Feasibility of low cost vermicompost production in Accra, Ghana

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ABSTRACT

Vermicomposting, the non-thermophilic decomposition of organic wastes by earthworms, is a popular waste management option in the Americas, Europe and the Indian sub-continent. Although the technology is inexpensive and produces an organic fertilizer as well as earthworm biomass, there are few examples of vermicomposting in sub-Saharan Africa. The objective of this thesis was to investigate the potential for vermicomposting in Accra, the capital city of Ghana, by conducting 1) an earthworm survey, 2) vermicomposting trials and 3) assessing farmers' perceptions of vermicompost as an organic fertilizer and other related issues. The earthworm *Eudrilus eugeniae* (Kinberg), was found in the soil-litter layer at seven locations across Accra. In a 20 d period, the *E. eugeniae* decomposed 99% of pineapple fibers and 87% of pineapple peels supplied, indicating that this earthworm is capable of vermicomposting. The nutrient value of the vermicompost was low, relative to other organic wastes in West Africa, probably due to the low nutrient content of pineapple wastes. Farmers were aware of the benefits to soil fertility from earthworm activity and associated the presence of earthworm castings with healthy soils. However, those involved in irrigated vegetable farming had insufficient space and time for on-farm vermicomposting and would prefer to purchase this fertilizer. Conversely, subsistence farmers lacked a reliable access to water necessary for on-farm vermicomposting. In summary, farmers were interested in the technology and were willing to adopt it, provided the vermicompost improved crop performance and was affordable and available.

RESUMÉ

Le vermicompostage est un procédé effectué par les vers de terre qui décomposent la matière organique sous des conditions non thermophile. Cette technique est populaire dans les Amériques, en Europe et aux Indes. Quoique la technique soit économique et produise un engrais organique ainsi que de la biomasse de vers, elle est rarement utilisée dans les régions au Sud du désert Sahara, en Afrique. L'objectif de cette thèse était d'étudier la possibilité d'effectuer du vermicompostage à Accra, la capitale du Ghana. Par ce projet, on a : 1) effectué un relevé des types de vers de terre retrouvés ; 2) réalisé des essais de vermicompostage, et ; 3) consulté les agriculteurs locaux pour savoir s'ils seraient intéressés à faire du vermicompostage et produire un engrais organique. Le vers de terre *Eudrilus eugeniae* (Kinberg), fut le plus commun, retrouvé à sept endroits dans la région d'Accra, dans la partie arable des sols. Lorsqu'offert des résidus fibreux et des pelures d'ananas, le vers *E. eugeniae* fut capable de les décomposer à 99% et 87%, respectivement, ce qui démontre que le vermicompostage est réalisable en Afrique. La valeur fertilisante du vermicompost était relativement faible comparativement aux autres résidus organiques disponibles en Afrique de l'Ouest, à cause de la faible teneur minéral des fibres et des pelures d'ananas. Les agriculteurs consultés étaient bien au courant des bénéfices qu'apportent les vers de terre et que leur présence signifie un sol fertile. Les agriculteurs qui cultivaient des légumes et pratiquaient l'irrigation, ne possédaient ni l'espace ni le temps nécessaire au vermicompostage ; ils préféraient acheter leurs engrais. Aussi, les agriculteurs de subsistance et les plus pauvres n'avaient pas suffisamment d'eau pour effectuer le vermicompostage sur leur ferme. Par contre, les agriculteurs étaient intéressés à la technologie du vermicompostage et son utilisation, à conditions d'obtenir de meilleurs rendements et que la pratique soit disponible et abordable.

PREFACE AND CONTRIBUTION OF AUTHORS

This thesis consists of a literature review and three manuscripts. The first chapter is a review of the literature regarding earthworms and vermicomposting in Africa. Chapters 2 to 4 were written in a manuscript style, in preparation for publication in scientific journals. The manuscript in Chapter 2 is co-authored by the candidate and his co-supervisor Dr. Joann Whalen. Chapters 3 and 4 are co-authored by the candidate, his supervisor Dr. Suzelle Barrington and Dr. Whalen. The candidate was responsible for conducting the experiments, analysis, and data collection described in the chapters, as well as preparing the manuscripts. Dr. Barrington and Dr. Whalen assisted with the manuscripts through general guidance, editing and encouragement. Dr. Whalen offered additional assistance with the statistical analysis.

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GENERAL INTRODUCTION

Vermiculture is gaining popularity as a means of converting various organic wastes into fertilizer. This earthworm-mediated decomposition process could provide new opportunities for improving soil fertility in sub-Saharan Africa. Soils in the region are highly weathered and traditional strategies for soil fertility management such as fallowing are not practical, considering land and population pressures. The situation is exacerbated by the rapid decomposition of organic matter and the fact that farmers often do not apply enough organic fertilizer to maintain soil organic matter pools. Ironically, urban centers generate a waste stream that is mostly organic byproducts that could be recycled and reapplied to agricultural lands, but these wastes are often disposed in a haphazard manner that contributes to poor urban sanitation and public health. There is an urgent and compelling need to implement organic waste recycling technologies, such as vermicomposting. There is very little information on the feasibility of vermicomposting in the sub-Saharan context, although this technology could be a way to transform organic wastes into a fertilizer that could maintain or build soil organic matter pools.

Introducing vermicomposting in locales where the technology has not previously been tested comes with its own set of challenges. The most important inputs (earthworms and organic wastes) have to be selected and managed with some care. Earthworms appropriate for vermicomposting can be imported at a significant cost, although at the risk of local ecology. In most cases, earthworms do not even survive the voyage. Local earthworms may be used for vermicomposting, but they must be present and capable of transforming organic waste into fertilizer in a reasonable amount of time. Organic wastes also have to possess characteristics (i.e. moisture, temperature and pH) conducive to the activity of the earthworm selected. Finally, there are social issues that need to be addressed, especially concerning farmers' perceptions of the technology and their willingness to use vermicompost as a fertilizer. Many innovative solutions to sub-Saharan Africa's soil fertility problems have been rejected because local farmers were not included in the research and development stages. Success therefore hinges on the inclusion of farmers' wisdom in the research process.

The objective of this thesis is to provide information on the potential for producing and using vermicompost as an organic fertilizer in Accra, Ghana. The literature review focuses on earthworm diversity in Africa, vermicompost production (processes and technologies), and the impact of vermicompost applications on soil fertility and crop production. The research for this thesis was conducted in Accra, Ghana. I sampled earthworm habitats and produced vermicompost with local earthworms (identified as *Eudrilus eugeniae*) collected during the survey, and agro-wastes (pineapple wastes). A survey of urban and peri-urban farmers was conducted to document farming practices, perceptions about fertilizer quality and earthworms, and the acceptability of vermicompost as an organic fertilizer. The thesis concludes with general conclusions and recommendations for future work.

CHAPTER 1: LITERATURE REVIEW

The ecological functions of earthworms

In temperate regions, earthworms such as those in the family *Lumbricidae* are well known to improve soil macroporosity and aggregation, and to increase nutrient and organic matter cycling (Lee, 1985; Vetter et al., 2004). They are considered 'ecological engineers', organisms that create physical structures and modify the availability or accessibility of resources for other organisms (Jones et al., 1994). Macronutrients are therefore abundant around earthworm casts and burrows; root growth is particularly enhanced in this area of the soil (Edwards and Bater, 1992). Earthworms make a similar contribution to soil fertility in tropical soils, sharing this niche with soil feeding termites (Fragoso and Lavelle, 1992), ants (Mora et al., 2005) and other soil fauna.

Earthworms are often grouped according to their physical appearance (body color, shape and size) and ecological functions such as burrowing abilities and food preferences (Bouché, 1977). This permits researchers to categorize earthworms in ecological classes, as epigeic, anecic and endogeic earthworms. Epigeic earthworms are small and live in the litter layer, typically ingest litter and humus without mixing organic and inorganic materials extensively (Lavelle, 1988). Anecics are large deep burrowing worms that come to surface when it is time to feed whereas endogeics live near the surface of soils in the organic horizons while producing horizontal galleries (Paoletti, 1999). Epigeics are typically found in the upper litter layer of the soil, endogeics in the first 10 to 20 cm and anecics in the deeper recesses of the soil. Anecic species are generally sparse in the tropical environment (Barois et al., 1999). Additional categories have been created to include the coprophagics, which live in manure piles and the arboricolous earthworms that live in suspended soils of humid tropical forests (Paoletti, 1999). Arboricolous are similar to epigeics, have large cocoons and can withstand long periods immersed in water, especially in pools of water that accumulate in bromeliads in the cloud forests.

In the tropics, earthworm communities are influenced by a suite of hierarchical factors with temperature dominating, followed by edaphic (nutrient status) and environmental (seasonality) factors (Fragoso and Lavelle, 1992). Earthworm densities versus annual rainfall follow a bell curve relationship in tropical rainforests, peaking at approximately 3000 mm of rainfall (Fragoso and Lavelle, 1992). Rainforests with less than 2000 mm of rainfall are too dry, whereas 4000 mm or areas with periodic flooding are too wet for earthworms. In arid regions with temperatures above 35ºC, annual rainfall less than 900 mm and a dry season longer than 5 months, termites are the dominant soil macrofauna and earthworms are rarely found (Lavelle, 1988). However, earthworms can survive dry periods by migrating to deeper soil layers, which leads to a seasonal change in the vertical distribution of earthworms (Fragoso and Lavelle, 1992). Horizontal distribution is thought to be random and structured at different spatial scales (Rossi, 2003; Decaëns and Rossi, 2001). Populations of earthworms sampled from a grass savannah in Cote d'Ivoire were found in randomly distributed clusters of variable size, suggesting a local influence was responsible for the observed pattern (Rossi, 2003).

Most of the information on earthworm ecology comes from studies in natural ecosystems (forests, savannahs) and managed agroecosystems. However, the data on earthworm abundance in urban ecosystems is sparse. Studies undertaken in temperate regions, including New York City (Steinberg et al., 1997; McDonnell et al, 1997; Pouyat et al., 1997), Baltimore-Washington Metropolitan Area (Csuzdi and Szlávecz, 2003), Stockholm (Erséus et al., 1999) and London (Smith et al., 2006) reported higher earthworm abundances with increasing urbanization. The authors attribute this to the anthropogenic introduction of exotic species in urban centers (in the case of New York, the region has low earthworm abundance and variety, a legacy of glaciation) and the island effect, which contributes to higher temperatures in cities. Cities offer diverse habitats within a small area, another reason for the high level of species richness in urban ecosystems (Rebele, 1994; Smith et al., 2006). As far as I am aware, there is no report in the scientific literature of earthworm abundance in urban ecosystems of tropical regions.

