GROWTH AND CHEMICAL COMPOSITION OF *Beta vulgaris* var. *cicla, Brassica oleracea* var. *capitata and Lactuca sativa* TREATED WITH INDUSTRIAL AND MUNICIPAL WASTES.

BY

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ABSTRACT

The purpose of the study was to examine the effects of industrial and municipal liquid wastes on the growth (leaf number, leaf length, and leaf width), biomass productivity and plant tissue composition of three different vegetable species. Furthermore, the study attempted to detect the toxicity symptoms and concentration of some of the heavy metals (Cd, Cr, Cu, Ni, Pb, and Zn) on the vegetables as a result of the treatment.

Three different vegetable species *Beta vulgaris* var. *cicla* (swiss chard), *Lactuca sativa* (lettuce) and *Brassica oleracea* var. capitata (cabbage) were allowed to grow under three different treatments, i.e., tap water(control), industrial and municipal liquid wastes (experimental). Fluvial soil, which was free from industrial and municipal liquid wastes was sample, for experiment. Industrial and municipal liquid wastes were brought from Akaki textile factory and Bulbulla river respectively.

The experiment was conducted under glasshouse condition. The growth parameters of the vegetable species were recorded at every seven days interval. Plant material analysis has been administered at two stages, after the 6th week and during harvest. The descriptive statistics, and analysis of variance were applied to analyze the effect of the treatments on the vegetable species. The physical and chemical properties and concentrations of heavy metals in the soil samples were determined using laboratory analysis. The concentrations of heavy metals were analyzed using atomic absorption spectrophotometer (AAS).

The result showed that vegetables treated with municipal liquid waste exhibited a relative better growth in leaf number, leaf length, leaf width and shoot biomass productivity than the other two treatments. Similarly, the distribution of total organic carbon, organic matter, total nitrogen, available phosphorus, exchangeable bases, soil pH and CEC were observed to be significantly high in the soil samples treated with the municipal liquid waste than tap water and industrial liquid waste treated soils.

In addition, the leaf number, leaf length, leaf width and dry matter yield of vegetables treated with municipal liquid waste were found to have a positive and significant correlation with soil total organic matter, total organic carbon, organic matter, total nitrogen, available phosphorus and exchangeable bases. Yet, except for Cd, and Pb, an increase in the concentration of some of the heavy metals (Cr, Cu, Ni, Zn) was observed on the analyzed soil samples treated with both industrial and municipal liquid wastes. On the other hand, however, the research findings indicated that the difference in the level of concentration /accumulation/ of heavy metals as a result of industrial and municipal liquid wastes application, between the sampled vegetable species was insignificant for Cd, Ni, and Zn. However, the concentration difference for Cr, Cu and Pb within and between the vegetables was significant. In the study, neither toxicity symptoms nor reduction of yields in biomass was observed in all sample vegetables. Furthermore, from the findings it was observed that the degree of concentration of heavy metals in each of the sampled vegetables was below the range of toxicity level.

1. INTRODUCTION

Vegetables are used as food stuff in human nutrition because of their high nutritive value. In big towns vegetables are grown through application of sewage and sewage sludges to soils. Industrial and municipal liquid wastes in a varied degree of composition contain organic materials and elements which can either enhance or affect both plant growth and consequently human health (Rowell, 1993). On the one hand, liquid wastes contain organic wastes which help maintain or even increase soil organic matter levels and provide significant quantities of essential nutrients which can give fast plant growth and better harvest. On the other hand, the organic wastes also contain toxic heavy metals which due to their concentration can create adverse effects both on plant growth and consequently human health.

Industrial and municipal liquid wastes commonly applied to land include: conventionally treated sewage, wet sewage sludge (about 95% water), liquid animal waste; and effluent from fruit or vegetable processing plants, animal processing plants, dairies, and fiber products industries, etc. Although these wastes vary widely in their composition, they all commonly contain organic material, nitrogen, phosphorus, dissolved salts, heavy metals and micro-organisms (Chancy and Herman, 1974; Manahan, 1993).

Sewage and sewage sludge have been applied to agricultural land for many years. From the agricultural point of view, sludge is an abundant and inexpensive source of humus producing organic matter (OM), nitrogen (N), phosphorus (P), potassium (K), and other plant macro-and micronutrients. At present, although other plentiful sources of plant nutrients are available, there still exists considerable interest in the land application of sewage sludge. The application of sludge to agricultural fields is presently being considered as one of the most inexpensive methods of waste disposal. However, there are a number of problems associated with the agricultural use of sludge. Because of the diversity of urban industrial discharge through public sewer systems, it is expected that the sewage sludge will contain toxic heavy metals, non-metals, and organic matter. Of particular concern is the potential accumulation of heavy metals in digested sewage sludge and sludge-treated soils, and their ability to affect soil productivity and quality of crops (Chattopadhyay, 1976).

In Ethiopia, especially in areas where there are heavy industries, like Addis Ababa, farmers use municipal and industrial liquid wastes for growing vegetables. For example, the vegetable farms at Akaki and Peacock recreation area are constantly irrigated with industrial and municipal liquid wastes respectively. This practice is believed to have a significant influence on the quality and yield of vegetables. Of the large population of Addis Ababa, the higher proportion not only live around areas polluted with industrial and municipal wastes, but also consume vegetables grown in areas irrigated with liquid wastes.

It seems obvious today why certain metals are of environmental concern. They are hazardous in one way or another to human and/or to other forms of life. The hazard to humans may be in the form of acute or chronic toxicity. Plant growth may be adversely affected by metals in soils and irrigation water, or may concentrate them in leaves, stems, or roots where they can subsequently affect the food chain (Reinhold, 1990; Donald, 1972; Olsen and Kemper, 1968; Sharron et al., 1993). Cumulative effects of metals or chronic poisoning occur as a result of long-term exposure to lower levels of metals. Hence, it is vital to examine the effect(s) of municipal and industrial liquid wastes on the quality and yield of *Beta vulgaris* var. *cicla* (swiss chard), *Lactuca sativa* (lettuce) and *Brassica oleracea* var. *capitata* (cabbage) vegetables grown in such localities.

The study is planned to investigate the effect of industrial and municipal liquid wastes on the growth and yield of *Beta vulgaris* var. *cicla* (swiss chard), *Lactuca sativa* (lettuce) and *Brassica oleracea* var. *capitata* (cabbage). Furthermore, the study intends to measure the degree of accumulation of heavy metals in the vegetables as a result of the treatments (i.e. industrial and municipal liquid wastes). For the study, soil material free from both industrial and municipal liquid wastes was sampled and prepared. Three different treatments; namely; irrigation with tap water, with industrial liquid waste from Akaki Textile factory and municipal liquid waste from Bulbula river were applied on the three vegetables (*Beta vulgaris var.cicla* (swiss chard), *Lactuca sativa* (lettuce) and *Brassica oleracea* var. *capitata* (cabbage)).

This study, therefore, has the following major objectives:

- To assess the growth and yield of the vegetables through leaf weight, leaf number and measurement of leaf length and width.
- To determine the contents of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg) and some trace elements such as cadmium (Cd), chromium (Cr), copper (Cu), nickel (Ni), lead (Pb), and zinc (Zn) in the edible parts of the vegetables.
- To assess the productivity of the vegetables as measured in terms of shoot and root biomass accumulation.

2. LITERATURE REVIEW

Heavy metals refer to the groups of metals and metalloids with an atomic density greater than 6g/cm^3. It is applied to the elements such as Cd, Cr, Cu, Ni, Pb, and Zn which are commonly associated with pollution and toxicity problems (Alloway and Ayres, 1993). According to Holdgate (1979), pollution is defined as 'the introduction by man into the environment of substances or energy liable to cause hazards to human health, harm to living resources and ecological systems, damage to structures or amenity, or interference with legitimate uses of the environment'.

Dix (1981) defined sewage as a turbid liquid, consisting of 99% water containing a complex of organic and inorganic matter, in the form of visible suspended solids, colloidal particles, dissolved compounds, and micro-organisms such as protozoa, bacteria, and viruses. Soaps and detergents are important sources of phosphorus in domestic sewage, often making up more than half the total phosphorus in effluents. Industrial sources of nutrients may be locally important, depending on the type of industry, the volume of effluent and the amount of treatment it receives. According to Mason (1996), food processing generally and those concerns such as the wool industry that require substantial washing procedures, are likely to produce effluents containing high concentration of nitrogen and phosphorus.

Manahan (1993) stated that sewage from domestic, commercial, food processing, and industrial sources contains a wide variety of pollutants, including organic pollutants. The sludge produced as a product of the sewage treatment processes contains organic material which continues to degrade slowly; refractory organics and heavy metals. Better control of sewage sources is needed to minimize sewage pollution problems. Particularly, heavy metals and refractory organic compounds need to be controlled at the source to enable use of sewage or treated sewage effluents, for irrigation, recycle to the water system or groundwater recharge.

Sewage sludge is the solid by-product of domestic and/or industrial waste water-treatment plants. The composition of the sludge varies from one sewage treatment plant to another, depending on the nature of the treatment and the degree to which the organic material is allowed to digest. Levels of heavy metals, such as zinc, lead, copper, iron, manganese, and cadmium are determined largely by the degree to which industrial wastes have been mixed with domestic wastes. If the contents of these elements is too high, the sludge may be of little value or even harmful for agricultural purposes (Brady, 1990).

Waste water flows are not steady or uniform, but vary from one hour to another, from day to day, from month to month and from year to year. The composition of domestic wastewater and municipal wastewater varies significantly both in terms of place and time. This is partly due to variations in the discharged amounts of substances. However, the main reason is variation in water consumption, infiltration and exfiltration (Henze, 1995).

Michel *et al.* (1995) pointed out that wastewater sludges produced by sewage treatment plants are good sources of macronutrients and micronutrients and generally contain a high quantity of organic matter. Their application in agriculture improved soil fertility. Sludges also help maintain soil structure, soil water-holding capacity, soil cation exchange capacity (CEC), and soil biological activity.

Municipal and industrial wastes cause drastic changes in microbiological, chemical, and physical properties of the soil. Growth of vegetables on contaminated areas may be prevented, retarded, or accelerated depending on changes taking place in soil properties (Lehman, 1982). The principal criteria for evaluating the quality of water have to do with the total concentration and composition of soluble salts in the water. Soluble salts in the soil solution may affect crop plants in several ways: increased concentration of any solute makes it more difficult for plant roots to take up water from the soil. Furthermore, certain salts often found in the water may be toxic to some plants (Gerritse *et al.*, 1983).

Along with other heavy metals present in the vegetables grown on soils treated with municipal sludge, Cd is considered to be hazardous to human and animal health and may be present at undesirable levels in human and animal feeds grown on sludge treated soil. An additional environmental feature of Cd is that it may inhibit microbial decomposition of plant litter and soil organic matter by soil microorganisms. This has implications for the rate or release of plant nutrients which result from the biological mineralization of indigenous soil organic matter and organic matter present in sludge entering the soil system (Macgregor and Naylor, 1982).

Vegetables differ markedly in accumulation of heavy metals. The potential for contamination of the food chain with heavy metals through their bioaccumulation in plants has recently increased attention (Cieslinski *et al.*, 1996). The determination of both major and trace constituent levels of elements in food and food products is becoming increasingly important for nutritional and food safety considerations. What might be a major (%) constituent in one food product can often be at a trace (milligram) concentration in another (Benton, 1984).

Human and other animals are exposed to liquid waste chemicals *via* water, soils, and their diets. These chemicals enter the body through ingestion (mainly in the diet and in water, and also on hands, in soil on vegetables). Municipal and industrial processes have resulted in the introduction of metals into the environment. Ingested metals may invoke no response or result in toxic responses. Even essential metals in high enough dosage can be toxic. Metals can react with protein and deoxyribonucleic acid (DNA) and ribonucleic acid (RNA), affecting the metabolic processes, and with other substances resulting in physiologic changes. They may also cause enzyme inhibition and produce changes in the rates of catalytic decomposition of metabolites (Loon, 1985; Guthrie and Hodgson, 1980).

Arora and Brar (1995) have studied the chemical properties, extractable nutrients, and potentially toxic elements in soils in sewage affected vegetable growing areas compared with those in soils in sewage-free vegetable growing areas. Their result showed that, the sewage treated-soils accumulated higher organic matter and extractable nutrients such as N, P, K, etc., as well as potentially toxic elements such as Cr, Pb, Zn, etc., than the sewage-free soils. The contents of most of the extractable nutrients and other elements were positively and significantly correlated to the organic matter content of the soils.

Non-tolerant crop plants readily accumulate heavy metals when grown in mildly contaminated soil. The concentrations of Cd, Ni, Cu, and Zn in the edible portions of crop plants are substantially increased when grown on soil treated with sewage sludge (Carlton-Smith, 1987). Vegetables grown on soils contaminated by wastes contain elevated metal concentrations. In one study, the blood Pb concentrations of women resident in a metal-contaminated Pb mining area were found to be 25% higher among individuals who consumed locally grown vegetable in comparison to women who consumed no locally grown vegetables (Hardman *et al.*, 1993).

