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Full Length Research Paper

Earthworm abundance related to soil physicochemical and microbial properties in Accra, Ghana

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The introduction of vermicomposting as a cost effective method of managing organic waste in Ghana depends on the suitability of local earthworms. At nine locations across Accra, the capital of Ghana, the soil-litter layer was sampled to evaluate the occurrence and abundance of surface dwelling earthworms (0 - 10 cm depth) and to investigate the relationship between earthworm abundance and soil properties (physicochemical and microbial). *Eudrilus eugeniae* (Kinberg), a rapidly growing large worm (adults reach 14 cm long), was the only earthworm collected from seven of the nine locations. Small unpigmented holonephric worms were collected at the other two locations. Earthworm densities ranged between 35 and 2175 individuals m^{-2}. Significant (*P*< 0.05) negative correlations existed between earthworm abundance and organic C and exchangeable Na. All locations tested positive for the microbial indicators; Total coliforms, *Escherichia coli*, *Staphylococcus,* Yeast and Moulds and *Aspergillus*. There was a significant (*P*< 0.01) positive correlation between earthworm abundance and all the bacterial indicators tested. Earthworm abundance was also weakly correlated *(P* < 0.1) with the yeast and mould loads.

Keywords: *Eudrlius eugeniae*, earthworms, soil-litter layer, soil physicochemical and microbial properties, urban peri-urban Accra, West-Africa.

INTRODUCTION

Vermicomposting is gaining worldwide popularity as a means of waste remediation, organic fertilizer production and animal feed protein production. Yet studies promoting vermicomposting in Equatorial Africa are limited to a few scattered projects in the Ivory Coast (Tondoh, 1998), Nigeria (Hauser, 1993; Mba, 1996; Ayanlaja et al., 2001), and Ethiopia (Bierwirth et al., 2000). Further work is needed, especially in urban centers that lack a coherent waste management system. Accra, the capital city of Ghana, is no exception to this phenomenon. Here, waste is frequently dumped by residents into open drains and vacated plots (Boadi and Kuitunen, 2003). When waste is collected, private contractors transport the waste to unsanitized landfills designated by the metropolitan authority. Nutrients leaching from informal dump sites and landfills, in contributing to eutrophication in many waterways. Blue-green algae and their carcinogenic mycotoxins have already been measured in Accra's main water supply (Addico et al., 2006). Although vermiculture is not expected to solve all these social and environmental problems, it could play a vital role, alongside other low cost interventions.

Despite the relative low-tech nature of vermicomposting, there are barriers to introducing the process. Not all earthworms are appropriate. A few species, typically epigeic earthworms that consume primarily carbon-rich substrates, are well-adapted for vermicomposting (Blakemore, 2000). Since financial and ecological constraints will limit the importation of foreign earthworms into the country, earthworms have to be obtained locally.

Unfortunately, surveys on earthworms in Ghana are sparse (Table 1) . The only work conducted on the subject in Ghana, Sims (1965) collected 14 species of Acantho-drilidae and Eudrilidae in grasslands, semi-aquatic habitats, agricultural fields and forests during the addition to nutrient-rich agricultural runoff, are probably early 1960s. Among other studies, *Hyperiodrilus africanus* has

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Table 1. Earthworms commonly found in sub-Saharan Africa.

Species	Country/Region	Suitable for vermin composting
Agastrodrilus opisthogynus	Ivory Coast	No
Amynthas minimus	South Africa, Asia	No
Amynthas rodericensis	South Africa, Asia	Yes
Chuniodrilus palustris	Ivory Coast	No
Chuniodrilus zielae	Ivory Coast	No
Dichogaster affinnis	West Africa	No
Dichogaster agilis	Ivory Coast	No
Dichogaster annae	West Africa	Yes
Dichogaster bolaui	West Africa	Yes
Dichogaster gracilis	West Africa	Unknown
Dichogaster grafii	Congo	No
Dichogaster itolienses	Rwanda	No
Dichogaster modigliani	West Africa	No
Dichogaster saliens	West Africa	No
Eminoscolex lavellei	Rwanda	No
Eudrilus eugeniae	Ghana, Ivory Coast, Nigeria, West Africa	Yes
Gordiodrilus peguanus	Central Africa	No
Hyperiodrilus africanus	Ghana, Ivory Coast, Nigeria, West Africa	Yes
Millsonia Anomala	Ivory Coast	No
Millsonia ghanensis	Ivory Coast	Unknown
Millsonia inermis	Burkina Faso	No
Millsonia lamtoiana	Ivory Coast	No
Millsonia schlegeli	Ivory Coast	No
Nemoatogenia lacuum	Congo	No
Pontoscolex corethrurus	South Africa, South America	No
Stuhlmania variabilis	Rwanda	Yes

