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Treated Municipal Wastes: Are they Contaminating or Enriching the Soil?

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Additional information is available at the end of the chapter

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Abstract

Treated municipal wastes could be a mixture of treated sewage biosolids and green wastes (Kala compost) that can be applied for agricultural production. It can improve soil fertility and plant growth. However, long-term application of treated sewage biosolids could result in heavy metal accumulation and some health problems. The objective of this study is to evaluate the effect of different fertilizers, especially Kala compost, on the soil fertility and plant productivity. An open field was divided into nine plots and received either treated municipal wastes (Kala compost) or inorganic fertilizer, or a mixture of both fertilizers. The field was irrigated by drip system, and commercial cucumber, tomato, cabbage, lettuce, carrot, and potato were grown in each plot. Soil and plant were monitored continuously and samples were taken at different stages of the study. No symptoms of physical or chemical problems were observed in the open field and measured soil samples. Moreover, the soil had sufficient amount of different nutrients for plant growth and all measured micronutrients (heavy metals) were within the safe limit and below the allowable safe limit of the international standards. Good growth was observed in all grown crops and no symptoms of element toxicity were observed. Chemical analysis for fruit samples did not show any accumulation of heavy metals and all measured elements were within the safe limit for human consumption. It can be concluded that treated municipal wastes (Kala compost) were good media for plant growth that can enrich the soil with different elements needed for higher yield. However, more monitoring is needed with treated biosolid application and good management could be the key to avoid any adverse effect of any contaminant.

Keywords: treated wastewater, biosolids, Kala compost, heavy metals, plant growth

1. Introduction

Sewage sludge or biosolids, which are one of the final products from wastewater treatment plants, are considered the most promising waste that can be utilized in an effective and environmentally friendly manner. Sewage sludge creates very little to zero environmental impact if utilized properly. Throughout the world, the safe disposal of the sewage sludge is one of the major environmental concerns. However, opinions on the utilization of the sewage sludge vary due to the possible positive and negative points associated with the handling and treatment. In fact, sewage sludge is increasing annually as the population increases and it is a renewable product that will never stop forming. It can be treated differently with various methods depending on the purpose of the treatment [1, 2]. Sewage sludge is composed of organic compounds, macro- and micronutrients, trace elements including toxic metals, microorganisms, and micro-pollutants. Micro- and macronutrients serve as a source of plant nutrients, whereas organic constituents serve as soil conditioner. It contains high concentrations of N, P, Ca, and Mg. Potassium is, however, deficient in sewage sludge [3]. Sludge amendment improves soil properties such as porosity, bulk density, aggregate stability, and water-holding capacity. Sewage biosolids are often used as a fertilizer on farms to grow corn and cereal crops such as wheat. Using sewage biosolids as a nutrient source for field or forage crops or for improved pasture (1) improves soil fertility—offsetting the need for commercial fertilizers; (2) reduces production costs; (3) improves soil fertility; (4) enhances soil structure, moisture retention, and soil permeability; (5) adds organic matter—enhancing soil structure, moisture retention, and permeability, while reducing the potential for wind and water erosion [3].

Higher level of heavy metals in sewage sludge may be a cause for problems when applied in field used for agriculture. Whether any problem actually takes place will depend on soil pH, soil organic matter content, cation exchange capacity, movement of heavy metals in the soil profile, and changes that take place in the forms of heavy metals [4]. It is always advisable to use sewage sludge in low doses to reduce bioavailability of toxic heavy metals [5]. Sewage sludge amendment increases the production of a variety of plants including vegetables, cereals, grasses, and trees. The use of sewage sludge also results in more robust plants with faster development and greater biomass production [6]. It has been observed that crops contain heavy metals at concentrations harmful to human health when such crops were grown in soil amended with extremely high level of sewage sludge [7]. However, the metal concentrations in the sewage sludge depend on several factors such as (i) sewage origin, (ii) sewage treatment processes, and (iii) sludge treatment processes.

In Oman, “Haya Water” is a government company that is responsible for building, operating, and managing wastewater projects in Muscat Governorate. Haya Water has developed its pioneering Kala Composting Plant to enable the efficient reuse of sewage biosolids and green waste enabling their conversion to a compost product that can be used for agriculture, landscaping, and for individual gardens. The use of Kala compost (KALA) has various benefits such as farmers reusing a waste product, municipal authorities reducing their dependence on chemical fertilizers, as well as reducing greenhouse gas emission due to the use of

environmental friendly waste management process [8]. However, high application of sewage biosolids could result in heavy metal accumulation and many health problems. Therefore, sewage biosolids applied to agricultural land must be well treated and continuously monitored to avoid any environmental risk problems. The objective of this study is to evaluate the effect of different fertilizers especially Kala compost on the quality of soil and crops. Specifically to (1) conduct research to assess the performance of the tested crops under different fertilizers, (2) to determine the changes in physicochemical properties of the soil treated by different fertilizers, (3) to determine the amount of water that can be saved using Kala compost, (4) to determine the effect of Kala compost on plant growth and find out any heavy metal accumulation in soil and plant, and (5) to monitor characteristics and yield components of crops grown and treated by different fertilizers.

2. Materials and methods

Research studies were carried out to achieve the set goals through detailed experimentation at Sultan Qaboos University (SQU), Agricultural Experiments Station (AES) open field.

New field at AES was prepared by removing rocks and big stones. The field was divided into nine plots and each plot (43.2 m²) received either 216 kg of Kala compost or 4.5 kg of inorganic fertilizer (NPK) or a mixture of both fertilizers (MIX). Drip irrigation system was installed all over the field. Commercial cucumber, tomato, cabbage, lettuce, carrot, and potato were grown in each plot.

Soil salinity, moisture content, and temperature were monitored by using wet-sensor device. Moreover, direct soil samples were taken at depths of 0–15, 15–30, and 30–45 cm. Plant growth and yield of each crop treated by different fertilizers were observed. Fruits quality and quantity were assessed. Samples from soil and plants were taken for different physical, chemical, and biological analyses. All physicochemical analyses for soil and plants were done in soil and water labs (SQU) following standard methods and using inductively coupled plasma (ICP) machine for metal analysis, whereas biological analysis for plant samples was done in Muscat Municipality laboratories.

3. Result and discussion

3.1. Pure Kala compost

Pure Kala compost (saturated extract sample) was analyzed for physical, chemical, and biological properties. From **Table 1**, it was found that all measured parameters were within the acceptable level of the international standards and the compost can be applied to improve soil fertility. Actually, Kala compost is a mixture of different municipal wastes such as treated sewage sludge, plant materials, and cow manure. Therefore, it is expected to have low concentration of heavy metals and good values of different nutrients that can support plant

growth. It was reported by the Ministry of Agriculture, Forestry, and Fisheries (MAFF) [9] that different compost will behave differently in the soil based on the processes used to generate waste materials.