No harmful effect was observed on the growth and yield of *Lactuca sativa* (lettuce) following sewage sludge treatment. The content of heavy metals in the vegetables, particularly Zn, increased at increasing rates of sewage sludge (Dinesh *et al.*, 1994).

According to Manahan (1993), possible accumulation of heavy metals is of the greatest concern in so far as the use of sludge on cropland is concerned. Rich in nutrients, waste sewage sludge contains around 5% N, 3% P, and 0.5% K on a dry weight basis and can be used to fertilize and condition soil. The humic material in the sludge improves the physical properties and CEC of the soil. Among the factors limiting this application of sludge is the presence of heavy metals in the sludge. Sewage sludge is an efficient heavy metal scavenger. On a dry basis, sludge samples from industrial cities have shown levels of upto 9, 000 ppm zinc, 6,000 ppm copper, 800 ppm cadmium and upto 600 ppm nickel. These and other metals tend to remain immobilized in soil by chelation with organic matter, adsorption on clay minerals, and precipitation as insoluble compounds, such as oxides or carbonates. However, increased application of sludge on cropland has caused distinctly elevated levels of Zn and Cd in both leaves and grains of plants.

Aita *et al.* (1993); Hajabbasi and Schumacher (1994) and Kraske and Fermandez (1990) have indicated the immediate effects of sludge from the municipal sewage plant, on the yield of dry matter and N, P, and K uptake by vegetables. The treatments consisted of different rates of sludge application. At the end of their experiment, a linear increase in dry matter yield and N, P, and K uptake by vegetables with increasing rates of sewage sludge was observed. In addition, the soil total N and P contents were increased with addition of sewage sludge.

Cavallaro *et al.* (1993) have made field experiments to evaluate the effect of municipal sewage sludge on soil properties and growth of crop species. Soil samples taken from each plot, before municipal sewage sludge application and at harvest of the crops were compared to determine any effects of the sludge on pH, cation exchange capacity (CEC), and extractable P and trace metals. According to their result, municipal sewage sludge application in the soil showed remarkable growth of the plant species and increase in CEC and extractable P. Increases in extractable Cu and Zn in the soils were similar to the amount of these elements added to the soil in the municipal sewage sludge.

Hardman *et al.* (1993) stated that the mobility and bioavailability of metals present in soils depend on physico-chemical properties of both the metal and the soil. In comparison to sandy soils, soils that have high organic and clay mineral contents are able to accumulate large quantities of metals due to abundance in the soil matrix of cation exchange surfaces and organic ligands capable of complexing with metal ions. The extent and nature of the organic fraction is strongly influenced by the activity of soil micro-organisms (bacteria and fungi). In unpolluted soil ecosystems these organisms typically account for more than 90% of the biomass present and for 90% of chemical decomposition of organic material.

According to Baker (1987); Davies *et al*, (1987) and Parfitt (1978), metals in soils are associated with a number of different phases. They may be present as part of the soil minerals, as precipitated compounds, sorbed onto inorganic and organic exchange surfaces or present in the soil solution as soluble inorganic and organic species. Metals present in the different phases are not equally available for plant uptake; the tissue concentration of plants growing in contaminated soils normally correlates most strongly with the metal content of one particular phase, not with total soil concentration.

Srikanth and Raja (1991) examined levels of metal contamination of vegetables grown on urban sewage sludge. Vegetable samples were collected along the cultivated sites, which carries the urban sewage load. Using atomic absorption spectrophotometer (AAS), Pb, Cd, and Cr levels of these metals were detected in soil and food vegetables. The result obtained indicated possible health hazard for consumers.

Romstad *et al.* (1997) have studied the uptake of Cd, Cu, Ni, Pb and Zn by cabbage, carrot, and lettuce. The vegetables were grown for three consecutive years (1993-1995). After analysis of plant material have been done, uptake of the metals by the vegetables were consistent and in the order: Zn > Cu > Ni > Cd > Pb. This reflected the total soil content (Zn > Pb > Ni $\geq$ Cu > Cd) and intrinsic solubilities of the metals in the soil (Cd > Zn > Cu > Ni > Pb). When compared the concentrations of the trace elements in the above vegetables, *Lactuca sativa* (lettuce) had the highest relative trace element concentrations and *Brassica oleracea* var *capitata (*cabbage*)* the lowest.

Heavy metal pollution can affect all environments but its effects are most long lasting in soils due to relatively strong adsorption of many metals onto the humic clay colloids in soils. The duration of contamination may be for hundreds and thousands of years in many cases. Unlike organic pollutants, which will ultimately be decomposed, metals will remain as metal atoms although their speciation may change with time as the organic molecules binding them decompose or soil conditions change (Mortland, 1970).

Shuval *et al.* (1986) pointed out that soluble salts found in the water may also have an undesirable effect on the physical properties of the soil. An excess of sodium concentration in the water will cause clay particles to disperse instead of aggregate and in cases also to swell. This results in a soil with low porosity, poor permeability, and poor aeration when wet and often its pH will also be excessive.

Soil organic matter has a higher CEC than other soil colloids (clays) and play a very important part in adsorption reactions in most soils even though it is normally present in much smaller amounts (1-10%) than clays (<80%). Sandy soils with low contents of both organic matter and clay tend to have low adsorptive capacities and are thus prone to contaminants infiltrating down to the water table. The selectivity of clay mineral and hydrous oxide adsorbents in soil and sediments for divalent metals generally follows the order Pb>Cu>Zn>Ni>Cd, but some differences occur between minerals and with varying pH conditions. However, in general, Pb and Cu tend to be adsorbed most strongly and Zn and

Cd are usually held more weakly, which implies that these latter metals are likely to be more labile and bioavailable (Alloway and Ayres, 1993; Clairon and Mench, 1991; Lindsay, 1972).

Although the recycling of sludge is an attractive alternative to growing vegetables, its use often brings about certain risks to the environment caused by accumulation of heavy metals and organic compounds and potential contamination from pathogenic organisms. High metal content in agricultural crops is not desirable and is potentially dangerous. Wastewater sludge fertilization is found to be effective when undertaken on soils poor in nutrients. In some cases, the biomass productivity of treated plots can be two to three times that of control plots (Christersson, 1986; Cobbina et al., 1989).

The uptake of heavy metals by plants and the transfer of these metals into the human food chain, as a result of the application of sewage sludge to agricultural land, pose a potential threat to human health. Kloke *et al.* (1984) gave generalized transfer coefficients of heavy metals in the soil plant systems as follows: Cd 1-10, Cr 0.01-0.1, Cu 0.01-0.1, Ni 0.1-1.0, Pb 0.01-0.1, Zn 1-10. The transfer coefficients are based on root uptake of metals but it should be realized that plants can accumulate relatively large amounts of metals by foliar absorption of atmospheric deposits on plant leaves. It can be seen that Cd and Zn have the highest transfer coefficients which is a reflection of their relatively poor sorption in the soil. In contrast, metals such as Cu, Cr, and Pb have low transfer coefficients because they are usually strongly bound to the soil colloids.

Heavy metal concentration in soil solution plays a critical role in controlling metal availability to plants (Bruemmer *et al.*, 1986; Gerritse *et al.*, 1983). However, the uptake of heavy metals by plants (i.e.

solubility and bioavailability) have been shown to be influenced by a wide range of soil variables, including:

- temperature (Siriratpuriya *et al.*, 1991),
- chloride salinity (Bingham *et al.*, 1983),
- pH (Andersson and Nilsson, 1974; John, 1972; McClean, 1976; Tyler and McBride, 1982; Xian and Shokohifard, 1989) and
- organic matter (McClean, 1976).

Some elements such as Cd and Pb are normally present in low concentration and are highly toxic. The requirements for, and potential toxicity of heavy metals results from the fact that they are transitional elements, able to form stable co-ordinated compounds with a range of both organic and inorganic ligands (Fergusson, 1990; Morgan and Stumm, 1991). Although Cd is not essential for plant growth (Kabata-Pendias and Pendias, 1992), it is readily taken up and accumulated by plants in appreciable quantities (Florijin and Besusichem, 1993; Morghan, 1993). The accumulation of toxic trace metals in vegetables is receiving a great deal of attention. Cadmium for instance, can be accumulated in leafy vegetables to such an extent that limits of acceptable human intake are easily exceeded.

In the process of plant material analysis, plant tissue is obtained by sampling a particular portion of a plant, at a certain time of growth, or during a certain stage of the plant's morphological development. The best time for sampling is just before the plant begins its reproductive growth. When plants begin setting and developing fruits and seeds, the nutrient concentration of the vegetative portions change considerably (Dirk, 1983).

3. MATERIALS AND METHODS

3.1 Soil collection and preparation

A reconnaissance survey was made between August and September 1997 across the areas of northern Shoa and southern Wollo to find fluvial soils which are free from contamination from municipal and industrial wastes. The site selected for soil collection was southern Wollo administrative zone, Kalu woreda, Degan kebele.

Soil samples from Degan kebele were collected from fluvisol, a depth of 10-20 cm from the selected area in September 26, 1997. The collected soil samples were air dried by spreading them on plastic sheet. Then, the soil samples were thoroughly mixed and passed through a 2 mm sieve. Later on 12 kg of the soil samples were filled in wooden boxes of 35 x 35 x 30 cm size for growing different set of vegetables.

3.2 The glasshouse and its environmental conditions

The experiment was conducted from October 1997 to February 1998 in a glasshouse located in Science Faculty of the Addis Ababa University. Mean minimum and maximum temperatures of the glasshouse were 15.03 ± 0.4 °C and 33.7 ± 0.8 °C respectively; and the relative humidity was 66 to 75%.

3.3 Seed germination and seedling transplantation

Packed vegetable seeds of *Beta vulgaris* var. *cicla* (swiss chard), *Brassica oleracea* var. *capitata* (cabbage) and *Lactuca sativa* (lettuce) were bought from seed shops in Addis Ababa town. In October 23, 1997, the seeds were moistened with tap water and allowed to germinate in the glasshouse in wooden boxes filled with the soil brought for the experiment.

In November 14, 1997, seedlings of *Beta vulgaris* var. cicla (swiss chard), *Brassica oleracea* var. *capitata* (cabbage) and *Lactuca sativa* (lettuce) which had uniform size and equal leaf numbers were collected (i.e. differences between the vegetables were minimized by selecting uniform seedlings) and transplanted in similar wooden boxes. For each vegetable type there were replicates of three wooden boxes. As a precaution extra seedlings in each wooden box were planted. After a time, when the seedlings become well established, the extra seedlings were reduced based on the recommended number per box. Four seedlings in one wooden box (i.e. a total of twelve seedlings) for every treatment of vegetable type were allowed to grow (108 vegetables in total). The wooden boxes were then set up in a complete randomized block in the glasshouse.

3.4 Watering process

The source of water for the growth of vegetables was from three different sources. Tap water from the glasshouse was used as a control while industrial and municipal liquid wastes were brought daily from Akaki Textile factory and Bulbula river, respectively. The experiment was set up in three groups:

Group 1- Control seedlings treated with tap water

Group 2- Experimental seedlings treated with industrial liquid waste

Group 3- Experimental seedlings treated with municipal liquid waste

Equal volume of industrial and municipal liquid wastes was added to group 2 and 3 experimental seedlings respectively, and the same amount of tap water was added to the control seedlings at the same time interval. The seedlings were watered twice a day for the first three weeks. There after, watering process was conducted once a day.

3.5 Data collection

Starting from two weeks after the period of seedling transplantation, growth and development of the vegetables were monitored and various growth parameters were recorded. They were:

(a) number of leaves

(b) length of leaves and

(c) width of leaves per vegetable at 7 day interval. The process of data collection was carried out from November 28, 1997 up to February 27, 1998.

3.6 Plant sampling and preparation

Plant tissue sampling was done twice in this experiment. The first leaf samples were taken at the 6th, 7th and 8th week-old stage of *Lactuca sativa* (lettuce), *Beta vulgaris* var.*cicla* (swiss chard), and *Brassica oleracea* var *capitata* (cabbage) respectively, while the second was during harvest period (60, 90, and 101 days for *Lactuca sativa* (lettuce), *Beta vulgaris* var.*cicla* (swiss chard) and *Brassica oleracea* var *capitata* (cabbage) respectively).

The samples were taken from recently matured leaves. This is because the nutrient composition is stable compared to that of younger leaves which can undergo rapid change. After leaf samples (the upper most leaves) have been taken, the following steps of sample preparation were followed:

(a) Cleaning of samples- The samples were successively washed once with tap water and twice with distilled water.

(b) Drying of samples- Following washing, the samples were shredded, placed in paper pockets and dried at 65 °C for 48 hours in a hot air oven.