Source: Sims, 1965 ; Madge, 1969; Hauser, 1993; Fragoso et Lavelle, 1992 ; Barois et al.,1993 ; Blanchart et al., 1997; Tondoh, 1998; Fragoso et al., 1999; Dominguez et al., 2001; Rossi, 2003; Omodeo et al., 2003; Dlamini and Haynes, 2004; Ouédraogo, 2004.

has been identified as one of the broadly distributed species (Barois et al., 1993) existing throughout West and Central Africa in disturbed and undisturbed fields (Madge, 1968; Tondoh, 1998). Other species found in humid and sub-humid Africa include *Chuniodrilus zielae, Sthulmania porifera, Millsonia anomala* (Blanchart et al., 1997; Rossi, 2003), *Eudrilus eugeniae* (Dominguez et al., 2001) , *Millsonia ghanensis, Millsonia lamtoiana, Agastrodrilus opisthogynus, Dichogaster agilis* (Tondoh, 1998), *Dichogaster bolani* and *Dichogaster saliens* (Dlamini and Haynes, 2004).

Although earthworm abundance and diversity is expected to be low in semi-arid tropical regions (Fragoso and Lavelle, 1992), some earthworms can tolerate such dry conditions. *Millsonia inermis,* a deep burrowing earthworm species residing 30 - 40 cm below the ground, was found in a semi-arid tropical soil in Burkina Faso receiving between 750 mm and 1000 mm of rainfall annually (Ouédraogo, 2004). The presence of surface casts in the study plots suggested that earthworms came to the surface to feed on organic residues, despite the arid conditions. A recent study in the semi-arid Maghreb region of North Africa, sampling native woodlands, planted stands of trees, Mediterranean scrublands, aquatic and semi- aquatic habitats, grasslands, agricultural land and other anthropogenic habitat, reported the presence of 27 species, 5 new records for the region, thus raising the known species diversity to 38 (Omodeo et al., 2003). In a survey of native forests, pastures and plantations in northern Kwa Zulu-Natal, South Africa, Dlamini and Haynes (2004) found a mixed earthworm community of the South American Glossoscolecidae, *Pontoscolex corethrurus,* and the Asian Megascolecidae's, *Amynthas rodericensis* and *Amynthas minimus,* in 8 of the 11 land uses. While soil moisture has a major influence on earthworm abundance and diversity, other soil properties such as texture, pH and organic matter content may be important (Edwards and Bohlen, 1996). Earthworms are sometimes more abundant in areas with higher soil organic carbon content (Hendrix et al., 1992; Poier and Richter, 1992; Nuutinen et al., 2001), but not in all studies (Whalen, 2004; Rossi et al. 2006). The activity of the soil microbial community is also important, and was correlated positively with the presence of more sensitive earthworm species in agroecosystems (Ivask et al., 2008).

There is a need to identify earthworms found in Accra that are capable of vermicomposting, if the technology is to be applied locally. The objectives of this study were to: 1) document the occurrence and abundance of surface dwelling earthworms, and 2) investigate the relationship between earthworm abundance and soil properties (physicochemical and microbial).

MATERIALS AND METHODS

Study area and site selection

Accra is located in the southern coastal savannah belt of the country along the Gulf of Guinea (5 º 34 N, 0 º 10 W) (Twumasi and Asomani-Boateng, 2002). The city's settlements occupy an area of approximately 751 km^2 (Møller-Jensen et al., 2005) with a general elevation of 75 m above sea level. The mean monthly temperature ranges from 24.7ºC in August to 28.1ºC in February, and the mean annual rainfall is 846 mm. Most rain falls from May to July, with another important rainfall period from September to November.

