.97 ±0.15	24.13 ±0.06	23.90 ±0.10	22.80 ±0.10	23.63 ±0.15	24.07 ±0.15	24.67 ±0.61	24.33 ±0.06	23.83 ±0.15	21.17 ±0.06	23.77 ±0.15	25.77 ±0.35	22.50 ±0.70	21.03 ±0.06	19.33 ±0.06	21.93 ±0.12	23.00 ±0.10	23.37 ±1.54	25.33 ±0.12
Variety UP-B 50 ppm	Mean Cond. µS/cm	70.00	84.33 ±1.15	101.33±7.51	122.67±13.65	132.33±16.17	139.67±18.88	146.67±21.59	155.00±25.63	169.00±31.51	171.67±34.50	174.33±36.07	174.00±36.04	177.33±37.11	181.00±36.17	178.00±35.68	176.33±35.92	176.67±36.91	179.67±39.32	183.00±41.07	188.67±40.38	195.00±43.49
	Mean. Temp.°C	22.07 ±0.06	21.87 ±0.06	22.63 ±1.10	24.23 ±0.15	23.63 ±0.25	22.63 ±0.25	23.57 ±0.06	23.53 ±0.47	24.37 ±0.25	24.10 ±0.20	23.60 ±0.20	21.23 ±0.06	23.83 ±0.12	24.43 ±0.38	22.07 ±0.15	21.00 ±0.10	19.40 ±0.17	21.97 ±0.06	22.87 ±0.25	24.07 ±0.21	24.57 ±0.23
	MEAN pH	5.43± 0.02	6.05± 0.03	6.42± 0.07	6.67± 0.12	6.90± 0.13	6.69± 0.49	7.05± 0.13	7.10± 0.11	7.09± 0.11	7.09± 0.10	7.09± 0.10	7.12± 0.12	7.16± 0.12	7.20± 0.12	7.26± 0.10	7.30± 0.09	7.15± 0.12	7.18± 0.12	7.22± 0.14	7.22± 0.10	7.29± 0.13
	Mean Temp.°C	22.07 ±0.06	21.87 ±0.06	22.63 ±1.10	24.17 ±0.15	23.63 ±0.25	22.63 ±0.25	23.57 ±0.15	23.53 ±0.47	24.37 ±0.25	24.13 ±0.15	23.77 ±0.15	21.20 ±0.10	23.77 ±0.15	24.43 ±0.38	22.17 ±0.15	21.27 ±0.57	19.40 ±0.17	21.90 ±0.10	22.83 ±0.31	24.07 ±0.21	24.57 ±0.23

Appendix XVI: The Mean conductivity, pH and temperature of lead solutions in which variety UP-C was immersed

Variety	Parameter/ Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Variety UP-C 0 ppm	Mean Cond. µS/cm	0.00	6.33±1.53	9.00±1.73	9.00±1.73	8.67±1.15	8.67±1.15	8.00	8.00	8.00	8.00	8.00	7.00±1.00	6.671.15±	6.67±1.15	6.67±1.15	6.67±1.15	7.00±1.73	7.33±1.53	7.33±2.31	7.33±2.31	7.33±2.31
	Mean Temp.°C	24.67±0.12	21.97±0.15	25.00±0.56	24.23±0.06	24.03±0.42	22.77±0.21	23.67±0.06	24.40±0.53	25.43±0.61	24.17±0.15	23.90±0.36	20.93±0.06	23.80±0.10	26.70±1.01	22.17±0.15	20.87±0.12	19.03±0.06	21.90±0.10	23.33±0.45	25.37±0.12	25.17±0.06
	Mean pH	5.21±0.01	6.00±0.06	6.13±0.07	6.19±0.12	6.24±0.16	6.23±0.13	6.27±0.17	6.34±0.20	6.20±0.25	6.09±0.26	6.26±0.56	5.97±0.09	5.95±0.07	5.90±0.08	6.04±0.05	6.16±0.06	5.83±0.04	5.84±0.07	5.87±0.13	5.86±0.13	5.96±0.06
	Mean Temp.°C	24.67±0.12	21.93±0.15	25.00±0.56	24.20±0.10	24.00±0.46	22.77±0.21	23.67±0.12	24.40±0.53	25.43±0.61	24.17±0.15	23.90±0.36	20.90	23.80±0.10	26.63±1.07	22.17±0.15	20.87±0.12	19.07±0.06	21.80±0.10	23.33±0.45	25.37±0.12	25.23±0.06
Variety UP-C 10 ppm	Mean Cond. µS/cm	17.33±1.53	26.67±4.93	37.00±5.20	45.00±5.00	48.00±4.00	52.00±4.58	55.67±5.69	55.67±7.37	47.67±10.02	39.67±9.07	37.33±8.74	31.00±10.82	28.33±10.69	27.00±10.54	27.00±10.54	27.00±10.54	25.67±11.37	25.00±10.27	18.67±9.67	17.33±8.67	15.67±6.67