Samples	pH	EC (dS/m)	N (%)	OM (%)	TOC (%)	IC (%)	TC (%)	FC (FC media)
Kala 1	6.7	23.8	3.15	38.68	22.49	0.011	22.50	0
Kala 2	6.7	24.8	3.20	36.67	21.32	0.89	22.21	0
Kala 3	6.7	24.3	3.18	37.10	21.57	0.84	22.41	0

Samples	Elements concentration (mg/l)							
	Mn	Cd	Cu	Fe	Zn	B	P	Al
Kala 1	0.107	<0.001	0.160	0.590	0.068	0.451	2.506	0.127
Kala 2	0.082	<0.001	0.116	0.545	0.063	0.320	1.608	0.105
Kala 3	0.065	<0.001	<0.0004	0.394	0.001	<0.001	0.327	0.098

Samples	Elements concentration (mg/l)							
	Ba	Ca	Cr	Co	Pb	Mg	Ni	Ti
Kala 1	0.037	15.570	0.053	0.060	0.154	2.991	0.013	0.010
Kala 2	0.039	14.635	0.042	0.068	0.182	3.077	0.009	0.009
Kala 3	0.039	14.185	0.035	0.064	0.128	3.017	<0.001	0.008

*EC: Electrical conductivity; N: nitrogen; OM: organic matter; TOC: total organic carbon; IC: inorganic carbon; TC: total carbon; FC: fecal coliform bacteria.

Table 1. Chemical analysis for pure Kala compost.

3.2. Soil samples

Kala compost was a good source for organic matter and organic carbon that can support soil physical parameters. Organic matter could be the main reason in improving water-holding capacity of the soil amended by Kala compost (Figure 1). Moreover, it added more nitrogen to the soil and improved plant chlorophyll content (Figure 2). In addition, Kala compost reduced soil-compaction problem by improving soil bulk density where Kala compost gave 1.53 g/cm³ and chemical fertilizer gave 1.72 g/cm³. The good result for bulk density under Kala compost is supporting Kala application in which organic fertilizer can improve soil aggregate stability, soil structure, and support root growth.

Recent studies indicate that compost of biosolids in combination with woodchips or sawdust is used to grow horticulture crops under field or pots condition. It helps in improving soil

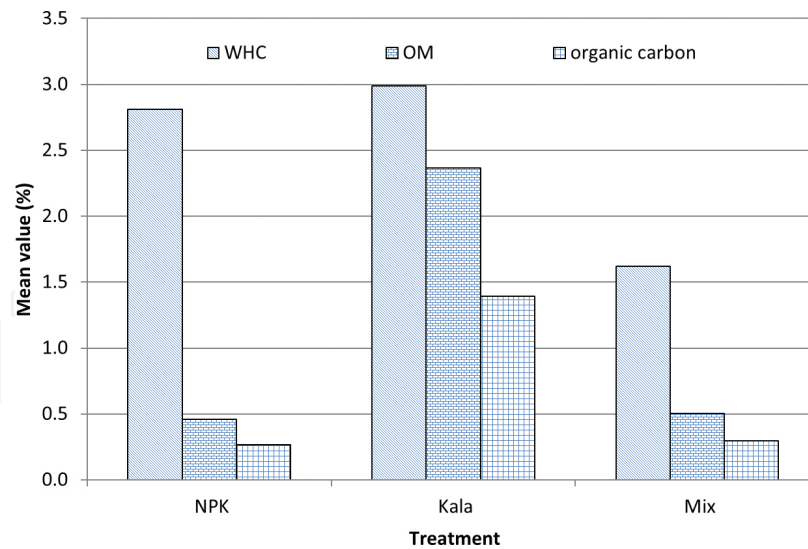


Figure 1. The effect of organic matter (OM) on soil organic carbon and water holding-capacity (WHC) at different treatments.

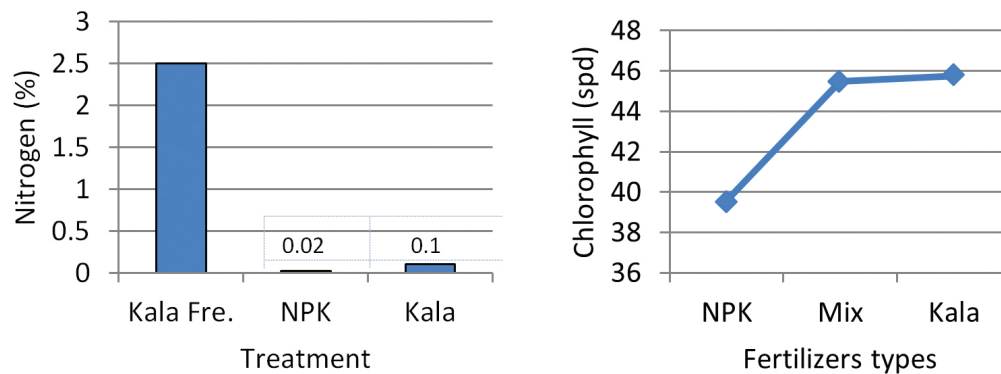


Figure 2. Soil nitrogen and plant chlorophyll values as affected by different treatments.

physical properties such as lowering bulk density, increasing water-holding capacity, increasing total soil porosity, and aggregate stability [10]. According to Wang et al. [11], sludge is shown to be efficient fertilizers as it improves soil physical properties such bulk density, porosity, aggregate stability and water retention and movement. Other properties also can be improved such as pH and contents of organic matter and nutrient contents as the raw sludge is rich in nutrients such as nitrogen, phosphorus, organic matter, and essential trace elements. A study showed clearly that water retention capacity was increased when 0.5% sewage sludge was added to soil. In fact, that increase was higher for raw sludge-amended soil than deposited sludge-amended soil [12].

3.3. Soil salinity

Soil salinity is a good indicator for soil fertility and salt toxicity. Using saturated paste extract method, it can be seen that chemical fertilizer (NPK) gave the highest value (3 dS/m) compared to other treatments (**Figure 3**). Whereas, Kala treatment gave reasonable value that was accepted by many crops. In all cases, salts could be added or diluted or leached down when

the land is irrigated by good-quality water. Soil pH for all treatments was around 8. It was slightly affected by compost application.

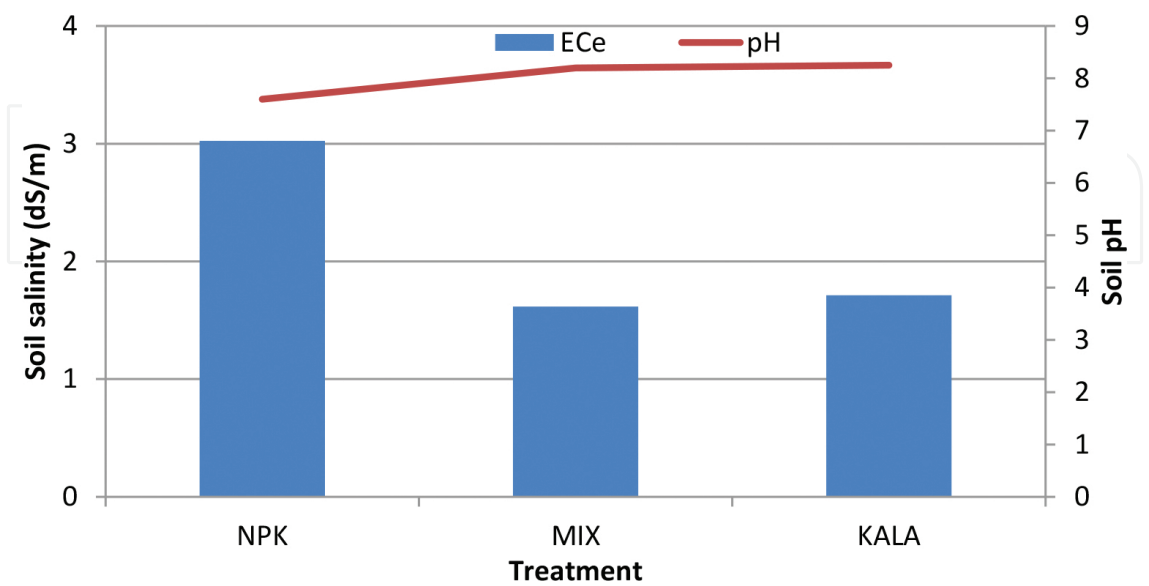


Figure 3. Soil electrical conductivity (ECe) and pH at the beginning of the study.