(c) Grinding of samples- The dried samples were finally ground using a mortar and pestle in order to make the sample homogenized, reduce to a suitable physical consistency so that it can be easily measured or weighed to a specific amount and pass through a 1 mm mesh sieve.

(d) Storage of samples- The ground samples were then stored in an air-tight container in the dark at reduced temperature.

3.7 Harvesting

At maturity or when ready for consumption (i.e. after 60 days of treatment for *Lactuca sativa* (lettuce) after 90 days for *Beta vulgaris* var. *cicla* (swiss chard) and after 101 days for *Brassica oleracea* var. *capitata* (cabbage), the edible parts of the vegetables were harvested. At harvest, the vegetables were partitioned into roots and leaves. Vegetable samples were taken immediately after harvesting. Fresh weights of each vegetable roots and leaves were recorded. Roots of the vegetables were separated from the soil in the wooden box by the method of washing out the roots. The roots and the edible components of the vegetables were washed with tap water and distilled water successively, prior to oven drying.

3.8 Plant material analyses

The plant material was digested following Wet Oxidation method (Cheong and Salt, 1976) by employing a triacid mixture (nitric, sulfuric and perchloric acids). 1.00 ± 0.01 g samples were weighed into a 250 ml digestion tube. Three ml concentrated sulfuric acid, 4 ml of 60% perchloric acid and 6 ml of concentrated nitric acid were added to each sample. The tubes were then placed in a digestion block and heated at 150°C for 60 minutes. Then, the temperature was raised to 200 °C and digestion continued for another 60 minutes. The tubes were then removed from a digestion block and were allowed to cool. The digest was then transferred from 250 ml digestion tube into 100 ml volumetric flask, diluted to the mark with distilled water, the contents were mixed and sediments were allowed to settle overnight. Finally, the clear supernatant was aspirated for the determination of elements by atomic absorption spectrophotometer (AAS). Reading of the elements was done in chief laboratory of the Institute of Geological Survey Addis Ababa.

3.9 Steps and procedures used in soil analysis

Soil analyses were performed partly in Ecophysiology laboratory of Science Faculty of the Addis Ababa University and partly in Ministry of Mining, chief laboratory of the Institute of Geological Survey Addis Ababa.

Prior to the wooden box experiment, texture, pH, organic matter content (OM), cation exchange capacity (CEC), and analysis of some elements such as N, P, K, Ca, Mg, Cd, Cr, Cu, Ni, Pb and Zn of the untreated soil were determined. Soil samples taken before treatment and after harvest of the vegetables were compared to determine the effect of the liquid wastes on pH, texture, organic matter content, cation exchange capacity (CEC), extractable macronutrients and the trace elements. During all steps of sample processing, necessary measures were taken to avoid any additional contamination

Some of the methods used for soil analysis are described as follows:

(a) All physical and chemical soil analyses were made in duplicates on an air dried fraction of the sample passed through a 2 mm mesh sieve. The average values were later recorded.

(b) Soil pH was determined by following Juo`s (1978) method. The pH was determined in a 1 : 1 soil to distilled water ratio using a Beckman pH-meter after standardizing with buffer solutions of pH 4 and 7.

(c) Jou`s (1978) particle fractionation and particle size analysis was followed to determine the texture of the soils. Soil textural analysis was made by the hydrometer method (Bouyoucos method) after pre-treatment with 9% hydrogen peroxide and 5% sodium hexametaphosphate.

(d) Chapman`s (1965) Cation Exchange Capacity (CEC) determination by ammonium saturation method was followed. This method was also used to determine K, Ca and Mg.

For the CEC, each of 5 g soil from untreated soil, tap water treated soil, industrial liquid waste treated soil and municipal liquid waste treated soil was weighed and put on a filter paper. Five ml of 1 N ammonium acetate was added to each soil sample and all were left to stand overnight. The soil solutions were each washed five times with 30 ml of 1 N ammonium acetate (with pH=7) each time and the leachate was collected into a 250 ml volumetric flask. Finally, the flask was filled up to the mark with distilled water. The leachate was used to determine the exchangeable cations (Ca^{2+}, Mg^{2+}, and K^+) using atomic absorption spectrophotometer (AAS).

The remaining soil on each filter paper was washed with repeated portions of 30 ml of alcohol (ethanol) until the excess ammonium from the ammonium acetate was totally removed. Complete removal of excess ammonium ion was tested by Nesser`s reagent which turns yellow in the presence of ammonium ion and remains colourless when absent. When all excess ammonium ion were removed, the soil was taken for distillation. The soil was distilled with 30 ml of 40% sodium hydroxide. The distillate was received into 25 ml of boric acid with mixed indicator. After the distillation was over, the distillate was titrated against 0.01N sulfuric acid to determine the amount of ammonium ion concentration that was in each soil.

(e) Fiskel`s (1965) hydrochloric acid extraction method was followed to determine the available heavy metals (Cd, Cr, Cu, Ni, Pb and Zn). Two g soil from each sample were placed in 50 ml glass centrifuge tube. Twenty ml of 0.1N hydrochloric acid was added to each tube and the tubes were shaken on a horizontal mechanical shaker for one hour. The solutions were filtered and the filtrate was used to determine the concentration of heavy metals (namely; Cd, Cr, Cu, Pb, Ni and Zn) using atomic absorption spectrophotometer (AAS).

(f) Total nitrogen was determined following the modified kjeldahl digestion method (Bremner, 1965) with copper sulfate-selenium mixture as a catalyst. The soil sample was digested with concentrated sulfuric acid to convert all forms of nitrogen to ammonium nitrogen. The solution was made alkaline by the addition of 50 ml of 40% sodium hydroxide and distilled in a kjeldahl flask into 2% boric acid. The ammonium ion was then titrated with 0.01N sulfuric acid.

(g) Olsen and Dean's (1965) method was followed to determine the available phosphorus. Two g of soil from each sample were weighed and put in a 250 ml extracting bottles. A tea spoonful of phosphorus-free activated charcoal was added to each bottle to absorb colour due to organic matter. Fourty ml of 0.5M sodium bicarbonate adjusted to pH of 8.5 was added. The bottles were then shaken on an orbital shaker for 30 minutes. The digest was then filtered. Using pipette, 10 ml of the aliquot from each filtrate was put into a 50 ml volumetric flask. Then, 2.5 ml of 2N sulfuric acid was added separately to the flasks to remove CO_2 from excess sodium bicarbonate (to avoid interference in the colorimetric readings). When all the CO_2 gas was removed, 5 ml of 1% ammonium molybdate solution was added to each flask and was mixed well. Each volumetric flask was diluted with distilled water up to the neck. Two ml of the reducing agent, stannous chloride was then added and the volume of each flask filled to the mark with distilled water. The flasks were left for 10 minutes for the blue colour to develop fully. Finally, the absorbency was read using spectrophotometer at 660 nm.

(h) Allison's (1965) method of organic carbon analysis was followed to determine the organic carbon content of the soil sample. One g of soil from each sample was placed in a 500 ml Erlenmeyer flask. Ten ml of 1N potassium dichromate was added to each flask. Twenty ml of sulfuric acid was then added. The contents in the flask were heated at 150 °C for one minute and cooled. Two hundred ml of distilled water was added to each flask and filtered. To each filtrate four drops of orthophenanthroline was added. Finally, each flask containing the filtrate was titrated with 0.5N ferrous ammonium sulfate. After having determined the organic carbon, the organic matter of each soil sample was calculated by multiplying the organic carbon by a factor, 1.724.

3.10 Analyses of Tap water, Industrial and municipal liquid wastes

All the elements in the liquid samples from tap water, industrial liquid waste and municipal liquid waste were determined by direct aspiration using atomic absorption spectrophotometer (AAS). Readings were made for cadmium (Cd); for chromium (Cr); for copper (Cu); for lead (Pb); for nickel (Ni) and zinc (Zn). For calcium (Ca) and magnesium (Mg), 10% lanthanum solution was added as an interference suppressant while for potassium (K), cesium chloride was added as a suppressant. Reading of the above elements was done in chief laboratory of the Institute of Geological Survey Addis Ababa.

3.11. Statistical analysis

The statistical analysis was carried out using the software package Statistica for Windows Release 4.0 E Statsoft Inc. 1993. The significance of the means of the vegetables growth and biomass variables were subjected to analysis of variance (ANOVA) and Newman-Keuls test was run to compare differences in means within the experiment.

4. RESULTS

4.1. Soil analysis

pH Values obtained from the soils treated with tap water, industrial and municipal liquid wastes are shown in Table 1. The pH values found in soils treated with municipal liquid wastes were higher as compared to soils treated with industrial liquid waste and tap water. Analysis of variance ($P<0.05$) showed that, there was a significant difference between the pH values of the control soil and liquid waste treated soils. However, in the soils treated with industrial and municipal liquid wastes, the variation was not significant.

Textural analysis results showed that there was no significant difference among soils treated with tap water, industrial liquid waste and municipal liquid waste. Soil textural class investigated was cleyey in all soils with different treatments.

The mean percentage distribution of total nitrogen (N), total organic carbon (OC) and organic matter (OM) of soil samples from different treatments is shown in Table 1. Total nitrogen, organic carbon and organic matter concentration were higher in soils treated with industrial liquid waste than the other soil samples.

Analysis of variance ($P<0.05$) indicated that there were significant variations in total nitrogen, organic carbon and organic matter contents between control soil (soil treated with tap water) and soils treated with industrial and municipal liquid wastes. However, the difference between industrial liquid waste treated soil and municipal liquid waste treated soil was not significant.

The concentrations of available phosphorus and exchangeable bases are shown in Table 1. Phosphorus content was found to be higher in soils treated with municipal liquid waste than the soils treated with tap water and industrial liquid waste. Analysis of variance ($P<0.05$) indicated a significant difference between control soil and liquid waste treated soils.

The result of soil analysis also indicated variations in the concentrations of exchangeable K, Ca and Mg in different treatments. The concentrations of exchangeable base-forming cations were found higher in soils treated with municipal liquid wastes than those soils treated with industrial liquid waste and tap water. The concentrations of exchangeable base-forming cations were found lower in tap water treated soils. Analysis of variance ($P<0.05$) showed significant differences in concentrations of exchangeable K, Ca and Mg between the soils treated with tap water and soils treated with industrial and municipal liquid wastes. However, the variation of K concentration between soils treated with industrial and municipal liquid wastes was insignificant.

The cation exchange capacity (CEC) values (Table 1) were found significantly different among the soils treated with tap water, industrial and municipal liquid wastes. The highest CEC values were found to be in soils treated with municipal liquid waste.

TABLE 1. Mean (± S.E.) Concentration of elements (ppm) and other parameters analyzed in untreated soils, treated with tap water, industrial and municipal liquid wastes.

Soil characteristics	Treatment			
	Untreated Soil	Tap Water	Industrial Liquid Waste	Municipal Liquid Waste
K	201 ± 3.7	198.3 ± 9.8	225.8 ± 10.6	235.3 ± 3.8
Ca	738 ± 2.6	730.0 ± 5.8	750.0 ± 11.5	780.0 ± 15.3
Mg	109 ± 1.2	101.0 ± 0.0	120.0 ± 0.0	123.3 ± 3.3
P	9.1 ± 0.8	8.7 ± 1.0	10.1 ± 1.2	11.9 ± 1.1
N	0.42 ± 0.7	0.3 ± 0.2	0.59 ± 0.9	0.58 ± 1.0
Cu	43.4 ± 0.6	43.0 ± 0.7	45.10 ± 0.5	48.2 ± 0.6
Ni	46.1 ± 0.4	45.0 ± 0.3	46.7 ± 0.6	46.8 ± 0.7
Zn	97.4 ± 1.2	103.7 ± 1.4	102.5 ± 1.1	99.5 ± 0.9
Cr	43.9 ± 0.01	43.8 ± 1.4	44.2 ± 0.8	46.7 ± 0.2
Cd	< 0.1	< 0.1	<0.1	< 0.1
Pb	< 0.1	< 0.1	< 0.1	< 0.1
CEC (Meq/100g)	24.3 ± 0.6	25.7 ± 0.2	28.7 ± 1.1	30.2 ± 0.9
pH	7.3	7.3	8.2	8.8
TOC (%)	5.1 ± 0.3	4.9 ± 0.6	6.0 ± 0.4	5.8 ± 0.5
OM (%)	8.7 ± 0.9	8.5 ± 0.7	10.3 ± 0.2	10.0 ± 0.1

The concentrations of heavy metals in the soils after the experiment have been completed were analyzed. The mean values (± S. E) of the metals under different treatments is shown in Table 1. From the result, there was insignificant increment of Cr, Cu and Ni concentrations on the sampled soils treated with industrial and municipal liquid wastes over the soils treated with tap water. The concentration of Zn in the sampled soil treated with tap water was found to be higher than the sampled soils treated with industrial and municipal liquid wastes. On the other hand, the concentrations of Cd and Pb in all sampled soils were found to be less than 0.1 ppm. However, analysis of variance ($p < 0.05$) indicated that there was no significant difference in the soil concentrations of Cd, Cr, Cu, Ni, Pb and Zn under different treatments.