	Mean Temp.°C	22.37±0.06	25.67±0.47	25.30±0.36	26.60±0.40	26.93±0.81	26.40±0.36	26.40±0.53	27.87±0.70	28.20±0.20	26.03±0.25	25.60±0.26	22.77±0.12	23.70±0.36	24.47±0.21	22.17±0.15	20.97±0.15	19.43±0.06	21.93±0.12	22.70±0.17	23.93±0.21	24.63±0.21
	Mean pH	5.46±0.06	6.53±0.07	6.54±0.15	6.78±0.11	6.87±0.05	6.82±0.05	6.78±0.12	6.76±0.12	6.74±0.21	6.61±0.15	6.59±0.12	6.61±0.13	6.64±0.23	6.59±0.15	6.76±0.12	6.74±0.21	6.78±0.11	6.87±0.05	6.87±0.05	6.82±0.05	6.78±0.12
	MEAN. Temp.°C	22.33±0.06	25.67±0.38	25.27±0.31	26.57±0.35	26.87±0.76	26.37±0.38	26.30±0.53	27.80±0.66	28.20±0.20	25.67±0.85	25.60±0.26	22.77±0.06	23.73±0.32	24.77±0.47	22.17±0.15	20.97±0.15	19.43±0.06	21.93±0.12	22.70±0.17	23.93±0.21	24.63±0.21
Variety UP-C 20 ppm	Mean Cond. µS/cm	25.00	47.67±4.51	66.00±10.15	77.00±14.53	92.00±18.52	103.67±24.70	112.67±20.60	119.00±22.11	122.33±22.37	120.00±22.27	119.00±22.52	111.00±21.38	107.33±23.69	104.00±24.33	95.00±23.30	89.00±24.76	84.00±25.24	81.67±25.79	79.67±26.76	77.67±28.71	74.33±31.21
	Mean Temp.°C	22.87±0.64	22.03±0.06	23.67±0.21	24.20±0.10	23.73±0.15	22.70±0.10	23.67±0.12	23.83±0.15	24.57±0.15	24.20±0.17	23.70±0.10	21.20±0.10	23.73±0.15	25.07±0.21	22.13±0.15	21.03±0.06	19.37±0.06	21.90±0.10	22.83±0.21	24.20±0.17	24.73±1.15
	Mean pH	5.12±0.59	6.38±0.17	6.58±0.11	6.86±0.09	7.05±0.10	7.01±0.06	7.03±0.05	7.05±0.07	6.98±0.07	7.00±0.03	6.92±0.11	6.85±0.13	6.90±0.16	6.93±0.16	7.05±0.26	6.97±0.03	6.90±0.27	6.88±0.27	6.87±0.31	6.90±0.27	6.83±0.35
	Mean. Temp.°C	22.87±0.64	22.03±0.06	23.67±0.21	24.13±0.12	23.73±0.15	22.63±0.15	23.63±0.15	23.83±0.15	24.57±0.15	24.10±0.17	23.70±0.10	21.17±0.15	23.70±0.10	25.03±0.25	22.10±0.20	21.03±0.06	19.37±0.06	21.90±0.10	22.80±0.17	24.17±0.21	25.37±0.12
Variety UP-C 50 ppm	Mean Cond. µS/cm	70.00	85.00±3.46	114.33±4.51	130.67±6.11	146.00±10.54	155.33±11.59	162.67±14.05	177.00±20.52	182.33±15.18	188.67±13.32	196.00±12.49	197.33±9.07	201.67±7.57	206.67±4.93	205.00±4.00	204.00±3.61	203.67±4.62	209.33±6.51	214.00±9.17	224.00±13.00	234.67±19.30
	Mean. Temp.°C	22.10	21.93±0.06	23.47±0.31	24.20±0.10	23.67±0.64	22.73±0.15	23.70±0.10	23.67±0.35	24.27±0.31	24.10±0.20	23.53±0.25	21.23±0.06	23.83±0.15	24.23±0.35	22.17±0.15	21.00±0.10	19.47±0.06	21.90±0.10	22.73±0.15	23.93±0.21	24.63±0.21
	Mean pH	5.44±0.01	6.11±0.05	6.50±0.05	6.74±0.02	6.99±0.01	7.09±0.08	7.14±0.08	7.18±0.08	7.09±0.06	7.09±0.02	7.08±0.03	7.06±0.04	7.16±0.01	7.26±0.05	7.32±0.04	7.37±0.12	7.52±0.32	7.42±0.14	7.50±0.13	7.56±0.12	7.71±0.08
	Mean Temp.°C	22.10	21.93±0.06	23.47±0.31	24.17±0.15	23.67±0.64	22.73±0.15	23.70±0.10	23.67±0.35	24.27±0.31	24.07±0.25	23.53±0.25	21.20	23.80±0.10	24.23±0.35	22.17±0.15	20.97±0.15	19.43±0.06	21.93±0.12	22.70±0.17	23.93±0.21	24.63±0.21