Nine locations within the Greater Accra Metropolitan Area were selected for the study (Table 2). They were broadly categorized into three possible earthworm habitats: bathhouses, banks of streams and cultivated pastures. Consultation with project stakeholders and community members led us to realize the city's dry climate did not permit ubiquitous earthworm activity. Earthworms are not expected when the mean annual rainfall is less than 800 - 1000 mm per year and when the dry season exceeds 3 – 5 months (Lavelle, 1983). Thus, the locations selected as possible earthworm habitats were those where soils were often visibly moist.

Earthworm sampling

Sampling was conducted between October 2005 and June 2006. Live earthworm specimens were collected from the soil litter and root layers by digging and hand sorting, following the procedure of Omodeo et al. (2003). After preliminary sampling, two groups of Oligochaeta were observed: Megadriles (big worms) and Microdriles (smaller and mainly aquatic worms). Biomass and population size differences between the two groups compelled us to use different sampling techniques. Megadriles were extracted from a soil segment area of 60 by 60 cm, to a depth of 5 cm, and Microdriles from a soil area of 10 cm by 10 cm, to a depth of 10 cm. Microdrili samples were washed before counting because of the high clay content and small earthworm sizes. After counting, earthworms were washed with water and a few specimens were preserved to be transported to Canada and identified six months later (Sam James, personal communication).

Soil analysis

Two soil samples (10 cm by 10 cm, to a depth of 5 cm), were collected at each location with the spade and placed in appropriately labeled plastic containers. The first sample was stored in an ice chest immediately after extraction in preparation for microbiological analysis. The second sample was prepared for physico-chemical analysis by air-drying (2 days). One soil core from each sampling station was collected in a sampling ring and sealed with a plastic cap to preserve moisture. These cores were weighed before and after drying for 24 h at 105ºC to obtain moisture content and bulk density.

All chemical analyses were conducted in quadruplicate. The pH was determined in a media water suspension (1:1 w/v) using a glass cathode microprocessor pH meter (Hanna Instruments pH 210). Total nitrogen was presumed equal to and measured using the total Kjeldahl nitrogen method (Bremner, 1996), assuming limited amounts of nitrite/nitrate because little or no fertilizer was applied to the sampling locations. Total organic carbon was measured using the Walkley-Black method (Nelson and Sommers, 1996). Plant-available phosphorous was extracted with the Bray-1 method (Kuo, 1996) considered appropriate for the soils of the region, and the P concentration measured colorimetrically with the molybdate blue method at 712 nm using a Philips PU 8620 UV/VIS/NIR spectrophotometer. Exchangeable sodium, potassium, calcium and magnesium were extracted with the ammonium acetate method (Helmke and Sparks, 1996; Suarez, 1996). Na and K concentrations were subsequently measured with a Jenway PFP7 flame photometer whereas Ca and Mg were measured with the Ethylenediaminetetraacetic acid (EDTA) titration method (Walter, 1965). Cation exchange capacity consisted of an extraction of cations with the ammonium acetate method and measured colorimetrically with the acid titration method (Sumner and Miller, 1996). Particle sizes were analyzed with a combination of the hydrometer and sieve methods (Gee and Bauder, 1986) . Lead and cadmium were extracted with a wet digestion method (Amacher, 1996) and measured with a Perkin Elmer Atomic Absorption Spectrometer.

Soil Total Coliforms, *Escherichia coli* , Yeast and Mold, *Staphylococcus* and *Aspergillus* loads were evaluated from each sampling location. Microbial analyses were performed in quadruplicates, using standard aseptic methods. Culture media and incubation temperatures are listed in Table 3. A 10 g homogenous sample of each organic substrate was placed into a sterilized medicinal flat bottle containing 90 ml Ringer's solution. After dilution (10^{-3} and 10^{-4}), the media were inoculated with the pour plate method, incubated for 48 hours in Gallenkamp Pius 2 incubators set at the appropriate temperature, and the number of colonies was counted.

Statistical analysis

Pearson's correlation coefficients (r) were used to evaluate the relationship between earthworm abundance, soil physicochemical and microbial properties.