At the end of the study (Figure 4), the salinity value was almost similar to the result found in Figure 3. The main difference was that more salts or nutrients were released from Kala fertilizer. All salts found in each treatment were moved up or down the profile depending on air temperature for evaporation or amount of water added as irrigation or rainfall (Figure 5). Generally, Kala compost held less salts compared to NPK treatments, but at the same time all those salts were used to support plant growth and released slowly so they can be used as a source of nutrients without any problem of toxicity.

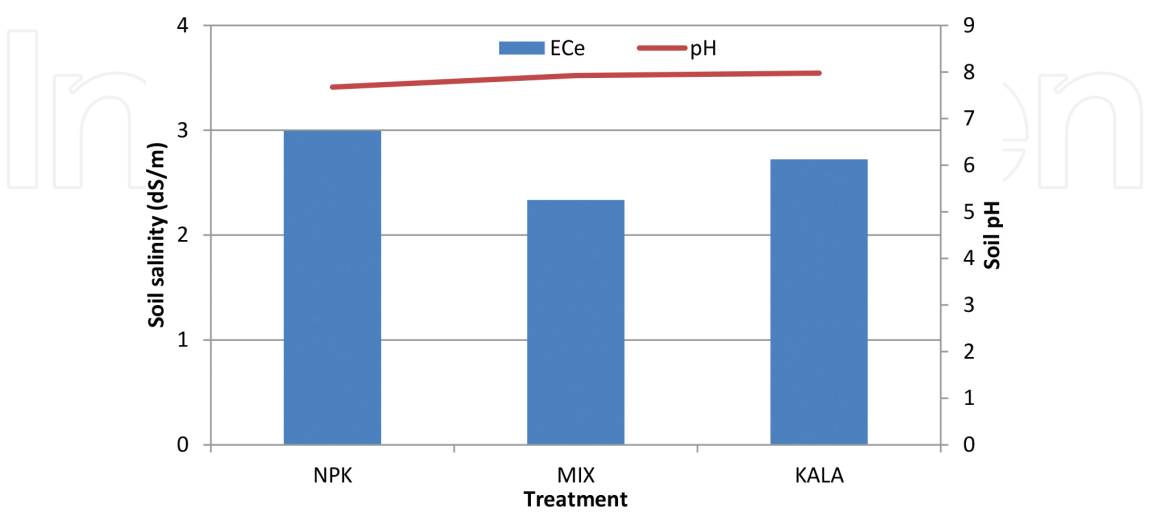


Figure 4. Soil electrical conductivity (ECe) and pH at the end of the study.

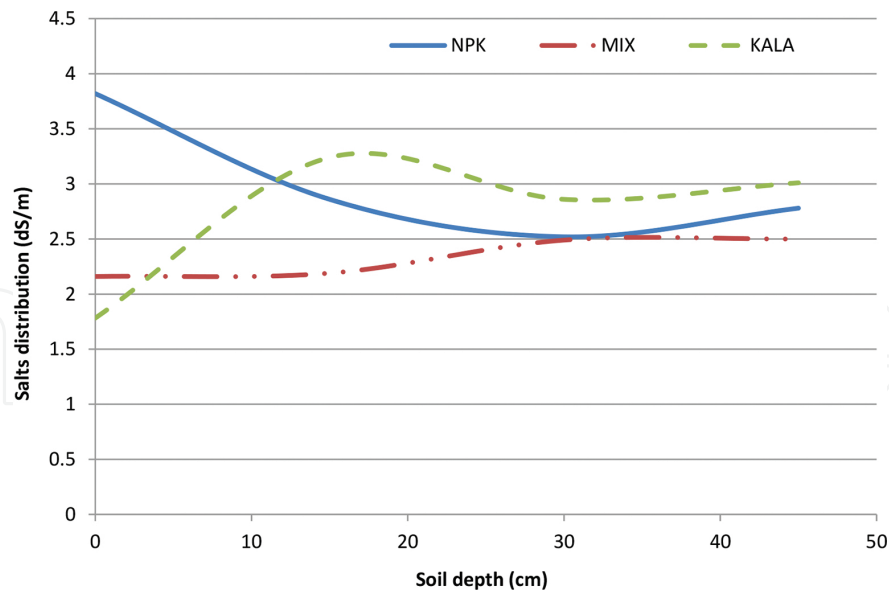


Figure 5. Salt distribution (EC_e) along the horizons.

Wet sensor is a good device for monitoring soil water content, temperature, and salinity. From **Table 2**, it can be seen that wet sensor confirms what was found in previous figures. Kala compost was maintaining much water that helped in reducing soil temperature with slow release of salts with time.

The application of organic amendment such as sewage sludge compost to agricultural field usually improves soil physiochemical properties through increasing the content of organic matter, the total nitrogen content, and the electrical conductivity, whereas it causes reduction in pH slightly [13]. Electrical conductivity could increase with sewage sludge compost application [14] as a result of acidification in combination with subsequent solubility of metallic elements.

Treatment	Time						
MC (% vol)	05-Jan	12-Jan	26-Jan	02-Feb	09-Feb	16-Feb	23-Feb
NPK	20.2	35.3	11.1	32.0	26.1	17.6	20.1
KALA	25.9	35.5	11.3	39.8	23.8	26.5	20.4
EC (dS/cm)							
NPK	176	170	211	178	135	97	122
KALA	133	137	149	211	130	133	115
Temp (°C)							
NPK	23.3	18.4	22.1	22.1	23.1	19.2	21.9
KALA	21.4	18.3	21.3	23.3	23.1	23.8	23.5

Table 2. Wet sensor readings for soil water salinity, moisture content (% vol), and temperature with time.

