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Action A09

Co-composting of Faecal Sludge and Solid Waste for Urban and Peri-urban Agriculture in Kumasi, Ghana

Final Report
February 2003

IWMI International Water Management Institute

KMA

KNUST

EAWAG
SANDEC
Water & Sanitation in Developing Countries

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FOREWARD

We are grateful to the French Foreign Ministry for funding this project in the framework of its programme on Sustainable Waste Management and Urban Sanitation

We appreciate the participation of the co-composting team of SANDEC as discussion partners in the project; the commitment of KMA staff in providing the local logistical support; the graduate students – Harold Esseku, Seth Agbottah, Omanhene Boateng, Daniel Nartey, Nikita Eriksen-Hamel, George Danso who were involved in field data collection as well as their academic supervisors. Thanks also to Sharon Quarshie, the pilot plant manager as well as John and Asare for the daily operations at the plant.

The report and output derived from the joint effort of all project team members at IWMI, SANDEC, KNUST and KMA. Thank you all.

Olufunke Cofie

Project Leader

February,2003

SUMMARY

The pilot project on *'co-composting of faecal sludge and municipal solid waste for urban and peri-urban agriculture'* was conducted in Kumasi, which is the second largest city in Ghana. The city has 1 million inhabitants who daily generate 860 tonnes of solid waste (SW) and 500m^3 of faecal sludge (FS) collected from on-site sanitation systems. In Kumasi, 90% of the population rely on latrines and septic tanks, while only 8% rely on sewerage. Faecal sludge were disposed of indiscriminately mainly into surface waters until a few years ago, when a temporary pond system was taken into operation. The system became overloaded, meanwhile with a concomitant low treatment performance. Hence there is the danger of environmental pollution. In Kumasi, intensive irrigated cultivation of vegetables in open land spaces is practiced at different sites on approximately 120 hectares of land. Backyard gardening is also a common phenomenon as well as peri-urban cultivation of maize and plantain. About 90% of fresh leafy vegetables (lettuce, spring onions,) consumed in Kumasi are from production within the city. Urban agriculture thus contributes considerably to food security.

Based on this background, the pilot project was developed on the premise that:

Co-composting municipal organic solid waste with faecal sludge could constitute in the long-term:

- A viable and meaningful option in waste management and,
- A valuable alternative nutrient source and soil conditioner for urban and peri-urban agriculture.

The specific objectives were to: gain scientific knowledge on the technical and operational aspects of co-composting; evaluate the socioeconomic aspect of co-composting by urban and peri-urban farmers as well as the impact of compost utilisation on crop and soil; and to enhance human capacity for urban waste management and related research with respect to co-composting. The expected output is to have at hand, decision support for the various stakeholders on the design and mode of operation of co-composting that matches the opportunities and constraints of Kumasi as an example of other African cities. Farmers would become aware of the usefulness of co-compost as an alternative source of nutrients.

The project was developed and implemented by the International Water Management Institute (IWMI) in collaboration with the Department of Water & Sanitation in Developing Countries (SANDEC) of the Swiss Federal Institute for Environmental Science and Technology (EAWAG), Kwame Nkrumah University of Science and Technology (KNUST), Kumasi and the Waste Management Department (WMD) of Kumasi Metropolitan Assembly (KMA).

The project started with a roundtable discussion among key stakeholders in July 2001 after the contractual agreement was signed by IWMI. To achieve our set objectives, a pilot co-composting plant was established and became operational in February 2002 at 15km from the city centre of Kumasi where

faecal sludge from septic tanks and unsewered public toilets together with organic solid waste were co-composted. Various issues ranging from production to utilization of compost were studied. The investigations focused on:

- the efficiency of faecal sludge dewatering in drying beds;
- suitable mixing ratios of solid waste and faecal sludge and their impact on the composting process and compost quality;
- inactivation of pathogens in the co-composting process;
- demand and willingness-to-pay for compost;
- economic analysis of composting
- utilisation of compost in urban agriculture

This report is based on field work carried out from Feb-Dec 2002. Results obtained from the pilot project so far indicate that the sludge drying beds constitute a good option for obtaining dewatered or dried biosolids. Factors such as heavy rainfall in the early stages of dewatering cycles, sludge depth, structure and grain size of filter layer, and sludge strength can affect dewatering and thereby lead to a prolonged drying process. The duration of composting faecal sludge and organic solid waste is between 10-12 weeks. The product is hygienic and therefore could be used in urban vegetable production without restriction. The nitrogen content is low (1%) based on the few trials monitored. This may not be unexpected as nitrogen losses are likely to be substantial due to long pre-composting retention of the FS in the drying beds and due to the composting process itself (duration, turning, high temperatures). Preliminary investigation carried out in the field shows that the compost may be used at an application rate of 40 t/ha for intensive irrigated vegetable production on sandy soils.

The study revealed that there is a demand for 11,000 t y^{-1} for compost in and around Kumasi by different groups of people. The amount they are willing to pay ranges from 0.1 - 3.0 US$ per 50 kg. If compost would have to be sold at a price, to cover the cost of its production, approximately 2,500 t y^{-1} would be marketable. However, the economic appraisal of the plant shows that it could be economically viable, though financially it might not be. The break-even analysis indicates that the ideal range of operation of a co-composting station of the type used in the pilot scheme is from 10-45 tons of compost per annum. The break-even weight is estimated at 45 tons per annum. This is the practical point at which direct costs and direct benefits are equal. The optimal level of operating the plant has therefore been estimated at 45 metric tons of compost per annum. This will require 225 m^3 of municipal solid waste and 430 m^3 of raw faecal sludge (or 135 m^3 of dewatered faecal sludge) to produce it. At 2002 constant prices, this volume of compost is expected to yield a net economic benefit of US$ 14,697. Therefore, some form of subsidies is required to enhance marketability.

Result and the database gathered to date are not sufficient to formulate a good decision support for planners and farmers. A longer period is required to tackle technical difficulties encountered and to develop a sustainable marketing strategy. Poultry manure is an easily available source of nutrients in

the urban area of Kumasi which can be obtained at no cost. This is one of the reasons why willingness-to-pay by urban farmers is low. Peri-urban vegetable and staple crop farmers showed more interest in the compost product due to their limited access to poultry manure. Added advantages of compost in improvement of soil quality) should be demonstrated. Farmers' response to planting trials using co-compost is of particular importance. All these constitute a process demanding considerable periods of field and action research. To be able to arrive at meaningful recommendations on the constraints, opportunities and impacts of recycling human and municipal organic waste back into agriculture through co-composting, a period of 3-4 years of investigations would be required. The pilot station has been monitored for less than one year but has shown potential for more impact if it is continued. The observation made by KMA on the pilot station is quoted below as expressed by the municipal sanitary engineer.

KMA's perspective on institutional arrangements for taking over buobai pilot co-composting project

The Kumasi Metropolitan Assembly very much appreciates the implementation of the Pilot Co-composting Project, which fits well into the Assembly's strategic plan for waste management in Kumasi city. The collaborative roles played by the various stakeholders especially the sponsors are worthy for commendation.

As the host and future operator of the station the KMA has over the period played its collaborative role in the areas of:

- Supervision of Composting Station construction;
- Collection and transportation of faecal sludge and organic solid waste to station;

and is expected to assume responsibility for:

- Management of the station after the study period; and
- Promotion/Marketing of compost.

In the view of KMA the following observations have been made:

1. The length of time for research activities has not been adequate particularly in respect of compost trials.

   Over the period, considerable amount of compost has been produced, however, authentic and reliable results from trials have yet to be obtained. To acquire results that can be confidently presented, defended and utilized. A longer time frame of not less than 2 years would be required. This will facilitate the trial of compost of varying composition with wider scope of crops varieties.

2. Lack of adequate information for effective marketing and promotion of compost.

   Effective marketing and promotion of compost requires adequate information based on results from compost trials if prospective compost users could be effectively sensitized.

The above two very important roles in the research activity have been the responsibility of IWMI, which has the requisite capacity to handle them.

In conclusion, there is no denying the fact that a number of questions need to be answered, and which answers will represent a marked proportion of the success of the project. Where as KMA would be prepared to take over and manage the facility beyond the piloting phase, we would appreciate if the funding could be extended by at least **Two Years** within which those gaps could be filled. KMA will continue to play its assigned roles to help ensure a completed project that all stakeholders could be proud of.

RÉSUMÉ

Le projet pilote sur le *'co-compostage des boues de vidange et des déchets solides municipaux pour l'agriculture urbaine et peri-urbaine'* a été réalisé à Kumasi, la deuxième plus grande ville du Ghana. Les habitants de cette ville (1 million) produisent quotidiennement 860 tonnes de déchets solides (DS) et 500 m^3 de boues de vidange (BV) collectées de systèmes d'assainissement individuels. A Kumasi, 90% de la population dépendent des latrines et des fosses septiques, alors que seulement 8% sont reliés à des égouts. Jusqu'il y a quelques années, les boues de vidange étaient en grande partie évacuées au hasard dans les eaux de surface, avant la mise en place d'un système de lagunage temporaire. Ce système temporaire est cependant toujours en opération. La surcharge du système a entraîné une baisse de la performance de traitement et pose par conséquent un risque de pollution environnementale. A Kumasi, la culture intensive de légumes irrigués sur des terrains vagues à différents endroits est pratiquée sur environ 120 hectares. Le jardinage pratiqué en arrière-cour est un phénomène commun aussi bien que la culture péri-urbaine de maïs et de plantain. Environ 90% des légumes feuillus frais (laitue, ciboule) consommés à Kumasi sont produits dans la ville. L'agriculture urbaine contribue ainsi considérablement à la sécurité alimentaire.

En tenant compte de ce contexte, le projet pilote a été développé en partant du principe que:

Le co-compostage de déchets solides organiques municipaux avec des boues de vidange pourrait présenter à long terme:

- une option viable et avantageuse de gestion des déchets et,
- une source de nutriments alternative ainsi qu'un amendement de sol précieux pour l'agriculture urbaine et peri-urbaine.

Les objectifs spécifiques étaient d'acquérir des connaissances scientifiques sur les aspects techniques et opérationnels du co-compostage; d'évaluer l'aspect socio-économique du co-compostage par les agriculteurs urbains et peri-urbains ainsi que l'impact de l'utilisation du compost sur les cultures et le sol; et de renforcer les capacités humaines dans le domaine de la gestion des déchets urbains et de la recherche sur le co-compostage. Ceci faciliterait la décision des différentes parties concernées quant à la conception et l'exploitation d'installations de co-compostage adaptées aux possibilités et contraintes de Kumasi en tant qu'exemple pour d'autres villes africaines. Les agriculteurs se rendraient compte de l'utilité du co-compost en tant que source alternative de nutriments.

Le projet a été développé et réalisé par «l'International Water Management Institute» (IWMI) (l'Institut international de gestion de l'eau) en collaboration avec le

département de l'Eau et de l'assainissement dans les pays en développement (SANDEC) de l'Institut fédéral suisse pour l'aménagement, l'épuration et la protection des eaux (EAWAG), l'Université Kwame Nkrumah de Science et Technologie (KNUST) à Kumasi et avec le Département de gestion des déchets (WMD) du Kumasi Metropolitan Assembly (KMA).

Le projet a débuté par une discussion réunissant les principaux acteurs à une Table ronde en juillet 2001 après que l'accord contractuel ait été signé par l'IWMI. Dans le but d'atteindre les objectifs fixés, une installation pilote de co-compostage a été établie et mise en service en février 2002 à 15 km du centre de la ville de Kumasi où des boues de vidange provenant de fosses septiques et de toilettes publiques non-reliées aux égouts ont été co-compostées avec des déchets solides organiques. Diverses questions ont été étudiées allant de la production à l'utilisation du compost. Les recherches se sont penchées notamment sur:

- l'efficacité de déshydratation des boues de vidange dans les lits de séchage;
- les rapports appropriés de mélange de déchets solides et de boues de vidange et leur impact sur le procédé de compostage et sur la qualité du compost;
- l'inactivation des agents pathogènes par le procédé de co-compostage;
- la demande et la volonté de payer pour le compost;
- l'analyse économique du compostage
- l'utilisation du compost en agriculture urbaine

Ce rapport reflète les résultats obtenus lors de travaux sur le terrain réalisés entre février et décembre 2002. Ils révèlent que les lits de séchage offrent un bon système de déshydratation des boues de vidange. Des facteurs tels qu'une précipitation intense au début des cycles de déshydratation, la profondeur de la couche des boues dans les lits, la structure et la granulométrie de la couche filtrante ainsi que le degré de stabilité des boues peuvent influencer le procédé de déshydratation et par conséquent le temps de séchage. De 10 à 20 semaines sont nécessaires pour composter des boues de vidange et des déchets solides organiques. Etant donné l'absence d'œufs d'helminthes viables, le produit ainsi obtenu est hygiénique et peut donc être utilisé sans restriction pour la production urbaine de légumes. Le nombre restreint d'essais contrôlés révèle une basse teneur en azote (1%). Ceci ne paraît pas surprenant étant donné que les pertes d'azote substantielles sont dues à la longue rétention des BV lors de la déshydratation dans les lits de séchage ainsi qu'au procédé de compostage lui-même (durée, retournement du compost, températures élevées). Une étude préliminaire sur le terrain révèle que le compost peut être utilisé à un taux d'application de 40 t/ha pour la production de légumes irrigués de manière intensive sur des sols sablonneux.

L'étude révèle que la demande de compost par différents groupes de personnes aux alentours et dans Kumasi s'élève à 11 000 t a^{-1}. Le prix qu'ils sont disposés à payer s'échelonne entre 0,1 et 3,0 US$ par 50 kg. La demande de compost au prix de US$ 3 par 50 kg (prix estimé de revient) est de 2 500 t a^{-1}. Néanmoins, l'évaluation économique de l'installation révèle que l'installation pourrait être économiquement viable, mais ne l'est probablement pas financièrement. L'analyse du seuil de rentabilité démontre que 10-45 tonnes de compost par an sont nécessaires pour atteindre une exploitation optimale d'une installation de co-compostage du type utilisé dans le projet pilote. Le poids de rentabilité se situe à 45 tonnes par an, équivalant à des coûts et bénéfices directs identiques. Une exploitation optimale de l'installation a été estimée à 45 tonnes métriques de compost par an, correspondant à 225 m^3 de déchets solides municipaux et 430 m^3 de boues de vidange fraîches (ou 135 m^3 de boues de vidange déshydratées). Basé sur des prix constants de 2002, ce volume de compost rapporterait un bénéfice économique net de US$ 14 697. Par

conséquent, une certaine forme de subvention est nécessaire pour optimiser sa commercialisation.

Les résultats et les bases de données actuels ne suffisent pas à formuler de bons critères de décision pour les planificateurs et les agriculteurs. D'avantage de temps est nécessaire pour aborder les difficultés techniques actuelles et développer une stratégie de commercialisation durable. Le fumier de volaille est une source de nutriments largement et gratuitement disponible dans la région urbaine de Kumasi. Ceci explique le manque de volonté de payer de la part des agriculteurs. Les agriculteurs péri-urbains et de cultures de base ont manifesté d'avantage d'intérêt pour le produit de compost en raison de leur accès limité au fumier de volaille. Il serait important de démontrer tous les avantages du compost en tant qu'amendement du sol, et de connaître les réactions des agriculteurs aux essais de culture avec du co-compost. Ceci demande cependant de longues périodes de recherches sur le terrain. Une période de 3-4 ans d'étude serait nécessaire pour formuler des recommandations sur les contraintes, le potentiel et les effets de réutilisation agricole des déchets urbains organiques et humains traités par co-compostage. Quoique l'installation pilote ait été suivie durant moins d'une année, son potentiel d'impact semble élevé. Les observations de l'ingénieur sanitaire municipal du KMA sur l'installation pilote sont citées ci-dessous:

Mesures institutionnelles concernant la future prise de contrôle du projet pilote de co-compostage Buobai par KMA –

Le «Kumasi Metropolitan Assembly» approuve la réalisation du Projet pilote de co-compostage car il s'intègre parfaitement dans sa stratégie de gestion des déchets de la ville de Kumasi. Le rôle participatif des acteurs principaux, notamment des organes de parrainage, mérite des éloges.