4.2 Tap water, Industrial and Municipal liquid wastes

pH values, total organic carbon (%), organic matter (%) and concentration of elements (ppm) of tap water, industrial and municipal liquid wastes used in the experiment are shown in Table 2. The pH value, total organic carbon, organic matter and total nitrogen contents of the analyzed industrial liquid waste were found to be higher than tap water and municipal liquid waste. On the other hand, the concentrations of P, K, Ca and Mg were obtained higher in municipal liquid waste than tap water and industrial liquid waste. Except for Zn (0.3 ppm) in tap water, the concentration of other heavy metals (Cd, Cr, Cu, Ni and Pb) recorded in all treatments was less than 0.1 ppm.

TABLE 2 pH, TOC (%), OM (%) and Concentration of elements (ppm) of tap water, industrial and municipal liquid wastes used in the experiment.

	Tap Water	Industrial Liquid Waste	Municipal Liquid Waste
pH	7.1	8.6	8.4
TOC (%)	0.02	0.10	0.07
OM (%)	0.03	0.17	0.12
N	3	10.5	9.5
P	0.1	2	12
K	1.5	29	34.2
Ca	9	30	63
Mg	2	10	16
Cd	<0.1	<0.1	<0.1
Cr	<0.1	<0.1	<0.1
Cu	<0.1	<0.1	<0.1
Ni	<0.1	<0.1	<0.1
Pb	<0.1	<0.1	<0.1
Zn	0.30	<0.1	<0.1

Analysis of variance ($p < 0.05$) showed that there were significant differences in pH values, total organic carbon, organic matter and total nitrogen contents between tap water and industrial and municipal liquid wastes. However, the difference between industrial and municipal liquid wastes was not significant. On the other hand, the concentration of P, K, Ca and Mg found in municipal liquid waste was significantly different from those of tap water and industrial liquid waste.

4.3 Growth performance and yield production

Effects of industrial and municipal liquid wastes on performance of vegetables as measured through growth responses of *Brassica oleracea* var *capitata* (cabbage), *Lactuca sativa* (lettuce) and *Beta vulgaris var.cicla* (swiss chard) are shown in Figures 1, 2 and 3 respectively. Municipal liquid waste had remarkable effects on the growth performance of the vegetables. Distinctively higher growth responses in leaf number, leaf length and leaf width were observed on all vegetables grown on soils treated with municipal liquid wastes.

Analysis of variance ($P<0.05$) showed that there was a significant difference in leaf number, leaf length and leaf width of all the three vegetables treated with tap water, industrial liquid waste and municipal liquid waste. However, the difference in the leaf length of *Brassica oleracea* var *capitata* (cabbage) treated with industrial and municipal liquid wastes was not significant.

The mean values (± S.E.) of leaf numbers, leaf length and leaf width of the vegetables grown on soils under different treatments is shown in Table 2.

Brassica oleracea var *capitata* (cabbage) had a mean leaf length of 12.9 cm in the control (treated with tap water), 16.3 cm for that treated with industrial liquid waste while the vegetable attained the highest leaf length (18.3 cm) for the one treated with municipal liquid waste. *Lactuca sativa* (lettuce) treated with municipal liquid waste attained its highest mean leaf length (20.4 cm), and the one treated with industrial liquid waste attained 18.3 cm length while the control was 16.2 cm long. The leaf length of

Beta vulgaris var.*cicla* (swiss chard) treated with municipal liquid waste was 36.4 cm while that treated with industrial liquid waste was 26.3 cm and the control was 23.2 cm long.

Brassica oleracea var *capitata* (cabbage) treated with municipal liquid waste had maximum mean leaf width (10.4 cm) while the one treated with industrial liquid waste was 7.8 cm wide and the control was 5.8 cm wide. *Lactuca sativa* (lettuce) treated with municipal liquid waste had maximum mean leaf width (9.8 cm) compared to the one treated with industrial liquid waste (7.8 cm) and the control was 6.3 cm wide. *Beta vulgaris* var.*cicla* (swiss chard) treated with municipal liquid waste attained maximum mean leaf width (10.5 cm), 8.4 cm treated with industrial liquid waste while the control was 6.8 cm wide.

The mean shoot dry weight and root dry weight of *Brassica oleracea* var *capitata* (cabbage), *Lactuca sativa* (lettuce) and *Beta vulgaris* var.*cicla* (swiss chard) grown on soils treated with tap water, industrial and municipal liquid wastes is also shown in Table 3. Vegetables grown on soils treated with municipal liquid waste provided more dry matter than the vegetables grown on soils treated with tap water and industrial liquid waste.

Analysis of variance ($p < 0.05$) showed significant differences in dry matter production and shoot to root ratio of the vegetables grown on soils under different treatments.

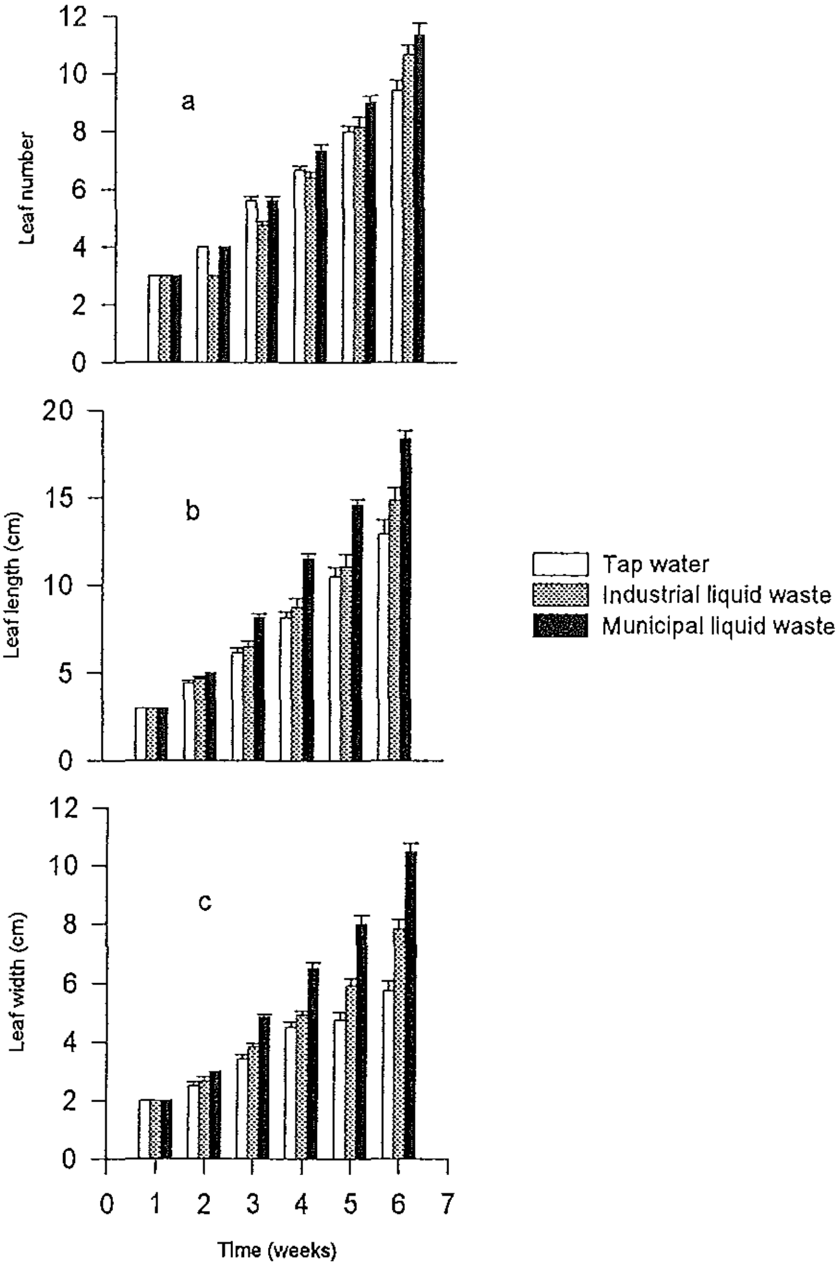

Fig. 1 *Brassica oleracea* var. capitata (cabbage): leaf number (a), leaf length (b) and leaf width (c) treated with tap water, industrial and municipal liquid wastes

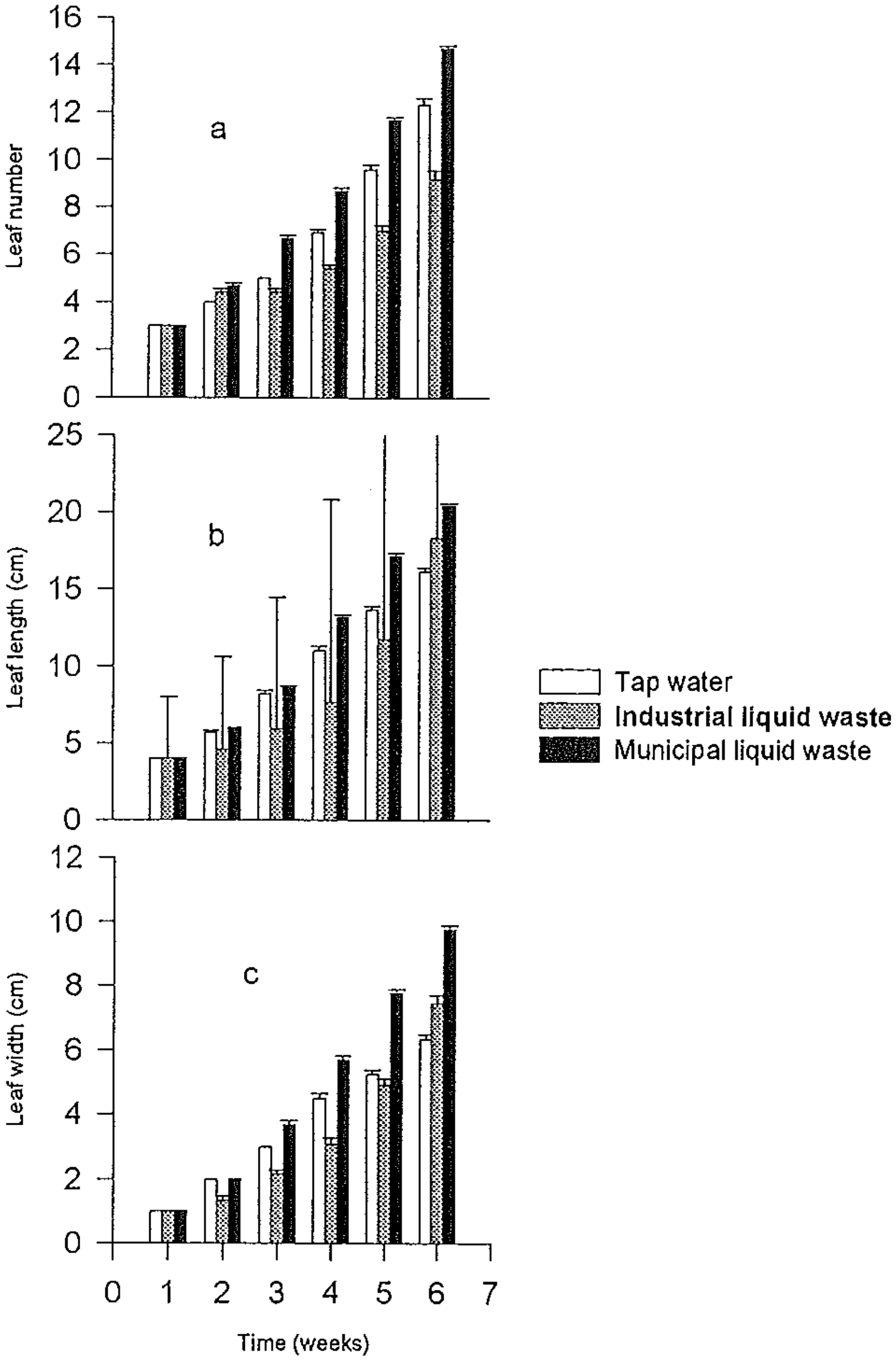

Fig. 2 *Lactuca sativa* (lettuce):leaf number (a), leaf length (b)and leaf width (c) treated with tap water, industrial and municipal liquid wastes.

