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DYNAMICS OF SOIL NEMATODES AND EARTHWORMS IN URBAN VEGETABLE IRRIGATED WITH WASTEWATER IN THE NAIROBI RIVER BASIN, KENYA

[DINÁMICA DE NEMATODOS Y GUSANOS DE TIERRA EN CULTIVOS URBANOS DE VEGETALES IRRIGADOS CON AGUAS DE DESECHO EN LA CUENCA DEL RÍO NAIROBI, KENIA]

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SUMMARY

The effects of heavy metals lead (Pb), Cadmium (Cd) and Cromium (Cr) on nematode communities and earthworm density and biomass were studied in the wastewater irrigated farms of the Nairobi river basin. The levels of Cr and Pb in the wastewater were below the threshold values considered to be toxic while those of Cd exceeded the permissible limit. Heavy metal accumulation in soils in the Kibera and Maili Saba farms were Cd (14.3 mg kg^{-1}), Cr (9.7 mg kg^{-1}) and Pb (1.7 mg kg^{-1}) and 98.7 mg Cd kg^{-1}, 4.0 mg Cr kg^{-1} and 74.3 mg Pb kg^{-1}, respectively. High heavy metal concentrations as well as soil organic matter were negatively correlated with plant feeding nematodes in the genera *Criconema, Meloidogyne, Paratylenchus, Pratylenchus* and *Scutellonema.* Bacterial feeding nematodes genera *Rhabditis, Plectus, Cephalobus* and *Acrobeles* were predominant in the gardens treated with wastewater. An average density of 198 m^{-2} earthworms and a biomass of 68 g m^{-2} and 102 earthworms m^{-2} with 33g m^{-2} biomass were recorded in Kibera and Maili Saba, respectively. The earthworms isolated from both sites were all epigeic with the metal content in Maili Saba suppressing their populations. This study has demonstrated that the use of untreated urban wastewater for irrigation has adverse effects on nematode and earthworm abundance and diversity and their potential as bioindicators of heavy metal presence.

Key words: Heavy metal accumulation; soil fauna; diversity

RESUMEN

Se estudió el efecto de los metales pesados plomo (Pb), cadmio (Cd) y cromo (Cr) sobre las comunidades de nematodos y la densidad y biomasa de gusanos de tierra en las granjas irrigadas con aguas de desechos en la cuenca del rió Nairobi. Los valores de Cr y Pb se encontraron por debajo de los niveles considerados tóxicos mientras que los niveles de Cd excedieron los límites permitidos. La acumulación de metales pesados en los suelos de las fincas de Kibera y Maili Saba fue de Cd (14.3 mg kg^{-1}), Cr (9.7 mg kg^{-1}) y Pb (1.7 mg kg^{-1}) y 98.7 mg Cd kg^{-1}, 4.0 mg Cr kg^{-1} y 74.3 mg Pb kg^{-1}, respectivamente. Altas concentraciones de metales pesados así como de materia orgánica del suelo fueron negativamente correlacionados con la presencia de nematodos que consumen cultivos de los géneros *Criconema, Meloidogyne, Paratylenchus, Pratylenchus* y *Scutellonema.* Nematodos que se alimentan de bacterias de los géneros *Rhabditis, Plectus, Cephalobus* y *Acrobeles* fueron predominantes en los cultivos que recibían aguas de desecho. Se encontró una densidad promedio de gusanos de tierra de 198 gusanos m^{-2} y una biomasa de 68 g m^{-2} y 102 gusanos m^{-2} con 33g m^{-2} en Kibera y Maili Saba respectivamente. Los gusanos de tierra encontrados en cada sitio fueron epigeicos y el contenido de metales en Maili Saba eliminó a la población. Este estudio muestra que el uso para irrigación de aguas de desechos urbanas no tratadas tiene efectos adversos sobre la abundancia y diversidad de nematodos y gusanos de tierra, así como su potencial como bioindicadores de la presencia de metales pesados.

Palabras clave: Acumulación metales pesados; fauna del suelo; diversidad

INTRODUCTION

Soil, water and plant pollution is projected to rise due to increase in urbanization and industrialization, which has generated and increased municipal waste water (Emongor, 2007). Anthropogenic activities like mining, ultimate disposal of treated and untreated waste effluents containing toxic metal chelates and also indiscriminate use of fertilizers and pesticides in agriculture result in deterioration of soil health (Kar *et al.*, 2008). The soil health concept is increasingly gaining popularity, referring to the inherent capacity of a soil to function within an ecosystem, whilst sustaining biological productivity, maintaining environmental quality and at the same time, promoting plant health (Langat *et al.,* 2008).