RESULTS AND DISCUSSIONS

Earthworm species

E. eugeniae (Kinberg), commonly known as the African Nightcrawler, was the only earthworm collected from seven of the nine locations. The low earthworm diversity observed is consistent with other studies on invertebrate ecology in urban areas (Paul and Meyer, 2001). *E. eugeniae* is a *eudrilid* of West African origin and is plentiful in coastal shaded grasslands (Blakemore, 2000). Sims (1965) collected 60 clitellate specimens during a

Table 2. GPS coordinates and brief description of sampling locations in Accra.

Location	GPS Coordinates	Description
Afiaman-Santana	5º 36.6 N 0º 13.6 W	Samples collected from stream created by waste water flow from various bath-houses and auto mechanic shops. Plastic and other non-decomposable waste materials found in litter layer. Fecal matter visible and emitting odors. Site located alongside Odaw canal. Temporary structures visible, lower-income households. Some farming and metal working conducted in vicinity. Vegetation includes papaya trees, plantain/banana trees and shrubbery.
Aladzo	5º 35.8 N 0º 12.7 W	Samples collected from banks of stream. Plastic and other non-decomposable waste materials found in litter layer. Permanent structures but old buildings. Low income households. External bathhouses erected alongside stream. Effluent flows into stream. Cottage-scale fish processing and smoking conducted in close proximity to sample site. Prolific grasses and a sugarcane plant only vegetation.
Ashaiman	5º 41.8 N 0º 3.3 W	Samples collected from irrigation fields designated for research. Rice and maize grown. Irrigation water sourced from nearby reservoir. Farming community residing within low income shanty community. No plastics or other materials in litter layer. Some grasses and shrubbery with resemblance to species found at seaside.
Avenor	5º 34.8 N 0º 13.3 W	Samples collected from banks of stream. Plastics and other non-decomposable waste materials in litter layer. Fecal matter visible and emitting odors. On border of low-income neighborhood and industrial area. Waste water from nearby industries (construction, etc) flow into stream. Farm nearby. Cattle frequently brought over for grazing. Vegetation includes papaya trees, coconut trees, plantain/banana trees, mango trees and other shrubbery.
Dzorwulu	5º 36.5 N 0º 12.3 W	Samples collected from domestic effluent stream. Cottage scale textile (tie and dye) enterprise and farms nearby. Residential neighborhood, higher income households. In close proximity to Ebony/ECG, Plant pool and Aladzo Polo Park farms. Prolific grasses.
Labadi-Palmwine Junction	5º 34.6 N 0º 10.0 W	Samples collected from banks of stream flowing through domestic backyard. Permanent structures and abandoned buildings. Lower to middle income households. Palm trees and other plants providing shade.
Oblogo	5º 33.6 N 0º 18.8 W	Samples collected from bathhouse effluent streams. Peri-urban village close to metropolitan land fill site. Plastics and other non-decomposable materials found in litter layer. Plantain/banana trees, cocoyam and grasses found at site.
Tema-Community 2	5º 41.0 N 0º 1.3 W	Samples collected from banks of small stream located in auto mechanic's yard/garage. Waste water from mechanic's operations flow into stream. Plastics and other non-decomposable waste materials in litter layer. Plantain/Banana trees, cocoyam and grasses found at site. Light industrial area at northern edge of Tema.
Timber Market-Agbogbloshi	5º 32.5 N 0º 13.2 W	Samples collected from edges of open air communal bathhouse. Damp zone created at edges where debris left to collect and rot. Plastics and non-decomposable materials found in litter layer. No vegetation besides one coconut tree.

survey in Aburi, approximately 60 km north of Accra.

E. eugeniae is a large worm (adults reach 14 cm long) that grows rapidly, taking as little as 5 weeks to reach maturity, and is extremely prolific (Dominguez et al., 2001) . Its feeding habits (surface feeder, deposits its casts on the surface) make it ill suited for certain vermin-composting systems, such as the raised gantry-fed beds (Borges et al., 2003). *E. eugeniae* has a narrower optimal temperature range, between 20 – 29ºC (Neuhauser et al., 1988), than other vermicomposting earthworms, and as such is better suited for tropical than temperate applications. Individuals have been known to perish above 30ºC (Loehr et al., 1985; Viljoen and Reinecke, 1992; Dominguez et al., 2001). In addition, this species is more sensitive to disturbance than *Eisenia fetida* and may occasionally migrate from breeding beds (Dominguez et al., 2001). Despite these disadvantages *E. eugeniae* is capable of rapidly converting a wide range of organic