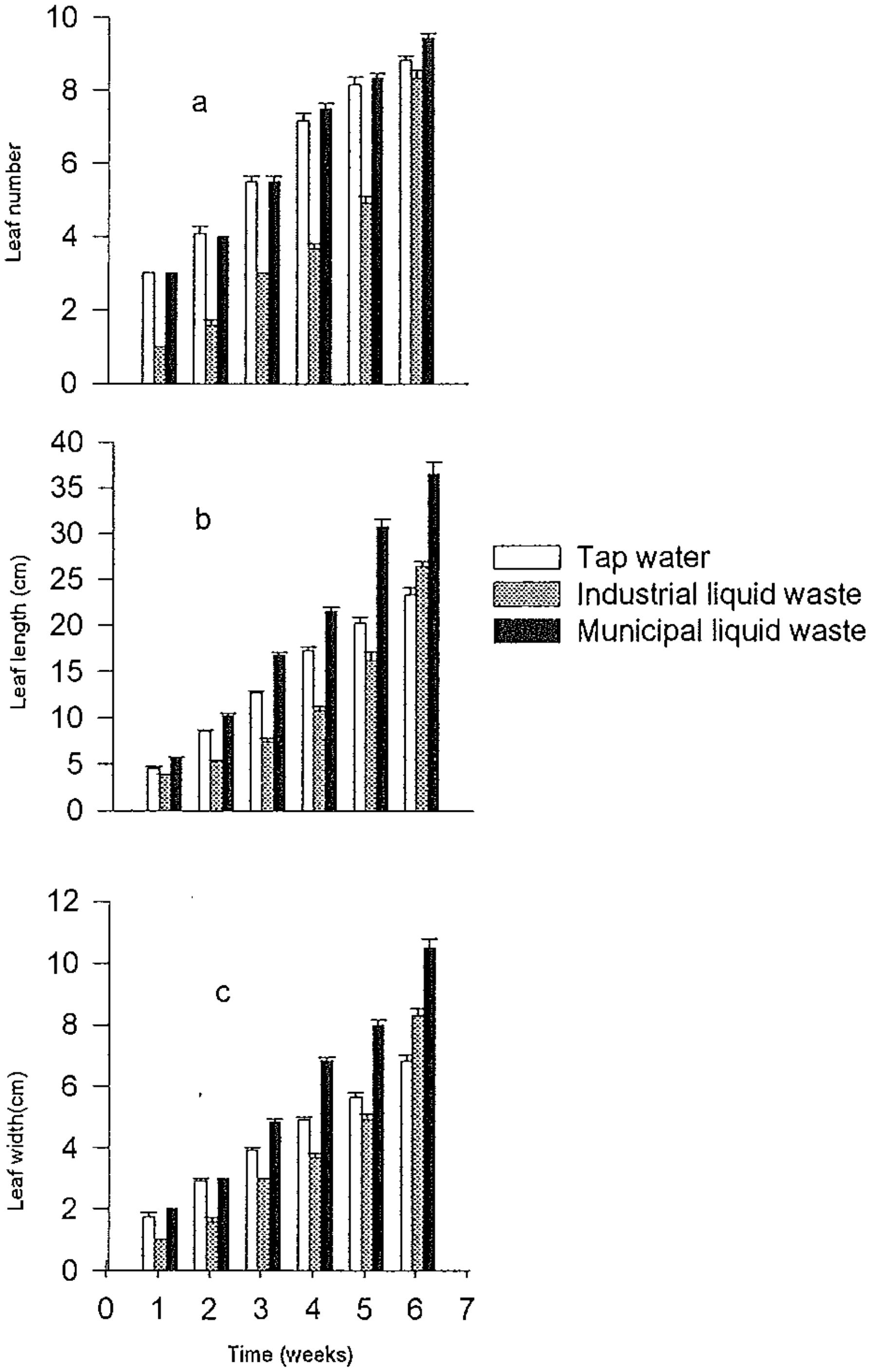

Fig.3 *Beta vulgaris* var.cicla (swiss chard): leaf number (a) leaf length (b) and leaf width (c) treated with tap water, industrial and municipal liquid wastes.

4.3 plant material analysis

As indicated in section 3.6, plant material analysis was done twice. First leaf samples were analyzed at the 6th, 7th and 8th week-old stage of *Lactuca sativa* (lettuce), *Beta vulgaris* var.*cicla* (swiss chard) and *Brassica oleracea* var *capitata* (cabbage) respectively, while the second was at harvest period (60, 90 and 101 days for *Lactuca sativa* (lettuce*), Beta vulgaris* var.*cicla* (swiss chard) and *Brassica oleracea* var *capitata* (cabbage) respectively).

At the 6th week old stage of *Lactuca sativa* (lettuce), analysis of variance ($p < 0.05$) showed that there was a significant difference in the concentration of K ($p = 0.001$), Ca ($p = 0.001$), Mg (0.001), P ($p = 0.000$), N ($p = 0.001$), Cr ($p = 0.003$) and Zn ($p = 0.002$) in the leaves of *Lactuca sativa* (lettuce). However, the difference in the concentrations of Cd, Pb and Ni was insignificant.

At the 7th week old stage of *Beta vulgaris* var.*cicla* (swiss chard*)*, analysis of variance ($p < 0.05$) showed that there was a significant difference in the concentration of K ($p = 0.021$), Mg ($p = 0.001$), P ($p = 0.049$), N ($p = 0.001$), Cr ($p = 0.004$), Zn ($p = 0.003$) and Cu ($p = 0.002$) in the leaves of *Beta vulgaris* var.*cicla* (swiss chard). However, the difference in the concentrations of Ca, Cd, Pb and Ni was insignificant.

At the 8th week old stage of *Brassica oleracea* var *capitata* (cabbage), analysis of variance ($p < 0.05$) showed that there was a significant difference in the concentration of Ca ($p = 0.034$), Mg ($p = 0.027$), P ($p = 0.000$), N ($p = 0.013$) and Zn ($p = 0.002$) in the leaves of *Brassica oleracea* var *capitata* (cabbage). However, the difference in the concentrations of K, Cd, Pb and Cu in the leaves of *Brassica oleracea* var *capitata* (cabbage) under different treatments was insignificant.

TABLE 3 Effect of different treatments on leaves, shoot and root dry weights of the vegetables

Species	Treatments	LN	LL	LW	SDW	RDW
Brassica oleracea var.capitata (cabbage)	1	9.3±0.4a	12.9±0.1a	5.8±0.3a	118.1±0.4a	12.3± 0.1a
	2	10.7±0.3bc	16.3±0.7b	7.8±0.3b	154.6±0.3b	14.9±0.1b
	3	11.3±0.4c	18.3±0.5c	10.4±0.3c	180.5±0.3c	19.0±0.1c
Lactuca sativa (lettuce)	1	12.3±0.3d	16.2±0.2d	6.3±0.2d	27.4±0.2d	9.6±0.1d
	2	9.2±0.4e	18.3±0.4e	7.8±0.3e	31.1±0.2e	11.7±0.2e
	3	14.7±0.1f	20.4±0.1f	9.8±0.1f	54.9±0.21f	14.0±0.1f
Beta vulgaris var.cicla (swiss chard)	1	8.3±0.3g	23.2±0.9g	6.8±0.2g	44.2±0.4g	12.0±0.1g
	2	8.2±0.2g	26.3±0.6h	8.4±0.2h	50.6±0.5h	14.8±0.1h
	3	9.7±0.1h	36.4±1.3i	10.5±0.3i	72.8±0.4i	19.1±0.1i

NOTE: 1 =Tab Water; 2 = Industrial Liquid Waste; 3 = Municipal Liquid Waste; LN = Leaf Number; LL = Leaf Length (cm); LW = Leaf Width (cm); SDW = Shoot Dry Weight (g); RDW = Root Dry Weight (g). Mean Values (± S.E.) within columns followed by different letters are significantly different at $P < 0.05$.

At harvest, analysis of variance showed that:

(a) there was a significant difference in the concentration of K (p=0.001), Ca (p=0.001), Mg (p=0.000), P (p=0.001), N (p=0.002), and Zn (p=0.002) in the leaves of *Brassica oleracea* var *capitata* (cabbage). However, the difference in the concentrations of Cd, Cr, Pb and Cu was insignificant.

(b) there was a significant difference in the concentration of K (p=0.000), P (p=0.000), N (p=0.001) and Zn (p=0.001) in the leaves of *Lactuca sativa* (lettuce). However, the difference in the concentrations of Ca, Mg, Cd, Cr, Ni and Cu was insignificant.

(C) there was a significant difference in the concentration of K (p=0.000), Ca (p=0.000), Mg (p=0.000), P (p=0.000) and Cu (p=0.002) in the leaves of *Beta vulgaris* var.*cicla* (swiss chard). However, the difference in the concentrations of Cd, Cr, Pb, Ni and Zn was insignificant.

5. Discussion

5.1 Soil analysis

The potential of yield production of vegetables basically depends on the fertility of the soil, mainly on the quantities of essential nutrients found in the soil in forms available to plants. Total nitrogen, organic carbon and organic matter contents in the soil are among other factors responsible for contributing to higher nutrient status of the soil.

The results indicated in Table 1 show that industrial and municipal liquid wastes bring about significant enrichment to the soils, particularly with respect to organic carbon, organic matter and total nitrogen. The results obtained are in line with what has been observed by Mason (1996), Michel et al. (1995); Arora and Brar (1995); Chancy and Herman (1974) and Manahan (1993).

Organic matter is an important component of the soil. It acts as a store house for plant nutrients. As it gradually decomposes, organic matter releases substantial quantities of nitrogen, phosphorus, potassium and other stored nutrients needed by plants (Brady, 1990).

Although the difference is not significant, the concentration of available phosphorus was found to be quite high in the soils treated with municipal liquid waste than that of industrial liquid waste. This finding is in agreement with the result observed by Chattopadhyay (1976), Dix (1981) and Mason (1996).

In general, phosphorus plays an important role in the growth and development of vegetables. Next to nitrogen, it is the most critical essential element in influencing plant growth and production (Brandy, 1990). The high content of available phosphorus observed in soils treated with municipal liquid waste is, therefore, attributed to better growth performance and yield productivity of the vegetables.

Table 3 shows the concentration of different elements in tap water, industrial and municipal liquid wastes that have been used in the experiment for the growth of vegetables. Certainly, as indicated in Table 3, there were higher contents of Ca, Mg, and K in the liquid wastes, resulting in relatively higher pH values in both soils treated with industrial and municipal liquid wastes. The amount of the exchangeable base-forming cations found in the soils have, therefore, contributed towards the reduction in soil acidity thus reducing bioavailablility and solubility of heavy metals in the soil. Resultantly, plants uptake of these metals will be reduced as well. The results obtained in this study are in agreement with Andersson and Nilsson (1974), John (1972), McClean (1976) and Tyler and McBride (1982).

The soils treated with industrial and municipal liquid wastes had higher levels of CEC due to the rise in organic carbon content as compared to the soils treated with tap water (Table 1). Michel, et al. (1995), Cavallaro et al. (1993) and Alloway and Ayres (1993) similarly reported high CEC values of soils treated with liquid wastes. In line with the results obtained in this study, a strong association between CEC and organic matter is evident giving rise to an improved nutrient status of the soil (Table 1). The impact of organic matter in increasing nutrient content of soils in relation to CEC values have also been observed by Clairon and Mench (1991) and Lindsay (1972).

In general, the application of industrial and municipal liquid wastes to soils provided beneficial chemical effects on soils. The organic wastes present in both industrial and municipal liquid wastes helped to maintain or even increase soil organic matter level and provide significant quantities of plant nutrients.

The total amount of Cd in most agricultural soils normally do not exceed 0.4-0.5 mg kg^{-1} and higher values may reflect the impact of human activity on the Cd status in soil (Kabata Pendias and Pendias, 1992). Zinc in agricultural soils usually present in the range of 10-300 ppm. Most soils contain only very small quantities of Ni, usually less than 100 ppm. Chromium in most soils found in small amount usually less than 100 ppm. The total Pb content of agricultural soils lies between 2-200 ppm (Mengel and Kirkby, 1982).

In the present study, after the greenhouse experiment have been accomplished, soil samples under different treatments were analyzed. As indicated in Table 1, the highest mean values (± S.E.) recorded in this study were 45.2 ± 0.6 ppm for Cu; 46.7 ± 0.6 ppm for Ni; 103.7 ± 1.4 ppm for Zn; 46.7 ± 0.2 ppm for Cr. The concentrations of the above metals in the soils are well below the level at which metal toxicity occurs. Therefore, the soils can be considered as non metal-contaminated.

Based on the atomic absorption spectrophotometer (AAS) reading, the concentrations of Cd and Pb in the sampled soils were found to be less than 0.1 ppm. Due to technical reasons on the atomic absorption spectrophotometer (AAS), specific readings of the concentrations of Cd and Pb was not possible. However, the concentrations of Cd and Pb in the sampled soils were below the level at which metal toxicity occurs.