Appendix XVII: The Mean conductivity, pH and temperature of lead solutions in which variety UP-D was immersed

Variety	Parameter/ Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Variety UP-D 0 ppm	Mean Cond. µS/cm	0.00	8.67±2.08	10.33±2.31	11.00±1.73	12.00±1.73	11.00±1.73	10.67±1.15	9.67±1.15	9.67±1.15	9.67±1.15	9.67±1.15	7.67±1.15	8.00±1.00	8.00±1.00	8.00±1.00	7.33±1.53	6.33±0.58	6.67±0.58	7.33±0.58	7.67±0.58	8.33±0.58
	Mean. Temp.°C	25.10±0.10	22.00±	25.03±0.35	24.30±0.10	24.10±0.20	22.60±0.36	23.57±0.06	24.17±0.15	25.23±0.15	24.27±0.06	23.67±0.23	21.03±0.15	23.60±0.44	26.10±0.87	22.23±0.15	20.97±0.06	19.07±0.06	21.90±0.10	23.33±0.15	25.17±0.12	25.23±0.12
	Mean pH	5.20±0.04	6.03±0.07	6.19±0.08	6.23±0.09	6.28±0.12	6.27±0.15	6.30±0.17	6.31±0.18	6.24±0.11	6.12±0.15	6.11±0.14	6.01±0.19	5.99±0.20	5.97±0.21	6.11±0.10	6.17±0.13	5.87±0.06	5.88±0.02	5.83±0.05	5.87±0.03	5.85±0.10
	Mean Temp.°C	25.10±0.10	22.00	25.03±0.35	24.30±0.10	24.10±0.20	22.60±0.36	23.57±0.12	24.17±0.15	25.23±0.15	24.23±0.15	23.70±0.17	20.97±0.06	23.63±0.47	26.10±0.87	22.20±0.10	20.97±0.06	19.03±0.06	21.87±0.15	23.33±0.15	25.17±0.12	25.20±0.10
Variety UP-D 10 ppm	Mean Cond. µS/cm	15.00±2.65	30.67±1.53	44.33±2.31	54.33±3.21	63.67±5.51	72.67±8.14	75.67±8.33	76.67±8.02	69.00±7.55	59.33±7.77	54.00±7.55	50.67±10.2	45.33±9.45	43.33±10.9	43.67±9.67	42.33±10.3	40.67±9.33	39.33±10.6	36.33±8.76	33.67±8.63	31.00
	Mean Temp.°C	22.30±0.10	25.47±0.40	25.07±0.31	26.43±0.35	27.07±0.70	26.60±0.56	26.23±0.42	27.53±0.71	27.17±0.25	25.87±0.21	25.53±0.25	22.43±0.15	23.67±0.25	24.47±0.23	22.25±0.07	21.05 0.07±	19.35±0.07	21.75±0.07	22.85±0.07	24.10	24.75±0.07
	Mean pH	5.40±0.03	6.30±0.13	6.59±0.03	6.86±0.07	6.89±0.07	6.91±0.10	6.86±0.10	6.85±0.05	6.78±0.22	6.62±0.12	6.55±0.13	6.55±0.18	6.60±0.23	6.54±0.19	6.78±0.21	6.62±0.14	6.55±0.13	6.55±0.18	6.59±0.06	6.86±0.09	6.89±0.07
	Mean. Temp.°C	22.30±0.10	25.43±0.35	25.10±0.30	26.43±0.35	27.07±0.70	26.40±0.61	26.23±0.42	27.47±0.76	27.17±0.25	25.50±0.56	25.10±0.36	22.50±0.10	23.70±0.20	24.37±0.32	22.25±0.07	21.05 0.07±	19.35±0.07	21.75±0.07	22.85±0.07	24.10	24.75±0.07
Variety UP-D 20 ppm	Mean Cond. µS/cm	25.00	57.67±16.86	87.67±33.38	103.33±37.90	122.33±48.23	145.33±62.93	155.33±69.87	166.67±77.39	173.33±83.72	174.67±92.09	175.33±101.08	171.33±114.93	171.67±130.19	172.00±142.90	82.00±5.66	72.00±4.24	66.50±4.95	61.00±4.24	54.50±6.36	52.50±7.78	50.50±7.78
	Mean. Temp.°C	22.40±0.10	21.90	23.50±0.10	24.20±0.10	23.70±0.10	22.70±0.20	23.63±0.15	23.83±0.12	24.40±0.10	24.33±0.06	23.60±0.10	21.23±0.06	23.83±0.12	24.63±0.15	22.25±0.07	21.05±0.07	19.35±0.07	21.85±0.07	22.80	24.10	24.70
	Mean pH	5.52±0.02	6.33±0.27	6.71±0.18	6.78±0.25	7.12±0.04	7.14±0.07	7.15±0.08	7.18±0.07	7.13±0.11	7.10±0.17	7.08±0.23	7.00±0.24	7.07±0.31	7.09±0.36	6.94±0.08	6.98±0.11	6.84±0.08	6.86±0.19	6.83±0.28	6.90±0.16	6.85±0.25
	Mean Temp.°C	22.40±0.10	21.90	23.50±0.07	24.17	23.70±0.07	22.70±0.14	23.63±0.14	23.83	24.40±0.07	24.23±0.14	23.60±0.07	21.23±0.07	23.83±0.14	24.63±0.21	22.25±0.07	21.05 0.07±	19.35±0.07	21.75±0.07	22.85±0.07	24.10	24.75±0.07
Variety UP-D 50 ppm	Mean Cond. µS/cm	70.00	85.33±5.51	112.67±8.50	138.33±15.50	162.33±26.08	171.67±23.54	182.67±23.18	193.67±24.85	218.67±37.87	223.33±38.08	230.33±36.46	230.00±36.17	232.00±38.00	236.67±38.44	232.00±38 00	226.67±37.23	222.33±38.70	141.00±98.81	226.33±42.25	231.67±45.00	235.33±54.64
	Mean Temp.°C	22.07±0.06	21.93±0.15	23.43±0.35	24.20±0.10	23.97±0.81	22.63±0.25	23.70±0.10	23.73±0.25	24.33±0.25	24.10±0.20	23.57±0.21	21.23±0.12	23.80±0.10	24.27±0.35	22.50±0.69	20.93±0.06	19.47±0.06	21.93±0.06	22.43±0.31	23.83±0.31	24.40±0.26
	Mean pH	5.46	6.08±0.07	6.39±0.10	6.75±0.08	6.71±0.52	6.88±0.54	7.24±0.04	7.27±0.05	7.22±0.12	7.26±0.13	7.27±0.14	7.23±0.14	7.29±0.13	7.33±0.15	7.38±0.15	7.43±0.17	7.24±0.17	7.19±0.18	7.28±0.15	7.30±0.11	7.41±0.11
	Mean Temp.°C	22.07±0.06	21.93±0.15	23.43±0.35	24.23±0.15	23.97±0.81	22.63±0.25	23.70±0.10	23.73±0.25	24.33±0.25	24.07±0.21	23.60±0.20	21.23±0.12	23.80±0.10	24.27±0.35	22.53±0.67	20.93±0.06	19.47±0.06	21.93±0.06	22.43±0.31	23.83±0.35	24.43±0.31

Appendix XVIII: The Mean conductivity, pH and temperature of lead solutions in which variety UP-16 was immersed