Earthworms in Africa

Climate in Africa is characterized by two seasons, with peak rainfalls occurring twice in some cases, especially in regions close to the equator. The agro-ecological zones are the arid, semi-arid, humid, sub-humid and the highlands; the humid, sub-humid and highland regions support the largest earthworm populations by virtue of their higher soil moisture content. In tropical regions, a group of ubiquitous exotic species are found in most countries, coexisting with native species common to the particular locality or region (Fragoso et al., 1999a). The general consensus is that tropical countries have more earthworm species than their temperate counterparts, partly because of the negative effect glaciation had on northern earthworm fauna (Fragoso and Lavelle, 1992).

Hyperiodrilus africanus 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). Some of the earthworms found in Africa are listed in Table 1.

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. Although these were the dominant species, some land uses supported up to 8 earthworm species. Populations of exotic earthworms are generally spread by anthropogenic activities leading to a dominance of exotic species in agricultural soils (Lee, 1985). The coexistence of dominant earthworms was also related to their ecological niche, since *A. rodericensis* was found in the surface litter layer, *A. minimus* was in the surface humus layer and *P. corethurus* was in the mineral soil (upper 20 cm). Information on earthworms in semi-arid soils of Ghana is limited – Sims (1965) collected 14 species of Acanthodrilidae and Eudrilidae in grasslands, semi-aquatic habitats, agricultural fields and forests of Ghana during the early 1960s. At present, the abundance and diversity of earthworms inhabiting soils around Accra, Ghana is unknown.

Vermicompost Production

Several earthworm species are recommended for vermicomposting, such as the corophragic earthworms *Eisenia foetida* and *Eisenia andrei* (Dominguez et al., 2001). Another is the epigeic *E. eugeniae*, a tropical earthworm with a high reproduction rate (Mba, 1983; Gajalakshmi et al., 2001). The anecic *Lampito mauritii* (Tripathi and Bhardwaj, 2004) noted for its ability to withstand environmental stresses, and the epi-endogeic *H. africanus* have also been recommended (Tondoh et al., 1998). These earthworms are capable of consuming a wide range of organic substrates from sewage sludge, animal wastes, crop residues (water hyacinth, mango leaves) to industrial refuse (Atiyeh et al., 2000). They rapidly convert the wastes, through a non-thermophilic process, into a humus-like substance with smaller particle size than the starting material (Arancon et al., 2003; Edwards and Burrows, 1988). Gajalakshmi and Abbasi (2004b) observed an increase in vermicast output as various earthworms (*E. euginiae, L. mauritii, P. excavatus* and *D. willsi)* acclimatized to the feed, gained weight and bred. A similar trend was observed in *H. africanus* (Tondoh et al., 1998), although earthworms collected from the field had a lower survival rate than those hatched in the laboratory.

In the conventional vermi-reactor, 50% of the reactor volume is occupied by successive layers of sawdust (1 cm), river sand (2 cm) and garden soil (4 cm) (Gajalakshmi et al, 2001; Jain et al., 2003). This design does not make full use of the reactor volume and it has been suggested that a modified vermi-bed, consisting of a single layer of moistened thick cotton cloth at the base of the feed, should be used for a four-fold increase in efficiency (Jain et al., 2003, Gajalakshmi et al., 2005). Though many potential pollution hazards are reduced during vermicomposting, some contaminants, labile nitrogen, phosphorous, sulfur compounds and potassium can leach, or be translocated by earthworm activity, into the bottom layers of the vermi-reactor (Mitchell, 1997). Large scale vermicomposting operations therefore require a highly absorptive or impermeable medium at the base of the reactor volume to contain nutrient leaching and other uncontrollable releases into the environment (Mitchell, 1997).

The effect of temperature on the earthworm life cycle was evaluated by growing *E. eugeniae* and *E. fetida* in dishes (12.5 cm diameter, 5 cm deep) containing 200 g of separated cattle solids (82% moisture content) (Dominguez et al., 2001). Earthworm cocoons reached sexual maturity most quickly when the temperature was 25 to 30^{o}C, regardless of the population density. The same study also observed that some *E. eugeniae* perished at 30ºC, but *E. fetida* withstood higher temperatures. Tripathi and Bhardwaj (2004) nevertheless recommend using a substrate with 70% moisture content and a pH of 6.5 and a temperature of 25^{o}C as optimal for *E. fetida* growth and development. The same authors recommend a substrate with 60% moisture content, pH 7.5 and a temperature of

30^{o}C as optimal for breeding *L. mauritii*. They also indicate that the maximum vermicomposting rate was related to earthworm biomass per unit waste, rather than the total number of earthworms. Earthworm biomass growth is slower in densely populated vermi-reactors, explaining why the cast output rates per earthworm are lower in high-density vermi-reactors than in low-density reactors (Jain et al., 2003; Gajalakshmi et al., 2005). Gajalakshmi (2001) nevertheless observed higher cast output rates per reactor volume in high-density vermi-reactors than in low-density vermi-reactors operating over the same period.

Vermicompost

Cleopatra declared earthworms sacred and the use of vermicompost as a soil supplement was allegedly documented by the Roman Statesman Cato circa 4 AD. However, the first reports in academic literature documenting the use of earthworms for vermicomposting appeared after the Second World War (Barrett, 1949). Applying vermicompost to soil increases microbial biomass N and orthophosphate levels (Arancon et al., 2003) while improving seed germination, seedling growth and crop productivity in a variety of cereals, legumes, vegetables, fruits, ornamental and flowering plants grown in greenhouses and to a lesser extent in the field (Atiyeh et al., 2002). Addition of N fixing microorganisms; *Azotobacter* and *Azospirillum,* and P solubilizing microorganisms; *Pseudomonomas striata,* with rock phosphate, will increase the plant-available N and P content of vermicompost further (Kumar and Singh, 2001). Vermicompost is also characterized by a more abundant and diverse microbial community than compost (Atiyeh et al., 2002).The greatest plant growth responses were observed when vermicompost occupied 10 to 40 % of the total volume of plant growth medium (Atiyeh et al., 2002). Incorporating larger proportions of vermicompost into growth media had little positive effect on plant growth, and past a threshold point, will reduce crop production indices (Subler et al., 1998).

Vermicompost is also thought to be more pathogen free than compost (Szczech, 1999) and has the ability to suppress plant disease (Szczech, 1993). Studies at the Ohio Agricultural Research and Development Center on soils under strawberries and grapes observed a larger population of fungivorous and bacterivorous nematodes in soils where vermicompost was applied than in soils with inorganic fertilizer treatments (Arancon et al., 2002). Vermicompost derived from sewage sludge suppressed arbuscular mycorrhizal fungi (AMF) colonization of clover and cucumber (Sainz et al., 1998), although AMF colonization of Salvia and Aster roots, growing in a garden soil mixture, was enhanced by vermicompost (Kale et al., 1987). It may be that the vermicompost produced from sewage sludge contained metals that impaired the AMF symbiosis, since excessive levels of heavy metals can reduce AMF colonization and fungal persistence in soils (del Val et al., 1999).

Potential for vermicomposting and vermicompost use in sub-Saharan Africa

Agriculture is a major economic activity in sub-Saharan Africa, providing employment to approximately 203 million people, or 56.6 percent of the total labor force, and serving as the basis for many industries (UNEP, 2007). However, most of the soils in sub-Saharan Africa are highly weathered, with low organic matter content and low fertility (Stangel, 1993). More nutrients are removed from cropped soils than are added from fertilizers, leading Stoorvogel (1993) to forecast that the soils in this region would have annual losses of 26 kg nitrogen ha^{-1}, 3 kg phosphorus ha^{-1} and 19 kg potassium ha^{-1} by 2000. Although inorganic fertilizers are a source of nutrients, they may cause soil structural degradation by accelerating the decomposition of soil organic matter, which can reduce soil aggregation, water-holding capacity and cation exchange capacity (Mba, 1996).

Fallowing, the application of manures and mulching are perhaps the most widely used soil fertility management strategies in Africa (Quansah et al., 2001; Harris and Yusuf, 2001; Harris, 2002). However, increasing population pressure has decreased the availability of arable land and it is no longer feasible to use extended fallow periods to restore soil fertility (Quansah et al., 2001; Bationo et al., 2007). In addition, organic resources in sub-Saharan Africa are in short supply (Giller et al., 2002; Danso et al., 2006). Not only are biomass production levels quite low, but organic resources are used as fodder, construction materials and cooking fuel (Lamers and Feil, 1993). In addition, cattle in the region need to graze on between 10 ha and 40 ha of rangeland, during the dry season, and between 3 ha to 10 ha of rangeland, during the wet season, in order to produce enough manure to fertilize 1 ha of cropland (Fernandez-Rivera et al., 1995). The scarcity of organic resources in sub-Saharan Africa requires farmers and researchers to consider non-traditional ways of recycling and returning organic wastes to agricultural land, essential for maintaining soil organic matter pools (Bationo et al., 2007). Although vermicompost has not been used much in Africa it is the preferred soil conditioner for farmers in India and is sometimes priced as much as three times higher than regular compost (Gajalakshmi et al., 2005). However, as stated earlier, important barriers to the introduction of the technology in sub-Saharan Africa include the availability of system inputs (organic wastes, moisture and earthworms) and farmer acceptance.

Agricultural entrepreneurs in sub-Saharan Africa have begun to look to commercial-scale agro-processing (e.g. fruit juice extraction) as a means of income generation (Yow, 2002) and in turn generate a significant amount of waste (Nwabueze and Otunwa, 2006). The wastes are generally unacceptable as fodder, fuel or mulch and thus, accumulate at factories (Yevich and Logan, 2003). In addition, they pose disposal problems with serious effects on the environment (Nwabueze and Otunwa, 2006). Here, vermicomposting the organic waste could serve as a means to stabilize the waste, divert it from legal and illegal dumpsites and finally, create an organic fertilizer that can be returned to agricultural land to supply nutrients for crop production and increase soil organic matter pools. However, the quality of the vermicompost product is contingent on feedstock characteristics (Aranda et al., 1999). In light of this, the nutrient and pathogen content of the vermicompost produced from agro-waste must be comparable to other organic fertilizers on the market, especially the manures.