5.2 Growth, biomass production and nutrient accumulation

The growth of vegetables (i.e. growth in leaf length, leaf width and leaf number) and biomass production was distinctively better on those grown on soils treated with municipal liquid waste than vegetables grown on soils treated with tap water and industrial liquid waste. The least growth performance and biomass production was obtained in vegetables treated with tap water (Fig. 4).

Brassica oleracea var *capitata* (cabbage) treated with municipal liquid waste resulted in greater growth over the control (treated with tap water) by 42% for leaf length, 22% for leaf number, 81% for leaf width and 51% for leaf biomass (Fig. 1 and Fig. 4). On the other hand, *Brassica oleracea* var *capitata* (cabbage) treated with industrial liquid waste showed better growth performance over the control by 26% for leaf length, 14% for leaf number, 36% for leaf width and 25% for leaf biomass (Fig. 1 and Fig. 4).

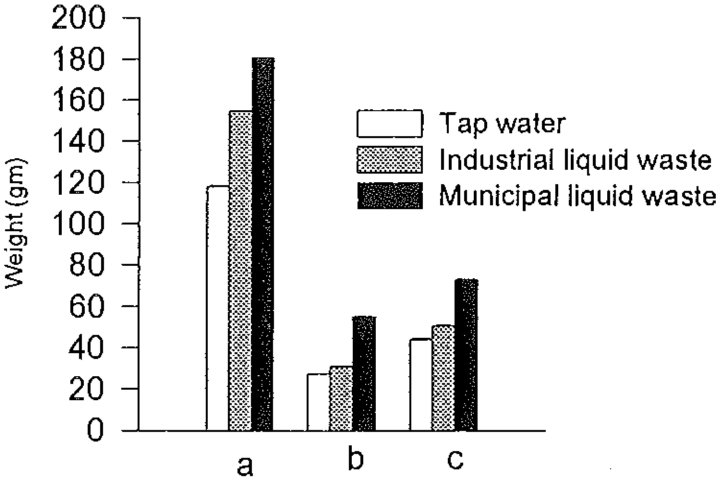

Fig. 4 Shoot dry weight of *Brassica oleracea* var. *capitata* (a), *Lactuca sativa* (b) and *Beta vulgaris* var. *cicla* treated with tap water, industrial and municipal liquid wastes

Lactuca sativa (lettuce) treated with municipal liquid waste resulted in greater growth over the control by 26% for leaf length, 19% for leaf number, 56% for leaf width and 24% for leaf biomass (Fig 1 and Fig.4). On the other hand, *Lactuca sativa* (lettuce) treated with industrial liquid waste relatively showed good growth over the control by 13% for leaf length, 24% for leaf width and 12% for leaf biomass (Fig 1 and Fig.4).

Beta vulgaris var.*cicla* (swiss chard) vegetables treated with municipal liquid waste resulted in greater growth over the control by 57% for leaf length, 09% for leaf number, 54% for leaf width and 63% for leaf biomass (Fig 1 and Fig.4). On the other hand, *Beta vulgaris* var.*cicla* (swiss chard) treated with industrial liquid waste relatively showed better growth over the control by 14% for leaf length, 23% for leaf width and 38% for leaf biomass (Fig 1 and Fig.4). The higher growth in leaf number, leaf length and leaf width in vegetables treated with industrial and municipal liquid wastes observed in this experiment is in line with those of Michel et al. (1995); Christersson (1986) and Cavallaro et al. (1993).

There was a significant interaction between treatments and leaf number, leaf length, leaf width, shoot fresh weight and shoot dry weight production in the three vegetables. The vegetables show the same general trend of response of increase in growth and yield production in relation to plant nutrient level in the treatments. The growth of the vegetables (i.e. leaf length, leaf number and leaf width) showed highly significant correlation with soil organic matter content and total nitrogen. This indicates that as the organic matter and total nitrogen content of soils increase, the vegetables grew better. However, leaf number of *Lactuca sativa* (lettuce) and *Beta vulgaris* var.*cicla* (swiss chard) treated with industrial liquid waste did not show any significant correlation with soil nutrient status. There was also significant correlation of the vegetables dry matter production with leaf length, leaf width, organic matter content and total nitrogen in the soil. The results obtained are in line with what has been observed by Aita (1993), Hajabbasi and Schumacher (1994), Kraske and Fermandez (!990) and Cobbina et al. (1989).

Since leaf area(i.e. leaf length and leaf width) is an important parameter contributing to photosynthetic activity, attainment of optimum leaf area is essential to maximizing productivity (Wittwer and Stringer, 1985). The reduction in the availability of nutrient content in the treatment decreases the leaf nitrogen concentration and leads to a lower photosynthetic capacity (Field and Mooney, 1986). As indicated in Table 2, the shoot biomass production by vegetables grown on soils treated with liquid wastes significantly exceeded the shoot biomass of vegetables grown on soils treated with tap water. The result observed in this study is in agreement with those of Hajabbasi and Schwmacher (1994); Chattopadhyway (1976) and Christersson (1986).

In general, the availability of essential soil nutrients is critical for growth, development and yield production in vegetables. Soil nutrients also affect root morphological and physiological characteristics that are important for some nutrients uptake. The greater growth rates and shoot biomass production due to availability of soil nutrients in vegetables grown on soils treated with industrial and municipal liquid wastes compared to the control vegetables appeared to be related to factors occurring during the earliest stages of growth including enhanced relative soil nutrient uptake rates and greater on development, relative growth rates and yield production.

Analysis of variance ($p < 0.05$) showed the difference in the shoot to root ratio of the vegetables under the different treatments to be statistically significant. All vegetables responded to treatment nutrient concentration by an increase in shoot to root ratio. High availability of nutrients in the treatment allowed the vegetables a biomass distribution favoring aerial parts. As a result, the shoot biomass productivity of the vegetables treated with liquid wastes exceeded those of the control vegetables. However, the highest shoot biomass productivity was obtained on those treated with municipal liquid waste. This result is in line with the observations of Christersson (1986) and Cavallaro et al. (1993).

A decrease in the dry weights of roots with increasing levels of nutrients concentration had also been established by many investigators (Clement et al., 1987; Hackett, 1965; Vose, 1962 and Calisay et al., 1992). Although in the present study, the weights of roots were not reduced at the higher concentration of nutrients in the treatments, observation on the root systems revealed differences resulting from the nutrient contents. In general , roots getting lower nutrient concentration in the treatment (tap water treated vegetables) were more finely divided and had plenty of intertwinned roots. In contrast at the higher nutrient concentrations in the treatment (vegetables treated with industrial and municipal liquid wastes) the roots were much thicker and sparse.

Plant analysis as a tool for assessing the nutritional status of plants has received much attention and many experiments have shown the relationship between mineral element content in the leaves and in the growth or treatment. Motivation for determination of nutrient concentration in the leaves for diagnostic purposes arises from the assertion that there exists a relationship between nutrient supply and levels of elements and that increase or decrease in concentration related to higher or lower yields, respectively (Evenhius and Waard, 1980; Okaye, 1980).

Changes in nutrient content appear to be reflected in the concentration of leaf nutrients which varies with the conditions of nutrient supply in the treatments. This variation in plant tissue concentration in response to a change in the external supply had been reported by other investigators (Smith, 1962; Vose, 1962; Kumar et al., 1994).

For most elements analyzed (Table 4 and 5), there was generally a rise in plant tissue concentration with continued treatment supply, though there were certain anomalities where nutrient concentration in the leaves did not respond to continued treatment supply. For instance, in *Brassica oleracea var capitata* (cabbage) that were supplied with tap water relatively showed higher percentage of Mg content

(9.06%) in leaf tissue than those treated with industrial and municipal liquid wastes which had 8.44 and 7.58 percent of Mg respectively. Percentage of Ca content in the leaf tissue of *Lactuca sativa (lettuce)* treated with tap water was 7.09% while in those treated with industrial and municipal liquid wastes, it was 5.94% and 6.16% respectively.

Since the supply of nutrients from soils due to the various treatments with different nutrient concentration can be variable, it is not surprising to find differences in the amounts of various nutrients content in the leaves. Differences in the amounts of nutrients could also be observed under controlled conditions, and furthermore much uniformity and much diversity are known to exist in the nutrient needs of plants and their ability to get them (Viets, 1980). In the same way, in the present study the contents of N, P, K, Ca, and Mg in the leaf tissues do show variation among the three vegetables.

TABLE 4 Nutrient composition (ppm) of elements on shoot dry matter of vegetables under different treatments and days.

Species	Treatments	K	Ca	Mg	P	N
Brassica oleracea var. capitata (cabbage) (60 days)	1	222.7±11.1	266.7±18.4a	60.7±5.4a	53.7±1.2a	53.4±6.8a
	2	218.7±4.7	182.7±16.2b	44.7±3.2ab	70.0±2.5b	71.1±7.9b
	3	215.3±7.7	154.0±9.4c	38.0±1.3b	64.0±1.5c	74.3±7.1bc
Lactuca sativa (lettuce) (42 days)	1	601.7±7.3d	17.7±0.4d	17.3±0.3c	119.0±3.5d	64.6±2.7d
	2	591.6±14.9d	16.3±0.6e	18.5±0.3c	167.6±4.6e	79.8±3.2e
	3	570.0±16.7e	14.0±0.3f	31.5±4.4d	104.0±4.1f	80.6±1.9ef
Beta vulgaris var.cicla (swiss chard) (50 days)	1	439.7±21.0d	19.8±0.0	114.0±1.5e	73.0±0.5g	64.9±3.7g
	2	511.0±14.6e	42.0±10.7	99.3±4.9f	82.3±4.2h	87.4±3.9h
	3	470.3±14.8f	40.8±9.6	98.0±3.7gf	74.0±2.1ih	90.2±5.2ih

NOTE: 1 = Tap Water; 2 = Industrial Liquid Waste; 3 = Municipal Liquid Waste. Mean Values (± S.E.) within columns followed by different letters are significantly different at $P < 0.05$.

Leaves of all vegetables generally showed a higher percent of K content in all treatments than the other elements. A relatively higher percentage of N and Ca content was obtained in the leaves of *Brassica oleracea* var *capitata* (cabbage) than the other two vegetables and a higher percentage of P content was also obtained in *Lactuca sativa* (lettuce) than *Brassica oleracea* var *capitata* (cabbage), while the percentage of Mg content was highest in the leaf tissue of *Beta vulgaris* var.*cicla* (swiss chard).

Although leaf nutrient concentration is controlled primarily by nutrient content in the treatment, supply, there are many factors indirectly influencing the mineral element content of plants. The final manifestation is the resultant of all parameters influencing each other and the plant (Cottenie, 1980 and Okaye, 1980). Among these factors, maturity or physiological age of the plant, seasonal and climatic factors, soil parameters and plant species are known to affect the composition of the plant tissue (Donohue et al., 1981; Cherney and Robinson, 1985; Frankenberger and Martens, 1992; Clark, 1983).

5.3 Heavy metals

Heavy metal concentration in soil solution plays a critical role in controlling metal availability to plants. However, the solubility, and therefore bioavailability of heavy metal ions is altered by a number of physical and chemical soil properties. Of these factors, soil pH (Tyler and McBride, 1982; Xian and Shokohifard, 1989), calcium concentration (Tyler and McBride, 1982) and organic matter content in soil (McClean, 1976) affect heavy metals movement from soil to plants. Soil pH is known to modify the transfer of elements from the soil-phase-bound form to the soil solution (Kiekens, 1983; Xian and shokohifard, 1989).

Methods for evaluating heavy metal availability were based on the amount of the element absorbed by the vegetable in relation to heavy metal concentration in the soil. These relationships are dependent on physical and chemical characteristics of the soil, the liquid wastes and the species used. Liquid waste treatments increased the levels of analyzed metals in the soil except for Cd and Pb. This increase does not necessarily translate into an increase in the concentration of these metals within the vegetable.

As the generalized transfer coefficients of heavy metals in the soil plant system given by Kloke et al. (1984), the transfer coefficients of Cd and Zn showed higher values than those for other metals, indicating that these metals are more soluble in the soil solution, and thus are immediately available to the vegetables.

Although Cd is more soluble in the soil solution and can be transported readily from the soil *via* the root to the leaves, in most plant species transport of Cd into the shoot is usually directly proportional to the external proportion. The concentration of Cd in all vegetables observed at two stages of development was the same (0.1 ppm). On the other hand, the concentration of Cd obtained from the result of soil analysis was less than 0.1 ppm. Therefore, accumulation of Cd in the leaves of the vegetables appears to be related to external soil Cd concentration rather than ionic activity.

Zinc toxicity in plants results in a reduction in root growth and leaf expansion which is followed by chlorosis. For most plant species high amounts of Cu in the nutrient medium are toxic to growth. The effect appears to relate in part to the ability of Cu to displace other metal ions and particularly Fe from physiologically important centers. Chlorosis is thus a commonly observed symptom of Cu toxicity, superficially resembling Fe deficiency. The inhibition of root growth is one of the most rapid responses to toxic Cu levels. Acute Ni toxicity gives rise to chlorosis, the symptoms being similar to those of Mn deficiency. Plants suffering from severe Cr toxicity could have small roots and narrow brownish red leaves, covered in small necrotic spots. Toxicity symptoms of Pb could be recognized as brown roots or wilting leaves (Mengel and Kirkby).