	Parameter/ Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Variety UP-16 0 ppm	Mean Cond. µS/cm	0.00	10.33 ±2.08	12.33 ±1.15	12.00 ±1.00	12.33 ±1.53	10.33 ±0.58	9.67±1.15	9.00±1.73	9.00±1.73	8.67±1.15	8.00±1.00	7.00	7.67±0.58	7.67±0.58	7.67±0.58	7.67±0.58	7.67±1.15	8.00±1.00	8.33±1.53	8.00±1.00	8.00±1.00
	Mean Temp.°C	26.07 ±0.12	22.13 ±0.06	24.43 ±1.36	24.20 ±0.10	24.23 ±0.32	23.57 ±1.07	23.57 ±0.15	24.30 ±0.26	25.50 ±0.17	24.10 ±0.17	23.73 ±0.15	21.00	23.80	26.00 ±0.60	22.20 ±0.10	21.00 ±0.10	19.13 ±0.06	21.57 ±0.67	23.27 ±0.40	24.87 ±0.23	25.13 ±0.15
	Mean pH	5.28±0.01	6.01±0.05	6.09±0.08	6.17±0.08	6.25±0.08	6.28±0.08	6.30±0.07	6.31±0.07	6.25±0.14	6.21±0.06	6.23±0.08	6.12±0.05	6.16±0.07	6.11±0.03	6.14±0.04	6.18±0.02	6.11±0.03	6.04±0.04	6.00±0.11	6.04±0.08	5.97±0.15
	Mean Temp.°C	26.03 ±0.06	22.13 ±0.06	24.43 ±1.36	24.23 ±0.15	24.23 ±0.32	23.57 ±1.07	23.57 ±0.15	24.30 ±0.26	25.50 ±0.17	24.10 ±0.20	23.73 ±0.15	20.70 ±0.53	23.70 ±0.10	26.03 ±0.60	22.20 ±0.10	21.07 ±0.06	19.17 ±0.06	21.53 ±0.64	23.27 ±0.40	24.87 ±0.23	25.13 ±0.15
Variety UP-16	Mean Cond. µS/cm	15.67 ±1.15	30.00 ±3.61	43.00 ±4.58	53.00 ±3.61	59.00 ±1.00	63.67 ±3.79	70.67 ±2.08	69.67 ±5.86	64.00 ±7.21	59.67 ±10.41	55.67 ±12.34	70.33 ±39.53	69.67 ±38.42	68.33 ±38.08	66.67 ±32.33	63.67 ±30.67	59.67 ±16.57	56.33 ±12.33	54.00 ±19.67	51.33 ±16.37	48.67 ±11.67
	Mean Temp.°C	22.23 ±0.06	25.23 ±0.51	24.93 ±0.35	26.10 ±0.40	27.30 ±1.08	26.97 ±1.03	26.07 ±0.40	27.03 ±0.55	26.23 ±0.25	25.77 ±0.25	25.33 ±0.21	22.33 ±0.21	23.63 ±0.21	24.23 ±0.23	22.17 ±0.15	20.93 ±0.15	19.97 ±0.98	21.87 ±0.06	22.70 ±0.26	23.87 ±0.51	24.43 ±0.40
	Mean pH	5.41±0.03	6.45±0.07	6.58±0.05	6.79±0.05	6.89±0.05	6.87±0.09	6.83±0.10	6.80±0.14	6.74±0.14	6.67±0.17	6.66±0.20	6.60±0.14	6.80±0.19	6.66±0.17	6.58±0.05	6.79±0.09	6.89±0.08	6.87±0.09	6.83±0.10	6.80±0.14	6.74±0.14
	Mean Temp.°C	22.20 ±0.10	25.17 ±0.47	24.90 ±0.30	26.07 ±0.35	27.30 ±0.98	26.90 ±0.92	26.03 ±0.35	26.87 ±0.60	26.23 ±0.25	25.63 ±0.25	25.30 ±0.26	22.37 ±0.15	23.70 ±0.26	24.20 ±0.30	22.17 ±0.15	20.93 ±0.15	19.97 ±0.98	21.87 ±0.06	22.70 ±0.26	23.87 ±0.51	24.43 ±0.40
Variety UP-1620ppm	Mean Cond. µS/cm	25.00	49.00 ±9.85	66.00 ±12.77	78.33 ±14.29	91.33 ±18.58	103.33±36.56	107.67±37.82	111.67±39.21	114.33±37.55	113.67±34.53	111.67±31.01	108.00±26.51	104.67±21.03	102.67±16.17	96.33 ±11.15	89.67 ±18.01	95.00 ±33.05	93.67 ±13.33	87.33 ±18.37	85.00 ±12.67	83.67 ±16.67
	Mean Temp.°C	22.23 ±0.23	21.93 ±0.06	23.27 ±0.12	24.30 ±0.10	23.47 ±0.12	22.57 ±0.12	23.57 ±0.06	23.67 ±0.12	24.27 ±0.12	24.10 ±0.17	22.83 ±1.33	22.10 ±1.39	25.57 ±2.80	23.60 ±1.39	21.80 ±0.78	20.47 ±0.92	20.13 ±1.36	21.87 ±0.06	22.70 ±0.26	23.87 ±0.51	24.43 ±0.40
	Mean pH	5.51±0.03	6.23±0.10	6.56±0.03	6.79±0.09	7.08±0.07	7.07±0.06	7.10±0.10	7.14±0.15	7.11±0.14	7.09±0.16	7.14±0.10	7.09±0.13	7.12±0.13	7.09±0.24	7.16±0.15	7.12±0.08	6.93±0.15	6.99±0.09	7.08±0.07	7.07±0.06	7.10±0.10
	Mean. Temp.°C	22.23 ±0.23	21.93 ±0.06	23.23 ±0.15	24.23 ±0.06	23.47 ±0.12	22.57 ±0.12	23.57 ±0.06	23.67 ±0.12	24.27 ±0.12	24.07 ±0.12	22.83 ±1.33	22.07 ±1.42	25.57 ±2.80	23.63 ±1.33	21.77 ±0.75	20.47 ±0.92	20.10 ±1.30	21.87 ±0.06	22.70 ±0.26	23.90 ±0.46	24.43 ±0.40
Variety UP-16	Mean Cond. µS/cm	70.00	98.67 ±10.02	128.67±13.61	148.00±18.33	159.33±21.73	170.00±24.56	178.00±29.82	186.67±34.82	194.67±38.73	198.00±39.95	202.33±41.19	201.67±41.79	206.00±38.94	211.00±38.20	214.00±29.46	216.33±24.13	222.67±22.19	231.00±24.33	240.33±28.02	253.67±34.27	267.33±37.10
	Mean Temp.°C	22.07 ±0.06	21.80 ±0.35	23.37 ±0.40	24.30 ±0.10	23.67 ±0.21	22.70 ±0.20	23.47 ±0.15	23.80 ±0.17	24.37 ±0.21	24.03 ±0.15	23.53 ±0.12	21.20 ±0.10	23.67 ±0.40	24.30 ±0.30	22.17 ±0.15	20.93 ±0.15	19.97 ±0.98	21.87 ±0.06	22.70 ±0.26	23.87 ±0.51	24.43 ±0.40
	Mean pH	5.45±0.02	6.29±0.14	6.62±0.09	6.86±0.17	7.07±0.14	7.11±0.15	7.18±0.04	7.25±0.02	7.18±0.04	7.19±0.05	7.18±0.07	7.11±0.03	7.16±0.04	7.23±0.05	7.27±0.08	7.32±0.10	7.19±0.10	7.23±0.11	7.24±0.11	7.25±0.13	7.41±0.14
	Mean Temp.°C	22.07 ±0.06	21.80 ±0.35	23.37 ±0.40	24.30 ±0.10	23.70 ±0.17	22.73 ±0.15	23.47 ±0.15	23.80 ±0.17	24.37 ±0.21	24.00 ±0.20	23.53 ±0.12	21.20 ±0.10	23.67 ±0.42	24.33 ±0.31	22.10 ±0.17	21.30 ±0.62	19.87 ±0.81	21.87 ±0.06	22.70 ±0.26	23.90 ±0.46	24.43 ±0.40

Appendix XIX: The Mean conductivity, pH and temperature of control experiment for cadmium solutions setup.