Table 3. Media and incubation temperatures for microbial analyses

Microbiological Indicator	Media	Incubation Temperature [ºC]
Total Coliforms	Violet Red Bile Glucose Agar	37
E. Coli	MacConkey Agar	37
Yeasts and Moulds	Potato Dextrose Agar	25
Staphylococcus	Manitor Agar	37
Aspergillus	Sabourad's Malt Agar	25

substrates including animal wastes (Dominguez et al., 2001), sewage sludge (Graff, 1982), rubber leaf litter (Chaudhuri et al., 2002), water hyacinth (Gajalakshmi et al., 2001), neem leaf litter (Gajalakshmi and Abbasi, 2004), taro (Kurien and Ramasamy, 2006) and cassava peel (Mba, 1996). The worms' ability to move quickly and survive in various substrates, under polluted conditions, offers it advantages in the urban landscape.

Small unpigmented holonephric worms were collected at the other two locations of Ashaiman and Dzorwulu. Small earthworms belong to the Enchytraeidae, Tubificidae and Naididae families and are typically aquatic (Rombke, 2003) . It is a widely accepted fact that Sub-Saharan Africa remains largely *terra incognita* with regards to aquatic worms (Brinkhurst, 1999). An earlier assessment of live specimens from these locations by the Zoology Department of the University of Ghana, suggested that these worms belonged to the enchytraeid family. This conclusion was not confirmed; the samples did not preserve well, because of bruising, making a second identification in Canada impossible. In addition, the literature makes no mention of enchytraeids in Ghana.

Abundance

The earthworm densities measured in this study ranged between 35 and 2175 individuals m^{-2} (Table 4). Earthworm abundance is affected by many factors, especially soil moisture content and land use (Edwards and Bohlen, 1996), which explains the wide range of densities measured in this study and reported in the literature. Worms were most numerous at the Dzorwulu and Ashaiman sites, where they were found at a density of 2175 individuals m^{-2} and 850 individuals m^{-2}, respectively (Table 4). Between 35 and 200 individuals m^{-2} were positively identified as *E. eugeniae*. The earthworm densities in this study are within the ranges observed in the tropics (Jimenez et al., 1998; Fragoso et al., 1999), although it should be noted that our sampling depth was shallower than that reported by other researchers, since the focus was on collecting surface dwelling earthworms that could be used for vermicomposting.

Earthworm abundance and soil physicochemical properties

Soil physicochemical properties are presented in Table 4. The gravimetric soil moisture was less than 30%, reflecting Accra's dry climate, and ranged between 27.4% in Dzorwulu and 5.1% in Tema. Soils were light-textured (sandy loam to loam), slightly compacted (bulk densities ranged from 1.2 to 1.5 g cm^{-3}), with near-neutral pH (6.3 to 7.8). Total organic C, total N, Bray-1 P and other extractable nutrient concentrations were within the range reported for soils in the Greater Accra Region (FAO, 2005) , with one exception. The available Ca levels, at 3.9 to 8.7 g kg^{-1}, were about two orders of magnitude greater than previously reported in the region (FAO, 2005). Lead and cadmium were present at concentrations from 0.05 to 12.7 mg Pb kg^{-1} and 0.04 to 0.07 mg Cd kg^{-1} (Table 4). The Pb concentration was elevated at Aladzo compared to other sites, probably because of the adjacent cottage-scale fish roasting activities or the road 30 m away. The latter is more likely as some 90 % of all atmospheric lead emissions are vehicular (Kylander et al., 2003). All the Pb and Cd concentrations were nevertheless much lower than the 165 mg Pb kg^{-1} and 1 mg Cd kg^{-1} recommended for residential soils by the British government's Department for Environment, Food and Rural Affairs (Nabulo et al., 2006).