In the past, water in sub-Saharan Africa was abundant, however, the spatial and temporal variability of rainfall was high (van Koppen, 2002). Rainfall was erratic and often fell as convective storms with high intensity (Rockström et al., 2002). Water scarcity in the region had economic consequences, but resources and money to create reliable treatment and distribution networks were lacking (Molden et al., 2001). This has had serious impacts in the region as 60% of the population relies on rain-based rural agriculture and this represents between 30% and 40% of country GDP (World Bank, 1997). Today, sub-Saharan Africa is faced with shrinking water resources compounded by increased demands for human consumption/production and climate change.

Locally-obtained earthworms would be the most appropriate for vermicomposting in sub-Saharan Africa. The epigeic earthworm, *E. eugeniae*, used widely for vermicomposting and in vermiculture, is one of the most common earthworms in West Africa (Reinecke and Viljoen, 1988); about 60 clitellated samples of this earthworm were collected in Ghana by Sims (1965), and it has been observed in Nigeria (Hauser, 1993) as well as the west African island Sao Tomé (Csuzdi, 2005). This wide distribution is testament to *E. eugeniae*'s peregrine nature. Hauser (1993) concludes that permanent shading of the soil by hedgerows enhances *E. eugeniae* activity. In Rwanda, central Africa, corophragic species *Dichogaster sp1* and *S. variabilis* were observed in manure piles (Fragoso et al., 1999a). Even in semi-arid South-West Ethiopia where rainfall ranges between 950 and 1400 mm, unidentified local earthworms were collected from manure piles and around rotting *Ensete* plants (Bierwirth et al., 2000). These observations indicate that some earthworms known to be suitable for vermicomposting can be found in certain areas of sub-Saharan Africa.

Finally, the success of the vermicomposting technology is closely related to acceptance of the vermicompost as an organic fertilizer by farmers. Previous technological innovations attempting to address soil fertility degradation have not been successful because of the lack of farmer acceptance (Douthwaite et al., 2002). Local people often reject technologies that are imposed upon them ("top down" delivery) (Saïdou et al., 2004). This suggests that technology will not be adopted unless it is perceived to be appropriate and adaptable to local conditions. Researchers are encouraged to listen and learn from farmers' experiences, since they have an indigenous knowledge and wisdom of ecological conditions in their own region (Saïdou et al., 2004). They also can make judgments about whether new technologies will be acceptable given their socio-cultural beliefs and priorities (Singh and Singh, 2005).

Conclusion and opportunities for further research

Although vermicomposting could provide a new organic fertilizer for farmers in sub-Saharan Africa, there are many barriers to overcome before this technology can be widely adopted. Some concerns still persist regarding the availability of system inputs, the quality of the vermicompost produced and farmer adoption. Although local agro-processing plants are potential sources of organic wastes, there is little information on whether the quantity, quality and spatial distribution of these wastes will be appropriate for vermicomposting, and whether the quality of the vermicompost product is comparable to other organic fertilizers that are used currently. Where to source local earthworms capable of converting large amounts of assorted wastes also needs to be evaluated. In addition, farmers' perceptions regarding organic fertilizer performance must be collated. Future research must therefore 1) evaluate the abundance of vermicomposting earthworms available locally, 2) determine the quality of the vermicompost product produced from available agro-wastes and locally acquired earthworms, and finally, 3) assess farmers' perceptions on fertilizer performance criteria.

Tables

Table 1: Earthworms commonly found in Sub-Saharan Africa

Species	Country/Region	Suitable for vermicomposting
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

Source: Fragoso et al., 1999; Sims, 1965; Hauser, 1993; Blanchart et al., 1997; Rossi, 2002; Dominguez et al., 2001; Tondoh, 1998; Dlamini and Haynes, 2004; Ouédraogo, 2004; Omodeo et al., 2003.

CHAPTER 2: EARTHWORM ABUNDANCE RELATED TO SOIL PHYSICOCHEMICAL AND MICROBIAL PROPERTIES IN ACCRA, GHANA

Abstract

Vermiculture is a low-cost technology that could be used to manage organic wastes in Accra, Ghana, but it is not known whether earthworms for vermicomposting can be found locally. This study reports on the earthworms found in Accra, and the relationship between earthworms and soil properties. We found the African nightcrawler *Eudrilus eugeniae* (Kinberg), a suitable vermicomposting species, in the soil-litter layer at seven locations across Accra. Small (< 8 cm long) unpigmented holonephric worms were collected at two other locations. Earthworm densities ranged from 35 to 2175 individuals m^{-2}. Earthworm abundance was negatively correlated ($P < 0.05$) with soil organic C and exchangeable Na concentrations, but positively correlated ($P < 0.01$) with culturable bacteria (total coliforms, *Escherichia coli* and *Staphylococcus*). There tended to be more culturable yeasts and moulds in soil from locations with more earthworms. Around Accra, earthworms were more numerous in non-saline soils where bacteria and some fungi thrive. The earthworm *E. eugeniae* could be collected for vermicomposting in Accra.

Introduction

Vermicomposting is gaining worldwide popularity as a means of remediating waste remediation and producing organic fertilizer and animal feed protein. Successful vermicomposting projects have been documented in the Ivory Coast (Tondoh, 1998), Nigeria (Hauser, 1993; Mba, 1996; Ayanlaja et al., 2001), and Ethiopia (Bierwirth et al., 2000), but 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 addition to nutrient-rich agricultural runoff, are probably contributing to eutrophication in many waterways. Blue-green algae and their carcinogenic mycotoxins have already been detected 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, we have practically no information about what types of earthworms might be present in Accra. Sims' (1965) survey on Acanthrodrilidae and

Eudrilidae is the only known report of earthworms in Ghana. The objectives of this study were 1) To document the occurrence and abundance of surface dwelling earthworms and 2) To investigate the relationship between earthworm abundance and soil properties (physicochemical and microbial).

Materials and Methods

Study Area

Accra is located in the southern coastal savannah belt of the country along the Gulf of Guinea (5º 34′ N, 0º 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.

Site Selection

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). 2Thus, 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 layer (surface residues and the underlying soil to a depth of about 5 cm). After preliminary sampling, we noticed two groups of Oligochaeta: Megadriles (at least 10 cm long, with clitellate adults reaching 14 cm long) and Microdriles (typically < 8 cm, found in the wettest soils). We used two sampling techniques to collect these Oligochaeta, intended to provide an unbiased estimate of their biomass and population size (Omodeo et al., 2003). Megadriles were collected from soil blocks (60 cm by 60 cm to a depth of 5 cm) by handsorting. A soil core (10 cm by 10 cm to a depth of 10 cm) was collected and washed on sieves to collect the Microdriles, due to the high clay content and small earthworm sizes. After counting, earthworms were washed with water and a few specimens stored in a 95% ethanol solution, transported to Canada and identified about six months later.

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 deposited in appropriately labeled plastic containers. The sample for soil microbial analysis was placed in an ice chest immediately after collection and refrigerated until analysis. The second sample was prepared for physico-chemical analysis by air-drying (2 days). A soil core (8cm diameter and 4cm depth) was collected at each location and sealed with a plastic cap to preserve moisture. The core was weighed before and after drying (105 ºC for 24 h) to obtain gravimetric 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 measured with the total Kjeldahl nitrogen method (Bremner, 1996) and total organic carbon with the Walkley-Black method (Nelson and Sommers, 1996). Plant-available phosphorous was extracted with the Bray-1 method (Kuo, 1996) 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 ammonium acetate (Helmke and Sparks, 1996; Suarez, 1996). The Na and K concentrations were 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 was determined 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.

We evaluated total coliforms, *E. coli*, Yeast and Mold, *Staphylococcus* and *Aspergillus* loads in soil 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 discussion

Earthworm species

E. eugeniae, 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 survey in Aburi, approximately 60 km north of Accra.

E. eugeniae is a large worm (adults reach 14 cm long) that grows rapidly, reaching maturity within 5 weeks of hatching from a cocoon, and reproduces prolifically (Dominguez et al., 2001). Its feeding habits (surface feeder, deposits its casts on the surface) make it ill suited for certain vermicomposting systems, such as the raised gantry-fed beds (Borges et al., 2003). *E. eugeniae* has a narrower optimal temperature range (20-29^{o}C) than other vermicomposting earthworms (Neuhauser et al., 1988) and 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 decomposing many organic 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, 2004a), taro (Kurien and Ramasamy, 2006) and cassava peel (Mba, 1996). This earthworms' 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, 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, 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. Earthworms were most numerous at Dzorwulu and Ashaiman, where we found 2175 individuals m^{-2} and 850 individuals m^{-2}, respectively (Table 4). We found between 35 and 200 individuals m^{-2} that were positively identified as *E. eugeniae*. The earthworm densities in this study are within the range of values observed in the tropics (Jimenez et al., 1998; Fragoso et al., 1999b), 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.

Relationship between 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 and 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). We also provide values for lead and cadmium, which 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). The Pb and Cd concentrations reported here are lower than the 165 mg Pb kg^{-1} and 1 mg Cd kg^{-1} recommended for residential soils in the United Kingdom (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 earthworms consume more organic C in areas where they are numerous. McLean and Parkinson (1997) found the same trend while 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 Nair et al. (2005) observed no correlation between these variables. Evidently, the relationship between earthworm abundance and organic C is a complex one. A significant ($P < 0.01$) negative correlation was found between exchangeable 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; Robidoux and Delisle, 2001; Addison, 2002), as high salt concentrations cause dessication and eventually death (Schaefer, 2005).

Relationship between 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 colonized by coliforms and gram negative bacteria like *E. coli* can reduce the survival of *Salmonella*, and other bacteria, possibly due to competitive or predatory 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

As far as we know, this is 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 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.

Tables and Figures

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.

Location	GPS Coordinates	Description
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.

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

Table 4: Density of earthworms and mean values of physico-chemical and microbial parameters at sampled locations in Accra.

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

Location	1	2	3	4	5	6	7	8	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

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).

[a] Values expressed on a dry weight basis.

[b] Values are the mean of 4 analytical replicates.

Table 5: Pearson's correlation coefficients (r) of the relationship between Total Earthworm Density (ind/m2) and soil properties (physiochemical and microbial).

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

n=36
Significant at +, $P<0.1$, * $P<0.05$ and ** $P<0.01$.

CONNECTING PARAGRAPH

In the previous chapter we observed specimen of the popular vermicomposting earthworm, *E. eugeniae*, at nine sites across Accra. In the next chapter we assessed the ability of *E. eugeniae* specimen, collected from four of the nine sites, to process pineapple wastes. In addition, the nutrient quality, microbial loads and phytotoxicity of the vermicompost produced were assessed.