	Parameter/ Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Blank 0 ppm	Mean Cond. µS/cm	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Mean Temp °C	21.77±0.58	23.63±0.06	23.67±0.32	24.07±0.06	22.73±0.06	23.20	23.47±0.06	23.20±0.17	23.07±0.46	22.90±0.10	22.80±0.10	23.33±0.12	23.53±0.06	23.93±0.06
	Mean pH	5.09±0.17	5.14±0.10	5.45±0.13	5.40±0.10	5.28±0.12	5.25±0.10	5.52±0.17	5.85±0.11	5.45±0.44	5.63±0.29	5.48±0.18	5.35±0.06	5.35±0.06	5.39±0.06
	Mean Temp °C	21.77±0.58	23.63±0.06	23.67±0.32	24.03±0.06	22.70	23.20	23.47±0.06	23.20±0.17	23.07±0.46	22.93±0.12	22.80±0.10	23.33±0.12	23.53±0.06	23.93±0.06
Blank 10 ppm	Mean Cond. µS/cm	20.00	20.33±0.58	19.67±0.58	18.00±1.00	17.00	17.00	17.33±0.58	18.00±1.00	18.67±0.58	18.00±1.00	18.00±1.00	18.00±1.00	17.67±1.15	19.00±1.00
	Mean Temp °C	21.44±1.06	23.70±0.61	23.97±0.06	24.20±0.10	22.97±0.06	23.30	23.57±0.06	23.27±0.06	22.67±0.12	22.67±0.15	22.80±0.10	23.40±0.10	23.83±0.12	24.10
	Mean pH	4.66±0.01	4.67±0.02	4.86±0.02	5.16±0.12	5.380.06 ±	5.56±0.08	5.63±0.04	5.69±0.56	5.660.57 ±	5.60±0.52	5.38±0.59	6.03±0.04	6.26±	5.65±0.05
	Mean Temp °C	21.44±1.06	23.67±0.59	23.97±0.06	24.20±0.10	22.97±0.06	23.30	23.57±0.06	23.27±0.06	22.67±0.12	22.70±0.10	22.80±0.10	23.40±0.10	23.83±0.12	24.10
Blank 20 ppm	Mean Cond. µS/cm	43.00	42.33±0.58	42.33±0.58	41.67±0.58	42.33±1.15	41.33±0.58	41.00	40.67±0.58	41.00	40.67±0.58	40.33±0.58	40.33±0.58	40.33±0.58	40.00±1.00
	Mean Temp °C	22.00	23.87±0.15	23.67±0.06	23.83±0.06	23.10±	23.33±0.40	23.30	23.03±0.06	22.77±0.06	22.73±0.15	22.83±0.15	23.10	23.53±0.06	23.80±0.10
	Mean pH	4.50±0.01	4.51±0.02	4.66±0.03	4.72±0.05	4.75±0.07	4.92±0.13	5.50±0.31	6.20±0.04	6.33±0.11	6.27±0.10	6.34±0.07	6.44±0.09	6.54±0.17	6.37±0.03
	Mean Temp °C	22.00	23.87±0.15	23.67±0.06	23.83±0.06	23.03±0.06	23.33±0.40	23.30	22.97±0.06	22.77±0.06	22.70±0.20	22.77±0.15	23.10±0.00	23.53±0.06	23 80±0.10

Appendix XX: The Mean conductivity, pH and temperature of cadmium solutions in which variety UP-A was immersed

	Parameter/ Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Variety UP-A 0ppm	Mean Cond. µS/cm	0.00	4.00±1.00	5.00±2.00	4.67±1.53	5.00±2.00	5.33±1.53	4.67±0.58	4.33±0.58	4.33±0.58	4.330.58 ±	4.33±0.58	4.33±0.58	4.33±0.58	4.00
	Mean Temp °C	22.03±0.06	23.73±0.12	23.90±0.10	24.03±0.12	22.80	23.20±0.10	23.50±0.10	23.20±0.10	22.80±0.10	23.07±0.21	22.87±0.06	23.13±0.15	23.40±0.10	23.83±0.12
	Mean pH	5.00±0.02	5.77±0.16	6.06±0.14	6.10±0.15	5.94±0.10	6.09±0.14	6.10±0.11	6.26±0.17	6.22±0.07	6.21±0.08	6.22±0.07	6.21±0.10	6.03±0.09	5.88±0.12
	Mean Temp °C	22.03±0.06	23.73±0.12	23.90±0.10	24.00±0.10	22.77±0.06	23.20±0.10	23.50±0.10	23.20±0.10	22.80±0.10	23.07±0.21	22.80±0.10	23.13±0.15	23.40±0.10	23.83±0.12
Variety UP-A 10ppm	Mean Cond. µS/cm	19.67±0.58	37.00±7.21	46.67±2.31	51.00±4.58	54.33±4.93	60.33±7.77	64.67±13.32	73.33±16.92	92.33±22.19	154.33±42.44	188.67±17.21	226.67±11.02	233.00±2.00	245.33±7.09
	Mean Temp °C	22.03±0.06	24.00	23.93±0.12	24.07±0.15	23.07±0.15	23.23±0.12	23.50±0.10	23.17±0.15	22.67±0.15	22.80±0.10	22.83±0.06	23.10±0.10	23.63±0.12	24.13±0.15
	Mean pH	4.66±0.02	5.78±0.09	6.34±0.15	6.48±0.08	6.19±0.55	6.76±0.03	6 69±0.02	6.93±0.03	6.92±0.03	6.99±0.01	7.01±0.10	6.95±0.03	7.32±0.09	7.43±0.14
	Mean Temp °C	22.03±0.06	24.00	23.93±0.12	24.07±0.15	23.07±0.15	23.23±0.12	23.50±0.10	23.17±0.15	22.67±0.15	22.77±0.15	22.80±0.10	23.10±0.10	23.63±0.12	24.13±0.15
Variety UP-A 20ppm	Mean Cond. µS/cm	44.33±1.15	65.33±12.06	73.33±12.01	75.33±13.50	78.67±14.01	90.00±10.44	98.33±11.24	107.33±13.80	140 67±16.62	146.67±30.44	206.67±43.65	224.33±51.62	242.00±58.00	238.67±60.35
	Mean Temp °C	21.97±0.12	23.83±0.15	23.57±0.12	23.77±0.12	23.13±0.06	22.97±0.06	23.27±0.06	22.87±0.12	22.83±0 06	22.67±0.15	22.47±0.42	23.20±0.44	23.53±0.06	23.77±0.12
	Mean pH	4.52±0.02	5.73±0.04	6.36±0.16	6.55±0.15	6.56±0.17	6.86±0.15	6.75±0.03	7.01±0.07	7.00±0.01	7.02±0.03	7.02±0.03	7.00±0.10	7.39±0.04	7.56±0 12
	Mean Temp °C	21.97±0.12	23.83±0.15	23.57±0.12	23.47±0.40	23.13±0.06	23.00	23.27±0.06	22.87±0.12	22.83±0.06	22.67±0.15	22.47±0.42	23.20±0.44	23.53±0.06	23.77±0.12

Appendix XXI: The Mean conductivity, pH and temperature of cadmium solutions in which variety UP-B was immersed