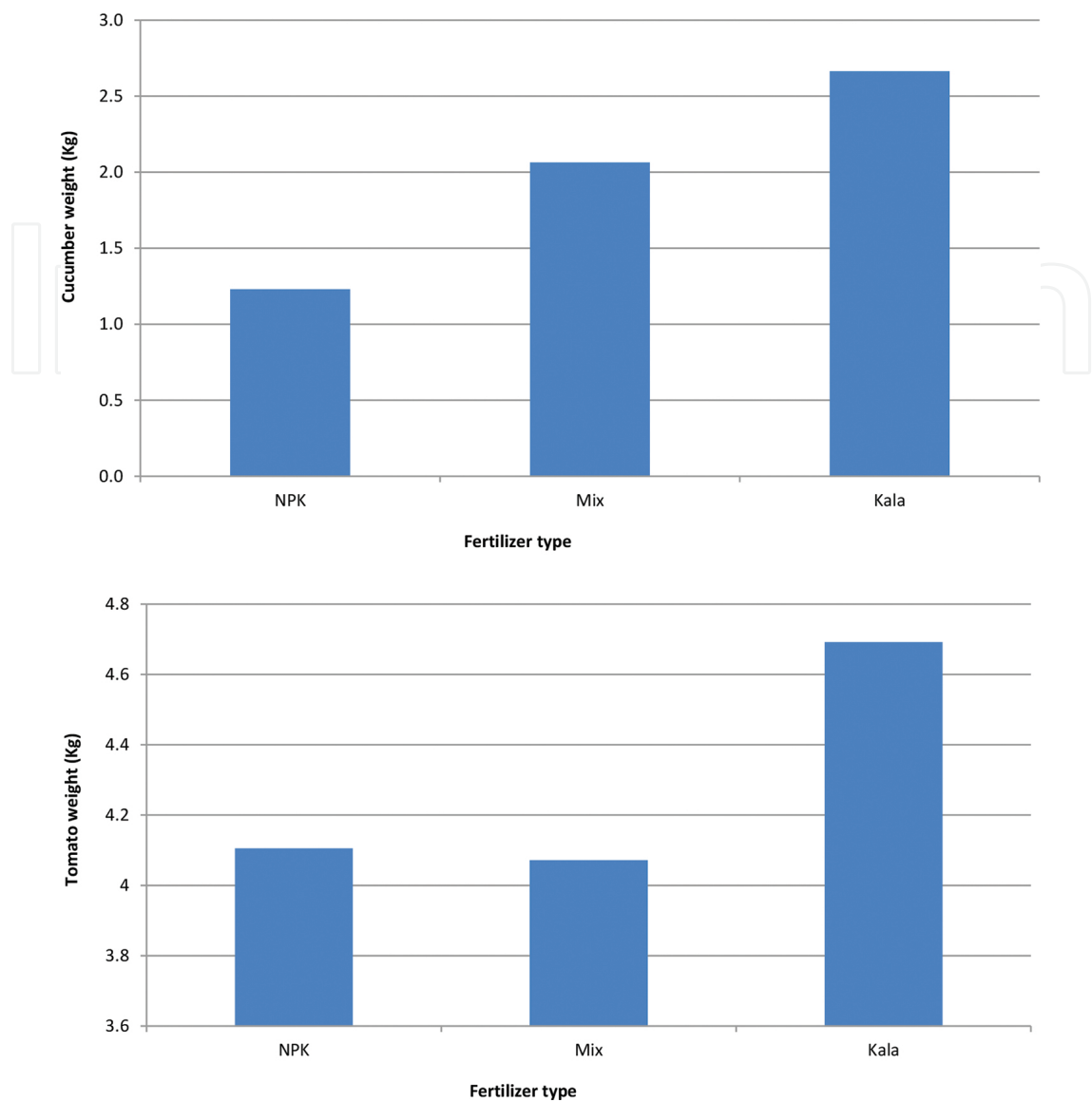


Figure 6. Average yield of cucumber and tomato.

3.4. Plant samples

From Figures 6–8, it can be seen that the best productivity of all tested crops was mostly with Kala compost followed by mix treatment and finally by NPK fertilizer. It does not mean that NPK treatment was bad but may be some plants did not get the right amount of fertilizer in the right time. The organic or mix of both organic and inorganic fertilizers usually is the best for consumer and surrounding environment. It seems that Kala compost was creating a good environment for plant by releasing multinutrients, reducing evaporation and keeping much water in the root zone compared to NPK treatment.

Good results were also found in Nielson et al. [15] study when the municipal biosolids were added to cultivate carrots and chard on irrigated soils. A significant increase in yield was found in plants growing biosolid-amended soil as compared to those grown in non-amended soil. In

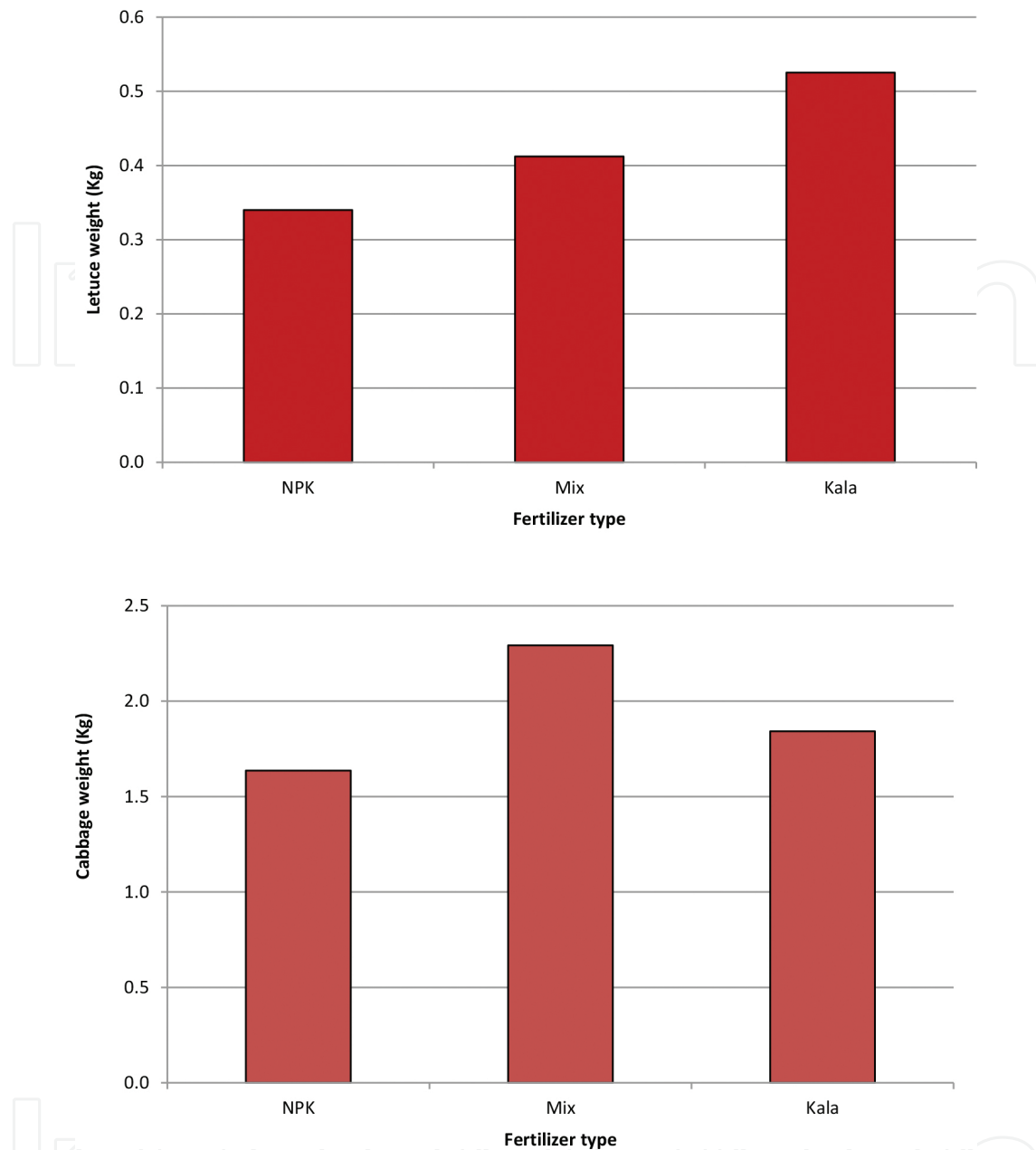


Figure 7. Average yield of lettuce and cabbage.

addition, a similar study with cotton (*Gossypium hirsutum*) also showed advancement of flowering and fruiting by 2–3 weeks under sludge-amended soil as compared to fertilizer-amended ones [16]. The grain yield of barley increased significantly under repeated sewage sludge application. The leaf protein concentration and dry matter accumulation in the plants grown in sludge-amended soil was higher from the beginning of development to ear emergence [17]. Moreover, it was found that the sludge amendment at the rate of 0.80, 160, and 320 t/ha dry wt. in soil increased the average dry weight of sunflower plants (*Helianthus annuus* L.) [18]. Even in saline soil, Verlinden and McDonald [19] showed that compost amendment increased *Limonium sinuatum* and *Celosia argentea* yield. By supplying nutrients, particularly N and P, compost can improve the mineral-nutrient status and growth of plants in saline soils.