CHAPTER 3: VERMICOMPOSTING PINEAPPLE WASTES WITH EARTHWORMS NATIVE TO ACCRA, GHANA

Abstract

Pineapple wastes were vermicomposted using local earthworms (*Eudrilus eugeniae* Kinberg) collected from the banks of streams and bath houses in Accra, Ghana. In a 20 d period, local earthworms decomposed 99% of pineapple fibers and 87% of pineapple peels supplied, indicating that they could be used in vermicomposting. Pilot-scale vermidigesters containing about 90 earthworms received a mixture of pineapple fibers and peels (1:1 w/w) regularly during a 4 month period, followed by 1 month with no feeding. Vermicomposting of the acidic pineapple waste (pH= 4.4) generated a vermicompost with neutral to alkaline pH (7.2 to 9.2). The vermicompost contained as much as 0.4% total N, 0.4% total P and 0.9% total K, and had a C:N ratio of 9-10. The nutrient value of the vermicompost was low, relative to other organic wastes in West Africa, probably due to the low nutrient content of pineapple wastes. Vermicompost was not phytotoxic to *Zea mays* seed germination. The reduction in *E. coli* load by 31-70% during vermicomposting was probably due to the activities of antagonistic soil foodweb organisms, not earthworms. However, local earthworms reduced the *Aspergillus* loads in pineapple waste by 78-88%, which was much greater than the 16% reduction in *Aspergillus* achieved in earthworm-free boxes. The rapid comminution of the pineapple wastes by Accra's local earthworms demonstrated the viability of vermicomposting as a simple and low cost technology for waste recycling in Accra and surrounding areas.

Introduction

Accra's rapid urbanization, coupled with Ghana's national debt, has left the metropolitan authority with insufficient resources for waste collection (Boadi and Kuitunen, 2003). This is especially evident in low-income areas where waste collection from communal dumpsites is subcontracted to private companies by the Accra Metropolitan Assembly (Anomanyo, 2004). Financial constraints and other logistical problems have led to irregular collection, and communal dumpsites are often filled to capacity. Consequently, many residents dispose of wastes improperly, at informal dumpsites and in canals, water bodies and surface drains (Boadi and Kuitunen, 2003). One strategy to reduce indiscriminate dumping is to divert organic materials from the waste stream and convert them into fertilizer. About 85% of Accra's solid waste is food leftovers, rotting fruits, vegetables, leaves, crop residues, animal excreta and bones, which could be recycled (Asomani-Boateng and Haight, 1999; Boadi and Kuitunen, 2003). Pineapple wastes are particularly ubiquitous because surpluses from this new export industry are consumed locally. Local fruit juicing companies also produce significant amounts of pineapple wastes.

Previous large-scale efforts to recycle organic wastes in Accra were not successful. A centralized and highly mechanized composting plant established in Accra in the 1980s failed due to high operational and maintenance costs (Anomanyo, 2004). Small-scale waste recycling by vermicomposting, the biological degradation of organic matter when earthworms feed on organic waste materials (Hervas et al., 1989), holds some promise as a waste management technology. The simplicity and low cost of vermicomposting could make it an attractive venture for resource poor informal waste collectors in the city. The skills required for operating these small-scale systems are comparable to livestock and snail rearing, and easily transferable to novices. Another compelling argument for vermiculture is that the vermicompost can be sold to urban and peri-urban farmers. In 2000 there were an estimated 2,400 individuals involved in small scale commercial vegetable farming in Accra (Armar Klemensu and Maxwell, 2000). Horticulturists, aqua-culturists and home-owners with gardens also represent a potential market for vermiculture products. A waste recycling approach that includes vermicomposting could bring the communities involved closer to achieving the United Nation's Millennium Development goals for sanitation, health and employment (United Nations, 2006).

Many earthworm species are used for vermicomposting, including *Eisenia fetida*, *Eisenia andrei*, *Perionyx excavatus*, *Eudrilus eugeniae*, *Amynthas cortices*, *Amynthas gracilis*, *Eisenia hortensis*, *Eisenia veneta* and *Lampito mauritii* (Blakemore, 2000). With the exception of the anecic earthworm *L. mauritii*, most species are litter-dwelling (epigeic) earthworms that consume large quantities of organic substrates, grow rapidly and reproduce prolifically, compared to soil-dwelling earthworms. Anecic earthworms also consume organic substrates at the soil surface, although they dwell permanently in the soil (James and Hendrix, 2004). They are not considered as well suited for vermicomposting as their epigeic counterparts but can still consume significant amounts of organic material, albeit at a slower rate (Gajalakshmi et al., 2001; Tripathi and Bhardwaj, 2004).

At the outset of this study, we had no information on the earthworm species present in Accra. In one of the few surveys on *Oligochaeta* in Ghana, Sims (1965) observed 60 clitellate specimens of *E. eugeniae* in Aburi, a town about 60 km north of Accra. This species, known as the "African night-crawler", is popular among vermiculture practitioners. When well-characterized vermicomposting species are not present, Blakemore (2000) suggested that the first step to establishing a vermicomposting program would be to collect local species found naturally in organically rich substrates. Then the fecundicity rates (cocoons/adult/year) (Tondoh, 1998; Borges et al., 2003) and vermicast output rates (mg l^{-1} d^{-1}) (Gajalakshmi et al., 2005) of the local species could be quantified. However, researchers without training in earthworm taxonomy may have difficulty in determining the species-level identity of local earthworms. This remains a challenge for vermiculture practitioners in Accra and elsewhere.

A convenient approach is to evaluate the overall effects of the earthworms during vermicomposting i.e. decomposition rates and vermicompost characteristics. The mass of organic wastes lost during vermicomposting, due to the activities of earthworms and other soil food web organisms, is an indicator of the decomposition rate and the time required to achieve a mature vermicompost. Nutrient contents and pathogen loads are well accepted measurements of vermicompost quality. Vermicompost contains plant-available nutrients and organic matter, making it a valuable fertilizer and soil conditioner, with between 0.36 and 4% N, 0.13 to 4.37% P, and 0.22 to 3.74% K reported for various vermicomposts (Aranda et al., 1999; Kaviraj and Sharma, 2003). Since there is relatively little heating during vermicomposting, relative to composting, the presence of pathogens and parasites could pose a health hazard to vermicompost producers and end-users. Yet, there were equal amounts of *Aspergillus fumigatus* and *Aspergillus flavus* in the *Scedosporium* state found in mature compost and vermicompost (Anastasi et al., 2005), suggesting that vermicomposting was equally effective as composting at reducing the pathogen load. However, pathogens may not be degraded when they pass through the earthworm intestinal tract. After feeding *Lumbricus spp.* cow manure, Pederson and

Hendriksen (1993) observed similar concentrations of *Eneterobacter cloaca* in the dung and earthworm casts. Another study suggests that the long term persistence of *Escherichia coli* O157:H7 in soil and vermicompost may be unaffected by earthworms (Williams et al., 2006). Routine monitoring is required to verify that the pathogen levels in mature vermicompost do not pose a hazard to human health and the environment.

This study was conducted in Accra, Ghana, with the objectives 1) to evaluate the decomposition of pineapple waste during vermicomposting with local earthworms and 2) to measure the nutrient content and microbial pathogen loads of the pineapple waste vermicompost.

Materials and Methods

Study area

Accra, the capital city of Ghana, 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 24.7º C 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. Vermicomposting experiments and laboratory analyses were conducted in the Soil Science Department, University of Ghana, Legon, Accra.

Earthworm culture and pineapple waste

Live earthworm specimens were collected from the soil litter and root layers at four sites in Accra (Table 6), on the banks of streams and from bath house effluents. Earthworm cultures were wooden boxes containing a mixture of pineapple wastes, soil and leaf litter. A few clitellate adults collected from each sites were preserved (95% ethanol), transported to Canada and subsequently identified as *Eudrilus eugeniae* (Kinberg). Pineapple peel, approximately 5 cm long and 1.5 cm wide, were obtained from a community dump in Aladzo. Pineapple fibers, very fine pulp with particle size less than 2 mm, were from the Milani food processing company. A mixture of pineapple peels and fibers (1:1 w/w) was dried in the sun for 2 days in preparation for analysis.

Decomposition of pineapple waste during vermicomposting

Experiments were conducted in a greenhouse at the University of Ghana between January and April, 2006. The decomposition of pineapple waste, measured as the mass loss of the organic substrate during a period of time, was evaluated in vermidigesters. These were wooden boxes (0.6 m by 0.6 m and 0.1 m depth) with plywood sides and open at the top, which contained about 15 kg of the culture medium (soil, leaf litter and decomposed pineapple waste) and approximately 90 earthworms. We also had wooden boxes with 15 kg of earthworm-free soil, to serve as a control. Two treatments, pineapple peels and pineapple fibers, were applied to the vermidigesters (n=12 for each treatment) and control boxes (n=12) during the experiment. We spread 3 kg of pineapple peel or 6 kg of pineapple fiber evenly on top of the vermibed or soil layer. On the 5th, 10th, 15th and 20th day after feeding with pineapple peel, the surface waste was gently collected to exclude earthworm casts and earthworms. After weighing on a Camry 20 kg spring scale, the pineapple peel waste was returned to the correct vermidigester or control box, and all boxes were watered to maintain moisture. The same procedure was used to evaluate the decomposition of pineapple fiber, although sampling dates were the 5th, 10th and 15th day after feeding.

Vermicompost production from pineapple waste

Three vermidigesters and one earthworm-free control (described above) were each fed 4 kg of mixed pineapple peels and pineapple fibers (1:1 w/w) every three weeks between January and April, 2006. The vermidigesters and control boxes were watered regularly during the feeding period and for one more month after the last pineapple waste application. Then, castings (top 5 cm layer of the vermibed) were removed from each vermidigester and dried in the sun for 2 days in preparation for analysis. We also removed and dried the top 5 cm of decomposed pineapple waste and soil from the earthworm-free control. For laboratory analysis, we sent 3 samples of vermicompost (one from each vermidigesters) and 1 sample from the control box.

Chemical and microbiological analyses

Air-dried samples of fresh pineapple waste (mixed peels and fibers, 1:1 w/w), vermicompost and decomposed pineapple waste from the control box were ground (< 2 mm mesh) in preparation for analysis. All chemical analyses were conducted in triplicate. 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 measured with the total Kjeldahl nitrogen method (Bremner, 1996) and total organic carbon with the Walkley-Black method (Nelson and Sommers, 1996). Samples were digested with perchloric acid for total phosphorous determination, while plant-available phosphorous was extracted with the Bray-1 method (Kuo, 1996). The P concentration was then measured colorimetrically with the molybdate blue method at 712 nm using a Philips PU 8620 UV/VIS/NIR spectrophotometer. Potassium was extracted by wet acid digestion (Helmke and Sparks, 1996) and measured with a Jenway PFP7 flame photometer.