Pearson's correlation coefficients of the relationship between earthworm abundance and soil physicochemical properties are presented in Table 5. A significant (P< 0.05) negative correlation existed between organic carbon and earthworm abundance perhaps because the presence of earthworms depends on factors more important than organic C, and when present, organic C is consumed by earthworm. McLean and Parkinson (1997) found the same trend whilst observing the epigeic earthworm *Dendrobaena octaedra* in a pine forest. Other researchers (El Duweini and Ghabbour, 1965; Hendrix et al., 1992) report a positive correlation between soil organic C and earthworm abundance, whereas other researchers observed no correlation between these variables (Whalen, 2004; Nair et al., 2005; Rossi et al., 2006). Evidently, the relationship between earthworm abundance and organic C is a complex one. A significant (P< 0.01) negative correlation was found between ex-

Table 4. Density of earthworms and mean values of physico-chemical and microbial parameters at locations in Afiaman-Santana (1), Aladzo (2), Ashaiman (3), Avenor (4), Dzorwulu (5), Labadi-Palm Wine Junction (6), Oblogo (7), Tema-Community 2 (8) and Timber Market-Agbogbloshi (9).

Location	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Earthworm Density (ind/m^2) [b]	65	200	850	99	2175	35	59	57	*42*
E. eugeniae Density (ind/m^2)	65	200	0	99	0	35	59	57	*42*
Moisture Content (g kg^{-1})[a]	103	92	208	84	274	120	97	51	*104*
Bulk Density (g/cm^3)	1.4	1.5	1.3	1.2	1.4	1.5	1.5	1.3	*1.5*
Sand (g kg^{-1}) [b]	417	771	519	821	364	840	503	705	*841*
Silt (g kg^{-1}) [b]	427	126	313	110	387	110	329	208	*105*
Clay (g kg^{-1}) [b]	156	103	169	69	250	50	169	8.8	*54*
Soil Texture	Loam	Sandy Loam	Loam	Loamy Sand	Loam	Loamy Sand	Loam	Sandy Loam	Loamy Sand
pH[b]	6.4	7.4	6.5	7.7	7.2	7.6	6.5	7.8	*7.2*
Total Nitrogen (g kg^{-1})[a, b]	2.9	2.0	2.5	1.6	2.2	1.8	2.6	1.9	*2.0*
Total Organic Carbon (g kg^{-1})[a, b]	36.4	16.5	25.6	11.4	21.7	15.7	23.0	24.0	*19.8*
Bray-1 Phosphorous (mg/kg) [a, b]	42.78	38.65	6.46	17.48	36.42	33.56	44.51	2.35	*13.26*
Available Sodium (g kg^{-1})[a, b]	0.42	0.40	0.74	0.35	0.72	0.65	0.66	0.51	*0.49*
Available Potassium (g kg^{-1})[a]	0.31	0.35	0.14	0.26	0.24	0.46	0.54	0.15	*0.27*
Available Calcium (g kg^{-1})[a]	4.3	6.0	4.3	4.4	7.0	6.4	3.9	8.7	*4.9*
Available Magnesium (g kg^{-1})[a, b]	1.3	1.9	3.3	1.6	2.2	1.9	3.3	1.8	*1.0*
CEC (cmol/kg) [a, b]	40.8	62.8	63.2	47.8	69.3	64.7	62.2	75.1	*46.8*
Lead (mg/kg) [a, b]	1.20	12.70	0.05	0.08	0.10	0.07	0.05	0.56	*0.23*
Cadmium (mg/kg) [a, b]	0.06	0.05	0.05	0.05	0.05	0.05	0.04	0.06	*0.07*
Total Coliforms ($\times 10^4$ CFU/g)[a, b]	6.97	117	20.1	18.4	35.4	18.6	26.6	4.23	*66.9*
E. Coli ($\times 10^4$ CFU/g)[a, b]	3.65	22.3	4.99	9.49	3.53	20.4	3.56	1.86	*1.90*
Total *Staphylococcus* ($\times 10^4$ CFU/g)[a, b]	18.7	56.1	16.8	11.9	8.93	32.9	43.3	10.8	*24.2*
Yeast and Moulds ($\times 10^4$ CFU/g)[a, b]	1780	884	4.51	4010	15.9	13.4	13.9	1.80	*30.4*
Total *Aspergillus* ($\times 10^4$ CFU/g)[a, b]	0.78	2.25	1.71	1.71	1.67	6.28	2.43	0.24	*0.58*

[a]Values expressed on a dry weight basis.
[b]Values are the mean of 4 analytical replicates.
CFU – Colony forming units

changeable Na and earthworm abundance. Fang et al. (1999) also found a negative relationship between earthworms and exchangeable Na in a rural soil in subtropical China. It is well known that earthworms cannot tolerate high salinity (El Duweini and Ghabbour, 1965) as high salt concen trations cause dessication and eventually death (Schaefer, 2005).