	Parameter/ Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Variety UP-B 0ppm	Mean Cond. µS/cm	1.00	6.00±1.00	7.00±1.41	8.00±1.00	7.67±0.58	8.00±1.00	8.00±1.00	7.67±0.58	7.33±0.58	8.00±1.00	9.00±1.00	9.33±1.53	9.33±1.53	9.33±1.53
	Mean Temp °C	22.00±0.10	23.47±0.42	23.43±0.38	23.97±0.91	22.87±0.06	23.43±0.32	23.43±0.06	23.14±0.16	22.97±0.06	22.53±0.47	22.87±0.15	23.07±0.12	23.23±0.21	23.73±0.06
	Mean pH	5.00±0.02	5.76±0.67	6.39±0.11	6.37±0.14	6.16±0.19	6.35±0.15	6.33±0.11	6.55±0.27	6.38±0.06	6.41±0.06	6.46±0.05	6.51±0.06	6.43±0.11	6.30±0.12
	Mean Temp °C	22.00±0.10	23.47±0.42	23.43±0.38	23.60±0.56	22.83±0.06	23.43±0.32	23.23±0.29	23.14±0.16	22.97±0.06	22.53±0.47	22.83±0.15	23.07±0.12	23.23±0.21	23.73±0.06
Variety UP-B 10ppm	Mean Cond. µS/cm	20.00	88.33±24.79	86.33±22.30	89.67±22.50	92.00±21.93	96.67±21.73	100.00±19.29	101.33±19.50	106.67±18.15	113.002±0.88	129.00±16.70	145.33±13.05	155.67±9.61	153.33±8.02
	Mean Temp °C	22.00±0.10	23.90±010	23.77±0.15	23.90±0.10	23.03±0.06	23.20±0.10	23.40±0.10	23.07±0.12	22.60±0.10	22.67±0.15	22.87±0.06	23.10±0.10	23.37±0.32	23.97±0.15
	Mean pH	4.68±0.02	6.39±0.06	6.71±0.20	6.94±0.14	6.87±0.11	7.01±0.04	6.93±0.07	7.08±0.04	7.04±0.04	7.03±0.07	7.07±0.08	7.10±0.05	7.21±0.04	7.25±0.05
	Mean Temp °C	22.00±0.10	23.90±0.10	23.73±0.12	23.90±0.10	23.03±0.06	23.20±0.10	23.40±0.10	23.10±0.10	22.60±010	22.67±0.15	22.83±0.12	23.10±0.10	23.37±0.32	23.97±0.15
Variety UP-B 20ppm	Mean Cond. µS/cm	43.33±0.58	95.00±2.65	102.33±6.51	104.33±3.51	108.33±5.86	118.00±6.56	124.67±10.26	135.33±20.53	155.00±32.42	192.33±24.70	224.00±24.06	161.00±118.53	1266.00±1747.67	278.67±14.19
	Mean Temp °C	21.93±0.06	23.70±0.20	23.33±0.12	23.67±0.12	23.00±0.10	22.97±0.06	23.23±0.06	23.20±0.56	22.87±0.12	22.83±0.12	22.83±0.06	22.87±0.15	23.33±0.15	23.60±0.20
	Mean pH	4.53±0.01	6.15±0.09	6.76±0.03	6.79±0.09	6.78±0.09	6.79±0.09	7.01±0.06	6.82±0.60	6.80±0.63	7.17±0.04	7.20±0.06	7.23±0.06	7.32±0.15	7.62±0.27
	Mean Temp °C	21.93±0.06	23.70±0.20	23.23±0.15	23.67±0.12	23.00±0.10	22.97±0.06	23.23±0.06	23.20±0.56	22.83±0.15	22.77±0.15	22.80±0.10	22.87±0.15	23.33±0.15	23.60±0.20

Appendix XXII: The Mean conductivity, pH and temperature of cadmium solutions in which variety UP-C was immersed

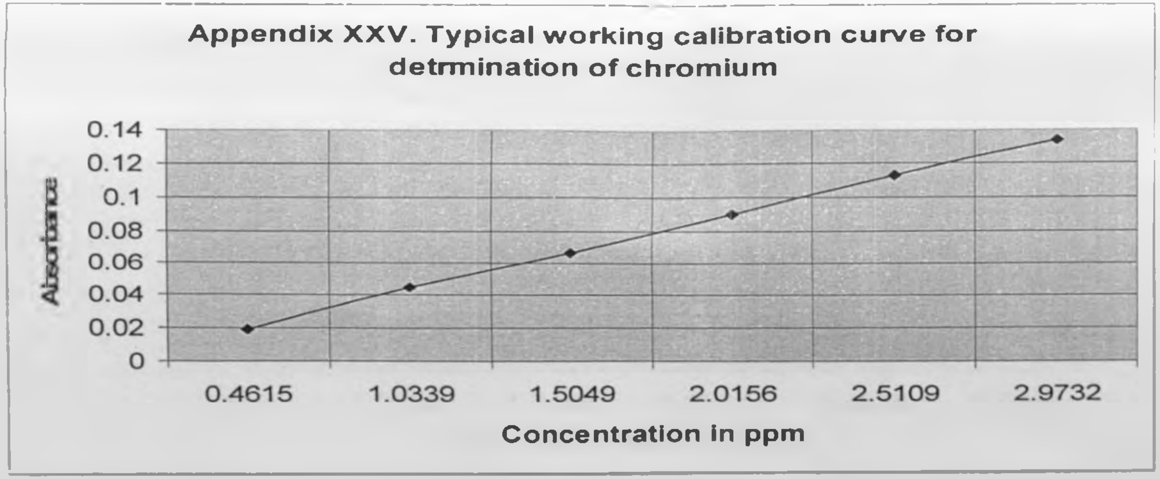
	Parameter/ Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Variety UP-C 0ppm	**Mean Cond. µS/cm**	1.00	2.33±1.53	2.33±1.53	2.33±1.53	2.33±1.53	2.67±1.15	2.67±1.15	2.33±0.58	2.33±0.58	2.33±0.58	2.67±0.58	3.00±1.00	3.00	3.00±1.00
	Mean Temp °C	21.97±0.12	23.73±0.12	23.80±0.10	23.97±0.12	22.83±0.06	23.13±0.12	23.40±0.10	23.13±0.12	22.97±0.15	22.87±0.15	22.87±0.06	23.07±0.06	23.37±0.06	23.73±0.12
	Mean pH	5.03±0.04	5.74±0.11	5.89±0.14	5.65±0.42	5.59±0.14	5.54±0.12	5.67±0.08	5.79±0.53	6.09±0.02	6.13±0.09	6.11±0.12	6.02±2.21	5.91±0.09	5.51±0.12
	Mean Temp °C	21.93±0.06	23.70±0.10	23.80±0.10	23.97±0.12	22.83±0.06	23.13±0.12	23.40±0.10	23.10±0.10	22.93±0.15	22.87±0.15	22.77±0.06	23.07±0.06	23.37±0.06	23.73±0.12
Variety UP-C 10ppm	**Mean Cond. µS/cm**	20.00	72.67±15.63	75.67±14.05	78.33±13.58	80.67±13.05	86.67±13.05	91.00±12.77	100.67±10.21	125.00±14.11	159.33±21.55	192.00±33.29	214.33±47.90	242.33±48 95	248.00±44 68
	Mean Temp °C	22.00±0.10	23.83±0.15	23.67±0.15	23.80±0.20	23.00±0.10	23.13±0.12	23.33±0.06	23.00±010	22.63±012	22.77±0.15	22.77±0.06	23.07±0.12	23.47±0.21	23.90±0.20
	Mean pH	4.68±0.01	5.95±0.06	6.70±0.11	6.80±0.11	6.81±0.08	7.03±0.15	6.90±0.13	7.02±0.08	6.98±0.06	7.05±0.06	7.05±0.09	7.05±0.11	7.33±0.12	7.48±0.18
	Mean Temp °C	22.00±0.10	23.83±0.15	23.67±0.15	23.80±0.20	23.00±0.10	23.13±0.12	23.33±0.06	23.00±0.10	22.63±0.12	22.77±0.15	22.77±0.06	23.07±0.12	23.47±0.21	23.90±0.20
Variety UP-C 20ppm	**Mean Cond. µS/cm**	44.33±1.15	75.00±5.29	80.00±3.61	84.67±4.93	88.33±4.73	95.67±4.04	102.67±4.93	115.33±11.50	143.00±23.90	179.00±47.44	207.67±60.37	231.00±76.62	252.33±78.70	257.67±82.71
	Mean Temp °C	21.93±0.06	23.67±0.15	23.37±0.06	23.50±0.10	22.90±0.10	22.77±0.06	23.13±0.06	22.77±0.15	22.93±0.06	22.87±006	22.80	22.87±0.06	23.33±0.06	23.30±0.26
	Mean pH	4.53±0.01	5.68±0.09	6.53±0.05	6.66±0.03	6.67±0.06	6.99±0.02	6.78±0.05	6.78±0.05	7.06±0.05	7.17±0.15	7.31±0.10	7.35±0.12	7.49±0.07	7.62±0.07
	Mean Temp °C	21.93±0.06	23.67±0.15	23.37±0.06	23.50±0.10	22.90±0.10	22.77±0.06	23.13±0.06	22.77±0.15	22.93±0.06	22.87±0.06	22.80	22.87±006	23.33±0.06	23.30±0.26