We evaluated the *E. coli* and *Aspergillus* load in fresh pineapple waste (mixed peels and fibers, 1:1 w/w), vermicompost and decomposed pineapple waste from the control box described above. Microbiological analyses were performed in quadruplicates, using standard aseptic methods. MacConkey Agar and Sabourad's Malt Agar were used as media for *E. coli* and *Aspergillus*, respectively. 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 37ºC for *E. coli* and 25ºC for *Aspergillus*, and the number of colonies was counted.

Vermicompost phytotoxicity test

The phytotoxicity test to assess vermicompost maturity was based on the method of Zucconi et al. (1981), with some modifications. We tested vermicompost (3 samples) and decomposed pineapple waste from the control box (1 sample), and there were 4 analytical replicates of each organic waste sample, plus analytical controls that received distilled water only. Briefly, cotton wool was placed inside 20 sterilized glass petri-dishes (15mm by 100 mm) and wetted with 10 ml of 1:10 organic waste/water extract or 10 ml of distilled water. Then, 20 *Zea mays* seeds were placed in the petri-dishes, covered with petri-dish lids and kept in the dark for 5 days. The number of germinated seeds in each petri-dish treated with organic waste extract (*G*) was counted and the percent germination (PG) calculated according to the formula:

$$PG = \frac{G}{G_0} \times 100$$

where G_0 is the average number of germinated seeds for the distilled water.

Statistical analysis

The decomposition rate of pineapple waste was evaluated using exponential decay curves and the k values were compared statistically with a t-test at the 95% confidence level (Montgomery and Runger, 2007). The chemical and microbiological characteristics of fresh pineapple waste, vermicompost and decomposed pineapple waste were evaluated by one-way analysis of variance, followed by contrast analysis (vermicompost versus fresh pineapple waste, vermicompost versus decomposed pineapple waste) at the 95% confidence level.

Results and Discussion

Pineapple waste decomposition rates

During the decomposition trial, 98.9 % ($\pm$ 0.8) (wet weight) of the pineapple fiber was consumed in the vermidigesters and 77.5 % ($\pm$ 4.4) in the controls (Fig. 1a.). Pineapple peel treatments showed a less dramatic mass loss, with 86.9 % ($\pm$ 3.2) loss in the vermidigesters and 70.7 % ($\pm$ 4.5) loss in the controls. The mass loss data was transformed with a natural log function, and the decay coefficients for pineapple waste were found to range from -0.061 d^{-1} to -0.287 d^{-1} (Fig. 1b). The decomposition of pineapple waste was accelerated by earthworm activity, since the decay coefficients followed the order Fiber VC> Peel VC ≥ Fiber C > Peel C. The slower decomposition rate of pineapple peels can be attributed to their larger particle size and higher lignin content, compared to the pineapple fibers. The local earthworms from Accra consumed pineapple waste and also mixed it into the vermibeds. We observed earthworms depositing casts on pineapple waste in such large quantities that the waste was gradually enveloped, which is consistent with the behavior of *E. eugeniae* (Borges et al., 2003; Dominguez, 2004). Wastes in the vermidigesters were processed into a homogenous mass, but in the earthworm-free controls, pineapple waste remained in distinct clumps on the soil surface. A similar observation was reported by Atiyeh et al. (2000) in vermidigesters with *E. andrei* decomposing a cow manure substrate.

Chemical composition of vermicompost

Initially, the fresh pineapple waste was moderately acidic (pH = 4.4), but after vermicomposting or decomposition in earthworm-free soil, the pH ranged from 7.2 to 9.2 (Table 7). In other vermicomposting studies, the pH of the substrate has gone from alkaline to acidic (Mitchell, 1997; Ndegwa et al., 2000; Garg et al., 2006), although the pH increased from acidic to neutral during the vermicomposting of winery by-products (Nogales et al., 2005). Ndegwa et al. (2000) suggested that the pH of the vermicomposting system is substrate dependent and changes during the bioconversion of organic matter. Since the change in pH was similar in vermidigesters as the earthworm-free control (Table 7), it suggests that earthworms did not affect the pH of the vermicompost. This is consistent with data from Dominguez (2004), who suggested that earthworms do not affect the pH of organic substrates, although they do exert physiological control (secreting intestinal Ca, excreting NH_4-N) to maintain neutral pH in their digestive tract.

Earthworms avoid substrates with a pH less than 4.5 and prolonged exposure to such acidic conditions can be lethal (Edwards and Bohlen, 1996). Predictably, the acidity of the pineapple feed was problematic for the earthworms and we observed that some individuals perished a day or two after feeding. Colonization of the pineapple waste usually proceeded on the third day. Acidic materials can be treated with limestone prior to vermicomposting to avoid this problem (Dominguez, 2004). Alternatively, pre-composting acidic fruit wastes for just two week has also been shown to increase the pH to near neutral (pH = 6 to 7) (van Herdeen et al., 2002) and could be cheaper than liming. The total N content of pineapple waste declined by as much as 53% during vermicomposting (Table 7). This is in stark contrast with other vermicomposting studies where the N concentration remained stable or increased (Elvira et al., 1998; Atiyeh et al., 2000; Garg and Kaushik, 2005; Nogales et al., 2005), perhaps because of an adequate N supply from mineralization (Atiyeh et al., 2000) and the lowering of pH (Garg and Kaushik, 2005) enhanced by earthworm action. A decrease in pH during vermicomposting is considered to be favorable for N retention, since NH_3 volatilization is more probable when the substrate has an alkaline pH (Hartenstein and Hartenstein, 1981; Garg and Kaushik, 2005). The increase in pH observed during pineapple waste decomposition could have led to NH_3 volatilisation. In addition, nitrification of the available ammonia and the subsequent frequent watering of the vermidigesters could stimulate leaching of NO_3-N or gaseous N loss via denitrification.

The average losses in total organic C (78%) during vermicomposting (Table 7) are consistent with the 19 to 67% loss of organic C from substrates during vermicomposting (Elvira et al., 1998; Kaushik and Garg, 2004; Kaviraj and Sharma, 2003; Garg and Kaushik, 2005; Nogales et al., 2005; Garg et al., 2006). The decline in organic C during vermicomposting occurs via respiration and leaching of the water soluble C fractions. Fresh pineapple wastes had a C/N ratio of about 21, but vermicompost had a C:N ratio less than 12, the limit accepted for stable composts (Bernal et al., 1998). Similar reductions in C:N ratios of organic residues during vermicomposting have been reported in the literature (Elvira et al., 1998; Atiyeh et al., 2000; Kaushik and Garg, 2004).

There was a 55.6% loss in extractable K during pineapple waste decomposition in vermidigesters and earthworm-free control (Table 7). The loss of K from the waste was probably another consequence of frequent watering and the subsequent leaching of this soluble element. Similar trends have been observed in some vermicomposting studies (Benitez et al., 1996; Elvira et al., 1998; Nogales et al., 2005). Benitez et al. (1996) reported high K concentrations in vermicompost leachates and suggested that they be used as liquid K fertilizer. In contrast, other authors reported an increase in extractable K during vermicomposting, probably because they did not water excessively (Tripathi and Bhardwaj, 2004; Kaushik and Garg, 2004; Garg et al., 2006).

The total P and available P concentrations were greater in vermicompost than decomposed pineapple waste and fresh pineapple waste (Table 7). Other researchers have reported an increase in total P and available P during vermicomposting (Elvira et al., 1998; Kaushik and Garg, 2004; Tripathi and Bhardwaj, 2004; Nogales et al., 2005; Garg and Kaushik, 2005; Garg et al., 2006). This may be attributed to P mineralization and mobilization from bacterial and faecal phosphatase activity in earthworm casts (Garg et al., 2006), direct action of phosphatase and other enzymes in the earthworm digestive tract and indirect stimulation of the mycoflora in the vermibed (Mansell et al., 1981; Satchell and Martein, 1984; Garg et al., 2006). Since P is not volatile and tends to be sparingly soluble, it tends to become concentrated as the mass of waste decreases through earthworm- and microbial-mediated decomposition. .

The total N and K content in vermicompost produced from this study were lower than values reported for animal manures in Ghana and nearby countries, but vermicompost had a greater total P content than most animal manures (Table 8). The organic carbon content (32 %) of cattle manure from Togo (Bationo and Mokwunye, 1991) was also much greater than in the vermicompost generated during this study. Pineapple waste is not a nutrient rich substrate, since it has a lower total N content than most animal manures (Table 8), and the N and K levels declined during the vermicomposting process as the pH became more alkaline (possibly contributing to NH_3 volatilization) and soluble forms of N and K were leached. We propose that controlling the pH and watering regime during vermicomposting would conserve more N and K in the vermicompost, but this remains to be confirmed.

E. coli and Aspergillus loads

Fresh pineapple waste contained appreciable *E. coli* and *Aspergillus* loads, but there was a 31-70% reduction in *E. coli* loads and a 78-88% reduction in *Aspergillus* loads during vermicomposting (Table 7). Similarly, the *E. coli* declined by 75% in the earthworm-free control after 5 months of decomposition, but the *Aspergillus* population only declined by 16% (Table 7). This suggests that the reduction of *E. coli* was the result of antagonistic interactions with soil foodweb organisms, but not earthworms. Williams et al. (2006) concluded that both the epigeic *Dendrobaena veneta* and anecic *Lumbricus* *terestris* sustained *E. coli* O157:H7 populations in soils and vermicomposts, indicating that they have little ability to reduce pathogen loads. We suggest that bacterial and fungal grazers like protozoa and nematodes were responsible for the reduction in *E. coli* and *Aspergillus*, and that they were less effective in vermidigesters than in the earthworm-free control, possibly because they were consumed by earthworms (Brown and Doube, 2004) or because earthworms modified the habitat in a way that limited predator-prey interactions. These possibilities merit further investigation. There was less *Aspergillus* in the vermidigesters than the earthworm-free control, suggesting it was consumed by the earthworms. Alauzet et al. (2001) noted that the epigeic earthworm *E. andrei* preferentially grazed on fungi from the *Aspergillus* family. The low pathogen load in vermicompost, compared to the fresh pineapple waste, indicates that it is a safer material to handle, store and transport, although appropriate sanitation practices (i.e., hand-washing after handling) are recommended.