Finally, the faster development and greater biomass production in plants grown in sludge-amended soil may be responsible for an early reproductive cycle. Moreover, the complex organic and the inorganic compounds of sewage were broken down into simpler forms, and thus the final treated sludge became useful and beneficial to the seedling growth [20].

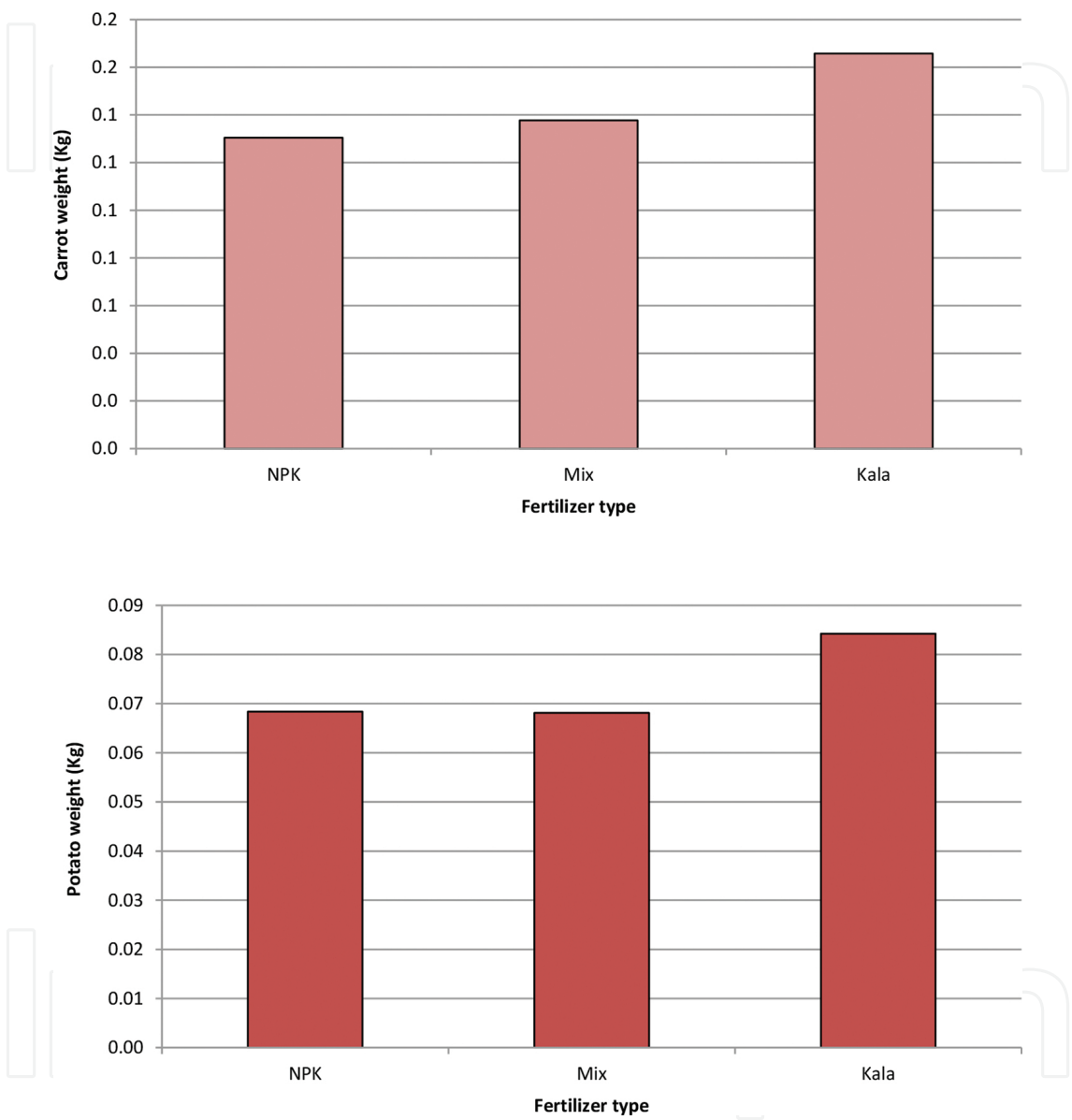


Figure 8. Average yield of carrot and potato.

3.5. Metal concentrations in soil samples

3.5.1. At the beginning of the study

From **Table 3**, it can be seen that all major cations were found in good amount for all treatments, whereas minor cations and heavy metals were detected in low concentrations. This means that

all fertilizers had good concentrations of different nutrients in which they positively affected soil fertility. For heavy metals, all measured elements were within the acceptable level of international standards.

	Mg	K	P	Cd	Co	Cr	Cu
NPK	17.3957	92.9470	0.0300	<0.0010	0.0647	0.0613	<0.0004
KALA	9.0521	107.3446	3.4602	<0.0010	0.0696	0.0500	<0.0004
MIX	6.7443	91.3614	0.2732	<0.0010	0.0556	0.0456	<0.0004
	Fe	Mn	Ni	Pb	Ti	Zn	B
NPK	0.3477	0.0352	0.0100	0.2273	<0.0050	0.0211	0.0828
KALA	0.3602	0.0199	0.0410	0.2986	<0.0050	0.0302	0.0730
MIX	0.3397	0.0188	0.0050	0.2187	<0.0050	0.0010	0.0422

* Mg: magnesium; K: potassium; P: phosphorus; Cd: cadmium; Co: cobalt; Cr: chromium; Cu: copper; Fe: iron; Mn:4 manganese; Ni: nickel; Pb: lead; Ti: titanium; Zn: zinc; B: boron.

Table 3. Soil metal concentration (mg/l) in saturation extract at the beginning of the study.

3.5.2. At the end of the study

From **Table 4**, it can be seen that elements such as K, P, and Mg were found in good concentrations, which is good for plant growth, whereas microelements and heavy metals were in low concentrations and within the international standards for all treatments. As mentioned before, irrigation water was the main cause of releasing the nutrients to the root zones. However, the similarity in concentrations of most elements in NPK and Kala fertilizers means that original soil was a source for some elements (rock materials) and the added values came from each treatment.

	Mg	K	P	Cd	Co	Cr	Cu
NPK	15.0237	85.3755	0.0300	<0.0010	0.0592	0.0654	<0.0004
KALA	38.5184	52.9741	0.4517	<0.0010	0.0566	0.0467	<0.0004
MIX	14.9962	60.2882	0.1451	<0.0010	0.0616	0.0484	<0.0004
	Fe	Mn	Ni	Pb	Ti	Zn	B
NPK	0.3356	0.0193	0.0050	0.2352	<0.0050	0.1488	0.1039
KALA	0.3376	0.0290	0.0114	0.2208	<0.0050	0.0232	0.2645
MIX	0.3340	0.0241	0.0050	0.2495	<0.0050	0.0656	0.0780

* Mg: magnesium; K: potassium; P: phosphorus; Cd: cadmium; Co: cobalt; Cr: chromium; Cu: copper; Fe: iron; Mn:4 manganese; Ni: nickel; Pb: lead; Ti: titanium; Zn: zinc; B: boron.

Table 4. Soil metal concentration (mg/l) in saturation extract at the end of the study.