En tant qu'hôte et futur exploitant de l'installation, KMA a joué dès le début un rôle participatif dans les domaines suivants:

- surveillance des travaux de construction de l'installation de compostage;
- collecte et transport des boues de vidange et des déchets solides organiques à l'installation.

Ses responsabilités futures seraient les suivantes:

- gestion de l'installation après la période d'étude et
- promotion/marketing du compost.

Les observations faites par KMA sont les suivantes:

3. le temps nécessaire aux activités de recherche était inadéquat, notamment en ce qui concerne les tests d'application de compost.

   Au cours de cette période, une quantité considérable de compost a été produite, néanmoins, les essais n'ont pas encore abouti à des résultats plausibles et fiables. Une période d'au moins 2 ans est nécessaire pour obtenir des résultats concrets, justifiés et applicables. Ceci faciliterait la réalisation d'essais d'application de compost de composition diverse sur différents types de cultures.

4. Manque d'informations adéquates quant à la commercialisation et la promotion efficace du compost.

   Pour atteindre une sensibilisation réelle de l'utilisateur potentiel de compost, une commercialisation et promotion efficace du compost présupposent des informations adéquates basées sur des résultats d'essais réalisés avec du compost.

L'IWMI, qui dispose de la capacité requise, a assumé les deux rôles extrêmement importants d'activité de recherche mentionnés ci-dessus.

Il est par conséquent incontestable que les réponses aux questions non résolues contribueront de manière significative au succès du projet. Etant donné que KMA est disposé à assumer la responsabilité et la gestion de l'installation au-delà de la phase pilote, un prolongement du financement d'au moins **deux ans** serait apprécié car il permettrait de combler les lacunes existantes. KMA continuera à jouer les rôles attribués afin d'achever le projet de manière à satisfaire les acteurs principaux.

ABBREVIATIONS AND GLOSSARY

Abbreviations

UPA	Urban and Peri-urban Agriculture	SS	Suspended Solids
BOD	Biochemical Oxygen Demand	TKN	Total Kjeldahl Nitrogen
COD	Chemical Oxygen Demand	TOC	Total Organic Carbon
FC	Faecal Coliforms	TS	Total Solids
FS	Faecal Sludge	TVS	Total Volatile Solids
NH_4-N	Ammonium Nitrogen	WSP	Waste Stabilisation Ponds
NH_3-N	Ammonia Nitrogen	WWTP	Wastewater Treatment Plant

Glossary

Faecal sludge	Sludges of variable consistency collected from so-called on-site sanitation systems; viz. latrines, non-sewered public toilets, septic tanks, and aqua privies
Septage	Contents of septic tanks (usually comprising settled and floating solids as well as the liquid portion)
Public toilet sludge	Sludges collected from unsewered public toilets (Usually of higher consistency than septage and biochemically less stabilised)
Percolate	The liquid seeping through a sludge drying bed and collected in the underdrain

Part A

Project Background, Context and Justification

1 INTRODUCTION

The cities in sub-Saharan Africa (SSA) are growing at an exceptional rate of 5% annually. By 2020, more than 50% of the population of this region will be urban (World Resources Institute, 1998). The United Nations estimates that in the next twenty years, two out of three West Africans will live in urban centres. With this rapid in-migration, urban growth and its implications can be predicted in terms of the demand for food and raw materials, or 'inputs' and generation of wastes and pollution, or 'outputs' (Vasquez, 2001). These challenges are not waiting twenty years, but are already being experienced today. Waste management is one of the most immediate and serious environmental problems confronting urban governments in developing countries. Solid wastes (SW) are often found littered all around the cities. Faecal sludge (FS) accumulating in the commonly used on-site sanitation systems are periodically collected and dumped indiscriminately into natural watercourses, drainage ditches or on unused land, leading to continued spread of diseases and causing severe ground and surface water pollution. Moreover, food is becoming a very expensive commodity. In Ghana as typical of developing countries, most households in the cities spend 50-80% of their average income on food because they have fewer coping strategies than the rural inhabitants. The rapid increase in urban population and the challenge of urban food security has facilitated the entrance of agriculture into the cities ranging from backyard farms for household subsistence to intensive vegetable production. This urban and peri-urban agriculture (UPA) which is usually embarked upon to satisfy increasing food demand and also to make use of the ready urban market for such perishables requires large amount of inputs, particularly plant nutrients and soil ameliorants because, most of the crops are repeatedly grown throughout the year.

On the other hand, once the food is consumed or processed in the city, related market and household refuse as well as human excreta contribute to urban pollution due to the lack of adequate sanitation services or end in landfills. In both cases large amounts of resources including nutrients are simply 'wasted'. This calls for intensified research into appropriate solutions taking into account not only technological but also socio-cultural and economic aspects. One step in improving the situation is through biological treatment of municipal waste. This could lead to reduction of disposal costs and allow the reuse of valuable nutrients in agricultural production.

1.1 Background and Justification

The city of Kumasi, Ghana, is located 300 km Northwest of Accra the capital. It offers a good environment for a pilot co-compost station. Kumasi is the second largest city in Ghana. The city is an industrial centre with formal industries in timber, food processing (including beer brewing) and soap manufacturing, together with informal activities in woodworking, light engineering, vehicle repair, footwear, furniture manufacture and metal fabrication. The city has about 1 million inhabitants. Population growth rate (3%) and waste generation rates are high (2000 Population and Housing census, Ghana Statistical service; KMA, 2000). It is located on latitude $6^{o}35'$N – $6^{o}40'$N and longitude $1^{o}30$W – $1^{o}35'$W. The city has an approximate land area of 254km2 and falls within the plateau of the south-west physiological region which ranges from 250 – 300m above sea level. The climate falls within the wet sub-equatorial climate type with two rainy seasons, the major one, from late February to early July and the minor one, from mid September to early November. However, there have been slight variations in recent years, with the rains starting in late March and with sporadic rains falling till late November. The monthly rainfall ranges from 15mm in January to 214mm in June.

1.2 Waste Generation and Management

The current domestic daily waste generation in Kumasi 860 is tonnes. The bulk of the solid waste generated in the metropolis is collected by the private sector based on a mixture of contract and franchise arrangements. Two main collection methods are employed: House-to-house and Communal Container Collection systems. The House-to-house collection service covers about 1,500 houses in selected communities of the high-cost sector The 1,500 houses serviced in comparison with the over 45,000 houses in the metropolis leaves much to be desired. The Communal Collection System entails the location of metal containers (skips) at designated sites known as transfer stations, which are shared, by a number of houses within that community. There are 124 transfer stations, which are spread over the city (Leitzinger and Gyiele, 2000). When the skips are full, they are transported and emptied at the final disposal site by skip loading trucks. Where there are no containers, households deposit their refuse temporarily on the ground. The communal containers used for the service have been found to be too high, making them user-unfriendly. This results in waste being thrown about around the containers mostly by children. The current location of a temporary landfill site at Buokrom about 3.5km from the Kumasi Airport is highly undesirable and operations continue because of lack of alternative sites.

Sanitation

The following sanitation facilities are found in the city: public toilets mainly of VIP latrines, bucket latrines, water closet with septic tank, sewerage, pit latrines and free range. It was estimated that less than 4% of Kumasi's residents have access to sewerage, 40% of residents depend on public toilets, 15% on septic tanks, while less than 10% have household improved pit latrines (Salifu & Mumuni, 1998). Faecal sludges which are high in pathogens are discharged in some temporary ponds at Kaasi, a suburb of Kumasi. The sanitary condition of Kumasi is rather precarious (Salifu, 1990). Currently most residents in Kumasi (about 38%) still use public toilets for which they pay between ¢20 and ¢100 per visit depending on the type of facility. Another 26% use household water closet facilities. The unhygienic bucket latrine system caters for around 12% of the population; 8% rely on sewerage (Asafo, 4BN, KATH, KNUST Ahinsan and Chirapatre Housing Estates); while pit latrines (KVIP/traditional; 10%) and the bush provides for the rest of the population (Mensah, 2002). The above data represents a slight improvement on the former situation following the successful implementation of the IDA/GOG-financed Urban Environmental Sanitation Project (UESP) - 1996-2002. There is no proper faecal sludge disposal mechanism yet. Sludge is being discharged in the temporary disposal facility at Kaasi, where it flows directly into the Subin River without treatment. There is the danger of pollution of water, soil and air (through dumping, leaching and burning) and high potential for epidemic in and around the city.

1.3 Potential for Waste Recycling in Urban Agriculture in Kumasi

There is potential for waste recycling into urban agriculture in Kumasi. Urban agriculture (UA) is loosely defined as the growing, raising, processing, production and distribution of food and non-food products through plant and tree cultivation, animal husbandry and aquaculture within and/or on the fringe of urban areas (Mougeot 1998; Frojmovic 1996; OECD 1998; Rees 1997, Garnett 1996). The contributions and benefits of urban agriculture are many. Its main advantage is that it is making cities more self-reliant in certain food items and poor households more food secure (Mougeot, 2000). Not only does UA contribute to a steadier and more reliable source of food, it also contributes to an increase in nutritional quality of urban diets. Using different methodologies to measure the relative impact of UA on food

security indicators, self-producing households achieve greater food security, particularly with regards to nutritional status measured by caloric and protein intake and anthropometric measurements (for example stunting & wasting) (Mougeot, 2000). Maxwell *et al.* (1998) found that child nutritional status (height for age) in Kampala is significantly higher among households that farm compared to non-farming households when controlling for social and economic status.

Employment is another major benefit of urban agriculture. In some cities, as many as one-fifth to one-third of all families are engaged in agriculture, with as many as a third of these having no other source of income (Smit *et al.,* 1996).

In Kumasi, farming in open land spaces is practiced at different sites within the city on a total of approximately 120 hectares of land. In most cases, intensive (all year round) irrigated cultivation of vegetables such as cabbage, lettuce, carrot, cucumber, green pepper, and spring onions. Backyard gardening is also a common phenomenon in approximately 85,000 backyards within Kumasi (Figure 1-1) where crops such as plantains and maize are found. Peri-urban agriculture is located in an area up to 40 km beyond the urban boundaries producing a higher variety of food including cassava, tomatoes and meat products (Adam, 2001). These urban and peri-urban farming systems complement the rural-urban food flows and co-contribute to urban food supply. It was estimated that 90% of fresh leafy vegetables (e.g. lettuce, spring onions, etc.) consumed in the city are from the production within the cities (Cofie et al., 2001). These production systems require large amounts of inputs, including plant nutrients and in many cases, untreated poultry manure are used to replenish the soil for the production of vegetables which are often contaminated with pathogens (Drechsel et al 2000).

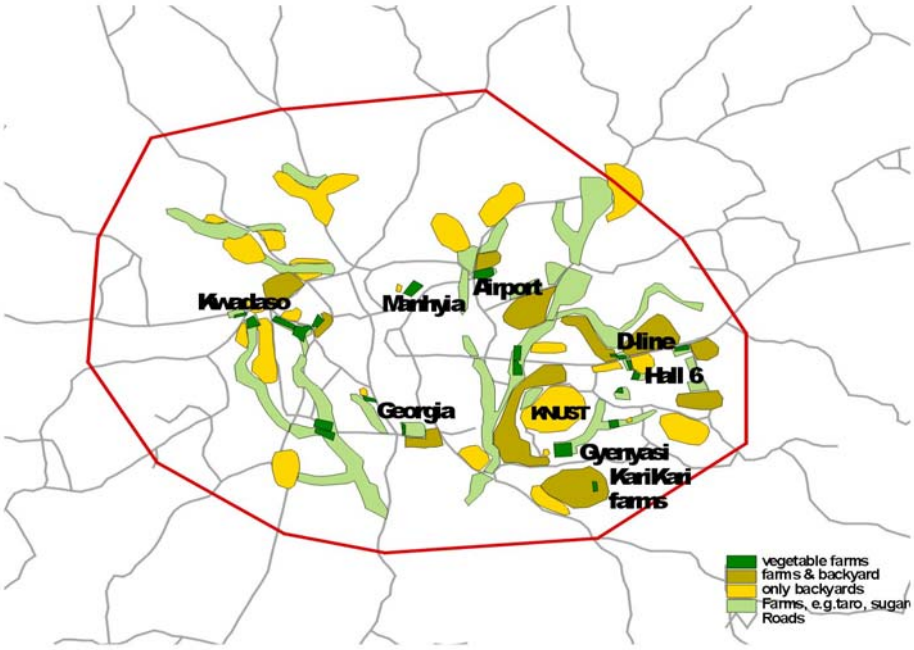


Figure 1-1 Urban Agriculture Sites in Kumasi

Fortunately, between 65 and 75% of the solid waste generated in Kumasi are biodegradable (Salifu, 1999) which together with the human excreta can be co-composted and utilized as fertilizer and soil ameliorant. Previous studies on organic

waste management in Kumasi using Material Flow Analysis (Leitzinger, 2000, Belevi, 2002) revealed that, the nitrogen demand of about 30% in UPA could theoretically be met by co-composting FS together with the SW being currently disposed in landfills. To meet this objective, 57% of the compost produced has to reach urban agriculture and the remaining 43% to peri-urban agriculture in the 40 km radius of Kumasi.

The Kumasi Metropolitan Assembly (KMA) has had composting as part of its strategic planning for waste management in the city over the years but no implementation had taken place. Under the World Bank financed Urban Environmental Sanitation Project (Urban IV), two FS treatment plants (FSTP) and a sanitary landfill have been planned and are being implemented. One FSTP has been completed (to be operational very soon) at Buobai. The utilization of the organic proportion of the solid waste and the stabilized sludge from the respective facilities will not only provide nutrients for urban agricultural enhancement but will also help prolong the useful life of the landfill facility.

In view of the foregoing background, the project on co-composting was developed by IWMI in collaboration with Department of Water & Sanitation in Developing Countries (SANDEC) of the Swiss Federal Institute for Environmental Science and Technology (EAWAG), Kwame Nkrumah University of Science and Technology (KNUST), Kumasi and the Waste Management Department (WMD) of Kumasi Metropolitan Assembly (KMA).

The Pilot Co-composting Project will provide the vital information for the planning and implementation of the large-scale project at the new landfill site. The KMA plans to utilize the compost in two ways. Some will be sold to farmers to be used as soil conditioner to improve agricultural activities and the rest used as cover materials on the landfill. The primary objective of the composting project as far as KMA is concerned is to reduce the quantity of waste to be landfilled thereby increasing the life of the landfill facility. Consequently, cost recovery will not be an objective in determining the selling price of the compost since that is likely to make it unattractive to the potential users.

1.4 Objectives and Expected Output

1.4.1 Objectives

The overall goal is to gain scientific and technical knowledge on the options of co-composting SW and FS to be used as decision support and for the benefit of municipal authorities and farmers. Specifically, the project had the following sub-objectives:

i) To monitor the technical and operational aspects of co-composting to assess its viability and sustainability

ii) To assess the environmental impact, and socio-economic aspects of co-composting

iii) To enhance human capacity for urban waste management and related research with respect to co-composting

iv) To raise awareness and know-how of co-composting as a waste recycling option.

1.4.2 Expected Output

The expected output of the pilot project is decision support for municipal authorities on: the mode of operation of a co-composting station that matches the opportunities and constraints of Kumasi, as an example of other African cities; and also, increased awareness for farmers on the use of co-compost as an alternative nutrient source. This was based on the premix of the initial hypothesis that:

Co-composting municipal organic solid waste with faecal sludge constitutes:

(i) in the long-term, a viable and very meaningful option in waste management and

(ii) a valuable alternative nutrient source for urban and peri-urban agriculture

1.5 Scope and Approach

1.5.1 Scope

The Project monitors various issues on technical and operational aspects of co-composting from production to utilization of the compost. The various studied components are:

- Sludge dewatering in drying beds
- Monitoring the flow rate, volume and quality of leachate from the drying beds to propose appropriate management for the leachate.
- Co-composting of dewatered sludge and organic solid waste testing different mixing ratio.
- Monitoring the removal of pathogens in the co-composting process
- Assessment of socio-economic aspect of co-composting
- Assessment of agronomic benefit of compost use

1.5.2 Approach

The approach used was to first set up a multidisciplinary team of engineers, agronomist, environmental scientist and biologist from IWMI, SANDEC, KNUST and KMA. This team met together for a roundtable discussion to plan and review project activities. A memorandum of agreement was signed with the municipal authority that later offered a piece of land for the establishment of a pilot co-composting plant at Buobai, Kumasi. Many partners were involved in the planning, monitoring and analysis at different stages. Table 1-1 shows the different individuals and institutions involved in the project as well as their responsibilities.