Vermicompost phytotoxicity

There was significantly ($P<0.05$) more germination when *Z. mays* seeds were exposed to vermicompost than the decomposed pineapple waste (Table 7). Many authors (Zucconi et al., 1981; Jimenez and Garcia; 1989; Mathur et al. 1993; Contreras-Ramos et al., 2004) state that composted or vermicomposted residues are toxic and or immature when the germination index falls below 50%. In this study, germination indices ranged from 88.9 to 106%, indicating that vermicompost and decomposed pineapple waste samples had reached maturity and were non-toxic. This complements conclusions drawn from the measured C:N ratio and pH, which indicate a desirable degree of stability in our compost. Here we must note the difference between compost stability and maturity.

“Compost stability” refers to the degree of organic matter decomposition and “compost maturity” to the presence of phytotoxic substances (Wu et al., 2000). Both stability and maturity are important parameters; unstable composts can compete with plant roots for oxygen and phytotoxic composts are generally toxic to plants. In this context the seed germination test is indicative of compost maturity whereas other parameters, such as the pH and C:N ratios, represent compost stability. A healthy vermicompost requires both stability and maturity. Although our results may not be directly comparable with other studies, since we used *Z. mays* rather than cress (*Lepidium sativum*) as the indicator plant, we found that vermicompost produced from pineapple waste had decomposed sufficiently after 5 months for phytotoxic substances to be degraded.

Conclusion

The local earthworms in Accra, Ghana were *E. eugeniae*. They were capable of vermicomposting pineapple waste, despite its acidity, and produced a homogenous humus-like material containing as much as 0.4% total N, 0.4% total P and 0.9% total K after 5 months. The nutrient content of the vermicompost was lower than animal manures found in the region, but this was due partially to the nutrient-poor organic substrate used and nutrient losses (volatilization, leaching) during vermicomposting. Mixing pineapple waste with other organic substrates, such as food processing residues, palm fiber, cocoa, and mineral supplements like rock phosphate, could boost the nutrient value of the vermicompost. In addition, pre-composting pineapple waste prior to vermicomposting is expected to increase the pH of the organic substrate and favor earthworm colonization and processing of the waste. Further research is required to investigate cost effective strategies for implementing these improvements. The reduction in *E. coli* load during vermicomposting was probably due to the activities of antagonistic soil foodweb organisms, not earthworms. However, local earthworms were effective at reducing the *Aspergillus* loads in pineapple waste significantly, compared to decomposition in earthworm-free boxes. Individuals who handle and apply vermicompost should be trained to follow appropriate safety and sanitation practices to protect their personal and public health.

Tables and Figures

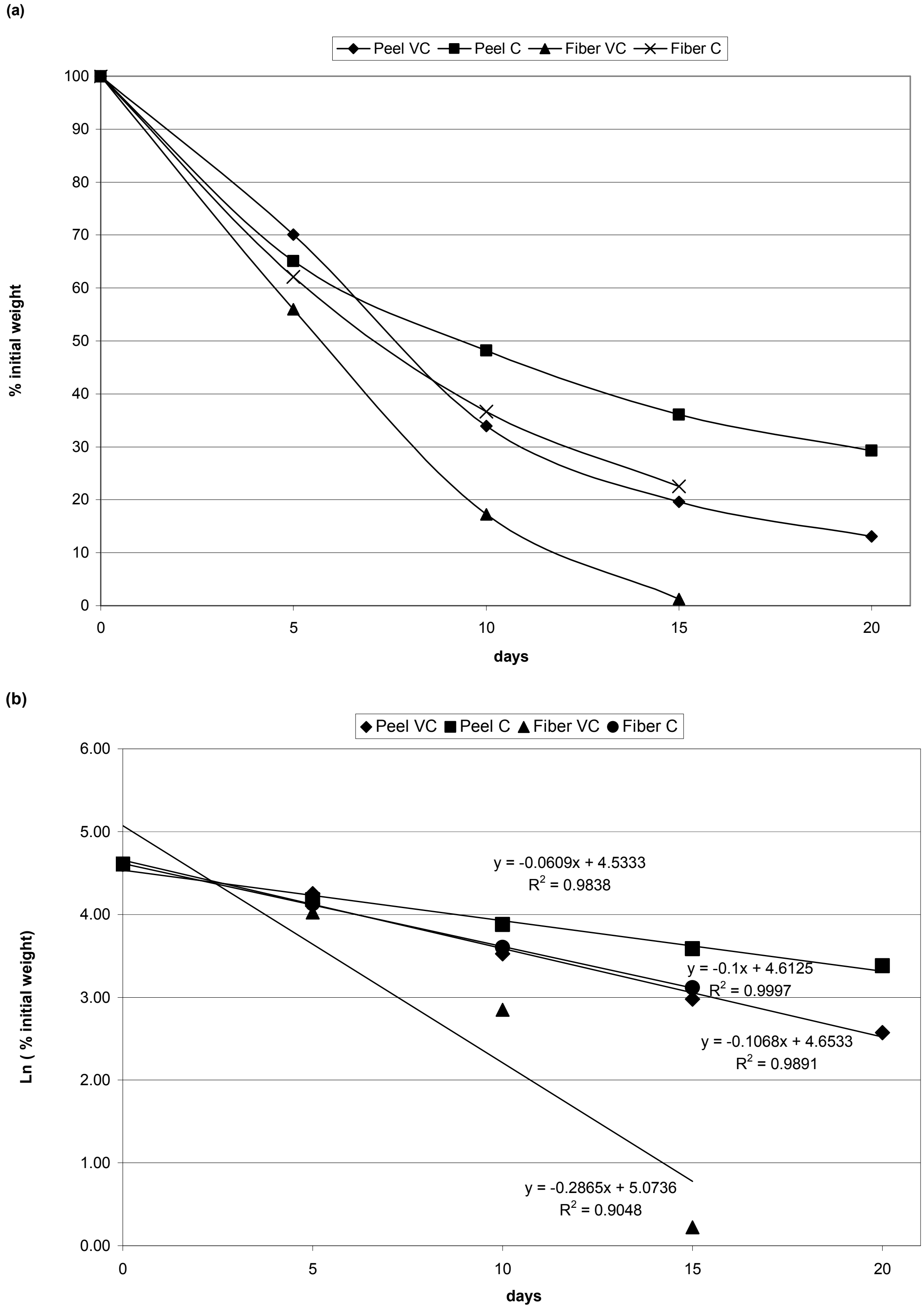

Figure 1: Rate of mass loss from pineapple residues
Rates expressed as (a) the % initial weight of pineapple peels and fibers and (b) the natural log of the % initial weight of pineapple peels and fibers, over a period of 20 days. VC = vermidigesters, C = earthworm free controls.
Values expressed on wet basis with 80% moisture content.

Table 6: Earthworm collection sites.

Location	GPS Coordinates	Description
Avenor	5º 34.8′ N 0 º 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.
Aladzo	5º 35.8′ N 0 º 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.
Afiaman / Santana	5º 36.6′ N 0 º 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
Oblogo	5º 33.6′ N 0 º 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.

Table 7: Chemical properties, microbial pathogen loads and germination of Zea mays seeds in fresh pineapple waste (PW), vermicompost samples (V1, V2, V3) and decomposed pineapple waste from earthworm-free control (C).

	PW	V1	V2	V3	C	V vs. PW[c]	V vs. C[c]
pH	4.4	7.2	9.2	7.9	8.7	P<0.001	NS[d]
Total Nitrogen (%)[a]	0.78	0.29	0.43	0.38	0.21	P<0.001	P=0.003
Total Organic Carbon (%)[a]	16.1	3.03	4.18	3.62	1.98	P<0.001	P<0.001
Total Potassium (%)[a]	1.43	0.46	0.92	0.52	0.31	P<0.001	P=0.034
Total Phosphorous (%)[a]	0.20	0.38	0.38	0.31	0.12	P=0.001	P<0.001
Bray-1 Phosphorous (ppm)[a]	191	344	349	304	50.6	P<0.001	P<0.001
E. Coli ($\times 10^4$ CFU/g)[a]	13.7	4.58	9.45	4.15	3.83	P=0.014	NS
Total *Aspergillus* ($\times 10^4$ CFU/g)[a]	24.4	3.00	4.00	5.30	20.4	P=0.003	P=0.006
Percent Germination (%)	ND[b]	96.8	102	106	88.9	ND	P=0.046

Values are the mean of 3 analytical replicates, except in the germination experiment (n=4)
[a] Values expressed on a dry weight basis.
[b] ND = not determined.
[c] Probabilities of significant differences between vermicompost (V), pineapple waste (PW) and control (C).
[d] NS = not significant.

Table 8: Nutrient composition of animal manures from West African countries.

Type of Manure (Origin)	Nitrogen (%)	Phosphorous (%)	Potassium (%)	Source
Poultry manure (Ghana)	2.20	0.79	0.91	FAO, 2005
Sheep manure (Ghana)	1.55	0.07	0.09	FAO, 2005
Cattle manure (Ghana)	1.20	0.14	0.12	FAO, 2005
Farmyard manure (Burkina Faso)	1.40	0.26	1.78	Harris, 2004
Goat manure (unknown)	2.80	0.60	2.40	Harris, 2004
Small ruminant (Burkina Faso)	2.20	0.12	0.73	Harris, 2004
Donkey manure (Nigeria)	0.98	0.15	0.75	Harris, 2004
Dry sheep manure (Nigeria)	0.48	0.14	0.28	Harris, 2004

CONNECTING PARAGRAPH

In the previous chapter we observed the local earthworm, *E. eugeniae*, processing pineapple wastes into a vermicompost product. Although nutrient quality was lower than manures in the region, the vermicompost did not exhibit any phytotoxicity to *Zea mays* seeds. In the following chapter, farmers' perceptions on introducing the vermicompost process and product on Accra's urban farms will be assessed. In addition, farmers' soil fertility management strategies, pesticide use habits and criteria for evaluating fertilizer performance will be evaluated.