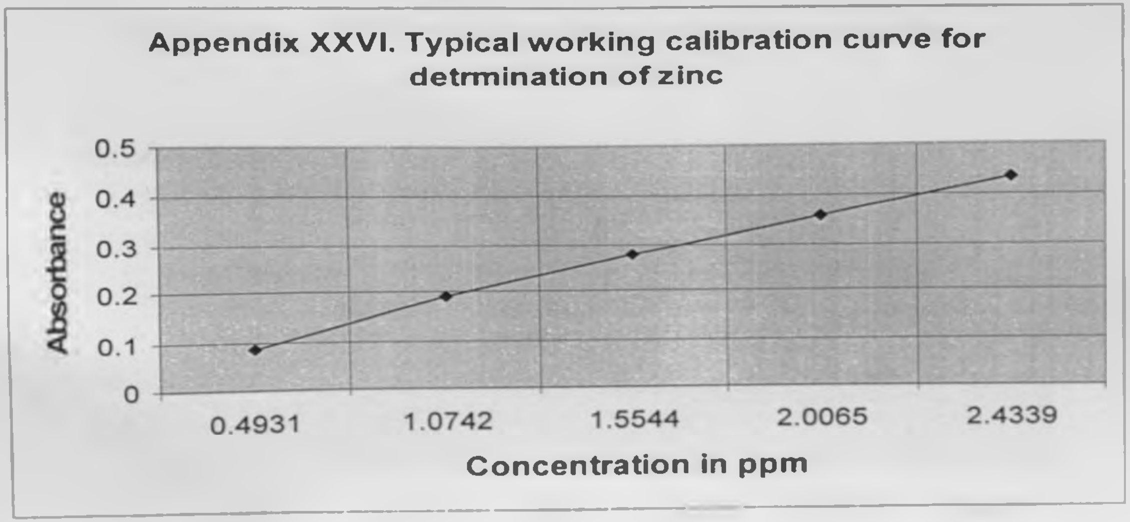
Appendix XXIII: The Mean conductivity, pH and temperature of cadmium solutions in which variety UP-D was immersed

	Parameter/ Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Variety UP-D 0ppm	Mean Cond. µS/cm	1.00	4.67±0.58	5.00	5.67±1.15	6.33±0.58	6.33±0.58	6.33±0.58	5.00	5.00	5.00	5.00	6.00	6.00	6.00
	Mean Temp °C	21.93±0.06	23.77±0.06	23.80±0.10	23.93±0.12	22.90±0.10	23.17±0.06	23.23±0.21	23.07±0.12	23.00±0.10	22.67±0.58	22.87±0.06	23.40±0.36	23.70±0.10	23.83±0.15
	Mean pH	4.71±0.55	5.76±0.07	5.75±0.47	6.14±0.14	5.91±0.08	6.03±0.09	6.00±0.03	6.39±0.05	6.21±0.02	6.26±0.06	6.28±0.03	6.29±0.02	6.42±0.51	5.89±0.10
	Mean Temp °C	21.93±0.06	23.77±0.06	23.80±0.10	23.93±0.12	22.90±0.10	23.17±0.06	23.23±0.21	23.07±0.12	23.00±0.10	22.67±0.58	22.87±0.06	23.40±0.36	23.70±0.10	23.83±0.15
Variety UP-D 10ppm	Mean Cond. µS/cm	20.00	61.00±34.77	75.00±6.24	77.33±4.62	78.00±3.46	84.67±5.51	88.67±3.79	96.00±9.54	108.33±20.65	126.00±26.91	136.00±31.95	146.00±42.33	170.00±36.17	186.67±31.56
	Mean Temp °C	21.97±0.12	23.90±0.17	23.70±0.20	23.87±0.21	23.03±0.06	23.17±0.06	23.33±0.21	23.03±0.25	22.77±0.15	22.80±0.10	22.93±0.15	23.40±0.20	23.70	23.93±0.25
	Mean pH	4.69±0.01	5.83±0.05	6.63±0.05	6.73±0.02	6.73±0.04	6.94±0.05	6.82±0.07	7.00±0.06	6.98±0.05	6.99±0.01	6.97±0.07	7.02±0.06	7.11±0.11	7.18±0.08
	Mean Temp °C	21.97±0.06	23.90±0.17	23.70±0.20	23.87±0.21	23.00	23.13±0.15	22.93±0.57	22.97±0.25	22.70±0.20	22.77±0.15	22.90±0.17	23.40±0.20	23.70	23.93±0.25
Variety UP-D 20ppm	Mean Cond. µS/cm	43.33±0.58	92.00±9.54	97.00±2.65	102.67±0.58	106.33±2.31	115.33±4.93	125.00±15.	134.00±30.32	147.00±43.31	166.00±46.51	175.33±58.86	183.33±66.40	195.67±74.90	208.00±72.99
	Mean Temp °C	21.93±0.06	23.57±0.15	23.27±0.15	23.33±0.31	22.87±0.12	22.67±0.12	23.00	22.60±0.20	22.90±0 10	23.10±0.70	22.77±0.06	22.73±0.15	23.27±0.38	23.47±0.12
	Mean pH	4.53±0.01	5.64±0.04	6.51±0.03	6.46±0.36	6.68±0.02	6.96±0.02	6.88±0.04	7.06±0.05	7.06±0.09	7.11±0.07	7.13±0.07	7.13±0.07	7.29±0.20	7.44±0.13
	Mean Temp °C	21.93±0.06	23.57±0.15	23.27±0.15	23.20±0.35	22.87±0.12	22.67±0.12	23.03±0.06	22.60±0.20	22.90±0.10	23.10±0.70	22.73±0.12	22.73±0.15	23.27±0.38	23.47±0.12