Chaney (1982) and Kabata-Pendias and Pendias (1992) have indicated the range of toxicity levels for some heavy metals in leaf tissues for various species to be as follows: Cd, 5 to 30; Cu, 25 to 40; Ni, 10 to 100; Pb, 30 to 300; Zn, 500 to 1500 mg kg^{-1} (dry matter bases). As indicated in Table 7, maximum leaf metal concentrations recorded in this study were below these levels in all treatments. In addition, the amount of heavy metals applied into the soils in the wooden boxes by the doses of industrial and municipal liquid wastes employed did not induce toxicity symptoms to vegetables and did not decrease yields in biomass.

The leaves of *Brassica oleracea* var *capitata* (cabbage) and *Lactuca sativa* (lettuce) vegetables treated with tap water were observed to have relatively higher concentration of Cr, than the rest of vegetables treated with both liquid wastes. On the other hand, tap water treated soil was found to have lower concentration of Cr compared to the other two sampled soils. The observed variation could be probably due to high soil pH which decreases the solubility and availability of Cr as a result of the application of industrial and municipal liquid wastes to the soils. The rate of uptake and translocation of Cr by plants is generally low. At normal condition, the Cr content of dry matter of a plant is about 0.02 to 1 ppm. The close association of Cr to the exchange sites in the root may result in a low rate of uptake of plant. Thus, the poor availability of Cr in the soil indicates the low level of it to be found in the plant material.

TABLE 6 Heavy metal contents (ppm) of shoot dry matter of vegetables under different treatments and days

Species	Treatments	Heavy metals					
		Cd	Cr	Cu	Pb	Ni	Zn
Brassica oleracea var.capitata (cabbage) (60 days)	1	0.10	0.10	0.15	0.09	0.30	0.40
	2	0.10	0.10	0.33	0.09	0.267	0.40
	3	0.10	0.10	0.43	0.09	0.30	0.30
Lactuca sativa (lettuce) (42 days)	1	0.10	0.10	0.15	0.09	0.27	0.43
	2	0.10	0.10	0.10	0.09	0.23	0.63
	3	0.10	0.10	0.10	0.09	0.27	0.37
Beta vulgaris var. cicla (swiss chard) (50 days)	1	0.10	0.10	0.10	0.09	0.20	0.47
	2	0.10	0.10	0.17	0.09	0.30	0.37
	3	0.10	0.10	0.10	0.09	0.30	0.53

NOTE: 1 = Tap Water; 2 = Industrial Liquid Waste; 3 = Municipal Liquid Waste.

TABLE 7 Heavy metal contents (ppm) of shoot dry matter of vegetables at harvest.

Species	Treatments	Heavy metals					
		Cd	Cr	Cu	Pb	Ni	Zn
Brassica oleracea var. capitata (cabbage) (101 days)	1	0.10	0.17	0.27	0.17	0.29	0.43
	2	0.10	0.10	0.50	0.17	0.27	0.40
	3	0.10	0.10	0.53	0.23	0.30	0.37
Lactuca sativa (lettuce) (60 days)	1	0.10	0.17	0.27	0.16	0.29	0.70
	2	0.10	0.10	0.50	0.16	0.30	0.67
	3	0.10	0.10	0.53	0.23	0.30	0.40
Beta vulgaris var.cicla (swiss chard) (90 days)	1	0.10	0.10	0.27	0.09	0.29	0.60
	2	0.10	0.10	0.50	0.09	0.30	0.53
	3	0.10	0.13	0.53	0.09	0.31	0.57

NOTE: 1 = Tap Water; 2 = Industrial Liquid Waste; 3 = Municipal Liquid Waste.

All the sampled leaves of the vegetables under different treatments were observed to have almost similar concentration of Ni (Table 7). However, the concentration of Ni in the soils treated with industrial and municipal liquid wastes was found to be relatively higher to that of the soil treated with tap water except for cabbage treated with industrial liquid waste (Table 1). Normally, the Ni content of a plant material is about 0.1 to 5 ppm of the dry matter. The higher the pH in the soil may result the lower solubility and availability of Ni. With this regard, from the study, the industrial and municipal liquid wastes have shown an effect in rising the pH of the soil samples.

Most plants retain between 2 to 20 ppm content of Cu in their dry plant material. In the study, however, the concentration of Cu in all the leaves of the sampled vegetables was below the normal level (Table 7). The leaves of the vegetables under different treatments showed different concentration of Cu. In the study, relatively higher concentration of Cu was found in the leaves of vegetables treated with municipal liquid waste than the vegetables treated with tap water and industrial liquid waste. However, the difference in the concentration of Cu between vegetables treated with industrial and municipal liquid wastes was not significant.

It is true that Cu is more strongly bound to organic matter than other micronuitrient cations (e.g. Zn^{2+}, Mn^{2+}) do. And hence, Cu organic complexes play an important role in regulating Cu mobility and availability in the soil. Generally, as soil pH increases, the availability of Cu in the soil decreases. As a result, with stronger Cu adsorption, its soil solution decreases during increment in soil pH. In relation to this, high concentration of Zn in the soil also strongly inhibits the uptake of Cu by plants. The result obtained in this study thus agrees well with what has been observed by Manahan (1993) and Kloke et. al. (1984).

As indicated in section 4.2, the concentration of Zn obtained in the sampled tap water was 0.3 ppm, while those of industrial and municipal liquid wastes was less than 0.1 ppm. In the study, all sampled leaves of vegetables treated with tap water showed relatively higher concentration of Zn when compared to the rest two treatments. When Zn interacts with soil organic matter, both soluble and insoluble Zn organic complexes are formed. Likewise, the intensity of Zn adsorption increases as the soil pH rises. This in effect, particularly in alkaline soils, restricts the mobility of Zn. In line to this, as Tyler and McBride (1982) and Xian and Shokohifard (1989) discussed, the solubility of Zn is low specially on soils with high pH.

From the study, the application of industrial and municipal liquid wastes brought pH change from soil pH=7.3 to pH=8.2 and pH=8.8, respectively. In turn, the observed changes in soil pH made an effect on the solubility and availability of Zn. As a result, Zn concentration become lower in those vegetables where soil pH was found to be higher. Thus, therefore, the findings of the study support the statements of Dinesh et al. (1994) that the higher the concentration of Zn in the soil, the greater its amounts found in the plant biomass.

Most plants usually have between 5 to 10 ppm Pb concentration in the dry plant material. However, the sample vegetables included in the study showed by far lower concentration of Pb (Table 7). As indicated on table 7, although the vegetables had lower Pb than the normal content, there is a marked variation of concentration between the treatments. *Brassica oleracea* var *capitata* (cabbage) and *Lactuca sativa* (lettuce) treated with municipal liquid waste resulted a higher accumulation of Pb (0.23 ppm) from those sample vegetables treated either with tap water or industrial liquid waste.

Contrary to the other two vegetable species, however, the leaves of *Beta vulgaris var.cicla* (swiss chard) under different treatments exhibited similar concentration of Pb (0.09 ppm). The condition probably shows a selective uptake of metals and species preference for different metals. In line to this Valcho and Niels (1996) , stated that in plants, 95% of the Pb is due to foliar uptake from polluted air. On the other hand, Juste and Mench (1992), and Petruzzelli et al. (1986) noted the relationship between preference for selective uptake of different metals and specificity of plant species. With this understanding, the findings obtained from the sampled *Beta vulgaris* var.*cicla* (swiss chard) leaves support the ideas of the above mentioned authors.

The mean concentration of heavy metals from sampled leaves at harvest is shown in Table 7. The highest concentration of heavy metal found in the vegetables due to industrial and municipal liquid wastes treatment was as follows:

(a) Chromium (Cr) - was found higher in in *Brassica oleracea* var *capitata* (cabbage) and *Lactuca sativa* (lettuce) treated with tap water.

(b) Copper (Cu) - was found higher in *Brassica oleracea* var *capitata* (cabbage), *Lactuca sativa* (lettuce) and *Beta vulgaris* var.*cicla* (swiss chard) treated with municipal liquid waste

(c) Lead (Pb) - was found higher in *Brassica oleracea* var *capitata* (cabbage) and *Lactuca sativa* (lettuce) treated with municipal liquid waste

(d) Nickel (Ni) - was found higher in *Beta vulgaris* var.*cicla* (swiss chard) treated with municipal liquid waste

(e) Zinc (Zn) - was found higher in *Lactuca sativa* (lettuce) treated with tap water, while the concentration of Cd in all vegetables under different treatments was found to be 0.1 ppm.

When compared the concentrations of the heavy metals in vegetables, *Beta vulgaris* var.*cicla* (swiss chard) and *Lactuca sativa* (lettuce) had the highest relative heavy metal concentrations and *Brassica oleracea* var. capitata (cabbage) the lowest. The result found in this study is in line with what has been observed by Romstad et al. (1997).

6. CONCLUSIONS AND RECOMMENDATIONS

Since many years, municipal and industrial liquid wastes have been considered as good water sources for farm lands around big towns. The liquid wastes, despite their economic advantage and contributions to faster plant growth, have their own problems in adding heavy metals both to the soil and plant harvest which consequently affect human health. The level of soil and plant toxicity as a result of heavy metal concentrations, may hold true particularly for farm lands using industrial and municipal liquid wastes. With this regard, the study tried to address the advantages and potential effects of the industrial and municipal liquid wastes on vegetable production.

From the study, highest performance of vegetable growth (leaf number, leaf length and leaf width) and yield productivity were recorded on all the three species: *Beta vulgaris* var. *cicla* (swiss chard), *Lactuca sativa* (lettuce) and *Brassica oleracea* var. *capitata* (cabbage) grown under the treatment of municipal liquid waste compared to industrial liquid waste and tap water treated vegetables. At the same time, the observed higher total organic carbon, organic matter, cation exchange capacity and exchangeable bases in the soil where municipal liquid waste have been applied seem to have contributed for better soil nutrient status. The condition in turn resulted in good growth performance and yield productivity of the same vegetables. The positive influence observed on the treatment leads one to conclude that the municipal liquid waste has benefits from economic stand point.

Though to a lesser degree than that of the municipal liquid waste, the vegetables grown with the Akaki textile industry liquid waste had also good growth performance and biomass productivity. Vegetables treated with the industrial liquid waste exhibited both better growth performance and yield productivity than those vegetables treated with tap water. The soil analysis made on the soils where industrial and municipal liquid wastes have been applied showed that both sampled soils had higher amounts of essential nutrients needed for vegetable growth.

On the other hand, however, the analysis made on soils where industrial and municipal liquid wastes have been applied revealed certain indications about the concentration of some heavy metals. From the result of soil analysis, a slight increment in the soil concentration of Cr, Cu, Ni and Zn was observed. While no increment in amounts of soil Cd and Pb was observed.

Regarding to the concentration of heavy metals in the leaves of the vegetables, with the exception of Cd, the concentrations of Cr, Cu, Pb, Ni and Zn increased at harvest. However, in the study the application of municipal and industrial liquid wastes did not induce toxicity symptoms to all vegetables and did not decrease yields in biomass.

In the present study, although the concentration of heavy metals did not reach to a significant level, industrial and municipal liquid wastes will have a long term effect to bring about soil toxicity in the areas. From the view point of the rapid establishment of the variety of cottage industries, and from the findings obtained, the researcher assumes that the level and rate of soil toxicity in the farm lands of Addis Ababa will be faster than ever before. Hence, the need for intervening measures is essential.

The nutritional and food safety considerations call for the need to determine the levels of both the major and trace constituent elements of consumable vegetables. The observed concentration of some of the heavy metals will gradually turn the soils to be toxic. Hence, there will be a potential danger of health as a result of consuming vegetables grown in those farm areas treated with industrial and municipal liquid wastes.

Therefore, the researcher forwards the following suggestions:

(a) Farmers who use the industrial and municipal liquid wastes as a water source of irrigation need to be informed to apply liming.

(b) Industries that discharge liquid wastes ought to be aware of the potential effects so as to take necessary safety measures.

(c) Frequent analysis should be made both on the soils and the liquid wastes.

(d) Health institutes and concerned public sectors should test and approve the condition of commercial vegetables before marketing.

(e) Finally, the researcher recommends a further and in depth study to be carried out in the farm areas where industrial and municipal liquid wastes are used as irrigation for growing vegetables.