Soil organic content, physical, chemical and biological properties are the most commonly used indicators of soil health. However, in Kenya, biological organisms, which offer immense ecosystem services, have only gained interest in the last decade following the launching of the CSM-BGBD UNEP-GEF project on Belowground Biodiversity in 2002, in which fauna groups such as nematodes and earthworms are being assessed as indicators of soil health. Although wastewater has great fertilizing value when used in crop production, it may contain high levels of toxic heavy metals, organic contaminants and excessive soluble salts (Vandescateele *et al.,* 2003). Among the inorganic contaminants of wastewater, heavy metals are gaining importance due to the tendency of absorption by soil colloids and thereafter get released in soil solutions. Though some of these metals like copper (Cu), iron (Fe), manganese (Mn), nickel (Ni) and zinc (Zn) are essential as micronutrients for life processes in plants and microorganisms, others like Cd, Cr and Pb with unknown physiological activity, but are detrimental beyond certain limits (Bruins *et al*., 2000). As a result, exposure to the toxic elements through direct diffusion impact on soil dwelling microorganisms and invertebrates and/or through the food chain by bio-accumulation through trophic levels with detrimental effects on soil fauna diversity and functional services (Ekschmitt and Korthals, 2006). Among soil organisms, nematodes have been shown to be potential bio-indicators for soil health since they have repeatedly been shown to respond differentially to xenobiotic substances (Jonker *et al.,* 2004). The composition of the soil nematode community relates to various aspects of soil status, and has been advocated as an indicator of soil disturbance, nutrient enrichment and pollution (Ekschmitt *et al.,* 2001).

In addition to variable sensitivity by soil nematodes to soil pollution, they also have elaborate sensorial equipment, including receptors for cadmium and copper ions (Ekschmitt and Korthals, 2006). Earthworms have equally been considered useful in assessing heavy metal pollution in soils because they have been found to be sensitive to pollution (Malley *et al.,* 2006). According to Van Nieuwenhuyse *et al,* (2001), earthworms form the bulk of terrestrial faunal biomass occupying a key position in the transfer of pollutants towards other trophic levels (Ekschmitt and Korthals, 2006). Malley *et al.* (2006), showed that earthworms could provide an index for heavy metals that are present in the bioconverted materials, giving an indication of potential environmental hazards. Earthworms stimulate microbial action by increasing the surface area for colonization of the substrate and improving enzymatic action. Apart from being used to breakdown a wide range of organic residues such as sewage sludge, animal wastes and crop residues (Vandescateele *et al.,* 2004), earthworms were found to have a high potential for Cd accumulation in polluted floodplains.

The importance of earthworms for heavy metal biomagnifications in terrestrial ecosystems is widely recognized. In situ observation of biomass and population dynamics of earthworms has been a means of determining long-term effects on environment (Kooch and Jalivand, 2008). This study aimed at investigating the impact of wastewater use for irrigation along the Nairobi river basin on nematode and earthworm abundance and diversity.

MATERIAL AND METHODS

Description of the study area

The study was carried out in Nairobi, Kenya located (latitude 1^0 00’ N, longitude 30^0 00’ E) at an elevation of 1670m above sea level (Hide et al., 2001). Nairobi’s annual rainfall is on average about 680 mm, depending on altitude and a mean annual temperature of 17^0C (Foeken and Mwangi, 2000). The city’s population was estimated at three million in 2009 with an annual urban growth rate of 4.5 percent (ASC, 2006). Sixty percent of this population lives in informal settlements, with headcount poverty levels ranging between 60 and 78%. The study sites were located in Kibera and Maili Saba and the wastewater irrigated farms are located along the Ngong river basin. The river passes through land under different urban use including forest, agriculture, industrial and residential. Both sites are informal settlements where water and sanitation facilities are limited (Hide et al., 2001). The main sources of pollution of the Ngong River basin are uncontrolled disposal of human waste, disposal of solid waste, blockages and/or breakages of sewage lines within the industrial area and untreated wastewater discharged from large-scale and cottage (Jua Kali) industries.