Earthworm abundance and soil microbial properties

Soil microbial loads are presented in Table 4. All locations tested positive for the microbial indicators, possibly from the wastewater, effluent and fecal material deposited nearby (Table 2). Although coliforms and *E. coli* are undesirable in drinking water due to their role in gastrointestinal diseases, the presence of these organisms in soil does not always suggest a health threat. Soils

Table 5. Pearson's correlation coefficients (r) of the relationship between Total Earthworm Density (ind/m^2) and soil properties (physiochemical and microbial), n = 36

Soil properties	*r*
Sand	0.19
Silt	-0.26
Clay	-0.03
Ph	0.16
Total Nitrogen	-0.21
Total Organic Carbon	-0.33*
Bray-1 Phosphorous	0.26
Available Sodium	-0.44**
Available Potassium	0.16
Available Calcium	0.04
Available Magnesium	-0.07
CEC	0.04
Total Coliform	0.49**
E. Coli	0.50**
Total *Staphylococcus*	0.47**
Yeast and Moulds	0.30 +
Total *Aspergillus*	-0.02

Significant at +, *P*<0.1, * *P*<0.05 and ** *P*<0.01.

colonized by coliforms and gram negative bacteria like *E. coli* can reduce the survival of *Salmonella*, and other bacteria, possibly due to competitive orpredatory pressures (Zaleski et al., 2005). The long-term survival of pathogenic bacteria is affected by ecological factors, such as interactions with soil protozoa, other soil bacteria and bacteriophages (Rogers and Smith, 2007).

Pearson's correlation coefficients of the relationship between earthworm abundance and soil microbial properties are presented in Table 5. There was a significant (*P*< 0.01) positive correlation between earthworm abundance and all the bacterial indicators tested, total coliforms, *E. coli* and *Staphylococcus*. Williams et al. (2006) observed that the epigeic *Dendrobaena veneta* and anecic *Lumbricus terestris* sustained and transported *E. coli* O157:H7 populations in soils and vermicomposts, suggesting a mutualistic relationship between earthworms and bacteria. Earthworm casts may contain up to 13 times more bacteria than uningested soils (Brown, 1995). Earthworm abundance was also weakly correlated (*P* < 0.1) with the yeast and mould loads. Fungal colonies are a primary source of food for many earthworms, particularly surface dwelling earthworms like *E. eugeniae* (Edwards and Fletcher, 1988; Brown, 1995; Bonkowski and Schaeffer, 1997). In addition, more fungal spores are found in earthworm casts than in surrounding soils (Tiwari and Mishra, 1993). However, the relationship between earthworms and fungus is not fully understood. Different earthworm species may suppress, enhance or have no effect on the germination of fungal spores (Brown, 1995). Our results suggest that the presence of many earthworms could favor the germination and growth of yeast and moulds, but that the growth of the fungus *Aspergillus* was independent of the number of earthworms found. This remains to be confirmed in future experiments.

Conclusions

This study is likely the first earthworm survey in Accra, Ghana. The litter cover and surface soils from sampling locations around Accra, Ghana contained the epigeic earthworm *E. eugeniae,* although their distribution was limited by soil moisture and land use. Small unpigmented holonephric worms were also present, in moister soils, but not as widely distributed as *E. eugeniae*. More earthworms were found in soils with a larger bacterial load (Total coliforms, *E. coli* and *Staphylococcus*). Earthworm numbers were also positively correlated with the number of CFUs (Colony forming units) of yeast and mould, but not *Aspergillus*. Earthworm abundance was negatively correlated with the total organic C and exchangeable Na in soils. The earthworm *E. eugeniae* is appropriate for vermicomposting and as fish bait, and could provide new opportunities to some residents of Accra.

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