Table 1-1 Individuals and Institutions Involved in the Kumasi Co-composting Project

Name	Institutions	Designation	Responsibility
Olufunke Cofie	IWMI	Project Leader	Project coordination and supervision
Agnes Montangero Martin Strauss Chris Zubrigg Hasan Belevi	SANDEC	Engineers	Discussion partners on technical and operational aspects of co-composting
Jacques Maradan	SANDEC		Project Assistant
Esi Awuah Robert Abaidoo Charles Quansah	KNUST	Lecturers	Co-supervisors of M.Sc. students
Alex Anakwa	KNUST	Monitoring Engineer	
Sharon Quarshie	IWMI	Plant Manager	Daily plant

			management and operation
Anthony Mensah Prosper Kotoka	WMD/KMA	Sanitary Engineer	Logistic support, liaison with KMA, waste collection and transportation
Harold Esseku	Colan Consult / KNUST	Post-graduate	Plant design Field data collection
Seth Agbottah Omanhene Boateng Daniel Nartey Nikita Eriksen-Hamel	KNUST WUR	Post-graduate	 Field data collection
George Danso Lucy Gyiele	IWMI	Agric. Economists	User perception, marketing and distribution of compost
Pay Drechsel	IWMI		Backstopping

Part B

Literature Review

2 REUSE OF FAECAL SLUDGE AND, ORGANIC SOLID WASTE

2.1 General Practices of Excreta and Solid Waste Use

All around the world, people in rural and urban areas have been using **human excreta** for centuries to fertilise fields and fishponds and to maintain or replenish the soil organic fraction, i.e. the humus layer. Until today, in both agriculture and aquaculture this continues to be common in China and Southeast Asia as well as in various places in Africa (Cross 1985; Timmer and Visker 1998; Visker 1998; Timmer 1999; Strauss et al. 2000). Reuse practices have led to a strong economic linkage between urban dwellers (food consumers as well as waste producers), and urban farmers (waste recyclers and food producers). Chinese peri-urban vegetable farmers have reported that customers prefer excreta-fertilised vegetables rather than chemically fertilised ones. Thus vegetables grown on excreta-conditioned soils yield higher sales prices.

Like excreta, the use of **organic solid waste** has a long history mainly in rural areas. Traditional reuse practices of organic solid waste are shown to be especially strong in countries where population densities are high. With the growth of urban areas, the importance of managing municipal solid wastes to avoid environmental degradation and public health risks has gained significance. Although informal recycling activities of waste materials is wide spread in developing countries, treatment and use of the biodegradable organic fraction is still fairly limited. Increasingly, national and municipal authorities are now looking at ways to manage their organic solid waste. In India national legislation was adopted with the “Municipal Solid Waste (Management & Handling) Rules 2000” (Ministry of Environment and Forests 2000) whereby one section of the rules requires Urban Local Bodies to promote and implement waste segregation at source and treat organic waste.

2.2 Municipal Waste Characteristics and Management

2.2.1 Faecal Sludge Characteristics and Management

Table 2-1 contains the **daily per capita volumes** and **loads of organic matter, solids and nutrients** in faecal sludges collected from septic tanks and pit latrines, as well as from low or zero-flush, unsewered public toilets. Values for fresh excreta are given for comparative purposes. The figures are overall averages, actual quantities may, however, vary from place to place.

Table 2-1 Daily per capita volumes; BOD, TS, and TKN quantities of different types of faecal sludges

Parameter	Septage [1]	Public toilet sludge [1]	Pit latrine sludge [2]	Fresh excreta
• **BOD g/cap·day**	1	16	8	45
• **TS g/cap·day**	14	100	90	110
• **TKN g/cap·day**	0.8	8	5	10
• **Volume l/cap·day**	1	2 (includes water for toilet cleansing)	0.15 - 0-20	1.5 (faeces and urine)

1 Estimates are based on a faecal sludge collection survey conducted in Accra, Ghana.

2 Figures have been estimated on an assumed decomposition process occurring in pit latrines. According to the frequently observed practice, only the top portions of pit latrines (~ 0.7 ... 1 m) are presumed to be removed by the suction tankers since the lower portions have often solidified to an extent which does not allow vacuum emptying. Hence, both per capita volumes and characteristics will range higher than in the material which has undergone more extensive decomposition.

Source: Heinss et al. 1998

In contrast to sludges from WWTP and to municipal wastewater, characteristics of faecal sludge differ widely by locality (from household to household; from city district to city district; from city to city) (Montangero and Strauss 2002).

A basic distinction can usually be made between fresh, biochemically **unstable** and "thick" vs. "thin" and biochemically fairly **stable** sludges (Heinss et al. 1998). Unstable sludges contain a relative large share of recently deposited excreta. Stable sludges are those, which have been retained in on-plot pits or vaults for months or years and which have undergone biochemical degradation to a variable degree (e.g. septage, which is sludge from septic tanks). Based on numerous FS monitoring studies in West Africa, Rosario (Argentina), Bangkok and Manila, Strauss (2002) found that FS can often be associated with one of these two distinct categories. In contrast to fairly stable sludges, fresh undigested and biochemically unstable sludges exhibit poor solids-liquid separability.

Table 2-2 shows typical FS characteristics and typical characteristics of municipal wastewater as may be encountered in tropical countries. Storage duration, ambient temperature, intrusion of groundwater into vaults or pits of on-site sanitation installations; installations sizing, and tank emptying technology and pattern are important factors influencing the sludge quality.

Table 2-2 Faecal sludges from on-site sanitation systems in tropical countries: characteristics, classification and comparison with tropical sewage

Item	Type "A" (high-strength) *	Type "B" (low-strength) *	Sewage ** (for comparison purposes)
Example	Public toilet or bucket latrine sludge	Septage	Tropical sewage
Characterisation	Highly concentrated, mostly fresh FS; stored for days or weeks only	FS of low concentration; usually stored for several years; more stabilised than Type "A"	
COD mg/l	20, - 50,000	< 15,000	500 - 2,500
COD/BOD	5 : 1 .... 10 : 1		2 : 1
NH_4-N mg/l	2, - 5,000	< 1,000	30 - 70
TS mg/l	≥ 3.5 %	< 3 %	< 1 %
SS mg/l	≥ 30,000	≅ 7,000	200 - 700
Helm. eggs no./l	20, - 60,000	≅ 4,000	300 - 2,000

Source: Strauss et al. 1997* and Mara 1978**

Various options are available for FS management. More information on this can be retrieved from. http://www.sandec.ch/sos/references.html

The fact that faecal sludges exhibit widely varying characteristics calls for a careful selection of appropriate treatment options particularly for primary treatment which involves separation of the solids and liquids, which make up FS.

If FS is still rather fresh it has to be biochemically stabilised first for solids and liquids to become separable. Anaerobic ponds, designed to also cater for separated solids accumulation, may serve the combined purpose of stabilisation and solids-liquid separation. Solids-liquid separation of FS, which has undergone considerable biochemical stabilisation (septage), may be achieved through sedimentation and thickening in ponds or in tanks, or through filtration and drying in sludge drying beds.

Sludge Drying Beds

Sludge drying beds serve to effectively separate solids from liquids and to yield a solids' concentrate. Two processes are responsible for sludge dewatering and drying. These are: gravity **percolation** and **evaporation**. In planted beds, **evapotranspiration** provides an additional effect.

Results from pilot sludge drying beds obtained by the Water Research Institute (WRI) in Accra, Ghana indicate their suitability for septage/public toilet sludge mixtures and for primary pond sludge (TS = 1.6-7 %). Experiments were conducted during the dry season with sludge application depths of $\leq$ 20 cm. Various types of sludges revealed the following drying behaviour over a period of 8 days:

- Mixtures of public toilet sludge (unstable) and septage (stable) at a 1:4 ratio:
  Good dewaterability, drying to max. 70 % TS in eight days

- Primary pond sludge:
  Rather good dewaterability, drying to 40 % TS

- Public toilet sludge (unstable):
  Erratic results, from almost no dewaterability to 29 % TS.

2.2.2 Solid Waste Characteristics and Management

Municipal solid waste consists of both degradable and non-degradable components in various proportions. Table 2-3 shows the composition of SW from different countries. As quoted in Obeng and Wright (1987) (from Algiers, Accra, Alexandria, Cairo, Sao Paolo) easily biodegradable fractions range between 44 and 87 %. (in weight). Similar average ranges (40-85 %) are also reported by Cointreau et al. (1985) for low-income countries. Data from the Kumasi Waste Management Department (2000) shows figures of 79 % biodegradable waste for the city of Kumasi.

There are many approaches to the management of solid waste, this could be by incineration, land filling or recycling. For composting purposes, the easily biodegradable fraction of SW is of immediate interest. This includes food waste, vegetables and fruits, and garden wastes (sometimes referred to as yard wastes) such as grass, leaves and small woody materials. Although organic waste materials such as paper and timber may also be composted, they are more resistant to microbial degradation due to the high lignin content (Richard 1996). If these materials are included in the composting process, their particle sizes are often reduced beforehand through shredding to allow for quicker decomposition. Given the high amounts of biodegradable waste, organic waste recycling through composting and reuse can have considerable advantages for a city. Zurbrugg and Drescher (2002) describe the potential benefits of organic waste management as reducing the environmental impact of disposal sites, extending the existing landfill capacity, replenishing soil nutrients and the soil humus layer

Table 2-3Characteristics of Solid Waste from Various Cities

Constituents (in %weight)	Kumasi, Ghana	Accra, Ghana	Cairo, Egypt	Abu Dhabi, UAE	Algiers, Algeria
Vegetables and fruits	44.0	87.1	43.8	22.5	72.0
Fabrics/Textiles	3.20	1.2	3.0	0.3	2.6
Paper/cardboard	3.10	5.7	9.2	42.4	16.0
Straw	-	-	7.7	0.4	0.1
Timber	-	-	2.5	2.9	1.0
Leather/rubber	0.30	-	0.9	-	1.2
Horn/bones	-	-	1.3	2.9	0.2
Plastics	3.52	1.3	2.0	6.3	2.5
Metals	0.64	2.6	3.0	14.0	2.5
Crockery	-	1.4	24.7	3.8	0.7
Glass/bottles	0.64	0.7	1.9	4.4	1.2
Miscellaneous		-	-	-	-
a) Ash food waste	34.60				
b) sand	10.0				
Total	100	100	100	100	100
Compostable portion	78.6	94.9	87.3	73.5	90.0

Sources: Obeng and Wright, (1987); Hughes (1986) KMA Waste Management Department (2000). Characteristics of solid waste from various cities (in %weight)

2.2.3 The Resource Potential of Municipal Waste

Excreta

Excreta are a rich source of organic matter and of inorganic plant nutrients such as nitrogen, phosphorus and potassium. Each day, humans excrete in the order of 30 g

of carbon (90 g of organic matter), 10-12 g of nitrogen, 2 g of phosphorus and 3 g of potassium. Most of the organic matter is contained in the faeces, while most of the nitrogen (70-80 %) and potassium are contained in urine. Phosphorus is equally distributed between urine and faeces. Table 2-4 shows that the fertilising equivalent of excreta is, in theory, nearly sufficient for a person to grow its own food (Drangert 1998). In a recent material flow study conducted in the City of Kumasi, Ghana, it was found that for urban and peri-urban agricultural soils, nutrients (N and P, Organic matter), could be fully replenished by using all the human waste and recycling all the organic market waste and the wastes from breweries, timber and food processing factories and from chicken farms (most of the wastes would have to be treated prior to use, though) (Leitzinger 2000; Belevi et al. 2000).

Excreta is not only a fertiliser, its organic matter content, which serves as a soil conditioner and humus replenisher is of equal or even greater importance. This is an asset not shared by chemical fertilisers –

Table 2-4 The Fertilization Equivalent of Human Excreta

	Nutrient in kg / cap·year			
Nutrient	**In urine (500 l/year)**	**In faeces (50 l/year)**	**Total**	**Required for 250 kg of cereals [1]**
Nitrogen (as N)	4.0	0.5	4.5	5.6
Phosphorus (as P)	0.4	0.2	0.6	0.7
Potassium (as K)	0.9	0.3	1.2	1.2
Carbon (as C) [2]	2.9	8.8	11.7	

[1] = the yearly food equivalent required for one person
[2] = indicative of the potential for soil conditioning, normally not designated a nutrient

Source: after Drangert 1998

New approaches in human waste management postulate that sanitation systems should, whenever feasible, be conceived and managed that again enable the recycling of organic matter and nutrients contained in human excreta (Winblad 1997; Esrey et al. 1998). A change in the sanitation management paradigm from flush-and-discharge to recycling of urine and faeces is gaining ground in Europe (Larsen and Guyer 1996; Otterpohl et al. 1997 and 1999; Otterpohl 2000). As a consequence, treatment strategies and technological options for faecal sludges and solid waste will have to be developed which allow the optimum recycling of nutrients and organic matter to peri-urban agriculture, while being adapted to the local situation and needs.

2.2.4 Municipal Organic Solid Waste

The resource potential of mixed municipal solid waste is more variable than for excreta as it depends on the waste composition, which varies considerably from city to city and also among city districts depending on income levels and consumption habits. Low-income countries generate significantly less waste than high- income countries. Cointreau (1985) gave an estimate of average municipal solid waste generation to be between 0.4 - 0.6 kg per capita per day in low-income countries, compared to 0.7 – 1.8 kg/cap and day in high-income countries. Typically in low-income countries the biodegradable fraction is significantly higher (40-85 %) than in high-income countries (20-50 %) where municipal waste consists mainly of

packaging materials (paper and plastics). Assuming a daily per-capita solid waste generation of 0.5 kg with a 60 % biodegradable fraction, 300 g/cap.day wet organic waste is being generated. Based on an assumption of 50 % water content of this organic fraction, this is equivalent to 150 grams dry organic solids/cap and day. Based on contents on a dry weight basis of 30-40 % carbon (C), 1-2 % nitrogen (N) and 0.4-0.8 % phosphorus (as P), and 1 % potassium (as K), the per-capita nutrient and carbon contributions from the organic fraction of MSW is as indicated in Table 2-5. The table shows that municipal organic solid waste although low in nutrients is particularly rich in organic matter can be thus be valued on its soil conditioning potential.

Table 2-6 The Fertilization Equivalent of Municipal Solid Waste

(org. fraction) before waste treatment

Nutrient	Contribution in kg / cap•year
Nitrogen (as N)	0.55 – 1.1
Phosphorus (as P)	0.2 – 0.4
Potassium (as K)	0.55
Carbon (as C) [1]	16 – 22

[1] = indicative of the potential for soil conditioning, normally not designated as a nutrient

2.3 Health Consideration in Re-use of Human Waste and Solid Waste

2.3.1 Pathogenic Health Risk

Diseases related to poor sanitation practices are very common in developing countries. Excreta and wastewater contain correspondingly high concentrations of excreted pathogenic bacteria, viruses, protozoa and helminths. Many such diseases are of public health importance and are of specific importance in waste reuse schemes. However, the agricultural or aqua-cultural use of excreta and waste-water can result in an actual risk to public health only if all of the following occur (WHO 1989):

- either an infective dose of an excreted pathogen reaches a field or pond, or the pathogen multiplies in the field or pond to form an infective dose;
- the infective dose reaches a human host;
- the host becomes infected; and
- the infection causes disease or further transmission

If the infection does not cause disease or further transmission then only a potential risk to public health exists. Moreover, if this sequence of events is broken at any point, the potential risks cannot combine to constitute an actual risk.

An important factor influencing transmission is the **die-off or survival** of excreted pathogens. The pathogens have varying resistance against die-off, and worm eggs are among the more resistant with *Ascaris* eggs surviving longest in the extra-

intestinal environment. The main factors influencing die-off are temperature, dryness and UV-light.