Long-term fertilization of biosolids enhances soil condition and shows increase in land production and that increment confirms the potential of substantial revenue expansion [21]. A study was conducted in China by Wang et al. [11] to identify the effects of using sludge in agricultural lands. The study concluded that the biomasses of grass used in the experiment were increased as well as soil organic matter compared to control treatment where no sludge was added. Furthermore, the heavy metals Pb, Cu, and Zn were determined and found not exceeding the standards of acceptable levels of heavy metals. It is wise not to generalize how metals interact in soil and ultimately taken up by plants because many factors influence such interactions and uptake such as the type of metal, physical, and chemical properties of the soil and the type of crop. As it is difficult to take into consideration all such factors, the regulation of sewage sludge application is based on the total metal loading or concentration in soils. Kiekens et al. [22] observed much lower metal solubility in a calcareous clay soil than in sand (pH 6) regardless of whether the metals were added as salt or sludge form.

3.6. Metal concentrations in plant samples

To evaluate the nitrogen content for the tested crops (Figure 9), it can be seen that Kala treatment obtained the highest values which was expected due to the high content of nitrogen in Kala fertilizer compared to NPK. This value was clearly reflected in soil nitrogen and chlorophyll content shown in Figure 2. The high value of nitrogen could be one of the reasons for obtaining better productivity with Kala compost compared to NPK.

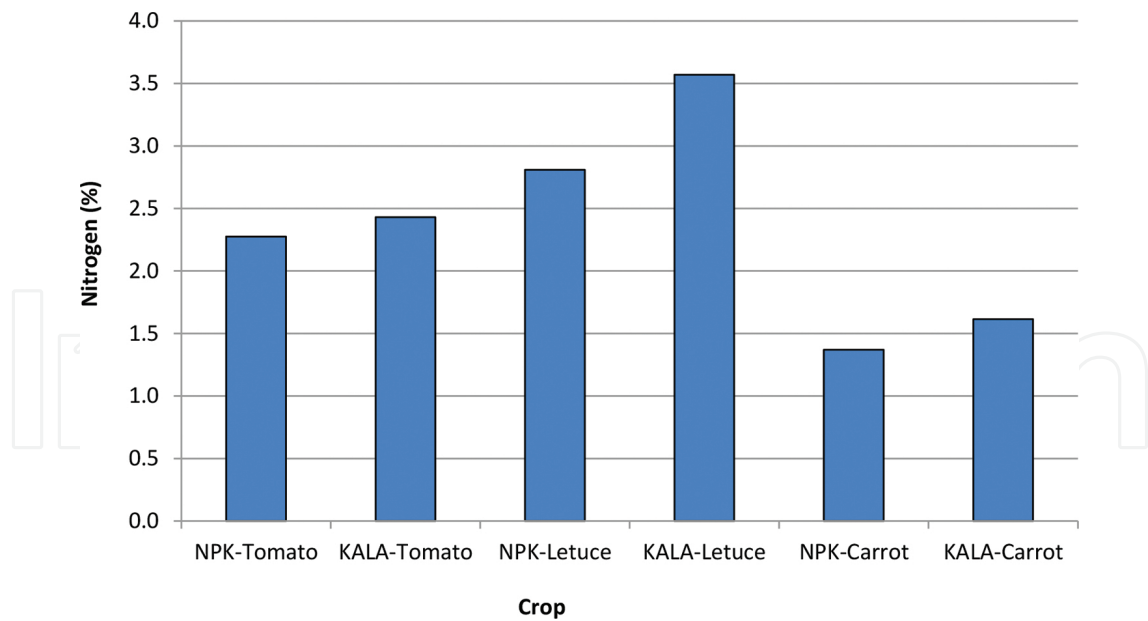


Figure 9. Nitrogen content in tested crops.

For microelement concentration in fruity plants, it can be seen from Figures 10 and 11 that there were small changes between NPK and Kala treatments. For short-season plants such as cucumber (Figure 10), it can be seen that in some cases NPK gave higher values for some

elements such as Mn, Pb, and Ni, whereas Kala gave higher values than NPK for others such as Fe, B, and Al.

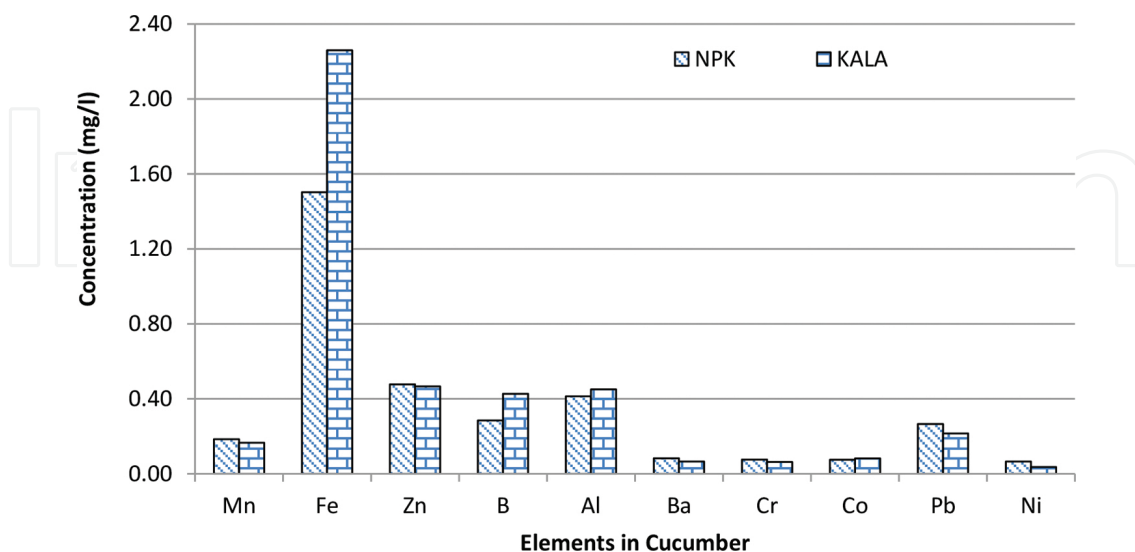


Figure 10. Heavy metal concentrations in cucumber.

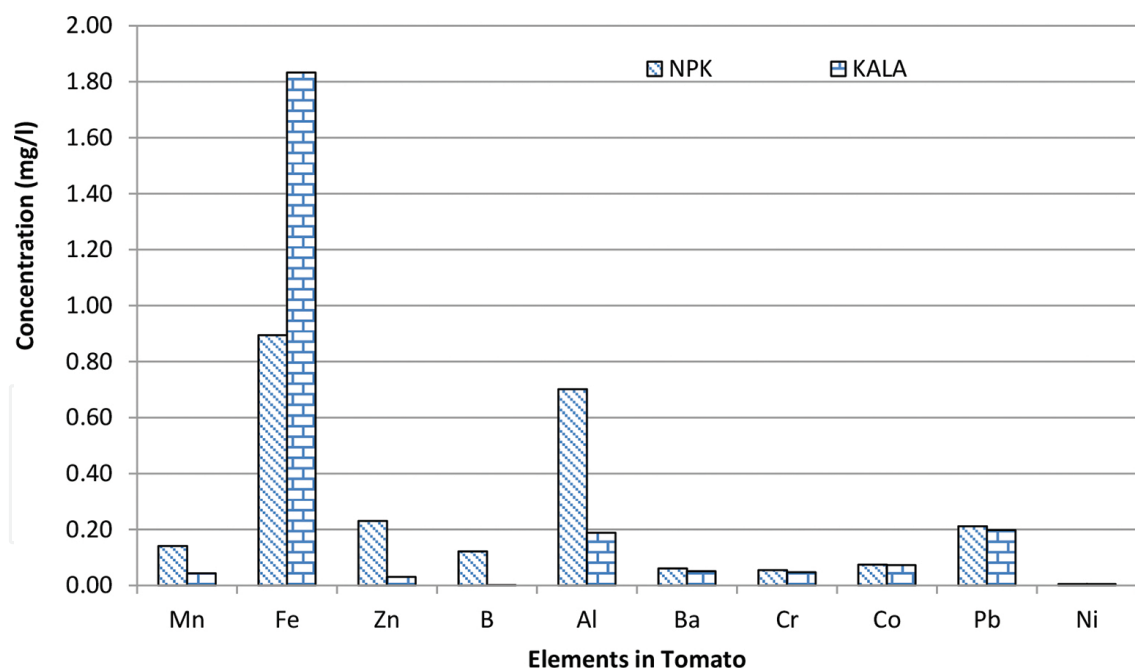


Figure 11. Heavy metal concentrations in tomato.