CHAPTER 4: VERMICOMPOST AS A FERTILIZER FOR URBAN AND PERI-URBAN FARMS: PERCEPTIONS FROM ACCRA, GHANA

Abstract

Vermicompost is considered a valuable organic fertilizer in many tropical regions, but has rarely been used in Sub-Saharan Africa. A study was conducted in Accra, Ghana, to assess Urban and Peri-urban (UP) farmers' fertilizer and pesticide use, knowledge of earthworms, fertilizer performance criteria and finally to evaluate farmers' attitudes towards the introduction of vermicompost as a fertilizer. Twenty six farmers involved in irrigated vegetable farming and three subsistence farmers were interviewed. Farmers were aware of the benefits to soil fertility from earthworm activity and associated the presence of earthworm castings with healthy soils. Some stated that frequent insecticide applications had reduced earthworm populations on their farms. Farmers used the greenness of leaves, crop emergence, stand and yield as indicators of fertilizer performance. Farmers resisted making statements about vermicompost before they tested it, but advised us to test its fertilizer value in the dry season to prevent experimental bias in crop responses from rainfall. Farmers involved in irrigated vegetable farming had insufficient space and time for on-farm vermicomposting and would prefer to purchase this fertilizer. Subsistence farmers lacked a reliable access to water necessary for on-farm vermicomposting. In summary, farmers were interested in the technology and were willing to adopt it, provided the vermicompost improved crop performance and was affordable and available.

Introduction

The need for organic fertilizers in Sub-Saharan Africa is urgent, as soils in the region are generally highly weathered and have low soil fertility (Stangel, 1993). Total annual nutrient loss across arable lands in sub-Saharan Africa was forecast to reach 26 kg N ha^{-1}, 7 kg P_2O_5 ha^{-1} and 33 kg K_2O ha^{-1} by 2000, with the most severe nutrient mining projected to occur in densely populated areas (Stoorvogel et al, 1993). Breman (1990) concluded that the application of mineral and organic fertilizers was the only way to address the problem. Farmers practicing subsistence agriculture are more likely to exhaust inexpensive internal inputs (organic fertilizers produced locally) before opting to purchase expensive external ones (mineral fertilizers, organic fertilizers transported from outside the local region). Vermicompost, an organic fertilizer created by earthworms, could be a good internal input for poor urban and peri-urban (UP) farmers in Sub-Saharan Africa. Using vermicompost is a potential "win-win" situation, since earthworms can convert large quantities of organic wastes from urban dump sites into inexpensive, nutrient-rich fertilizer at a low cost to local UP farmers.

African farmers have knowledge on how to manage soil fertility with mulching, cover crops and green-manuring. There is growing evidence that some farmers can accurately assess the quality of organic fertilizers and use this knowledge strategically (Lekasi et al., 2003). For example, farmers in the Kano Close-Settled zone, Nigeria, considered bird (chicken, duck and turkey) manures to be the best quality based on nutrient value and small ruminant manures to have the most consistent quality (Harris and Yusuf, 2001). Nigerian farmers also reported that rainy season manures were best suited to millet and dry season manures for peppers. Another study in the Kiambu District, Kenya, observed farmers ranking manures on the basis of crop response

(Mwarasomba et al., 1995). It is therefore logical to assume that for vermicompost to be adopted by farmers in Accra, it will have to fit into the local farming system and farmers' livelihood strategies (Saïdou et al., 2004). Farming practices such as pesticide use, organic and inorganic fertilizer use, and farmers' knowledge of earthworms will affect the rate of adoption. Vermicompost should perform as well as other organic fertilizers, based on farmers' fertilizer performance criteria, and it must be introduced in a manner acceptable to farmers.

The objectives of the present study were to: 1) report on the pesticide and fertilizer use by UP farmers; 2) determine farmer's knowledge of earthworms; 3) assess farmers' fertilizer performance criteria, and; 4) evaluate farmers' attitudes towards the introduction of vermicompost as a fertilizer.

Materials and Methods

Study Area

The study was conducted in Accra, the capital city of Ghana, between the months of February and May 2006. 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.

The agricultural practices conducted in and around the Greater Accra area of Ghana, are typical of urban agricultural activity. There are seven urban agricultural types;

backyard gardening, fish farming, livestock farming, irrigated vegetable gardening, small ruminants and poultry, seasonal crop farming and miscellaneous, which entails the raising of export crops, micro livestock, snail farming, and bee keeping (Danso et al., 2004). Irrigated vegetable gardening is the dominant practice (Armar-Klemensu, 2000), occurring on up to seven open spaces across the city, (Obuobie et al., 2006). In this study, open spaces are defined as undeveloped spaces some distance from human dwellings, beside drains, stream banks, road sides, abandoned waste dumps, around public buildings and on private lands that have been left idle (Obuobie et al., 2003). Some of these sites have been cultivated continuously for the last 50 years (Danso et al., 2004). In Accra, irrigated vegetable farming occurs on approximately 47 ha in the wet season and 100 ha in the dry season (Obuobie et al., 2006).

Qualitative Data Collection

Qualitative data can help researchers to understand the beliefs and attitudes held by farmers towards different technologies (Enyong et al., 1999). In this study, the qualitative data was obtained through open ended interviews with farmers. As in Desbiez et al. (2004), conversations were guided towards selected topics while remaining flexible enough to contain any other topics of interest to the respondents. The objectivity of the responses from interviews was preserved by triangulating responses between stakeholders, while preserving confidentiality, as recommended by Berardi and Donnelly (1999). Data collected from interviews was augmented with general observations by the researcher during field visits and from the literature. Twenty nine urban farmers were engaged during these interviews and important points recorded in a notebook. Urban farmers, in groups of two to three individuals, were asked a series of open-ended questions on their farming practices (pesticide and fertilizer use), about earthworms and earthworm habitats, how they evaluate fertilizers and other general issues concerning fertilizer performance (Table 9). All the farmers interviewed were approached by the researcher as they worked on their beds.

Results and Discussions

General Description

The farmers interviewed had a mean age of 43 years old and ranged in age from 24 to 62 years old (Fig. 2). Most farmers were illiterate, although two had completed primary school. Only one of the farmers interviewed was a woman, confirming the gender imbalance in commercial irrigated vegetable farming in Accra reported by Obosu-Mensah (1999), Obuobie et al. (2004) and Danso et al. (2004). We approached other women for interviews, but they would ask the men to answer queries while they tended to their beds. Although age, educational backgrounds and sex typically impact farmers' perceptions, there were no discernable correlations in this study, probably because of the widespread illiteracy and gender imbalance in the interviewees. Group interactions with farmers also made it difficult to separate the responses from elderly and younger respondents in the same group. Twenty six of the farmers cultivated beds located in a chain of irrigated vegetable gardens, on vacant plots, west of the Kotoka International Airport. As reported by Obuobie et al. (2003), farmed lands were always adjacent to major drains where water was available for irrigation. Here, farmers engaged in intensive year round irrigated vegetable farming, cultivating spring onions, lettuce, cabbage, carrots, beet root, green peppers, cauliflower, tomatoes and cucumbers. The remaining three farmers were squatting on University of Ghana property to the east side of the

Campus. These farmers were involved in rain-fed subsistence farming with little or no external inputs. They grew cassava, tomatoes, okro (*Abelmoschus esculentus*), garden eggs (*Solanum aethiopicum*), pepper and maize. None of the twenty nine farmers had legal tenure to the land they were cultivating. We assumed they were in some informal agreement with landowners (private and public), who in turn benefited from farmers keeping the land clear of weeds and preventing encroachment by land developers and other squatters (Obuobie et al., 2003; Obuobie et al., 2006).

The frequency of responses are presented in the ensuing paragraphs and displayed in brackets.

Fertilizer and Pesticide use

Farmers (23) appreciated the value of organic fertilizers, especially the chicken manure-sawdust mix (CM) that could be purchased at 10 to 30 cents (US $) per 30 – 35 kg bag (Danso et al., 2006). Organic fertilizers, including CM, cattle dung, black soil and even human excreta, were widely used by UP farmers in Accra, Kumasi and Tamale (Danso et al., 2006), but farmers preferred CM because of its low price, effectiveness (high content of available nutrients for plant growth) and long term effects on soil. Some farmers (11) stated that they applied CM to reclaim saline soils for cultivation, as inorganic fertilizers were ineffective on such soils. A few farmers (4) also mentioned using CM to increase soil water holding capacity. One farmer stressed that the indiscriminate application of inorganic fertilizers increased post-harvest spoilage. All vegetable farmers also applied inorganic fertilizers on their farms. Popular inorganic fertilizers included NPK (15-15-15 and 20-20-20), urea and monoammonium phosphate (MAP). When CM was applied it was usually in combination with inorganic fertilizers, or on problematic soils. Danso et al. (2006) also observed farmers in certain areas of Accra and Tamale combining CM with inorganic fertilizers and state that the practice was necessary to compensate for a scarcity of organic fertilizers in those areas. Some farmers (6) in our study did not use CM at all, because it was not easily available and they had little experience using it.

The three subsistence farmers used cow manure (priced at 30 cents per 40 - 50 kg) from nearby kraals on their fields. This organic fertilizer was sold by cattle herders also squatting on University of Ghana property. One of the farmers, through an informal arrangement with septic truck drivers, used wastewater from the University of Ghana campus septic tanks to increase soil fertility. Applications were maintained at two tank loads per month to avoid toxic shock to crops.

The pesticides Mektin™ and Karate™, with active ingredients Abamectin and Lambda Cyhalothrin respectively, were popular among farmers with irrigated vegetable farms. This is substantiated by a recent study where high levels of Lambda Cyhalothrin and other pesticides were found on lettuce, cabbage and spring onions from Accra's irrigated vegetable gardens (Amoah et al., 2006). There are reports of a significant reduction in *Eisenia foetida* cocoon production and cocoon hatchability after exposure to a sublethal dose of 0.25 mg Abamectin kg^{-1} soil (Diao et al., 2007; Jensen et al., 2007). Research on the effects of Lambda Cyhalothrin on earthworm cocoon production is scarce. However, there is some evidence that sublethal doses of this insecticide can significantly reduce the cocoon hatchability of the spiders *Erigone atra* and *Oedothorax apicatus* (Dinter and Poehling, 1994). Farmers' dependence on pesticides must not be understated. Some farmers (11) stressed there was no point in introducing organic fertilizers without the corresponding organic pesticides to deal with the diamondback moth larvae (*Plutella xylostella* Linnaeus) larvae and cabbage leafminer (*Liriomyza brassicae* Riley) problems. A few farmers claimed Neem seed oil reduced the quality of their produce by making it bitter and was more expensive than conventional pesticides.