Table 2-7 lists survival periods at ambient temperature in faecal sludges for temperate and tropical climates. Another important factor is the **infective dose** of a pathogen that is required to create disease in a human host. For helminths, protozoa (e.g. amoeba) and viruses, the infective dose is low (< 10^2). For bacteria, it is medium (< $10^{4)}$ to high (> 10^6).

Many studies have reported the microbial risks from human waste use in relation to use in agriculture (Scott (1952), Rudolfs et al. (1950, 1951), Akin et al. (1978), Feachem et al. (1983)). Strauss (1985) published a review on the survival of excreted pathogens on soils and crops –a factor of great relevance for the risk or non-risk of human waste use. Birley and Lock (1997) and Allison et al. (1998) have highlighted health impacts and risks of solid and human waste use in urban agriculture.

Table 2-7 Pathogen Survival Periods in Faecal Sludge

Organism	Average Survival Time in Wet Faecal Sludge at Ambient Temperature[1]	
	In temperate climate (10-15 °C) [days]	**In tropical climate (20-30 °C) [days]**
• **Viruses**	**< 100**	**< 20**
• **Bacteria:**		
-Salmonellae	**< 100**	**< 30**
-Cholera	**< 30**	**< 5**
-Faecal coliforms [2]	**< 150**	**< 50**
• **Protozoa:**		
-Amoebic cysts	**< 30**	**< 15**
• **Helminths:**		
-Ascaris eggs	**2-3 years**	**10-12 months**
-Tapeworm eggs	**12 months**	**6 months**

1 Conservative upper boundaries to achieve 100 % die-off; survival periods are shorter if the faecal material is exposed to the drying sun, hence, to desiccation

2 Faecal coliforms are commensal bacteria of the human intestines and used as indicator organisms for excreted pathogens

Sources: Feachem et al. 1983, Strauss 1985 and Schwartzbrod J. and L. 1994

The epidemiological evidence on the *agricultural use of excreta* can be stated as follows (Blum and Feachem 1985):

- Crop fertilisation with **untreated** excreta causes significant excess infection with intestinal nematodes in both consumers and field workers

- Excreta treatment, e.g. through **thermophilic composting, extended storage and/or drying**, significantly reduces or eliminates the risk of transmission of gastro-intestinal infections.

Ascaris eggs, being the most persistent of all pathogens, can be used as a hygienic indicator of treated excreta. For sludge or biosolids, Xanthoulis and Strauss (1991)

proposed a nematode egg standard of ≤ 3-8 eggs/gram of dry solids. This value is based on the 1989 WHO nematode guideline of ≤ 1 egg/litre of wastewater for unrestricted irrigation.

In **municipal solid waste**, the health risk by pathogens is determined by the amount of faecal matter contained in the solid waste or by pathogenic hospital and clinical waste, which may enter the municipal solid waste stream unintentionally. Non-pathogen risks can be more significant depending on the waste composition and the way the waste is managed (or not managed).

2.3.2 Non-Pathogenic Health Risks

Chemical contamination is a potential risk associated with waste use, notably in municipal solid waste. As organic solid waste is often stored and collected together with other waste fractions, contamination of the organic fraction is easily possible by chemical constituents, heavy metals in particular. When applying the contaminated compost product, these constituents can accumulate in soils. The contamination of soils by chemicals, the potential but as yet uncertain uptake by crops, and the possible chronic and long-term toxic effects in humans are discussed by Chang et al. (1995) and by Birley and Lock (1997).

Further non-pathogen risks result from impurities of non-biodegradable origin such as glass splinters or other sharp objects contained in the compost product. Such impurities can result from insufficiently sorted municipal solid waste before or after the composting process. Birley and Lock (1999) have highlighted these risks also including indirect health risks due to the attraction and proliferation of rodents and other disease carrying vectors.

In the majority of developing countries, no standards or guidelines have been set for the quality of biosolids from FS. Standards have usually been copied from industrialised countries without taking the specific conditions prevailing in the particular developing country into account. In most if not all cases, the standards were enacted having wastewater treatment and discharge in mind.

The EU adopted a rational strategy for public health protection in biosolids use. The general principle is to define and set up a series of barriers or critical control points, which reduce or prevent the transmission of infections[1]. Sludge treatment options, which were found to effectively inactivate excreted pathogens to desirable levels (e.g. co-composting), are typical “barrier points”, where the transmission of pathogens might be stopped (Matthews 2000). In Table 2-8, a set of effluent and plant sludge quality guidelines for selected constitutents is listed. The suggested values are based on the principle of defining and setting up barriers against disease transmission, which can be used as critical control points for securing safe biosolids quality.

Table 2-9 Suggested Faecal Sludge Effluent and Biosolids Quality Guidelines

	BOD [mg/l] total	BOD [mg/l] filtered	NH_4-N [mg/l]	Helminth eggs [no./L]	FC [no./100 mL]
A: Liquid effluent					
1. Discharge into receiving waters:					
• Seasonal stream or estuary	100-200	30-60	10-30	≤ 2-5	$\leq 10^4$
• Perennial river or sea	200-300	60-90	20-50	≤ 10	$\leq 10^5$
2. Reuse:					

[1] The principle follows the “HACCP” principle, which stands for Hazard Analysis and Critical control Points. It was first developed in the U.S.A. for food safety in manned space systems

• Restricted irrigation	n.c.	1)	≤ 1	≤ 10^5
• Unrestricted irrigation	n.c.	1)	≤ 1	≤ 10^3
B: Treated plant sludge				
• Use in agriculture	*n.c.*	n.c.	*≤ 3-8/ g TS* 2)	3)

1) ≤ Crop's nitrogen requirement (100 - 200 kg N/ha·year)

2) Based on the nematode egg load per unit surface area derived from the WHO guideline for wastewater irrigation (WHO, 1989) and on a manuring rate of 2-3 tons of dry matter /ha·year (Xanthoulis and Strauss, 1991)

3) Safe level if egg standard is met n.c. – not critical

Source: Heinss et al., 1998

2.3.3 Hygienic Quality of Biosolids

The residual concentration of helminth eggs in the biosolids is dependent on the prevalence and intensity of infection in the population from which FS or wastewater is collected and on various factors influencing parasite survival. Where biosolids use in agriculture is a practice or being aimed at, treatment or storage must be designed at reducing helminth egg counts and viability to acceptable levels.

Table 2-7 may serve to estimate pathogen (including helminth egg) die-off in faecal sludge during storage at ambient temperature, allows estimating the time required for *Ascaris* egg die-off in properly operated, thermophilic compost. Table 2-10 shows values for helminth egg counts and viability in untreated human wastes and in biosolids as reported in published and unpublished literature for a few selected wastewater and FS treatment schemes.

Table 2-10 Helminth Eggs in Biosolids from Selected Treatment Schemes

Place and scheme	No. of helminth eggs per litre of untreated ..		Helminth eggs in biosolids		Reference
	Faecal sludge	Wastewate	No. of eggs /g TS	Egg viability	
Extrabes, Campina Grande (Brazil); experimental WSP scheme	----	**1,000** (nematodes)	**1,400 – 40,000** (as distributed in sludge in a primary facult. pond; avg.= 10,000, approx.)	**2 – 8 %** (period of biosolids storage not reported but probably several years)	Stott *et al*. (1994)
Chiclayo (Peru); WSP schemes	----	**10 – 40** (mostly nematodes)	**60 – 260** (in sludge from a primary facult. pond)	**1 – 5 %** (biosolids stored for 4-5 years)	Klingel (2001)
Asian Institute of Techn. (Bangkok); pilot constructed wetland plant (planted sludge drying beds) for septage dewatering+stabilisation	**600-6,000** (septage; nematodes)		**170** (avg. nematode levels in dewatered biosolids accumulated over 3.5 years in planted sludge drying beds)	**0.2 – 3.1 %**	Koottatep and Surinkul (2000); J. Schwartzbrod (2000)

3 Composting and Co-composting

3.1 Process Definition

Composting refers to the process by which biodegradable waste is biologically decomposed under controlled conditions by microorganisms (mainly bacteria and fungi) under aerobic and thermophilic conditions. The resulting compost is a stabilised organic product produced in such a manner that the product may be handled, stored and applied to land according to a set of directions for use. Important to note is that the process of "composting" differs from the process of "natural decomposition" by the human activity of "control". "Control" has the goal to enhance the efficiency of the microbiological activity, to restrict undesired environmental and health impacts (smell, rodent control, water and soil pollution) and assure the targeted product quality.

Co-composting: This means composting of two or more raw materials together – in this case, FS and SW. Other organic materials, which can be used or subjected to co-composting, comprise animal manure, sawdust, wood chips, bark, slaughterhouse waste, sludges or solid residues from food and beverage industries.

Co-composting FS and MSW is advantageous because the two materials complement each other. The human waste is relatively high in N content and moisture and the MSW is relatively high in organic carbon (OC) content and has good bulking quality. Furthermore, both these waste materials can be converted into a useful product. High temperatures attained in the composting process are effective in inactivating excreted pathogens contained in the FS and will convert both wastes into a hygienically safe soil conditioner-cum-fertilizer.

3.2 Composting Systems

The technologies chosen for aerobic composting (or co-composting) will depend on the location of the facility, the capital available and the amount and type of waste delivered to the site. Two main types of systems are generally distinguished which are: 1) **open** systems such as windrows and static piles and 2) **closed** "in-vessel" systems. In-vessel or "reactor" systems can be static or movable closed structures where aeration and moisture is controlled by mechanical means and often requires an external energy supply. Such systems are usually investment intensive and also more expensive to operate and maintain.

"Open" systems are the ones most frequently used in developing countries. They comprise:

- **Windrow, heap or pile composting**
  The material is piled up in heaps or elongated heaps (called windrows). The size of the heaps ensures sufficient heat generation and aeration is ensured by addition of bulky materials, passive or active ventilation or regular turning. Systems with active aeration by blowers are usually referred to as forced aeration systems and when heaps are seldom turned they are referred to as static piles. Leachate control is provided by a sloped and sealed or impervious composting pads (the surface where the heaps are located) with a surrounding drainage system.

- **Bin composting**
  Compared to windrow systems, bin systems are contained by a constructed structure on three or all four sides of the pile. The advantage of this containment is a more efficient use of space. Raw material is filled into these

wood, brick or mesh compartments and aeration systems used, are similar to those of the above described windrow systems.

- **Trench and pit composting**
  Trench and pit systems are characterised by heaps which are partly or fully contained under the soil surface. Structuring the heap with bulky material or turning is usually the choice for best aeration, although turning can be cumbersome when the heap is in a deep pit. Leachate control is difficult in trench or pit composting.

3.3 Key Factors of the Composting Process

The **key factors** affecting the biological decomposition processes and/or the resulting compost quality are listed below. They comprise:

- Carbon to nitrogen ratio
- Moisture content
- Oxygen supply, aeration
- Particle size
- pH
- Temperature
- Turning frequency
- Microorganisms and invertebrates
- Control of pathogens
- Degree of decomposition
- Nitrogen conservation

Detailed description of the significance of the specific factors is explained more in detail in (Strauss, 2000).

The same process parameters valid for composting must be adhered to and play a role in co-composting of human waste together with solid waste. Special attention has to be paid, though, to the ratio at which human waste are co-mixed with other compostable material given their moisture as well as C and N content. Numerous mixing ratios of excreta and co-composted material are provided by Shuval et al. (1981). Dewatered or spadable sludges may be mixed at a volumetric ratio of approx. 1 (sludge) : 3 (solid organic material), whereas more liquid sludges (TS □ 5 %) may be mixed at ratios between 1:5 to 1:10.

3.4 Quality of compost

Gotaas (1956) lists ranges of the main constituents in final composts as reported in reviewed publications Table 3-1. The quality varies widely and depends on the initial mixture of material to be composted.

Table 3-1 Ranges of Constituents in Finished Compost

Constituent	Range (% of dry weight)
• Organic matter	25 – 50
• Carbon	8 – 50
• Nitrogen (as N)	0.4 – 3.5
• Phosphorus (as P_2O_5)	0.3 – 3.5
• Potassium (as k_2O)	0.5 – 1.8

Source: Gotaas, 1956

Compost which is dry (35% moisture or below) can be dusty and irritating to work with, while compost that is wet can become heavy and clumpy. The Composting Council (2000) recommends 40 % moisture for ideal product handling.

Usually, mature compost is sieved prior to sale and use. Sieves made of a wooden frame and wire mesh are suitable and can be easily made. Mesh sizes vary

according to the compost users requirements. Used as plant fertiliser, a mesh size of 10-20 mm could be chosen, for use as seedling production mesh sizes may be around 3 mm. The compostable sieving residues of larger particle size are usually recycled to windrows for further composting.

Table 3-2 Proposed Standards for MSW Compost in Developing Countries

Heavy metals	Proposed standards [ppm]
Arsenic	10
Cadmium	3
Chromium	50
Copper	80
Lead	150
Mercury	1
Nickel	50
Zinc	300

Source: Hoornweg et al. 2000

3.5 Quality Obtained by Co-composting Human Waste

3.5.1 Nutrient Content

Nutrient contents of composts, which have been produced from co-composting human waste (faecal or sewage treatment plant sludge) are shown in Table 3-3. In theory, such compost should exhibit higher nutrients than compost, which is produced from such material as organic municipal refuse, woodchips, sawdust, i.e. material with N contents lower than in human waste. However, the data show that nutrient, notably N, contents do not range particularly high when compared with the ranges listed in Table 3-1, which were collated from many references and for composts produced from many different raw materials, including human waste.

Table 3-3 Nutrient Levels in Compost Using Human Waste as one Raw Material

Constituent	% of dry weight	Reference
• **Nitrogen (as N)**	1.3 – 1.6	Shuval et al. (1981)
	1.3	Obeng and Wright (1987)[1]
	0.35 – 0.63	Kim, S.S. (1981)[2]
	0.45	Byrde (2001)[3]
• **Phosphorus (as P2O5)**	0.6 – 0.7	Shuval et al. (1981)
	0.9	Obeng and Wright (1987)[1]
		Kim, S.S. (1981)[2]
• **Potassium (K2O)**	---	Shuval et al. (1981)
	1.0	Obeng and Wright (1987)[1]
• **Organic matter (% TVS)**	12 - 30	Kim, S.S. (1981)[2]
• **Carbon (C)**	46 – 50	Shuval et al. (1981)
	13	Byrde (2001)[3]

[1] **Chosen as "typical values" by the authors in their chapter on the economic feasibility of co-composting**

[2] **Raw material composed of varying ratios of FS (TS = 4 %), household waste and straw**

[3] **Raw material composed of municipal solid waste and FS**

The reason for composts produced from human waste not exhibiting higher nutrient contents than other compost (as judged from the limited data available) might be due to nitrogen (ammonia) losses during pre-composting storage and treatment (e.g. by dewatering on sludge drying beds) of the human waste.

3.5.2 Control of Pathogens

A good operation of aerobic composting should be able to kill all pathogenic microbes, weeds and seeds especially if the temperature can be maintained between 60 and 70 degrees for 24-hour period. Table 3-4 below illustrates the thermal kill of pathogens and parasites.

Scott (1952) investigated *Ascaris* egg die-off during thermophilic composting in stacks, in which the composting material was turned every 5-10 days. The result shows that complete egg die-off was achieved within seven weeks. Greater than 95 % egg die-off was achieved within little more than three weeks already, though. These periods reflect the time required for *Ascaris* eggs to "disappear" from all sections of a windrow, hence it is dependent on the composting operations. This can be achieved by windrow turning or, alternatively, by mechanically aerating a static, non-turnable, pile.

The duration for thermal inactivation of excreted pathogens at the upper temperatures attained in thermophilic composting, are much shorter, though. Table 3-4 lists die-off periods at temperatures constituting thermal death points for a few selected pathogens.

Table 3-4 Thermal Inactivation of Selected Excreted Pathogens

Microorganism	Duration for Thermal Inactivation
Escherichia coli	Death within 1 hour at 55 ^{o}C and within 15-20 minutes at 60 ^{o}C
Salmonella sp.	Growth ends at 46 ^{o}C; death within 30 minutes at 55-60 ^{o}C and within 20 minutes at 60 ^{o}C
Entamoeba histolytica cysts	Death within a few minutes at 45 ^{o}C and within a few seconds at 55 ^{o}C
Taenia saginata	Death within few minutes at 55 ^{o}C
Ascaris lumbricoides eggs	Death in less than 1 hour at temperatures over 50 ^{o}C

Source: Tchobanoglous et al. 1993

A general rule of thumb for pathogen suppression is to maintain the composting process at 55^{o}C to 65 ^{o}C for 3 consecutive days (Tchobanoglous et al., 1993).