Sampling of soil and wastewater samples for chemical characterization

Samples were collected from fields with an extended history of wastewater use based on information given out by informed farmers during focused group discussions. Sampling was done in during the dry season and wet seasons, June–July and November-December 2007. Soil samples were taken using an auger at a depth of 0-30 cm. Undisturbed soil samples were collected using core rings. Wastewater samples were collected from the feeder furrows at four sampling points in each plot where a grab sample from each sampling point was taken to represent the water flowing into the plots. Soil and water samples were collected simultaneously and each sampling point was geo-referenced. Laboratory preparations were done on each of the soil and water samples eight hours after collection (Eaton *et al.*, 1995). Water samples were analyzed for pH, temperature, electrical conductivity (EC) and dissolved oxygen (DO) *in situ* using portable Wissenschftlich-Technische Werkstatten (WTW) microprocessor probes and meters. Pb, Cd and Cr contents, total suspended solids (TSS), total settleable solids, total dissolved solids (TDS), biochemical oxygen demand (BOD), nitrates, phosphates, calcium, magnesium, potassium, sodium, chloride, carbonates and bicarbonates were analysed following the procedures described by Clesceri *et al.* (1998). Undisturbed soil samples were analyzed for hydraulic conductivity, moisture characteristics (PF) and bulk density determinations *in situ* while the disturbed soil samples were air dried, crushed and sieved through 2 mm mesh and used for texture, pH, EC, organic carbon, total nitrogen, P, K, CEC, Na, Ca and Mg determination following the procedures described by Okalebo *et al.* (2002). Soil pH was determined in a soil-water suspension of 10 g in 25L of deionized water using a pH meter (aqualytica Model pH 17). For determination of heavy metals, soil samples were dried and passed through 0.5 mm sieve and digested in *aqua regia*; a mixture of 75 percent HNO_3 and 25 percent HCL (Fisher Scientific, Uk). The resulting solution was analyzed for total Cr, Cd and Pb using Flame Atomic Absorption Spectrophotometer (AAS) (Perkin-Elmer Model 2380).

Sampling of nematodes and earthworms

Farmer's fields (plots) to be sampled were selected based on cropping system. Monolith sampling earthworms was done using the procedures described by Anderson and Ingram (1993); Moreira *et al.* .(2008). A soil monolith of 25 cm x 25 cm x 30 cm depth was randomly taken in each plot replicated four times. The extracted soil was separated into three depth layers (0-10, 11-20 and 21-30 cm), and earthworms were collected by hand-sorting on plastic trays. Earthworms were killed in 75% alcohol, then fixed in 4% formaldehyde and stored in sealed vials before being transported to the laboratory for morphospecies analysis, enumeration and biomass determination. The earthworms were then placed into one of the following functional groups based on visual observation notes taken while in the field and/or in line with classification based on their habitat, food choice, feeding behaviour and ecophysiology (Lavelle *et al.*, 1997; Swift and Bignell, 2001): epigeics (those that live and feed on the soil surface); anecics (those transporting organic residues from the surface into vertical burrows and actively mixing them with soil), and endogeics (those foraging on soil organic matter and dead roots within the soil, largely forming horizontally-orientated burrows). Soil samples for nematode analysis were collected randomly to a depth of 30 cm from the middle rows of each plot. The samples were thoroughly mixed to form composite samples before being placed in plastic sampling bags, transported to the laboratory and stored at 10 ^{0}C. The nematodes were extracted from 200 cm^3 soil using the modified Baermann's procedure described by Hooper *et al.* (2005) and then fixed using the rapid Seinhorst technique. Identification of the nematodes was based on morphological characteristics and pictorial keys using high power microscope (Hunt *et al.*, 2005). After identification, the nematodes were assigned to trophic groups following the method described by Yeates *et al.* (1993).

Data handling and analysis

Earthworm biomass data were expressed on a fresh weight basis. Since earthworm weight was highly variable, earthworm biomass rather than was adopted as recommended by Vandescateele *et al.* (2004). Nematode abundance was transformed to Log (x+1) and compared between farms by analysis of variance (ANOVA). When the overall F-test was significant ($P \leq 0.05$), means were separated by the Fishers' least significant difference test (LSD). To compare nematode data across the two sites, nematode genera counts were expressed as relative proportions of their feeding type. To assess to fauna-environment correlative relationships, Redundancy Analysis (RDA) was run using the genera matrix data set as independent environmental variables and the significance of the relationship tested using restricted Monte Carlo Permutation tests. The Statistical software package (StatSoft Inc., Tulsa, OK) was used for all statistical analyses.