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Appendix 1: Effect of different treatments on leaves, shoot and root dry weights of Brassica oleracea var. capitata (cabbage)

Species	SDW	RDW	LN	LL	LW
CC1	115.85	11.87	11	18	7
CC2	117.80	12.28	12	17	6
CC3	118.69	12.36	8	12	5
CC4	116.29	12.13	9	13	5
CC5	118.14	12.42	9	15	5
CC6	120.32	12.68	8	14	7
CC7	117.03	11.93	10	10	5
CC8	117.81	12.51	9	15	8
CC9	119.89	12.48	9	11	6
CC10	118.52	12.16	8	10	6
CC11	120.16	12.51	10	10	5
CC12	116.43	11.85	9	10	4
CI1	155.88	15.06	10	14	7
CI2	153.46	14.63	11	15	9
CI3	154.62	14.96	12	17	8
CI4	155.24	15.01	10	12	6
CI5	156.37	15.10	11	18	9
CI6	154.92	14.81	9	18	8
CI7	153.76	14.62	10	14	8
CI8	154.49	14.73	10	15	9
CI9	155.16	15.02	13	20	9
CI10	153.97	14.80	10	16	7
CI11	154.86	14.92	12	19	6
CI12	152.74	14.56	10	18	8
CM1	180.94	19.56	12	20	10
CM2	179.72	18.42	11	18	9
CM3	179.93	18.63	13	18	10
CM4	181.89	19.68	12	19	11
CM5	180.53	19.03	13	22	12
CM6	179.84	18.41	11	18	10
CM7	181.65	19.36	10	16	9
CM8	180.12	18.74	12	18	10
CM9	182.41	19.74	12	17	10
CM10	179.36	18.67	8	16	12
CM11	178.68	18.52	10	18	12
CM12	180.63	19.24	12	20	10

Note: CC = Cabbage treated with tap water, CI = Cabbage treated with industrial liquid waste, CM = Cabbage treated with municipal liquid waste

Appendix 2: Effect of different treatments on leaves, shoot and root dry weights of *Lactuca sativa* (lettuce).

Species	SDW	RDW	LN	LL	LW
LC1	27.69	9.24	11	16	6
LC2	27.71	9.63	13	17	6
LC3	26.98	8.98	13	17	6
LC4	28.01	9.92	14	16	5
LC5	27.72	9.61	13	17	7
LC6	26.97	9.87	12	16	6
LC7	27.72	9.95	13	17	7
LC8	28.33	10.24	12	16	7
LC9	27.16	8.96	11	14	6
LC10	27.69	9.88	12	16	7
LC11	25.86	8.85	11	16	6
LC12	26.92	9.69	13	16	6
LI1	31.46	11.03	10	18	8
LI2	29.83	10.86	9	16	6
LI3	31.81	11.19	10	19	7
LI4	31.49	11.09	10	18	8
LI5	31.95	12.24	8	19	7
LI6	30.86	11.94	8	17	9
LI7	29.92	11.91	7	17	8
LI8	31.09	12.17	8	20	8
LI9	32.12	12.32	10	18	8
LI10	30.98	11.98	9	20	9
LI11	31.94	12.18	9	19	8
LI12	29.98	11.62	12	19	7
LM1	54.88	13.46	15	21	10
LM2	55.51	13.63	15	20	10
LM3	54.93	13.72	14	20	9
LM4	55.67	14.47	15	21	10
LM5	54.68	14.13	15	21	10
LM6	55.43	14.31	15	20	10
LM7	53.72	13.81	15	20	10
LM8	54.57	14.01	14	20	9
LM9	55.51	14.34	15	20	10
LM10	54.61	13.92	14	21	10
LM11	53.86	13.56	15	21	9
LM12	54.96	14.28	14	20	10

Note: LC = Lettuce treated with tap water (control), LI = Lettuce treated with industrial liquid waste, LM = Lettuce treated with municipal liquid waste.

Appendix 3: Effect of different treatments on leaves, shoot and root dry weights of Beta vulgaris var. cicla (swiss chard).

Species	SDW	RDW	LN	LL	LW
SC1	42.86	11.82	9	20	6
SC2	42.73	12.06	8	21	6
SC3	43.65	12.23	8	22	7
SC4	45.61	12.78	7	20	6
SC5	42.75	11.65	9	24	6
SC6	43.74	11.91	10	25	7
SC7	45.79	12.42	9	26	8
SC8	44.92	12.13	10	26	7
SC9	42.79	11.11	8	18	6
SC10	45.19	12.33	10	28	8
SC11	46.23	11.92	8	25	7
SC12	43.81	12.11	9	26	7
SI1	49.93	14.12	8	25	8
SI2	50.62	14.82	8	27	8
SI3	49.69	14.28	7	24	9
SI4	50.18	15.06	9	25	9
SI5	53.61	15.36	8	26	8
SI6	49.98	14.86	7	29	8
SI7	53.88	15.64	8	28	9
SI8	49.85	14.36	9	26	8
SI9	49.76	14.86	8	23	7
SI10	50.97	15.47	9	29	8
SI11	49.93	14.96	8	28	9
SI12	48.79	14.23	8	27	10
SM1	71.86	18.92	10	32	10
SM2	75.16	19.64	9	30	9
SM3	72.94	19.00	10	31	10
SM4	73.63	19.43	9	29	11
SM5	71.52	18.69	10	40	10
SM6	72.89	19.11	9	38	12
SM7	72.34	19.35	10	37	9
SM8	71.58	18.84	10	40	10
SM9	73.82	18.88	9	39	12
SM10	71.96	19.08	10	41	11
SM11	70.79	18.82	9	42	10
SM12	74.93	19.26	10	39	12

Note: SC = Swiss chard treated with tap water (control), SI = Swiss chard treated with industrial liquid waste, SM = Swiss chard treated with municipal liquid waste.

Appendix 4: Nutrient composition (ppm) of elements on shoot dry matter of *Brassica oleracea* var. *capitata* (cabbage) under different treatments at 60 days

Species	K	Ca	Mg	P	Cd	Cr	Pb	Ni	Zn	Cu
CC1	180	310	56	48	0.1	0.1	0.09	0.3	0.4	0.15
CC2	270	310	64	57	0.1	0.1	0.09	0.3	0.4	0.15
CC3	218	180	62	56	0.1	0.1	0.09	0.3	0.4	0.15
CI1	236	174	40	80	0.1	0.1	0.09	0.3	0.4	0.2
CI2	222	198	46	70	0.1	0.1	0.09	0.3	0.4	0.6
CI3	198	176	48	60	0.1	0.1	0.09	0.2	0.4	0.2
CM1	234	128	38	67	0.1	0.1	0.09	0.3	0.3	1.0
CM2	206	180	44	68	0.1	0.1	0.09	0.3	0.3	0.09
CM3	206	154	32	57	0.1	0.1	0.09	0.3	0.3	0.2

Note

CC = Cabbage treated with tap water (control)

CI = Cabbage treated with industrial liquid waste

CM = Cabbage treated with municipal liquid waste

Appendix 5: Nutrient composition (ppm) of elements on shoot dry matter of *Lactuca sativa* (lettuce) under different treatments at 42 days

Species	K	Ca	Mg	P	Cd	Cr	Pb	Ni	Zn	Cu
LC1	610	16.2	16	106	0.1	0.1	0.09	0.3	0.4	0.15
LC2	620	17.3	17	120	0.1	0.1	0.09	0.2	0.5	0.15
LC3	575	19.6	18.8	131	0.1	0.1	0.09	0.3	0.4	0.15
LI1	550	13.7	17.3	139	0.1	0.1	0.09	0.2	0.5	0.1
LI2	550	17	20	207	0.1	0.1	0.09	0.2	0.8	0.1
LI3	675	18.1	18.3	157	0.1	0.1	0.09	0.3	0.6	0.1
LM1	635	14.8	21.2	106	0.1	0.1	0.09	0.2	0.4	0.1
LM2	575	14.8	52	104	0.1	0.1	0.09	0.3	0.3	0.1
LM3	500	12.4	21.2	102	0.1	0.1	0.09	0.3	0.4	0.1

Note

LC = Lettuce treated with tap water (control)

LI = Lettuce treated with industrial liquid waste

LM = Lettuce treated with municipal liquid waste

Appendix 6: Nutrient composition (ppm) of elements on shoot dry matter of *Beta vulgaris* var. *cicla* (swiss chard) under different treatments at 50 days

Species	K	Ca	Mg	P	Cd	Cr	Pb	Ni	Zn	Cu
SC1	525	19.9	108	75	0.1	0.1	0.09	0.2	0.5	0.1
SC2	354	19.6	120	71	0.1	0.1	0.09	0.2	0.4	0.1
SC3	440	19.8	114	73	0.1	0.1	0.09	0.2	0.5	0.1
SI1	500	15.8	92	102	0.1	0.1	0.09	0.3	0.4	0.2
SI2	458	18.2	84	74	0.1	0.12	0.09	0.3	0.4	0.2
SI3	575	92	122	71	0.1	0.1	0.09	0.3	0.3	0.1
SM1	406	19.2	90	71	0.1	0.1	0.09	0.3	0.7	0.1
SM2	480	17.1	114	73	0.1	0.1	0.09	0.3	0.5	0.1
SM3	525	86	90	78	0.1	0.1	0.09	0.3	0.4	0.1

Note

SC = Swiss chard treated with tap water (control)

SI = Swiss chard treated with industrial liquid waste

SM = Swiss chard treated with municipal liquid waste

Appendix 7: Nutrient composition (ppm) of elements on shoot dry matter of *Brassica oleracea* var. *capitata* (cabbage) under different treatments at harvest.

Species	K	Ca	Mg	P	Cd	Cr	Pb	Ni	Zn	Cu
CC1	212	264	60	59	0.1	0.2	0.1	0.29	0.4	0.3
CC2	240	284	86	67	0.1	0.2	0.2	0.29	0.4	0.2
CC3	232	270	42	64	0.1	0.1	0.2	0.29	0.5	0.3
CI1	220	204	56	74	0.1	0.1	0.2	0.2	0.4	0.1
CI2	244	296	72	70	0.1	0.1	0.1	0.3	0.4	0.3
CI3	266	168	46	84	0.1	0.1	0.2	0.3	0.4	1.1
CM1	180	204	44	74	0.1	0.1	0.2	0.3	0.3	0.5
CM2	234	174	46	69	0.1	0.1	0.3	0.3	0.4	0.6
CM3	234	250	54	66	0.1	0.1	0.2	0.3	0.4	0.5

Note

CC = Cabbage treated with tap water (control)

CI = Cabbage treated with industrial liquid waste

CM = Cabbage treated with municipal liquid waste

Appendix 8: Nutrient composition (ppm) of elements on shoot dry matter of *Lactuca sativa* (lettuce) under different treatments at harvest.

Species	K	Ca	Mg	P	Cd	Cr	Pb	Ni	Zn	Cu
LC1	585	20.3	15.2	148	0.1	0.1	0.2	0.29	0.7	0.2
LC2	640	88	40	176	0.1	0.2	0.1	0.29	0.7	0.1
LC3	595	90	38	167	0.1	0.2	0.2	0.29	0.7	0.2
LI1	610	18	14	192	0.1	0.1	0.1	0.3	0.6	0.5
LI2	620	72	30	219	0.1	0.1	0.2	0.3	0.7	0.4
LI3	720	94	38	228	0.1	0.1	0.2	0.3	0.7	0.6
LM1	650	20.1	17.7	123	0.1	0.1	0.2	0.3	0.4	0.6
LM2	675	78	44	105	0.1	0.1	0.3	0.3	0.4	0.5
LM3	660	76	46	90	0.1	0.1	0.2	0.3	0.4	0.5

Note

LC = Lettuce treated with tap water (control)

LI = Lettuce treated with industrial liquid waste

LM = Lettuce treated with municipal liquid waste

Appendix 9: Nutrient composition (ppm) of elements on shoot dry matter of *Beta vulgaris* var. *cicla* (swiss chard) under different treatments at harvest.

Species	K	Ca	Mg	P	Cd	Cr	Pb	Ni	Zn	Cu
SC1	570	114	134	98	0.1	0.1	0.09	0.29	0.8	0.3
SC2	595	84	108	88	0.1	0.1	0.09	0.29	0.5	0.2
SC3	670	158	156	78	0.1	0.1	0.09	0.29	0.5	0.3
SI1	660	90	106	123	0.1	0.1	0.09	0.3	0.5	0.4
SI2	960	78	100	118	0.1	0.1	0.09	0.3	0.5	0.9
SI3	620	86	100	126	0.1	0.1	0.09	0.3	0.6	0.2
SM1	535	78	84	80	0.1	0.2	0.09	0.3	0.8	0.5
SM2	510	72	114	96	0.1	0.1	0.09	0.33	0.5	0.6
SM3	645	74	100	83	0.1	0.1	0.09	0.3	0.4	0.5

Note

SC = Swiss chard treated with tap water (control)

SI = Swiss chard treated with industrial liquid waste

SM = Swiss chard treated with municipal liquid waste