3.6 Benefit of Using Compost in Agriculture

Benefits derived from compost are numerous and have been well documented in the literature. Compost amendment in the soil affects the physical, chemical and biological characteristics of soils. It also enhances suppression of soil borne pathogens.

3.6.1 Influence of Compost Amendments on Physical Properties of Soil

Compost amendments to soil can significantly improve soil physical parameters such as moisture content, structure, workability, insulation, penetrability of roots and reduce erosion. Soil organic matter (SOM) (Martinez *et al.,* 1999; Soumare *et al.,* 2002), particulate organic matter (McSpadden-Gardener *et al.,* 2002) and organic carbon content (Chakrabarti *et al.,* 2000) in tropical soils can be increased by the addition of composts rich in organic matter. As a result of increased organic matter

content the pore size of soil particles increases and the water holding capacity of soils increases. Compost amendments can reduce soil bulk density, increase total porosity, and increase soil water content in various soils ranging from loamy sand to clay textures (Bulluck and Ristaino, 2002; Dick and McCoy, 1993; Soumare *et al.,* 2002). Significant improvements to soil productivity can be achieved through even a marginal improvement of the resistance of tropical soils against extreme dryness or heavy rainfall (GTZ, 1999).

Addition of compost to tropical soils, which are often low in organic matter will make the soil easier to cultivate and improve its water holding capacity, preventing cracking and erosion by wind and water (Winblad and Kilama, 1978 and 1980). Obeng and Wright (1987) have summarised published information on the impact of using compost on clayey or sandy soils as shown in Table 3-5.

Table 3-5 Impact of Compost on Clayey and Sandy Soils

Impact on sandy soils	Impact on clayey soils
Water content is increased	Aeration of soil is increased
Water retention is increased	Soil permeability is increased
Aggregation of soil particles is enhanced	Potential crusting of soil surface is reduced
Erosion is reduced	Compaction is reduced

Source: Obeng and Wright 1987

Compost can reduce the risk of erosion either directly or indirectly. Compost amended soils will have increased soil elasticity which will absorb the impact of large rain drops and help prevent small soil particles from being washed away (GTZ, 1999). The aggregate coalescence of amended soils decreases so that the aggregate framework of the soil is maintained and erosion is delayed (Bresson *et al.,* 2001). This improved structure will help to absorb more precipitation, and reduce pooling and runoff that is associated with water erosion. Indirectly, compost can aid the growth of soil-covering plants which reduce erosion by wind and water (GTZ, 1999).

3.6.2 Influence of Compost Amendments on Chemical Properties of Soil and Plants

Like all chemical inputs to soils, compost amendments influence the chemical properties of soils such as pH, CEC, salinity, and nutrient content. The organic matter content of composts can bind protons from the soil solution thereby increasing soil pH levels in amended soils (Wong *et al.,* 1998). Three tropical soils from Sumatra, Burundi and Cameroon experienced an increase in pH when amended with 1.5% (w/w) of plant residue compost, an urban waste compost, farmyard manure and peat (Wong *et al.,* 1998). Similarly, increases in soil pH due to composts amendments to two agricultural soils in Mali were observed by Soumare *et al.* (2003). Compost amended soils develop the ability to store larger amounts of cations in plant available form and to prevent them from being washed away (GTZ, 1999). The cation exchange capacity of soils is tremendously important and directly reflects the nutrient holding capacity of the soil. Bationo and Mokwunye (1991) reported that in the Sudano-Sahelian zone, the effective cation exchange capacity (ECEC) is more correlated to organic matter than to clay, indicating that an increase in organic matter content through compost ammendments will increase the ECEC, and subsequent nutrient holding capacity of those soils.

Compost field trials in the tropics have shown similar results to experiments conducted in temperate climates. Applications of sugarcane compost at 50t/ha 2-3 times a year increased soil-N considerably compared to treatments without compost (Midmore, 1994). Improved growth and yield of tomato was observed when a litter

compost was applied to sandy agricultural soils in Senegal at rates of between 10-40 t/ha (Soumare *et al.,* 2002). High application rates of compost in the tropics can lead to crop damage or contamination of food by toxins. High applications of 400t/ha of a sewage sludge compost on cassava in Puerto Rico resulted in a reduction in commercial yield (Martinez *et al.,* 2001)

3.6.3 Influence of Compost Amendments on Biological Properties of Soils

The biological properties of soils can experience significant changes due to compost amendments. The addition of organic substances to soils encourages the growth of many soil organisms. Populations of bacteria (Bulluck and Ristaino, 2002; Drinkwater *et al.,* 1995; Lazarovits, 2001; Pascual *et al.,* 2000; Smolinska, 2000;Tuitert *et al.,* 1998) fungi (Bulluck and Ristaino, 2002; Bulluck *et al.,* 2002a; Lazarovits, 2001; Pascual *et al.,* 2000; Smolinska, 2000), nematodes (Bulluck *et al.,* 2002b), Collembola (Miyazawa *et al.,* 2002), and Acari (Miyazawa *et al.,* 2002) are increased due to additions of organic matter to soils. Furthermore, microbial activity measured either as basal respiration (Bhattacharyya *et al.,* 2001; Blok *et al.,* 2002) or enzymatic activity (Bhattacharyya *et al.,* 2001; Madejon *et al.,* 2001; Pascual *et al.,* 2000) is increased through organic amendments. These increases in microorganism population and activity are dependent upon the availability of consumable substrate in the compost. Inhibition of substrate consumption can sometimes occur if the compost contains concentrations of heavy metals or saline ions that are phytotoxic to soil microorganisms (Brookes and McGrath, 1984).

3.6.4 Disease Suppression by Composts

Improved soil health, measured by a reduction in soil-borne plant diseases, may be achieved through organic amendments such as composts or green manures. Compost amended growing media can achieve consistent and sustained control of diseases caused by soil-borne plant pathogens (Hoitink and Boehm, 1999). Green manures or incorporated plant residues can also have inhibitory effects on pathogen activity, and may be used to decrease the incidence of some soil-borne diseases (Smolinska, 2000; Keinath, 1996). Four principal mechanisms of biological control of compost-amended soils have been identified: (a) competition, (Loper and Lindow, 1993). (b) antibiosis, (Handelsman and Stabb, 1996) (c) parasitism/predation, (Hoynes et al., 1999, Smolinska, 2000) and (d) systemic resistance (Hoitink and Boehm, 1999). (Pieterse et al., 1998) (Heil, 2001

Cases of suppression of soil borne diseases in compost amended soils are well documented (Erhart et al., 1999, Hardy and Sivasithamparam, 1991; Kwok et al., 1987) (Quarles and Grossman, 1995). Crop residues, animal manures and agro-industrial wastes used in composts have shown some success as disease suppressive composts. (Bulluck and Ristaino, 2002; Gorodecki and Hadar, 1990; Szczech,1999).

Studies concerning disease suppression of composts made from biowastes, organic household waste or municipal solid waste (MSW) are few (Blok et al. 2002, Pascual, et al., 2000). Tuitert et al. (1998) found that competition or antibiosis, or a combination of both is responsible for the suppressiveness of *Rhizoctonia solani* in cucumber exerted by mature compost made from organic household wastes.
The disease suppression of composts derived from municipal sewage sludge has been researched and attempted in temperate climates. Lumsden et al.(1983) Kuter et al. (1988) . Co-composted sewage sludge, animal and vegetable wastes applied at a 10 vol% significantly reduced the disease severity of Fusarium wilt on tomato in Spain (Cotxarrera et al., 2002).

Certain microorganisms found in compost suppress detrimental organisms like root-eating nematodes and specific plant diseases. Strengthened root systems reduce the need for pesticide use.

The Composting Council (2000) summarises the benefits of compost as follows:

- improves soil structure, porosity and density thus creating a better plant root environment
- increases infiltration and permeability of heavy soils, thus reducing erosion and runoff
- improves water holding capacity thus reducing water loss and leaching in sandy soils
- supplies a variety of macro and micronutrients
- may control or suppress certain soil borne plant pathogens
- supplies significant quantities of organic matter
- improves cation exchange capacities of soils and growing media thus improving their ability to hold nutrients for plant use
- supplies beneficial microorganisms to soil and growing media
- improves and stabilises soil pH
- can bind and degrade specific pollutants

3.7 Case-Studies on Co-composting

Scott (1952) reports extensively about the combined composting of faecal matter with a variety of other organic materials as practiced in China over centuries. Experiments with material available on farms, i.e. human excreta, animal manure and crop residues focused on nutrient (notably nitrogen) conservation and pathogen (notably helminth egg) inactivation. Scott and his co-workers found the following:

- *Ascaris* egg destruction was 95 % complete after 22 days and 100 % complete after 36 days in a stack whose contents were turned every 5-14 days and reached 60 ^{o}C after each turning.
- Nitrogen losses from raw materials and from compost exhibiting differing degrees of degradation during drying are significant. The losses found were approx. equal to the ammonia contents of the fresh material. The loss of nitrogen during co-composting amounted to about 50 % of the initial nitrogen present. The greatest loss occurred during the initial 5-10 days of composting.
- Omission of ash was assumed to have contributed to a lowering of N losses.
- Cooling the stacks with soil after the first few days of hot composting helped to considerably reduce nitrogen losses.

Shuval et al. (1981)[3] reviewed literature and collated information on historical and actual practices of co-composting "nightsoil"[2] and (sewage) sludge. Cases of excreta co-composting are reported about from India, China, Africa (e.g. Kano, Nigeria) where fresh faecal sludge collected from bucket latrines and frequently emptied latrine vaults were co-composted. The bulking material comprised various forms of household refuse and plant residues. Most of these composting initiatives and operations are reported as having been rather successful and producing compost at a regular rate. While many of the reported schemes may not be operational anymore nowadays, since they were initiated and operated under colonial administration, considerable informal co-composting is doubtlessly being practiced in many countries around the world.

Shuval et al. (1981) and Obeng and Wright (1987)[3] reported on numerous schemes in the U.S.A. and Europe, mainly, and on windrow or open systems, in which sewage

[2] This comprises, in most reported cases, the fresh faecal material, with or without urine, collected daily from households bucket latrines or at larger intervals from latrine pits or vaults

[3] Both Shuval et al. (1981) and Obeng And Wright (1987) use the term "composting" as encompassing either anaerobic, ambient-temperature degradation or "hot", aerobic and

treatment plant sludge ("biosolids") are or were composted together with other organic material, notably municipal refuse. All these installations make use of lower or higher degrees of mechanization. While the biochemical and pathogen inactivation processes are the same as in non-mechanised systems, mechanised co-composting schemes are largely inappropriate for developing countries except possibly in situations where there is a high demand for the product and it can be sold at high prices.

Shuval et al. (1981) provides detailed accounts of static pile or windrow co-composting works operated with forced aeration according to the Beltsville Aerated Rapid Compost ("BARC") system developed by the U.S. Department of Agriculture research station at Beltsville, Maryland, in the 1970-ies. Several hundreds of this type of co-composting system is in operation in the U.S.A. nowadays (Goldstein and Riggle, 1989). The original BARC system co-composts dewatered sewage sludge (TS = 20-25 %) and wood chips in ratios of around 1 (sludge) : 2 (wood chips). Windrows are covered with finished compost for insulation, moisture conservation and to prevent birds from feeding on fresh waste. Shuval et al. (1981) also report on a BARC-type scheme co-composting faecal sludge collected from latrine vaults in a national park with wood chips, sawdust and finished compost. The sludge (TS = 5 %) is mixed at a ratio of 1 (sludge): 3.2 (other org. material). Finished compost contained 1.3-1.6 % nitrogen on a dry solids basis. Compost storage for one year did reportedly not lead to nitrogen losses.

Shuval et al. (1981) and Obeng and Wright (1987) also reported on economic, agronomic and marketing aspects of co-composting and its respective product. In Europe and North America, mainly digested and dewatered sewage sludge is being processed in co-composting works. Cited investigations focused on the hygienisation effect of the process, mainly, and on the fate and concentrations of heavy metals in the finished product. Shuval et al. (1981), citing Julius (1977), remarks on the importance of proper and sustained compost marketing strategies, which are to comprise the demonstration of agricultural benefits of compost on trial plots, training, extension and awareness raising.

There are, doubtlessly, numerous co-composting activities and schemes in operation in developing countries, both formalised and informally operated ones, yet respective information has not been publicised. The following are schemes or practice, which are known to the authors either through retrievable literature, through personal communications or from own field visits:

Septage Co-composting –Massachusetts, U.S.A
A ***septage co-composting*** pilot plant was commissioned in the state of Massachusetts in 1977 to test the feasibility of co-composting of septage (Lombardi, 1977) following prohibition of admixing of septage to the wastewater treatment plant.

Latrine sludge co-composting –Port-au-Prince, Haiti
A ***pit latrine sludge co-composting*** pilot scheme was initiated at Saint Martin, a suburb of Port-au-Prince. A BARC-type composting system was installed, using forced-aerated windrows. Pit latrine sludge and partially composted refuse were mixed at a ratio of 5:1 to form piles of 21 m^3. Preliminary results from greenhouse planting trials indicated that the use of co-compost yielded "significantly greater plant growth and yield response" as compared to the use of refuse compost.
Bucket latrine sludge co-composting – Rini/Grahamstown, South Africa
An example of recent ***co-composting*** *operations using* ***bucket latrine sludge and MSW*** is the demonstration scheme at Rini near Grahamstown, South Africa (La Trobe and Ross 1992). The plant was commissioned in late 1992, following a two-

thermophilic dagrdation of organic matter. The authors of this report, however, prefer the term "composting" to exclusively designate the hot process.

year trial phase on pilot scale. The scheme became redundant, though, following the conversion of the bucket latrines into sewered toilets in 1997. In spite of this, the authors consider worthwhile to provide here a description of the plant and its operation.

Figure 3-1 Sprinkling FS over refuse at the Rini/ Grahamstown (South-Africa) co-composting plant

Figure 3-2 Sieving of matured compost in a rotary sieve at the Rini/Grahamstown (South Africa) co-composting works

The plant consisted of forced-aerated, static windrows. The faecal sludge was delivered to the station by a tractor-drawn vehicle daily. It was then screened and collected in a pump sump from where it was pumped by a macerating pump to two overhead, cone-shaped settling/thickening tanks. The tank supernatant was treated in waste stabilisation ponds, which were earlier receiving the bucket latrine sludge. The thickened FS (TS = 5 %) was gravitated over the windrow as the mixed refuse was being heaped up (Figure 3-1). Final windrow size amounted to around 100 m^3. The windrow was covered with finished compost for insulation and bird control. The volumetric mixing ratio was approximately 1:10 (FS:refuse). Measuring temperature at different spots of the windrow controlled the process. Temperatures of 55 °C were reached and the windrows left to react for 3 weeks. The compost was let to mature for another 3 weeks. The matured compost was sieved (Figure 3-2) and the rejects landfilled. The Grahamstown garden department used the compost. The finished compost was reportedly free of helminth eggs. Unfortunately, no scientific data were generated or published about this valuable co-composting experience.

Co-composting of biosolids from an FS pond treatment scheme –Cotonou, Benin

A pilot co-composting scheme is currently (October 2002) being implemented in Cotonou, Benin, as part of an action research programme of CREPA aiming at improvements in FS management (CREPA Benin, 2002). **Biosolids** generated in an FS pond treatment system will be co-composted with municipal refuse. Comparative planting trials will be conducted with co-compost and other plant/soil amendments.