RESULTS

Soil and water characteristics at Kibera and Maili Saba

Following the standard guidelines by Food and Agricultural Organization (1990), the textural classification of the soil profiles in Kibera and Maili Saba are clay and clay loam (Table 1). While the pH of the topsoil ranged from 5.0-5.9, the subsoil was slightly acidic to neutral. Medium to high levels of organic carbon (C) and nitrogen (N) levels, uniformly distributed throughout the soil profiles ranging from 0.50-3.48% and 0.07-0.36%, respectively. Although the phosphate levels ranged from high to extremely high (91-221 ppm) in the topsoil, extremely low levels (9.5-22.5 ppm) were observed down the profile. A high cation exchange capacity (CEC) was recorded (15-25 cmol kg^{-1}) in the farmers fields irrigated with waste water. Compared to sodium and potassium concentrations that ranged from medium to high, calcium and magnesium levels were very high.

Student's t-test comparison of the mean values of pH, EC, TDS, Pb, Cr, K and Na between Kibera and Maili Saba showed significant ($p<0.05$) differences (Table 2). While the pH of the wastewater was within the permissible range for irrigation water of 6.5-8.4. The electrical conductivity (EC) values ranged from 0.3 to 0.7. but had exceeded the recommended levels for irrigation water in Maili saba. Unlike chromium, lead and cadmium levels in the wastewater were below the threshold values considered to be toxic to crops according to World Health Organization (2006). Nitrate levels were significantly higher ($p<0.05$) in Maili Saba and even exceeded the recommended levels compared to Kibera.

Heavy metal accumulation in soils irrigated with wastewater and influence on soil biota

Significant differences in heavy metal loads were observed in Kibera and Maili Saba soils (Figure 1). The trend of heavy metal concentrations in Kibera soils was lead>cadmium>chromium while Maili Saba followed the trend lead>chromium>cadmium. While the mean levels for Pb in both soils were below the maximum permissible limit of 84 mg Pb/kg World Health Organization (2006), the Cd concentrations in both sites were above the critical limit above which pose a threat to public health.

Eleven genera of nematodes were isolated from soils irrigated with wastewater in both sites (Table 3). Similar studies by Hans *et al.* (2008) and Al-Sanchez Moreno and Navas (2007) found more than 36 genera of nematodes. Out of the eleven genera,, six were plant parasitic, four bacterial feeders and one fungal feeder. However, bacterial feeders were most abundant accounting for 57% compared to plant feeders and fungal feeders whose proportions were 26% and 17 %, respectively. Kibera had significantly more plant parasitic nematodes than Maili Saba in which the free living nematode dominated.

Table 1. Physico-chemical characteristics of soils from Kibera and Maili Saba

Farm	Depth (cm)	pH	Na	K	Ca	Mg	CEC	P	N	C	Texture
Kibera	0-11	5.15	0.60	1.55	4.29	2.63	23.0	96.00	0.36	2.56	Clay
	11-27	5.52	1.00	1.00	6.00	2.63	19.0	11.50	0.20	1.45	Clay
	27-61	5.79	0.80	0.65	5.00	2.63	14.6	22.50	0.11	0.69	Clay
	61-73	6.64	0.80	1.40	6.25	3.04	18.2	20.65	0.07	0.50	CL
Maili Saba	0-19	5.15	1.00	2.45	8.00	3.05	23.40	221.00	0.32	3.48	CL*
	19-38	5.26	1.10	3.05	8.00	3.05	23.80	13.35	0.22	2.06	CL
	38-61	5.65	1.00	2.30	5.25	2.93	19.60	9.50	0.09	0.85	CL

*CL = Clay loam

pH; Na; K; Ca; Mg and CEC, expressed as: cmol/kg

P expressed as: ppm

N and C expressed as: %

Table 2. Chemical characteristics of untreated wastewater used for irrigation at informal settlements in Nairobi.