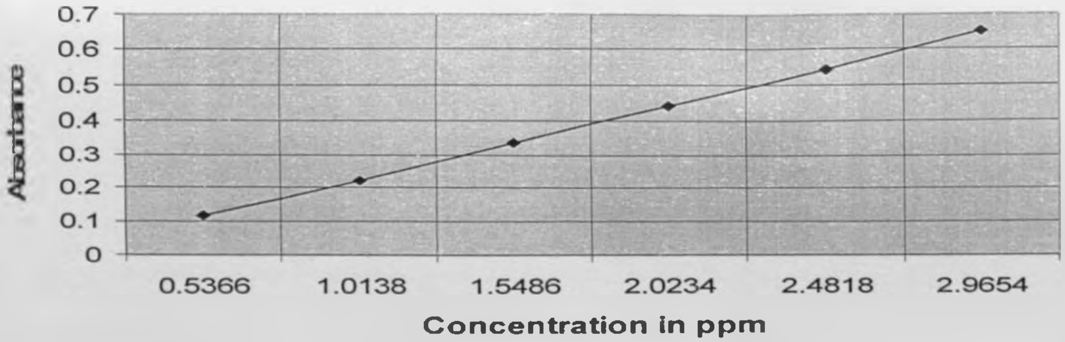
Appendix XXIV: The Mean conductivity, pH and temperature of cadmium solutions in which variety UP-16 was immersed

	Parameter/ Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Variety UP-16 0ppm	Mean Cond. µS/cm	1.00	3.67±1.53	3.67±1.53	3.67±1.53	3.67±1.53	3.67±1.53	3.67±1.53	3.00±1.00	2.67±1.15	3.00±1.00	3.33±1.53	3.33±1.53	3.67±1.15	4.00±1.00
	Mean Temp °C	21.93±0.06	23.87±0.06	23.53±0.47	23.63±0.55	22.93±0.06	23.10±0.10	23.50±0.10	23.20±0.10	22.97±0.12	22.87±0.06	22.73±0.06	23.10±0.10	23.53±0.15	23.90±0.10
	Mean pH	5.09±0.02	5.97±0.03	6.35±0.23	6.28±0.01	6.16±0.02	6.27±0.22	6.20±0.05	6.44±0.09	6.65±0.13	6.48±0.06	6.41±0.05	6.30±0.04	6.19±0.14	5.99±0.09
	Mean Temp °C	21.93±0.06	23.80±0.10	23.80±0.10	23.60±0.53	22.90	23.10±0.10	23.50±0.10	23.20±0.10	22.97±0.12	22.87±0.06	22.77±0.06	23.10±0.10	23.53±0.15	23.90±0.10
Variety UP-16 10ppm	Mean Cond. µS/cm	19.67±0.58	64.67±13.50	69.00±14.42	74.00±13.23	77.67±14.01	98.67±17.39	147.67±19.01	195.33±19.60	223.00±25.51	244.67±39.25	265.67±37.87	277.67±43.11	302.00±43.31	305.33±44.19
	Mean Temp °C	22.03±0.06	23.97±0.12	23.73±0.06	23.83±0.06	23.13±0.06	23.17±0.06	23.33±0.06	23.07±0.12	22.87±0.06	22.73±0.12	22.70±0.10	23.17±0.06	23.33±0.55	23.87±0.06
	Mean pH	4.69±0.01	6.04±0.09	6.74±0.11	6.89±0.11	6.90±0.09	7.07±0.11	7.01±0.11	7.32±0.08	7.36±0.04	7.43±0.04	7.36±0.06	7.34±0.09	7.55±0.05	7.69±0.02
	Mean Temp °C	22.03±0.06	23.93±0.06	23.70±0.10	23.83±0.06	23.13±0.06	23.17±0.06	23.33±0.06	23.07±0.12	22.87±0.06	22.73±0.12	22.70±0.10	23.17±0.06	23.33±0.55	23.87±0.06
Variety UP-16 20ppm	Mean Cond. µS/cm	43.67±0.58	92.33±7.51	97.67±8.74	100.67±7.02	108.00±7.94	113.67±8.02	130.33±14.29	161.33±37.63	191.67±63.14	226.67±82.71	253.33±102.40	227.33±188.08	294.67±124.02	310.00±126.57
	Mean Temp °C	22.00±0.10	23.43±0.06	23.13±0.15	23.53±0.25	22.80±0.10	23.00±0.61	23.03±0.06	22.43±0.12	22.77±0.06	22.77±0.15	22.43±0.38	22.60±0.10	23.07±0.06	23.37±0.06
	Mean pH	4.54±0.01	5.79±0.02	6.60±0.06	6.75±0.07	6.79±0.06	7.09±0.09	6.89±0.06	7.13±0.10	7.11±0.06	7.20±0.06	7.21±0.08	7.21±0.10	7.34±0.10	7.56±0.12
	Mean Temp °C	21.97±0.06	23.43±0.06	23.10±0.10	23.37±0.12	22.60±0.36	23.00±0.61	23.03±0.06	22.37±0.12	22.77±0.06	22.77±0.15	22.43±0.38	22.60±0.10	23.07±0.06	23.37±0.06


Appendix XXV. Typical working calibration curve for detrmination of chromium
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Absorbance
0.4615
1.0339
1.5049
2.0156
2.5109
2.9732
Concentration in ppm


Appendix XXVI. Typical working calibration curve for detrmination of zinc
0.5
0.4
0.3
0.2
0.1
0
Absorbance
0.4931
1.0742
1.5544
2.0065
2.4339
Concentration in ppm

Appendix XXVII. Typical working calibration curve for detrmination of cadmium



Appendix. XXVIII. Typical working calibration curve for detrmination of lead