Co-composting of solid waste and night-soil in Accra, Ghana

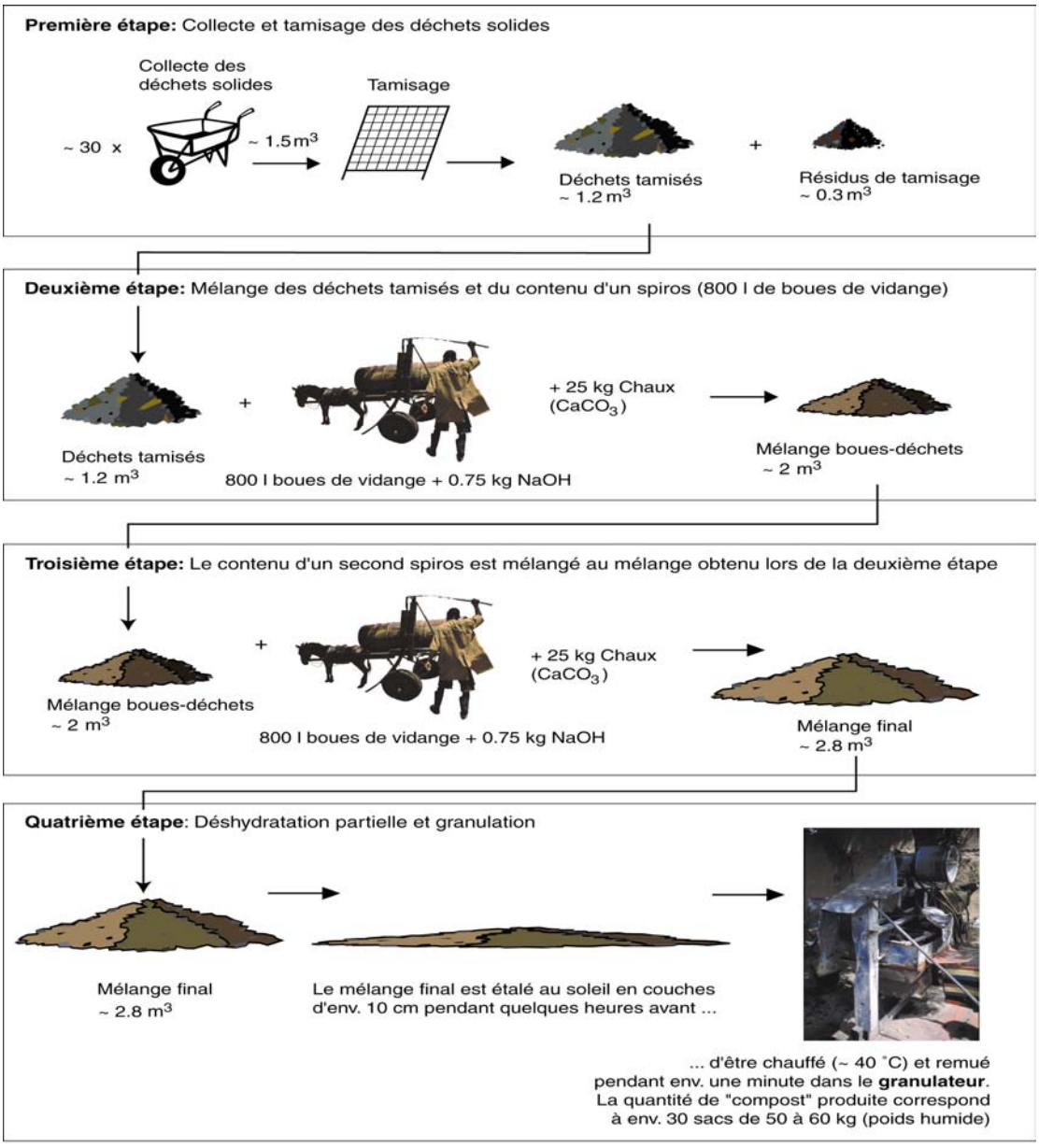
The composting plant at Teshi-Nungua in Accra was established in 1979 and started production in 1980. The plant has a site for composting solid household waste as well as a site for night-soil treatment. Theoretically, it can produce about 20 t compost per hour, which is approximately 38,000 t annually. For the composting process, it was originally planned that daily solid and liquid wastes are treated at the plant by windrow composting. However, the malfunction of the turning machine (payloader) made the whole system ineffective. For various reasons such as lack of

electricity, water, and technical problems, it has gradually become a near total disposal site. Because of the long storage period, much of the solid household waste has turned into compost by itself and mainly needs to be separated and sieved.

Co-composting of latrine sludge with organic refuse in Niono, Mali

A small fraction of the **pit latrine sludges** generated in the town of Niono, Mali (pop. =28,000) is **co-composted** with sorted refuse by a microentrepreneur. Faecal sludges are collected manually or by tractor-drawn vacuum tanks. The compost is sold to rice and vegetable farmers (Montangero and Strauss 1999). Figure 3-3 illustrates the processing of the FS with refuse and lime. Sieved refuse, liquid FS and lime are made up in batches of approx. 2.8 m3, let to sun-dry and then processed in the heated pelletizer (ret. period approx. 1 min.). The ratio of sieved refuse to liquid FS amounts to 1:1.3. Hence, lime (CaCO3) is added to dewater the liquid sludge.

The process allows inactivating excreted pathogens considerably, yet drying periods are too short and heating temperatures too low to achieve a reasonably safe "compost" all the time.



Source: Montangero and Strauss 1999

Figure 3-3 Co-composting of FS and sorted MSW in Niono, Mali

The hygienic quality of the end product may vary as a function of the concentration of parasites (helminth eggs) in the raw FS and on operational care taken during treatment.

A proposal was made to upgrade this non-thermophilic co-composting system into thermophilic processing by resorting to a scheme comprising sludge drying beds for FS dewatering followed by "hot", turnable windrow composting of the sludge cake/refuse mixture. This would enable effective and reliable inactivation of excreted pathogens. The authors do not have information, though, whether such changes of treatment technology have been effected meanwhile or not.

Despite the relative simplicity of composting, its suitability for developing countries and its compelling economic and environmental benefits, many projects initiated over the past decades in middle and lower-income countries have failed due to technical, financial and institutional reasons. Asomani-Boateng *et al* (1999) describe how African countries built ill fated, and highly sophisticated, mechanized municipal solid waste compost plants with the aid of foreign capital and other logistical assistance during the 1970s and 1980s.

3.8 Conclusion

Based on the foregoing review, the following conclusions regarding co-composting of FS and organic solid wastes can be made:

- Faecal sludges can be co-composted with any biodegradable, organic material if the rules of the art in process control are adhered to.
- Mixing ratios reported about in the literature vary widely, depend on the type of organic bulking material co-composted together with faecal matter, the consistency of the FS itself, the degree of dewatering prior to composting, and the co-composting practice and care.
- Reported mixing ratios of dewatered FS (TS = 20-30 %) and other, more bulky organic material tend to range from 1:2 to 1:4. For fresh, non-dewatered FS, ratios used and reported about tend to range from 1: 5 – 1:10.

- Factors contributing to minimising nitrogen losses during thermophilic composting comprise:

    - Keeping the maximum temperatures below 65 °C
    - Keeping the periods of maximum temperatures as short as possible
    - Limiting the frequency of turning
    - Keeping the water content of the composting material as high as possible (50-70 %)

- A combination of factors accounts for why few urban areas have been able to successfully construct and operate composting plants in developing countries.
- There is the need to investigate the technical as well as organisational, institutional, and financial aspects of co-composting as only scanty information is available on existing experiences

Part C

Methodology

4 METHODOLOGY

4.1 Plant Description

A pilot co-composting plant was established in February 2002 at Buobai, at the outskirts of Kumasi, about 15km eastward from the city centre. It is located on a faecal sludge treatment plant site (FSTP) of KMA. The pilot plant covers a total area of about 500m$^{2.}$ It consists of three main components viz: dewatering section, composting section, and offices/storeroom. Plant layout is presented in Figure 4-1.

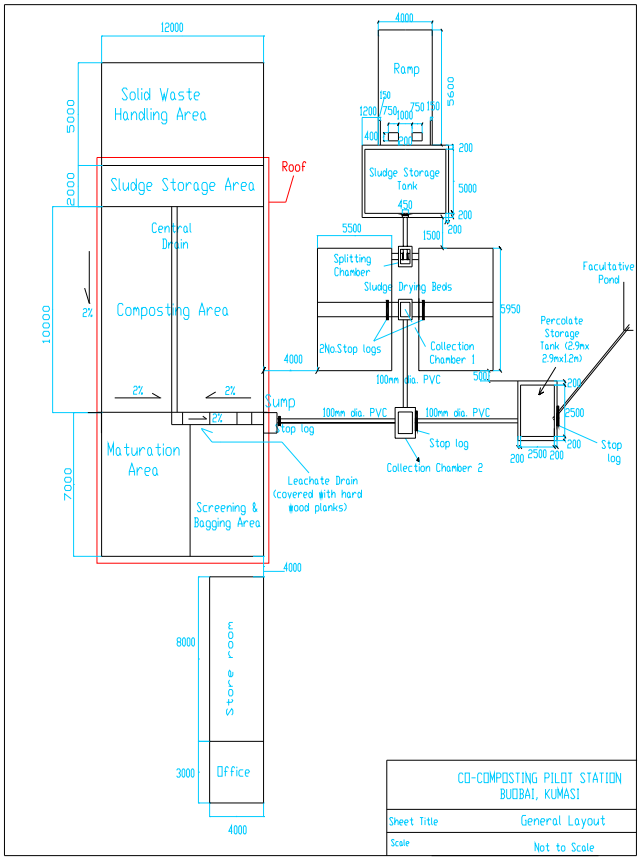


Figure 4-1 Outlay of the Pilot Co-compost Plant Showing the Various Sections

The plant is made up of:

- **Dewatering Area;** which consists of:
  Access Ramp, Stopping Blocks, Sludge Storage Tank, Drying Beds, Inlet and Outlet Drains, Splitting and Collection Chambers, Percolate Storage Tank
- **Composting Area;** which consists of:
  Solid Waste Handling Area, Dewatered Sludge Storage Area, Composting Area, Maturation Area, Screening and Bagging Area
- **Office** for the plant manager and **Storeroom** for bagged compost, tools and other supplies.

Table 4-1 contains the design criteria and assumptions.

Table 4-1 Design Criteria/Assumptions

Faecal Sludge Dewatering	▪ 3 dewatering cycles per month ▪ 3 sludge trucks per dewatering cycle (1 truck ~ 5 m^3) ▪ 15 m^3 per cycle ▪ Ratio: public toilet sludge (PTS) to septage 1 : 2 ▪ 1 truck containing PTS, 2 trucks containing septage ▪ Sludge storage tank (monitoring raw sludge mixture): 15 m^3 ▪ Sludge drying beds 15m3/30cm (fresh sludge layer): 50 m^2 ▪ Assume sludge volume reduction through dewatering: 90% ▪ Assume dewatered sludge production: 1.5 m^3/cycle, 4.5 m^3/month
Composting	▪ Ratio: solid waste to dewatered sludge 3:1 ▪ Composting time: 1 month thermophilic + 1-2 months maturation ▪ 1 composting cycle starting each month ▪ Sorted solid waste 3x4.5m^3/month: 13.5 m^3 ▪ Unsorted solid waste delivery: ca. 27 m^3/month (for 50% organic waste in household waste) ▪ Raw compost: 18 m3/month (4.5+13.5), 6x3m^3 windrows ▪ Mature compost: ca. 9m^3/month (volume reduction: 50%), ca. 4.5t/month

4.2 Technical And Operational Aspects

4.2.1 Plant Operation

Various activities were carried out at the plant. These are presented in a flow chart in Figure 4-2 and further elaborated in subsequent sections below. Collection and transportation of FS and SW to the plant were carried out by the waste management department (WMD) of KMA at no expense to the project.

Personnel Requirements

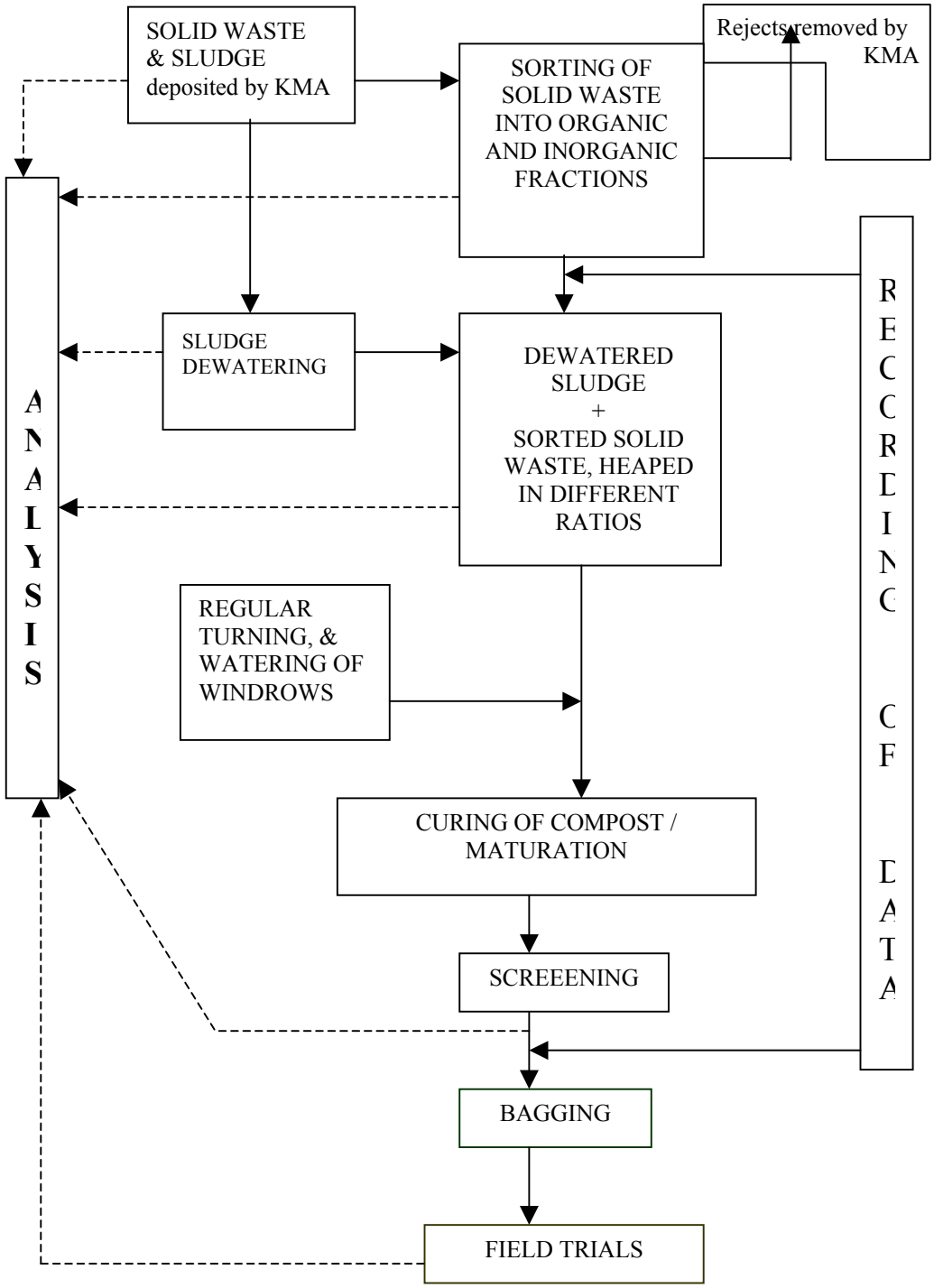
For efficient operation of the pilot plant there was the need for certain activities to be carried out by some personnel and organisations.

A **plant manager** was responsible for the overall management of the treatment plant and was responsible for:

- ordering through the Waste Management Department (WMD) of KMA the faecal sludge and solid waste delivery at the appropriate times
- supervising the faecal sludge loading onto the drying beds
- supervising desludging of the drying beds when the dewatered sludge was sufficiently dry
- supervising the solid waste sorting
- supervising the making of the heaps as well as turning and watering of the heaps, sieving and bagging of the mature compost
- supervising the monitoring of the pilot plant
- paying the workers

Two **workers** were in charge of:

- mixing the three sludge loads in the sludge storage tank
- desludging the drying beds
- sorting the solid waste
- making the compost heaps, turning and watering them when necessary
- sieving and bagging the mature compost



----- **Sampling Path**

Figure 4-2 Operational Processes at Buobai Co-compost Plant

The **WMD** was responsible for:

- delivering faecal sludge and solid waste to the pilot plant and
- transporting the sorted non compostable waste to the landfill

MSc students were responsible for

- monitoring of the drying beds
- monitoring of the composting and
- conducting field trials with the compost

4.2.2 Dewatering of FS

Pilot drying beds were designed and built based on lessons learnt from the experiment conducted in Accra between 1995 and 1997.