Parameter	Kibera	Maili Saba	Recommended maximum concentration (mg/l)*
pH Water (1:2.5)	7.68±0.11	6.98±0.07	Normal range 6.5-8.4
Temperature (^{0}C)	24.7±0.9	19.8±0.2	
Turbidity (NTU)	70.0±23.0	130.0±23.0	
Alkalinity (mg/l)	159.0±31.0	50.0±12.0	
Conductivity (dS/m)	0.5236±0.05	1.1196±0.12	0.7
Lead (mg/l)	0.26±0.02	00.09±0.01	5.0, 50^1, 15^2, 10^3,
Cadmium (mg/l)	0.00±0.00	0.00±0.00	0.01, 1^1, 10^2, 5^3.
Phosphates (mg/l)	0.02±0.01	0.06±0.02	
Chromium (mg/l)	0.48±0.05	0.00±0.00	0.1
Magnesium (mg/l)	34.10±23.15	44.78±9.25	
Calcium (mg/l)	17.6±4.2	55.9±4.0	
Sodium (mg/l)	53.9±1.9	65.6±4.1	900
Potassium (mg/l)	14.5±2.2	38.5±5.7	
Total hardness (mg/l)	187.0±94.0	116.0±7.0	
Chloride (mg/l)	46.12±3.0	94±5.0	1100
Bicarbonates (mg/l)	160.0±30.0	50.0±12.0	
Nitrates (mg/l)	88.3±11.9	117.9±8.0	5.0
Carbonates (mg/l)	0.3±0.3	0.0±0.0	
Biochemical oxygen Demand (mg/l)	156.0±62.0	648.0±121.0	
Dissolved Oxygen (mg/l)	3.79±0.90	2.97±0.36	
Total suspended solids (mg/l)	152.0±58.0	549±185	
Total settleable solids (mg/l)	4.0±1.0	25.0±8.0	
Total dissolved solids (mg/l)	314.2±28.2	671.8±71.0	450

*Sources: Ayers & Westcot (1985); Pescod (1992), ^{1}EC COUNCIL DIRECTIVE, 1980. ^{2}US PHS, 1997; ATSDR, 1997. ^{3}WHO, 1993

For nematodes, the eigenvalues of the first and second RDA axes constrained to the selected environmental variables were 0.43 and 0.18, respectively (Figure 2). The distribution of the inertia indicated that axes 1 and 2 accounted for 43 and 18% respectively. The sum of all canonical eigen values revealed that the variables (soil organic matter (SOM), Pb, Cr, Cd) that significantly contributed to the description of the variation in the nematode fauna explained 61% of the total variation observed. Axis 1 is mainly a soil organic matter/Pb gradient. Plant feeding nematodes *Criconema*, *Meloidogyne*, *Paratylenchus*, *Pratylenchus* and *Scutellonema* were negatively correlated with the heavy metals.

The two sites (Kibera and Maili Saba) had relatively low taxonomic richness (4 taxa), although Maili Saba appeared taxonomically diverse compared to Kibera. Four taxa (*Eudrilus eugeniae*, *Nematogenia lacuum*, *Dichogaster bolaui*, *Dichogaster affinis*) were sampled in Maili Saba compared to only 2 taxa (*Eudrilus eugeniae*, *Dichogaster affinis*) in Kibera. All these taxa are epigeic. Earthworms abundance and biomass were higher in Kibera than in Maili Saba. An average density of 198 earthworms/m^2 and a biomass of 68g/m^2 were recorded in Kibera, while 102 earthworms/m^2 and 33g/m^2 biomass were recorded in Maili Saba.

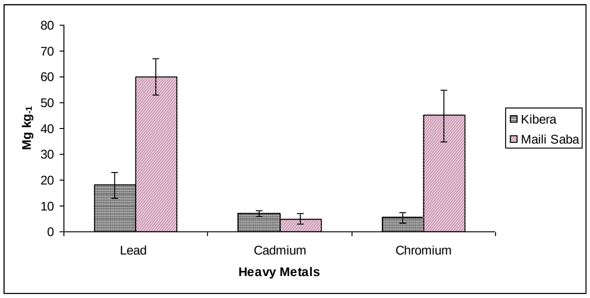

Figure 1. Heavy metal concentrations in soils from Kibera and Maili Saba

Table 3. Nematode genera and trophic groups associated with wastewater in Kibera and Maili Saba

	Nematodes /200cm^{3}soil	
	Maili Saba	Kibera
Plant feeders		
Pratylenchus	17	30*
Paratylenchus	10	15
Meloidogyne	26	20
Scutellonema	18*	11
Criconema	11*	5
Helicotylenchus	0*	15
Bacterial feeders		
Alaimus	45*	35
Rhabditis	86*	70
Acrobeles	35	45*
Cephalobus	48*	35
Fungal feeders		
Aphelenchoides	55	65*