For long-season plants such as tomato (**Figure 11**), it can be seen that NPK was higher in all measured elements than Kala except for Fe.

For leafy plants, it can be seen from **Figures 12** and **13** that similar scenario was repeated and small variations were found between Kala and NPK fertilizers.

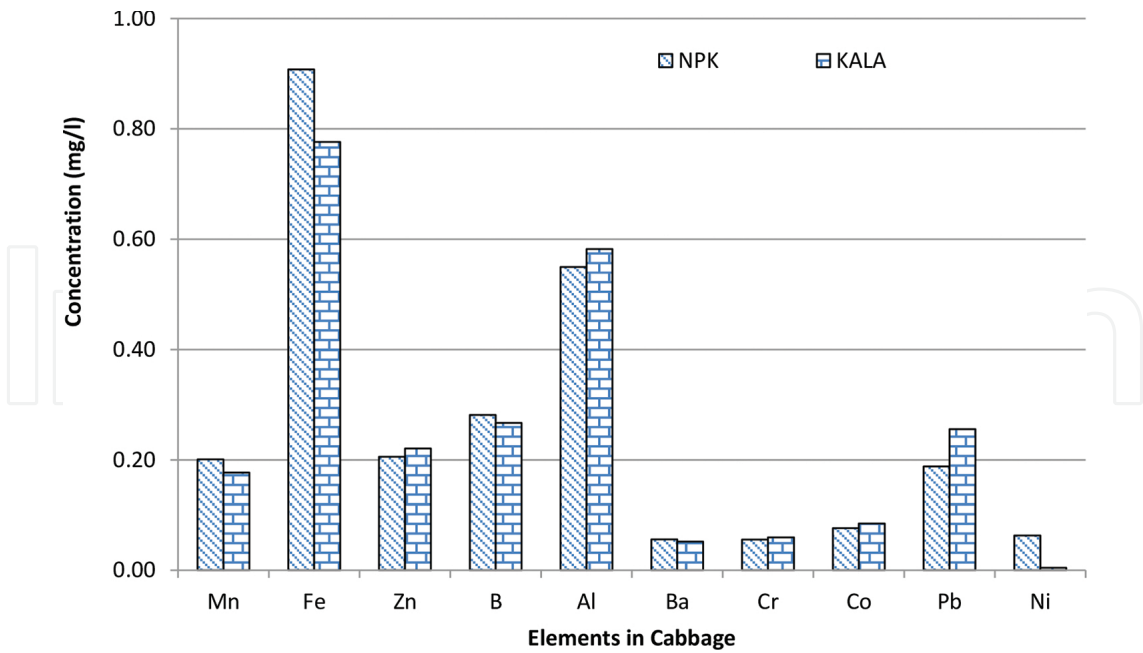


Figure 12. Heavy metal concentrations in cabbage.

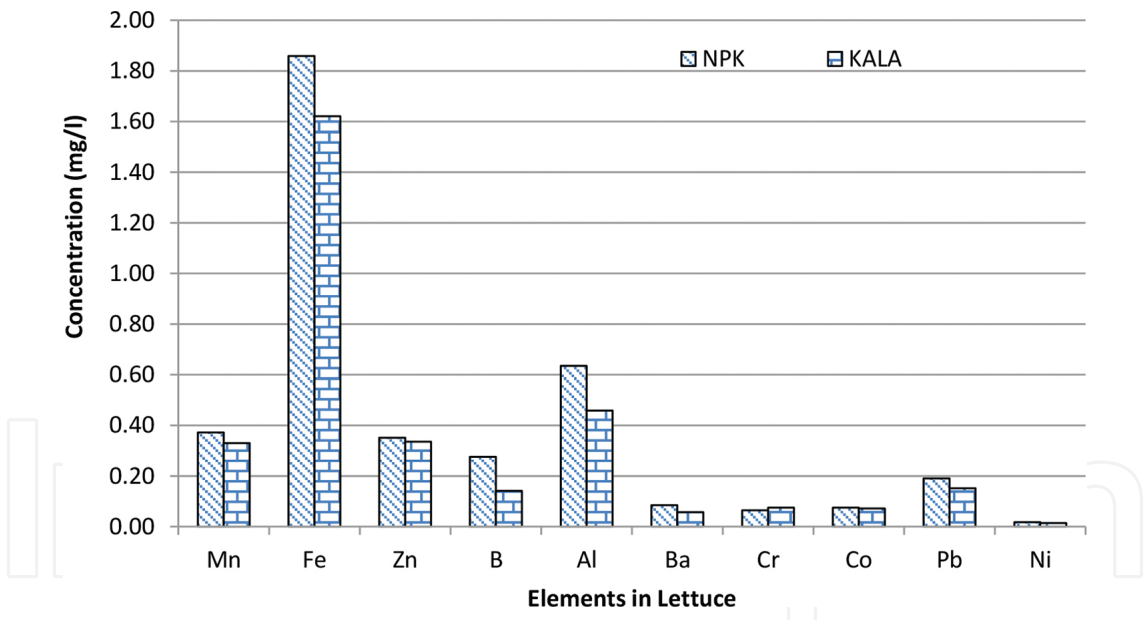


Figure 13. Heavy metal concentrations in lettuce.

For very short-season plant such as lettuce (**Figure 13**), it can be seen that all elements were in low concentrations with Kala compared to NPK. Iron (Fe) had the highest concentrations in all crops of both treatments.

For root crops such as carrot and potato (**Figures 14 and 15**), Iron (Fe) was high in both treatments of both crops. However, Kala compost was higher than NPK in some measured values.