The purpose of the FS dewatering step was to facilitate the mixing of sludge with SW and to obtain a compost mixture with an adequate water content and structure for aerobic composting. For this purpose, unplanted drying beds of different layers of gravel and sand were used. There are two drying beds. The surface area of each bed is 5.0m x 5.0m giving each bed an effective drying area of 25m^2. The beds are made up of three layers, with each layer having a different thickness/depth and a different particle size. Table 4-2 below shows the various layers and the function each performs.

Table 4-2 Characteristics of Drying Bed Layers

Layer	Location	Function	Thickness	Particle Size
1.	Bottom	Supporting	150mm	19mm
2.	Middle	Supporting	100mm	10mm
3.	Top	Filter layer for gravity percolation	150mm	0.2-0.6mm

The top layer acts as a solid-liquid separator by retaining the solid part. It is therefore important to pay particular attention to the quality of sand for this layer. The size and uniformity of the grains affect the performance and the amount of faecal sludge that can be treated. Effective sizes for sand filter media range from 0.3mm to 0.75mm in diameter. A uniformity coefficient of four or less is recommended for all filter media (Metcalf & Eddy). These requirements are applicable to the treatment of wastewater. No specific values have been found for faecal sludge. During this field investigation sand layer was topped after each desludging and bed washing was done occasionally.

For each dewatering cycle, 3 trucks discharged their FS load in the sludge storage tank. Dewatered sludge was desludged once it was dry enough to be shovelled out and stored prior to co-composting with sorted organic solid waste. The percolate is first collected and monitored in a percolate storage tank from where it flows into an existing waste stabilisation pond system.

Sludge dewatering was monitored for 9 cycles between February and December 2002: cycles 1 to 9. Cycle 2 could not be monitored because the filter layers had been damaged during the first cycle and sludge loaded at the beginning of cycle 2 could not be retained on the beds. Cycle 6 was unusually prolonged due to more damage on the filter layers leading to stagnation of sludge on the bed. For each cycle, three trucks (each 5 m^3 volume) discharged their loads in the storage tank prior to drying beds loading. It was planned that two of the three trucks should deliver

septage whereas the third one public toilet sludge to allow characterisation of the FS mix. However, this could not be observed for some of the cycles. Raw sludge was sampled before loading onto the beds whereas dewatered sludge and percolate were monitored during the entire dewatering period. The raw sludge sample consisted of several sub-samples taken in the sludge storage tank directly after the three sludge loads had been thoroughly stirred. Figure 4-3 illustrates the location of the sampling points. Dewatered sludge samples were taken every two to three days and at the end of the drying cycle. Three points were selected on each bed. The sludge at each selected point was stirred till it became homogenous (if the sludge was still relativelywet), an equal volume was taken from each point, and mixed together and a portion taken for analysis. Dewatered sludge was desludged once it is dry enough to be shovelled out and is stored prior to co-composting with sorted organic solid waste. The percolate flows into an existing waste stabilisation pond system. Percolate samples were taken daily (composite sample of one day percolate flow) and kept in the fridge. Samples taken on the first day, the last day and a composite sample (from the whole percolating period) were analysed in the laboratory. The daily flow rate was also determined.

Plate 4-1 Septic Emptier Discharging into the Sludge Storage Chamber

Plate 4-2 Photo of Drying Beds

COD, BOD, SS, TS, TVS, HE, pH and conductivity were analysed in raw sludge samples following methods outlined in Standard Methods for the Examination of Water and Wastewater" Greenberg *et al* 1995), (Detailed analytical procedures are given in Annex). TS, TVS and TKN were analysed in dewatered sludge samples. Temperature, turbidity, conductivity, TS, SS, pH, DO, COD, BOD, NH_3, TKN, NO_3, PO_4, FC and HE were analysed in the percolate.

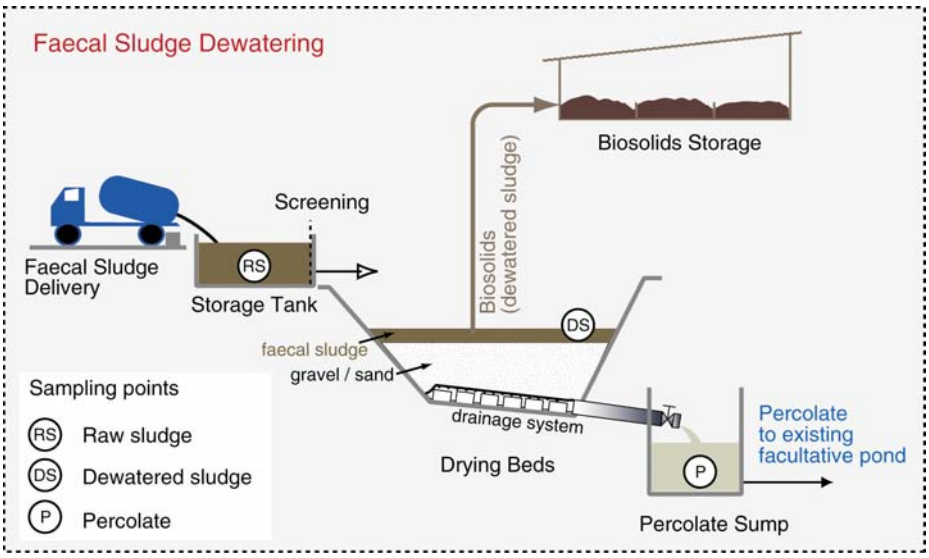


Figure 4-3 Faecal Sludge Dewatering – Sampling Points

4.2.3 Co-composting of FS and SW

Monitoring of the composting process aimed at:

- knowing the necessary composting/maturation time under the Kumasi conditions (climatic conditions as well as type of waste composted)
- knowing whether a dewatered sludge/solid waste mixing ratio of 1:2 or 1:3 allow aerobic composting
- knowing whether helminth eggs (present in dewatered sludge) are inactivated during composting
- knowing the quality and the quantity of the mature compost
- knowing the costs of the compost production (see chapter on economic analysis)

Household and market waste were delivered to the pilot plant, sorted, mixed with faecal sludge previously dewatered on the pilot drying beds and composted. The composting plant consisted of a composting platform equipped with a drainage system and covered by a roof. Solid waste was delivered to the pilot plant by the Waste Management Department (WMD) of the Kumasi Metropolitan Assembly (KMA). Two plant workers carried out the solid waste sorting using sticks and rakes. They were also responsible for making the compost heaps, turning and watering them when necessary and also sieving and baging the mature compost. Inorganic waste (rejects) was transported to the landfill by the WMD. Water for personal hygiene and for watering the heaps was supplied at the initial stage by water tankers from WMD. Later, a well that was dug at the treatment site was used on the project and by the workers for their personal needs.

Plate 4-3 Compost Windrow

Plate 4-4 Sample of Compost Bags

Three composting cycles were monitored from February – December, 2002. Only one heap of 0.86m^3compost was formed during the first cycle (trial cycle) whereas four heaps of 3 to 4 m^3 were set up and monitored during the second cycle. In the third cycle, Dewatered faecal sludge (DFS) obtained during the dewatering cycles 1 and 3 were mixed together and co-composted with solid waste in the first two composting cycles. Whereas sludge from cycles 4 to 6 were used for composting cycle 3. Sorted household waste (HW) was co-composted with dewatered sludge in cycle 1 and both sorted household and sorted market waste (MW) were co-composted with dewatered sludge in the other cycles. Heaps in the third cycle were made in duplicates. Another treatment consisting of poultry manure (PM) and HW was added during the third cycle to compare its composting process and quality with heaps containing faecal sludge.

Table 4-3Constituents of compost heaps

Composting cycle	Constituent of compost heaps						Period of composting& maturation
	Heap1	Heap 2	Heap 3	Heap 4	Heap 5	Heap 6	
Cycle 1 (Trial)	HW:DFS 3:1	-	-	-	-	-	10 Weeks
Cycle 2	MW: DFS 3:1	HW: DFS 3:1	MW: DFS 2:1	MW only	-	-	12 Weeks
Cycle 3	HW:DFS 3:1	HW:DFS 3:1	MW:DFS 3:1	MW:DFS 3:1	HW:PM 3:1	HW:PM 3:1	14 Weeks

Operations during Composting

The main activities carried out on the heaps during composting were turning, watering, measurement of temperature, weighing, sampling and laboratory analysis.

Temperature was measured daily at several locations in the heaps (centre, bottom and top). Samples were taken weekly for microbiological and physico-chemical (C, N, pH, moisture) analysis. From each heap, portions of compost were taken from the inner, outer, top, bottom and middle of the heap and mixed thoroughly before samples were taken. Portions were then blended in order to obtain homogenised

samples prior to analysis. K, Ca, Mg, P, Pb, Mn, Cu, Zn, Fe were analysed in compost samples taken at the beginning and end of the composting cycles. Chemical and microbiological analyses were carried out at the Soil Research Institute, Kumasi according to standard procedures (Annex). Volume and weight of compost heaps were determined at the beginning and at the end of the composting. At maturity, compost were sieved through a wire mesh of about 15 mm size and bagged in 50kg bags.

4.3 SOCIO-ECONOMIC ASPECT OF CO-COMPOSTING

4.3.1 Demand for Compost and Institutional Framework for Co-composting

This aspect of the study was done in collaboration with a related IWMI project on municipal waste recycling and urban agriculture in three cities of Ghana with funds from IDRC. The main focus of this aspect of the study is to investigate the perception and market potential of co-compost. The sub- objectives include:

- to know the potential and actual buyers of compost
- to assess their perception and willingness to pay for compost
- to quantify the demand for compost
- to assess institutional perception and propose appropriate institutional framework for co-composting in Kumasi

A total of 200 farmers were interviewed in Kumasi for the study. Questionnaire administration was adopted in the collection of data. The surveys included:

- Identification of potential customers, e.g. the different urban and peri-urban agriculture (UPA) farming systems, estate developers, garden operators, landscape designers, all with and without compost experience.
- This was followed by *stratification* for representative sampling using structured questionnaires (open, closed), and focus group discussions to analyse farmers' perception of co-compost. The interviews were conducted while describing the type of compost (FS + SW) envisaged and showing them samples.
- For the assessment of willingness to pay (WTP) for compost, *contingent valuation* method (CVM) was used. Probit analysis was used to explain variations in farmers' willingness to pay for compost.

On the institutional aspect, scheduled interviews were conducted with different authorities to survey their perceived role in the composting initiative. The following institutions were selected for analysis considering that they play an important role in the provision of sanitation and agricultural extension services.

1) Local government: Kumasi Metropolitan Assembly - Waste Management Department;
2) Area Councils
3) Environmental Protection Agency (EPA);
4) Ministry of Food and Agriculture (MOFA);
5) Metropolitan Health Services (MHS);
6) NGOs: GOAN and GROWTH;
7) Private Sector;
8) Representative of a financial Institution;
9) Area council Assemblyperson.

From the data gathered, an institutional framework for operating a small scale co-composting facility in Kumasi was developed

4.3.2 Economic Appraisal of the Pilot Co-composting Plant

Data from the pilot plant were subjected to economic analysis. This analysis was based on the performance of the pilot plant within the project period so far (one year).

The purpose is to help improve on the management quality by considering the amount invested and estimates the return to the capital and labour. The economic analysis is based on costs and prices that prevailed in 2002, which are adjusted to reflect macro-economic distortions in Ghana in accordance with World Bank standards.

The questions that this analysis seeks to answer are:
(1) Is co-composting suitable for Kumasi Metropolitan Area?
(2) What economic parameters must be adjusted to ensure a sustainable operating regime?
(3) At what levels of operations will the pilot project become cost-effective for replication in other areas?

The central components that constitute the framework for the economic appraisal include investment capital costs, running costs and overall costs; and direct and indirect benefits derived from the waste-processing method. The economic analysis of the investment portfolio was also made to determine the effect of the project on society's welfare. The direct costs and benefits are derived and calculated mathematically from first principles. The economic benefits derived from costs saved from waste transportation and landfill space are obtained from prices prevailing in the local markets, which are then adjusted by an index to reflect economic values, whereas the procedure for converting improvement in health standards into monetary terms has been adopted from Esrey et al (2002) and World Health Organisation estimates.

4.4 Assessment of the Agronomic Benefit of Co-Compost

The main focus of this aspect of the project was to study the agronomic benefits from the use of co-compost in Kumasi by finding out the effects of co-compost on soil characteristics and plant growth under intensive vegetable farming
In this type of farming, plants are either directly seeded or transplanted. The effect of compost in these two methods was studied. The germination success and the initial growth of seedlings of typical urban vegetables were determined for various concentrations of compost in one experiment. In another experiment, the changes to the physical and chemical properties of soil due to various compost applications were measured over three cropping seasons. Lettuce was chosen since it is a transplanted vegetable and has a short cropping season of 4-6 weeks. During this experiment the effects of compost application on yield was also measured. Since the value of compost will improve for every additional function that it provides, the ability of the compost to suppress soil-borne diseases was also studied.

The main sub-objectives were:

- To determine the effects of co-compost on seedling germination and growth for a variety of common urban vegetables.
- To determine the potential for suppression of soil borne diseases in co-compost amended soils
- To test with farmers the use of compost through determination of the changes in lettuce yield, growth and performance due to compost applications and changes in the chemical and physical properties of soil in the experimental plots.

Due to the volume of compost available, only three farmers out of the group interviewed in the perception and willingness to pay studies were able to participate in the field trials.

Plate 4-5 Greenhouse Trials **Plate 4-6 Farmers during Field Trials**

Parameters measured for the various experiments include: shoot length, leaf area, incidence and severity of pathogens, above ground plant weight. Data were subjected to Analysis Of Variance (ANOVA) or regression where appropriate using SPSS ver.10 (SPSS, 1999).

Details of the methodology and experimental design for each of these three experiments are in the Annex.

Part D

Results and Discussions

5 DEWATERING

5.1 Factors Affecting Sludge Drying Time

There are a number of factors affecting the drying of sludge on the drying beds. These factors include rainfall, sand quality or characteristics and degree of stabilisation of public toilet sludge (PTS) as well as its percentage.

Figure 5-1 shows the decrease in sludge depth as well as the increase of the TS content measured in the sludge layer drying on the pilot drying beds. The cumulative rainfall for each cycle is given in Table 5-1 below. For cycles seven to nine, the drying beds were covered. This was due to the heavy rainfall experienced for cycles five and six. The type of coverage is shown in Plate 5-1

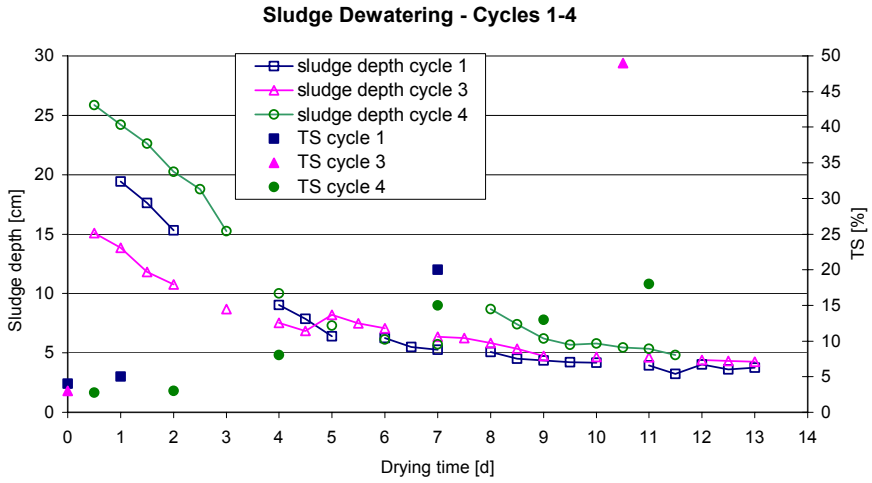


Figure 5-1 Sludge Depth and TS Variation over Time

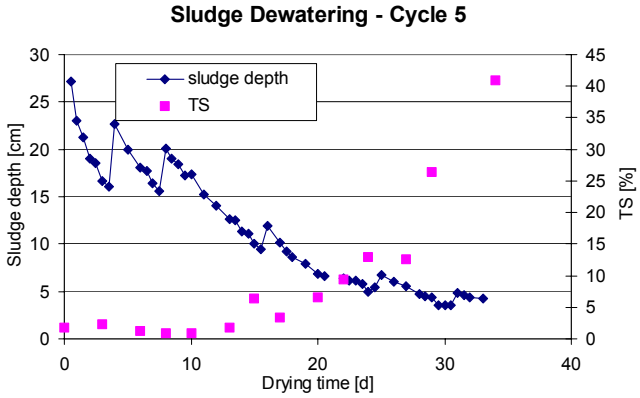


Figure 5-2 Decrease in Sludge Depth and Increase in TS Content Measured in Sludge Drying on the Drying Beds (Cycle 5)

Plate 5-1 Partially Covered Drying Bed

Drying time observed during the Kumasi investigations, were much longer than that for the investigations conducted in Accra: around 8 days for TS content in the dewatered sludge of 40%. But the Accra investigations were carried out during the dry season only, however that for Kumasi was carried out throughout the year (Feb. to Dec.) Several factors are responsible for the slow dewatering.