* Significant difference between pairs at P<0.05

DISCUSSION

Soil is an important component of terrestrial ecosystems owing to the key functions in fertility, decomposition processes, nutrient and energy flows. However, in this study, there is an apparent deterioration of the soil due to chemical contamination as a result of use of untreated wastewater for irrigation. The uniformly medium to high levels of organic carbon (C) and nitrogen (N) levels, distributed throughout the soil profiles may be due to high organic matter content in the organic-rich wastewater. The nitrogen levels observed in the soil were adequate for a wide range of crops (Mashner, 1986). As expected, the high cation exchange capacity was a reflection of enhanced ability of the soils to retain nutrients against leaching and thus classified as fertile. Prescod (1992), suggested that the relatively high levels of dissolved salts in the wastewater could be responsible for the EC values in the range of 0.7-3.0. While such levels may not pose danger at the moment, extended use of such may gradually result in soil salinization. Heavy metal accumulation was evident in this study.

The heavy metal loads of lead, cadmium and chromium observed in Kibera and Maili Saba soils could be attributed to the low soil pH. According to Emongor (2007), low pH 5.5-5.9, is the optimal range within which cataylses formation of heavy metals, among which organic-Pb complexes to become more soluble and bioavailable in the soil.

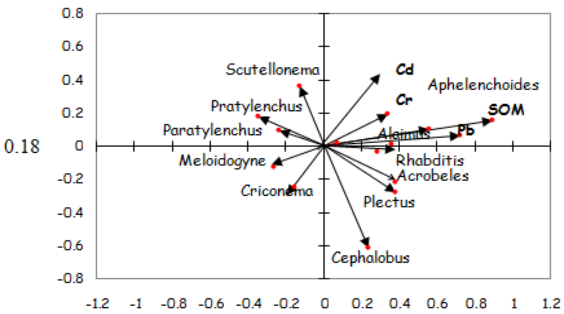

Figure 2. Redundancy Analysis (RDA) of nematode genera by RDA biplot showing correlation between nematode genera and the selected environmental variables (soil heavy metals and organic matter).

For instance, chromium in some forms may be cationic and therefore adsorbs onto clay particles, organic matter, metal hydroxide, and other negatively charged particles or adsorb to oxide and clay particles. Compared to water medium, the concentration of Cr ions in soil solution may be lower given the soil solution is a heterogenous mixture of ions which may interfere with the availability and uptake of Cr ions (Sivakumar_and Subbhuraam, 2005). Chromium may pose public health risks such as dermatitis especially when in direct contact with the skin. This is potentially hazardous in the study area because farmers do not wear protective clothing when irrigating crop fields. While the high nitrate levels are desirable for plant nutrition, they could lead to eutrophication (Fattal *et al.*, 2004).