Farmers' knowledge of earthworms

All the farmers (29) were aware that earthworm activity had positive impacts on soil quality. Nearly half of the farmers surveyed (12) went further and associated the presence of earthworm castings on fields with good soil fertility. Similar positives attitudes towards earthworms were observed in farmers from Kenya (Murage et al., 2000) and India (Singh and Singh, 2005). Some farmers in our study (14) had been told by fellow farmers and extension workers that earthworms were an indication of healthy soils. All farmers suggested cool moist locations, especially bath houses and stream banks, as potential earthworm habitats. This observed correlation between earthworm abundance and moisture content in local habitats was confirmed in Chapter 3. Farmers with irrigated vegetable gardens rarely saw earthworms in their beds, even during tilling. Farmers' perception was that earthworm populations were reduced by the frequent spraying of insecticides to control the diamondback moth larvae (*P. xylostella* L.) and cabbage leafminer (*L. brassicae* R.). As mentioned above, the insecticides applied to control these pests may interfere with cocoon production and hatchability, so it seems reasonable that repeated spraying for many years will eventually eliminate earthworm populations. Subsistence farmers, on the other hand, did not use pesticides and found earthworms on their farms while tilling during the rainy seasons.

Farmers' criteria for evaluating fertilizer performance

All of the 29 farmers interviewed mentioned crop performance indicators as criteria for evaluating fertilizer performance. The frequencies of the indicators were in the following order; greenness of leaves and stalks (23), speed of crop emergence (20), leaf formation (7), crop yield (4) and stand (3). Studies in Nepal (Desbiez et al., 2004) and Kenya (Murage et al., 2000) also reported that farmers used crop appearance as an indicator of soil fertility. In addition, all the indicators mentioned by the interviewees are related to standard measurements of crop performance and nutrient status in modern agriculture. For example, the greenness of leaves and stalks is related to the chlorophyll content of plant tissues. Deficiencies of nitrogen, magnesium, iron and sulfur may reduce leaf chlorophyll formation and lead to low chlorophyll densities, so greenness is a direct indicator of plant nutrition and the nutrient use efficiency from fertilizers (Shaahan et al., 1999). The leaf nitrogen content and fertilizer nitrogen requirements of crops can be estimated using a chlorophyll meter such as the Minolta SPAD-502 (Spectrum Technologies Inc., Plainfield, IL, USA), or by making visual observations, as is done by poor UP farmers in Ghana.

Acceptance of vermicompost as an organic fertilizer

Farmers were curious about the vermicompost product and were willing to test it once we provided them with samples. They resisted making statements, predictions or commitments about adoption prior to testing. This confirms previous conclusions in the literature that barriers to the use of composted urban organic waste are more technical than cultural (Warburton and Sarfo-Mensah, 1998; Danso et al., 2006). A few farmers (5) advised we test the vermicompost in the dry season because trials during the wet season would be skewed by the effects of rainfall on crop performance. Others (11) stated there was little space on irrigated vegetable farms to conduct vermicomposting or any other activities requiring space/land. In addition, irrigating crops, spraying with insecticides, tilling land, applying fertilizer and conducting other farm activities did not leave much time for farmers to manage the vermidigesters. The three subsistence farmers did show an interest in managing their own vermidigesters, but lacked the time and resources, especially water and organic wastes, to manage it.

Conclusions

Farmers in Accra are interested in testing vermicompost, but will only pay for the product on condition it improves crop performance at a reasonable price. This can be attributed to their preference for organic fertilizers, especially chicken manure. In addition, farmers associate earthworms and their castings with healthy and fertile soils. However, farming practices at the irrigated vegetable gardens, pesticide use in particular, may negate any additional benefits of vermicompost application on soil biodiversity. Farmers' fertilizer performance criteria revealed a series of standard crop performance indicators also used in modern science. The most popular indicator, greenness of leaves and stalks, hints at the importance of nitrogen fertilizers. Finally, farmers advised testing vermicompost in the dry season to avoid biases introduced by crop responses to rainfall. Farmers from the irrigated vegetable farms admitted time and space constraints would hamper on-site vermicomposting. Subsistence farmers, on the other hand, were interested in on-site vermicomposting, but did not have access to wastes and water. These time constraints and lack of resources, in combination with the tremendous demand for organic fertilizers in Accra, estimated at 18,500 t per annum (Danso et al., 2006) for the

1000 ha of arable land (Obuobie et al., 2006), make the case for small scale commercial vermicomposting stronger.

Tables and Figures

Table 9: Open-ended questions asked of urban farmers in Accra during this study and the justification for the queries.

Question	Justification
What crops are grown and for what purpose are they being grown?	To assess purpose of farming activity, especially economic motivation
What are the differences between organic and inorganic fertilizers?	To assess farmers knowledge on soil fertility management
How is fertilizer performance evaluated?	To assess farmers criteria for evaluating fertilizer performance
Are earthworms beneficial or detrimental to soil quality and fertility?	To assess farmers perceptions on earthworms and their benefits to soil fertility
Are earthworms present on farms?	To assess farmers perceptions on earthworm abundance on farms
Where are earthworms found?	To assess farmers knowledge on local earthworm habitats
How should vermicompost be evaluated?	To assess farmers strategies for evaluating vermicompost performance
Is there any interest in applying earthworm castings, from earthworms fed organic wastes, on farm beds?	To assess farmers perceptions on adopting vermicompost

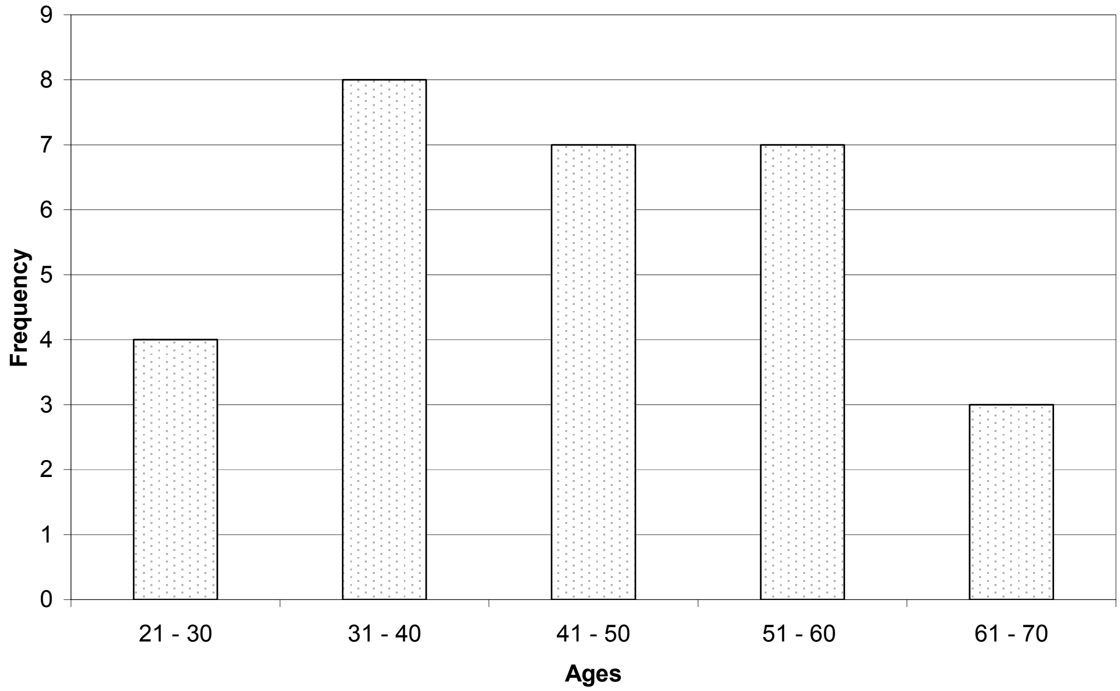

Figure 2: Age distribution of the 29 urban farmers interviewed

GENERAL CONCLUSIONS AND FUTURE DIRECTIONS

The case for vermicomposting in Accra, Ghana, although compelling, has challenges and barriers that require further assessment. That *E. eugeniae* is relatively abundant, despite the dry climate in Accra, and the widespread availability of agro-processing wastes implies the technology is sustainable. In addition, farmers' appreciation of organic soil fertilizers, their associating earthworm castings with soil fertility and the apparent lack of organic fertilizers in Accra also suggest there is a significant market for the vermicompost. However, the current blue water supply crisis and pathogen loads of local streams could present some constraints during vermicomposting operations. The risks of pathogen contamination from greywater use can nevertheless be remediated by curing the vermicompost after harvesting. The low N content of the vermicompost produced from pineapple wastes means that vermicompost is not as concentrated a nutrient source as other organic fertilizers. Farmers would have to purchase and apply relatively more vermicompost than manure, to get a growth response and observe the intense green foliage that indicates sufficient foliar N levels. Fortunately, the nutrient content of the vermicompost produced from pineapple wastes can be improved by augmenting the feedstock with other organic wastes, although the optimal feedstock combination to produce a high-quality vermicompost remains to be confirmed. The economic feasibility of vermicomposting within a local framework must be investigated further, in order to establish concrete sustainable strategies to assist farmers, researchers, government officials and entrepreneurs.

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APPENDIX A: ETHICS APPROVAL CERTIFICATE

MCGILL UNIVERSITY
FACULTY OF AGRICULTURAL AND ENVIRONMENTAL SCIENCES

CERTIFICATE OF ETHICAL ACCEPTABILITY FOR
RESEARCH INVOLVING HUMANS

Approval Period: DEC. 2, 2005 - DEC. 1, 2006 REB #: 853-1205

The Faculty of Agricultural and Environmental Sciences Ethics Review Committee consists of 4 members nominated by the Faculty of Agricultural and Environmental Sciences Nominating Committee and elected by Faculty, an appointed member from the community and an individual versed in ethical issues.

The undersigned considered the application for certification of the ethical acceptability of the project entitled:

Ecological Approaches to Vermicomposting for Peri-Urban Market Gardens and Household Farms in Accra, Ghana: Evaluating Indigenous Knowledge Frameworks as a Tool (Ghana)

as proposed by:

Applicant's Name	Nana-Osei K. Mainoo	Supervisor's Name	Dr. Suzelle Barrington
Applicant's Signature	[signature]	Supervisor's Signature	[signature]
		Supervisor's Name	Dr. Joann Whalen
		Supervisor's Signature	Joann Whalen
Degree/Program/Course	MSc Environmental Engineering	Granting Agency (ies)	International Development Research Council (IDRC)

Grant Title(s): AGROPOLIS – International Graduate Research Awards in Urban Agriculture

The application is considered to be:

A Full Review ______ An Expedited Review X

A Departmental Level Review ______________________
Signature of Chair / Designate

return duly signed form to:
Chair, FAES - Research Ethics Board
c/o Macdonald Campus Research Office
Raymond Building, Roo R3-032

[signature] December 2, 2005
Signature / date
Stan Kubow
Chair, FAES - Research Ethics Board

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