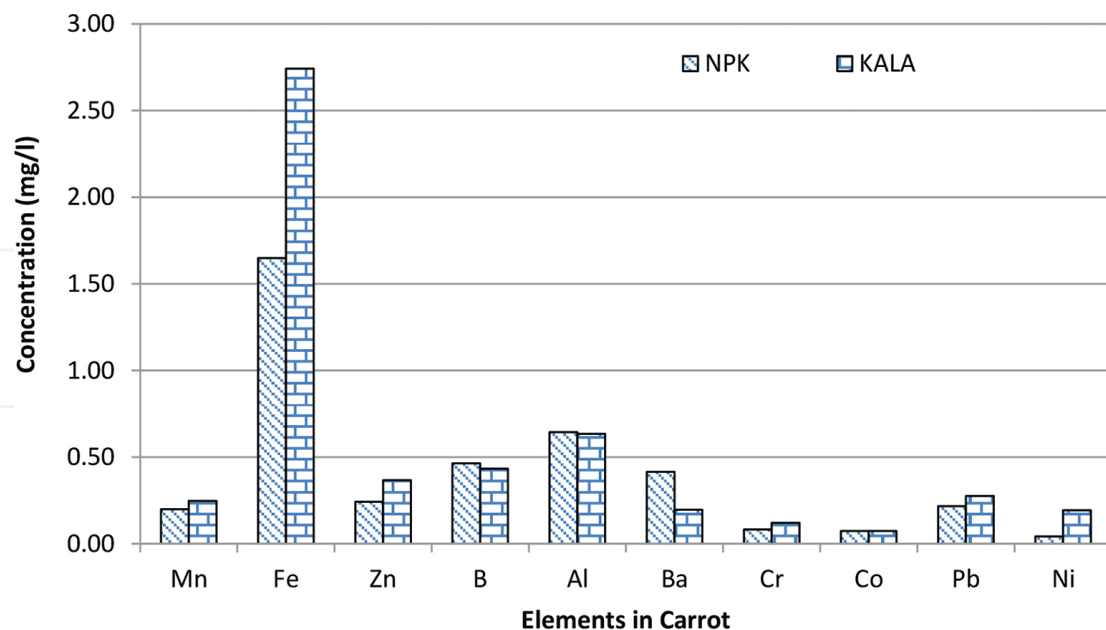


Figure 14. Heavy metal concentrations in carrot.

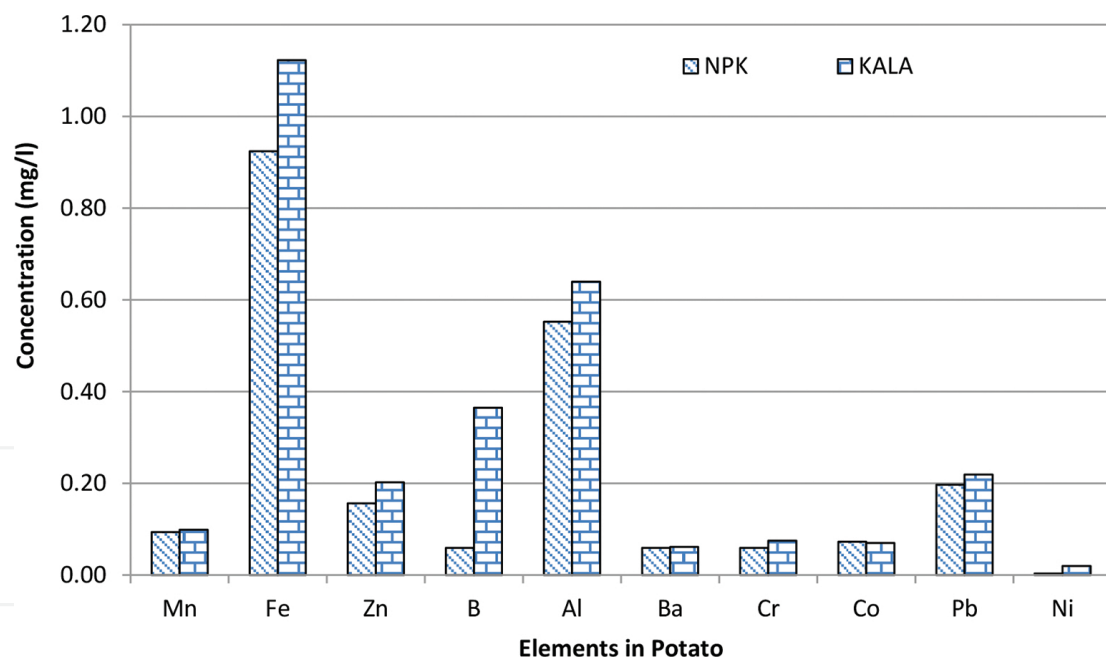


Figure 15. Heavy metal concentrations in potato.

For all treatments of all crops, cadmium (Cd) and copper (Cu) were found in very low concentration of <0.001 mg/l.

Several studies have evaluated the tissue concentrations of nutrients and heavy metals in plants when grown in the sewage sludge-amended soil. The accumulation pattern varied with soil type, plant species, phenology, and chelating effects of other metals [23]. Bonding of potentially

toxic elements to sludge solids and soils can limit transfer to roots. Some metals, such as Cr and Pb, have very low solubility in soils and show a particularly strong barrier. Leafy crops tend to have less protection in the uptake of metals in comparison to root crops. Many experiments have shown the metals have lower concentrations in seeds and fruits compared to roots, stems, and leaves. For example, Mo is more concentrated in soybean seeds than in the leaves [24], and Tl concentrations in rapeseed are higher than in the leaves [25]. For slightly-moderately Cd-contaminated soils, the transfer of Cd to the seed of linseed (flax), sunflower, corn, and wheat can be sufficiently high to exceed health standards in some countries [26, 27], whereas Zn uptake by corn (maize) in a multiyear sewage sludge experiment on calcareous soils was within the safe limit [28].

For copper concentration in crops, results for Cu were observed in the long-term field sludge experiments of Hinesly and Hansen [29], Hinesly et al. [30], and Soon et al. [28]. It was observed that Cu concentration increased in maize stover when there was an increase in Cu loading in the soil through sludge application. But interestingly, the increase was not directly proportional to the amount of increased Cu application. Reasons for such behavior are Cu sorption by sludge and soil organic matter and plants' strong physiological barrier to Cu translocation [31].

Because of the complicated nature as to how metals behave in soils especially when they are added through sewage sludge, it is almost impossible to provide generalized guidelines. For any particular situation, various considerations should be given before setting metal application guidelines. Such concentration should include soil physical and chemical properties especially adsorption characteristics, crops to be grown, and usage of grown crops. Contamination of such land by metals should be regarded as irreversible and must be kept to the lowest practicable level [9].

3.7. Biological analysis

To evaluate microbial contamination, multisamples were sent to the Muscat Municipality laboratory from all crops. Different tests were done such as the total aerobic plate count, Coliform bacteria, *Escherichia coli*, *Staphylococcus aureus*, *Salmonella* spp., yeast, and mold. No harmful bacteria were found, and according to that all crops can be eaten safely.

Same finding was reported by Boswell [32], when he noticed that sewage sludge amendment increased the fruit yield significantly compared to the un-amended control and no toxic or detrimental effects on fescue were noted.

3.8. Water productivity

Water productivity factor can be calculated by comparing water used in this study with plant production (water productivity = total fruit weight, kg/water applied, m³). The same amount of water was used to irrigate all crops, and as it was found in **Figures 6–8**, Kala compost gave better yield than NPK treatment, which means that water productivity of Kala compost was higher than NPK treatment.

Additions of organic fertilizers enhance soil fertility and improve soil structure. These improvements in soil physical properties increased water-holding capacity by promoting higher water retention in sludge-amended soils [33].

4. Conclusion

It can be concluded that treated municipal wastes (Kala compost) enriched the agricultural soil by improving soil physiochemical properties. Kala compost was a good conditioner for soil as it supported plants with many elements needed for high yield. Soil and plant chemical analysis did not show any problem of heavy metal accumulation. The application of Kala compost did not cause any environmental and human health problems. Therefore, it is safe to apply treated municipal wastes (Kala compost) in some agricultural crops if good management is practiced. Moreover, it is recommended that long-term records on application of treated municipal wastes (Kala compost) are reviewed, so clear findings can be generalized for future applications.

Acknowledgements

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