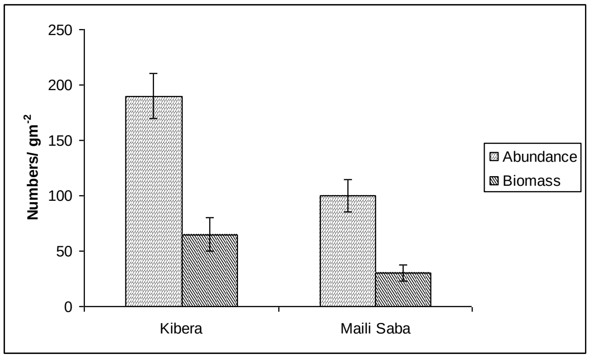

Figure 3. Earthworm abundance and biomass in wastewater treated plots

From this study, the diversity of nematodes recovered from waste water irrigated soils was lower compared similar studies by Hans *et al.* (2008) and Sa´nchez-Moreno and Navas (2007) who found more than 36 genera of nematodes. This loss of biodiversity may be attributed to heavy metal lodas in the soil. Ekshmitt and Korthals (2006) observed that heavy metal concentrations negatively correlated with plant parasitic nematodes attributing this to pronounced synergetic effect arising from the combination of heavy metals and organic matter enrichment. Many studies have shown that incorporation of organic manures in soils negatively impacted on plant feeding nematodes on crop fields (Langat *et al.*, 2008; Karanja *et al*,. 2007; Kimenju *et al.*, 2008). In this study, SOM (total soil carbon, nitrogen and nitrate) levels were unusually high in the wastewater irrigated farms. SOM negatively correlated with plant feeding nematodes namely *Criconema, Meloidogyne, Paratylenchus, Pratylenchus* and *Scutellonema*. It is widely known that decomposition of soil organic matter releases among other compounds nitrates (Wang *et al.*, 2004) which play an important role not only in suppressing plant feeding nematodes but also stimulate build-up of beneficial microbes including free-living nematodes (Desaeger and Rao, 2002). According to Akhtar and Malik (2000), a positive correlation between increase in soil organic matter and an increase in numbers of free-living nematodes exists, thereby explaining positive clumping of the bacterial feeders namely *Rhabditis, Acrobeles, Plectus, Cephalobus* and fungal feeders, *Aphelenchoides*. Studies by Bakonyi *et al,* (2003) demonstrated that numbers of fungal and bacterial feeding nematodes increased with the amount of untreated wastewater especially in the sites with higher heavy metal content. Among the free-living nematodes, bacterial feeders belonging to the genera *Rhabditis, Plectus, Cephalobus* and *Acrobeles* were the most dominant group in the farms treated with wastewater which is indicative of a bacterial driven decomposition pathways.

Agricultural systems are associated with such pathways where bacteria serve as a stimulus to increased numbers of bacterial feeding nematodes (Langat *et al.*, 2008). The abundance and diversity of free-living nematodes is thus an important soil health indicator, given their role in decomposition and regulation of bacterial and fungal microbes as has been shown by Sa´nchez-Moreno and Navas (2007).

Compared to other studies Neirynck *et al.*, (2000); Faber *et al.*, (2000), the earthworm biomass found in the wastewater irrigated soils of Kibera were within normal to high ranges while in Maili Saba the biomass were low. According to Faber *et al*., (2002) these biomass values were well within their observed ranges of 22.2-80.4 g/m^2 in soils irrigated with sewage water. This may be explained by the accumulation of Pb and Cr in the deeper soil profiles. If it is true that earthworms can selectively choose to feed on less polluted soil material, then this may also explain the relatively higher earthworm biomass found in the less polluted Kibera site. The higher earthworm biomass and density found soils from Kibera despite cadmium being above the World Health Ooragnization (2006) recommended standards (0.4 mg/kg) may suggest that worms could be tolerant to low cadmium concentrations. In a related study, Vandescateele, (2004) showed that up to 0.1 g/kg cadmium may be tolerated by earthworms. Studies have shown that toxic effects of heavy metals vary, depending on the state of heavy metals, concentration, reactivity, complex formation, and stability (Nieboer and Fletcher, 1996). Nevertheless, amongst the heavy metals under this investigation, Cd is known to be the most toxic (Vandescateele, 2004) while Cr and Pb may not significantly affect earthworm activities and growth according to Kumar *et al.,* (2008).

Cadmium toxicity is particularly dangerous because the metal is readily absorbed and accumulated by plants and animals and may be incorporated into the food chain and transferred to higher trophic levels. The high toxicity of cadmium in earthworms has been shown to be due to its preferred accumulation in earthworms rather than in cast, whereas heavy metals lead and chromium accumulated more in casts. Although earthworms may survive in very high Cd concentration, they are sensitive to Cd as manifested by low number of cocoons produced (Siekierska and Ska-Jasik, 2002). It has been well established that soil characteristics can have a great influence on the adsorption and, therefore, bioavailability and toxicity of metals in soils (Kumar *et al.*, 2008). Besides pH, soil characteristics like organic matter content and CEC are known to influence heavy metal availability and their uptake especially by earthworms. Studies have shown that a decrease in the pH of water resulted in increased toxicity of Cr to the earthworm.

The organic matter content, clay, and hydroxides of Al and Fe and pH, generally called capacity controlling parameters, are believed to determine the bioavailability of metals for organisms living in soil (Sivakumar_and Subbhuraam, 2005). Acidity of dredged sediment substrate was responsible for the absence of earthworms, since an older landfill with a higher pH harbored earthworms. In this case, pH, may explain the higher earthworm densities and biomass associated with Kibera site given the pivotal role it plays in determining the form, availability and uptake of cadmium.

CONCLUSION

The quality of wastewater used for irrigation in Nairobi has been undermined by presence of heavy metals. Even though the wastewater is rich in inorganic solids, macro elements and phosphates, heavy metal loads have led to accumulation of Pb, Cd and Cr, in agricultural soils which pose risk to human health and loss of diversity. There is need to address the quality of wastewater used for irrigation in the urban areas.

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