5.1.1 Impact of Rain on Sludge Dewatering

One important factor was the rainfall during drying. Figure 5-3 illustrates the impact of rain on sludge dewatering on drying beds (cycle 5). Rainwater increased the water content of the sludge especially when the sludge has been freshly discharged. When the sludge was partially dry, cracks formed on the surface allowed the rainwater to pass through without a significant impact on the moisture content. When the sludge was fresh and there was rainfall, the moisture content even tends to increase (see cycle 6) thus hindering the dewatering process.

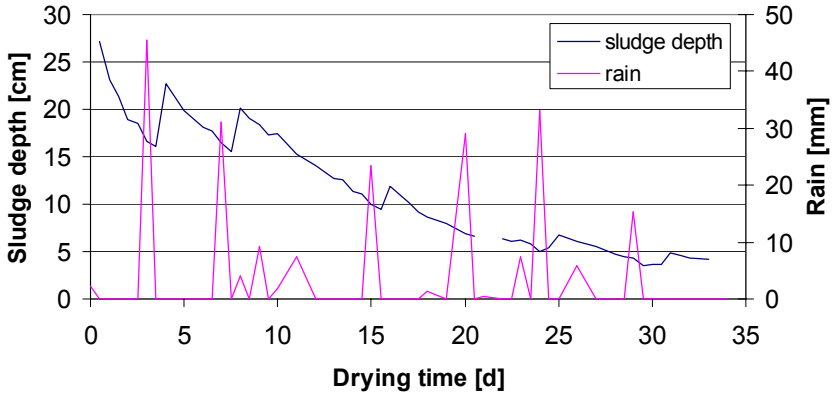


Figure 5-3 Sludge Depth & Rainfall on Drying Beds during Dewatering (cycle 5)

5.1.2 Sludge Stability

The fact that the proportion of fresh, unstabilised sludge to stabilised sludge in the raw sludge mix was very high also played a role as unstabilised sludge does not lend itself to dewatering and does not drain rainwater efficiently. However, no correlation between the percentage of public toilet sludge in the raw sludge or the stability of the raw sludge (TVS) and the drying time can be established with the data obtained. Neither does the TS load correlate with the drying time.

5.1.3 Characteristics of Sand Layer

Another important factor for sludge dewatering on drying beds is the characteristics of the sand. It was shown that the proportion of small sand particles (< 180 μm) in the sand used to form the upper filter layer of the Kumasi drying beds increased with time. It is supposed that the sand used was not of good quality, sand particles crumbled.

This implies that infiltration rate decreases and filter tends to clog. This could also explain why drying time increased in cycles 4 to 6. However, the database is too scarce to determine whether the amount of rain, the change in sand characteristics or the high amount of public toilet sludge in the raw sludge loaded onto the beds is the determining factor for the drying time. It can be concluded that heavy rain, bad sand quality as well as too high amount of public toilet sludge has led to unreasonably long drying periods.

Table 5-1 General Characteristics of Drying Cycles

Cycle	Raw sludge volume	Initial raw sludge depth on drying bed	Rain	drying time
	[m^3]	[cm]	[mm/drying period]	[d]
1	12.8	20	8	16
2	This cycle had to be stopped because of the damaged filter layers			
3	10.5	15	18	15
4	15.5	26	111	12
5	15.5	27	218	35
6	12.6	21		59
7	12.1	23	10.1	8
8	15.5	25	12.8	7
9	15.2	28	5.4	27

Table 5-1 gives volume of raw sludge, initial sludge depth on drying bed as well as the quantity of rain which potentially affected the drying time of sludge on drying beds.

At the end of cycle 5, a roof consisting of corrugated sheet placed on wood beams and slightly sloped so as to allow rainwater flow down the roof was installed at the pilot plant (see Plate 5-1). The roof was placed on the drying beds during rain events and during the night. It protects the biosolids efficiently but 2 persons are needed to install the roof on the drying beds. To improve the system, the roof could be installed on a rail or on wheels so that one person would be able to slide it easily on the beds when rain starts.

5.2 Quantity and Quality of Biosolids from FS dewatering

The average production of biosolids amounted to 1.5 m^3 per cycle corresponding to 0.1 m^3 biosolids per m3 raw FS (Table 5-2).

5.2.1 Microbial Parameters

Helminth, especially nematode infections are prevalent in Kumasi. Among the pathogens causing gastro-intestinal infections, nematodes, and in particular, *Ascaris*, tend to be more persistent in the environment than viruses, bacteria and protozoa (Ingallinella et al. 2001). That was the reason why helminth eggs (HE) were chosen as indicators to determine hygienic quality of biosolids/compost and safety of biosolids/compost reuse in agriculture in the Kumasi co-composting project. Sample preparation for HE analysis as well as eggs count requires considerable experience. No HE could be found in the percolate. The drying bed constituted an impermeable barrier for helminth eggs. It can be concluded that the eggs were therefore concentrated in the biosolids and thus need to be hygienised prior to reuse in agriculture. The subsequent co-composting should allow inactivation of the pathogens. Several months of storage would also lead to hygienisation of the biosolids.

5.2.2 Physico-chemical Parameters

The N content of the biosolids amounts to 3% (of the TS content). The C/N ratio of the dewatered sludge was determined prior to mixing dewatered sludge with solid waste. Dewatered sludges produced during dewatering cycles 1 and 3 were mixed together prior to composting. This dewatered sludge mix was used for the first two composting cycles. The C/N ratio was determined prior to these first two composting cycles and amounted to 29 and 27, respectively.

Table 5-2 Biosolids Quality Determined at the end of Dewatering

Cycle	**Drying time**	**Dewatered sludge vol.**	**Biosolids production**	**Biosolids density**	**TS**	**TVS**	**TKN**	**N**
	[d]	[m3]	[m3/m3]	[kg/m3]	[wt %]	[wt %]	[mg/kg]	[%TS]
1	16	1.7[1)]	0.13		20			
2	This cycle had to be stopped because of the damaged filter layers							
3	15	1.7	0.14		50	50		
4	12	2.0	0.13		18	72	4,450	2.5
5	35	0.9	0.06	700	41	42	13,050	3.2
6	58	0.8	0.06					
7	9	3.0	0.25	1181	22	68	1685	
8	7	1.1	0.07	1198	26	59	6000	
9	27	2.5	0.16	887	19	68	15000	
Average	**15**	**1.7**	**0.1**	**496**	**24.5**	**45**	**8,750**	**3**

5.3 Percolate Quantity and Quality

Figure 5-4 shows percolate flow rate for dewatering cycles 4 and 5. Percolate flow starts between 10 minutes and 4 hours after raw sludge loading onto the beds. As those cycles were conducted during the rainy period, rain has a major impact on percolate flow. The impact was lower during cycle 5 as a tarpaulin roof has been installed on the drying beds after the second week of cycle 5. However the strong wind used to rip it off reducing its efficiency considerably. Percolate flow peaks follow rain peaks but are much less pronounced than the rain peaks.

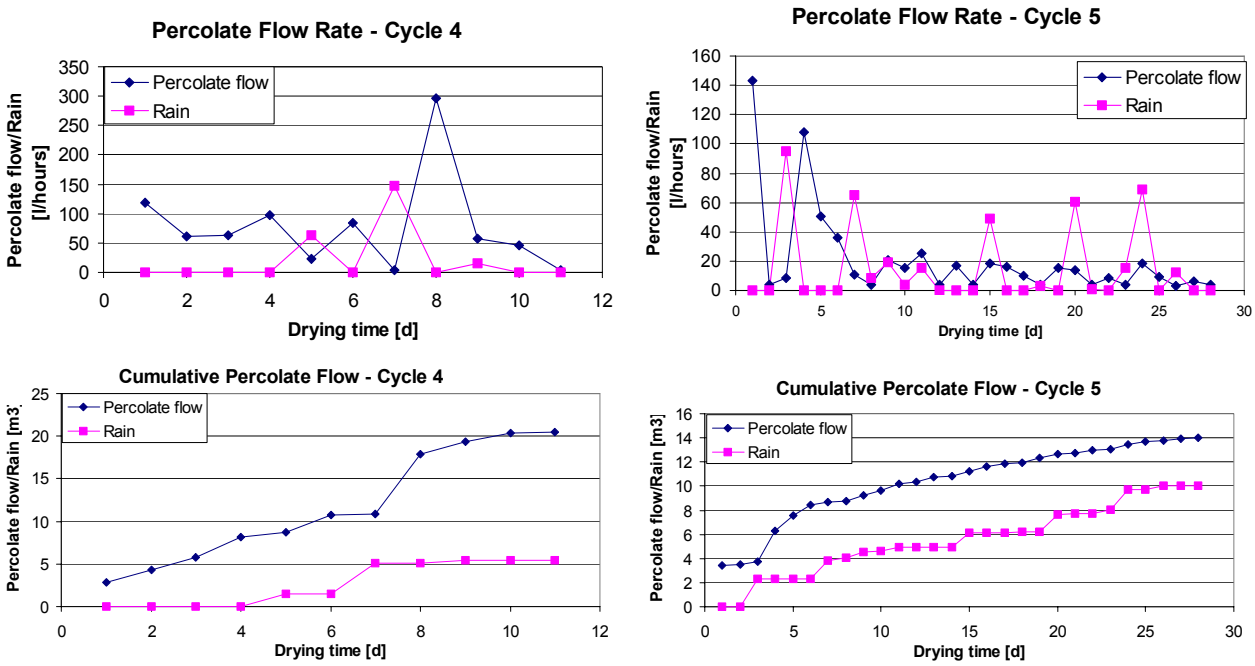


Figure 5-4 Percolate Flow Rate and Cumulative Percolate Flow and Rain

The amount of rain in the percolate was estimated based on the beds surface area of 50 m^2. This, however, does not allow the estimation of reasonable water balances over the drying beds. The main reason is that not only the amount of rain falling on the drying beds increased the percolate volume but also the rainwater falling directly into the percolate storage tank. Another reason is that the weather station is not located at the treatment site. Local differences (local thunderstorms) could also explain why the water balances could not be established based on the available rain and percolate flow data. Heinss et al. (1998) states that from 50 to 80% of the FS volume loaded onto drying beds will emerge as drained liquid.

Concentrations of parameters measured in the percolate vary widely. Measures tend to indicate that the concentrations were higher at the beginning than at the end of the percolation (Table 5-3). This could be due to the fact that the percolate collected on the first day of percolation has a shorter retention time than percolate collected at a later stage of the percolating period. The percolate collected at the beginning was likely to have followed preferential pathways in the filter. It has therefore not been filtered as efficiently as percolate characterised by a longer retention period. Moreover, a shorter retention time also leads to a shorter contact time between percolate and micro-organisms present in the filter layers and that could contribute to

the degradation of organic material. Another possible reason why percolate collected at the end of the percolating period was less concentrated is the dilution with rainwater.

Table 5-3 shows quality of raw sludge and percolate. The number of samples is written in parentheses. Composite samples of the daily percolate flow were taken each day and kept in the fridge. One composite sample was prepared with all daily composite samples taken during the percolating period. The first day, last day and the composite (whole period) samples were analysed.

Table 5-3 Quality of raw sludge and percolate

	pH	DO	Turbidity	EC	TS	SS	COD	BOD
		[mg/l]	[FAU]	[µS/cm]	[mg/l]	[mg/l]	[mg/l]	[mg/l]
Raw sludge	8.1 (6)			17,685 (2)	30,450 (8)	14,614 (7)	38,220 (8)	9,964 (7)
First day percolate	8.1 (7)	0.9 (5)	1,555 (4)	21,857 (6)	6,084 (6)	602 (7)	5,595 (8)	1,350 (8)
Last day percolate	7.9 (6)	1.4 (5)	227 (4)	11,380 (5)	5,686 (6)	293 (7)	3,644 (7)	873 (6)

	NO_3-N	NH_3-N	TKN	PO_4-P	HE
	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[no/L]
Raw sludge		1,504 (2)	2,082 (2)		14,600 (2)
First day percolate	48 (6)	518 (4)	588 (4)	245 (2)	0 (4)
Last day percolate	172 (7)	258 (5)	366 (5)	285 (2)	0 (4)

It is assumed that the high turbidity could have a negative impact on a subsequent pond treatment of the percolate as it reduces light penetration and hence photosynthesis and oxygen production. Because of the high conductivity, percolate cannot be used undiluted for irrigation. Conductivity should be lower than 3 dS/m (FAO, 1985). Percolate should therefore be diluted with river water prior to irrigation or be used for other purposes (e.g. brick construction) or be discharged into surface water after treatment. NH_3 concentration is also variable but the average is under the limit concentration ($\leq$ 400 mg/l NH_3+NH_4-N, for pH<8-8.5) that can be tolerated by algae (Heinss et al., 1998). They could therefore develop in a subsequent facultative pond (in case light penetration is sufficient). The BOD/COD ratio amounts to 25-30% that means an important fraction of the organic matter is not easily degradable.

It can be seen that the filter retained the solids efficiently (97% SS removal). The organic matter, mainly in the solids fraction, can also be reduced significantly. Approximately 85% of the TS load is retained in the biosolids whereas 15% flow out in the percolate. The removal efficiencies are similar as the ones determined during the Accra trials.

5.4 Efficiency of Drying Beds

The faecal sludge (influent) was very high in organic load, nutrients and pathogens. Table 5-4 shows average characteristics of the sludge and percolate as well as the efficiency of the drying beds.

Table 5-4 Drying bed dewatering efficiency

	TS (mg/l)	SS (mg/l)	COD (mg/l)	BOD (mg/l)	Helm. (no./l)
Sludge	30,450	14,614	38,220	9,964	14,600
Percolate	5,885	448	4,684	1,146	0
% Removal	81	97	88	88	100

Though the removal efficiency of the beds was highly impressive (81% for TS, 88%for BOD and COD, 97% for SS and 100% for helminth, the effluent quality parameters, except helminth eggs, far exceeded the EPA recommended discharge guidelines. pH and temperature were within the recommended guidelines. Thus the drying beds functioned as a pre-treatment system, hence the percolate (effluent) needs further treatment to meet the requisite discharge guidelines. Laboratory batch experiments were conducted using 11 litre buckets to investigate anaerobic degradation of the percolate. Results indicate that the COD concentration can be reduced by 40% within 3 days. As expected, FC concentration could not be reduced during the anaerobic treatment. A possible percolate treatment could consist of a sand filter (reduction of turbidity, organic matter and NH_3) followed by a series of ponds (further reduction of COD and reduction of FC). This will reduce the organic, N and FC load in the surface water in which the effluent will be finally discharged. However, it will not reduce the conductivity. Treated percolate can therefore not be used for irrigation unless it is “diluted” with less saline water.

For the influent, TS was in the range of 1.80 – 3.65%, indicating that the moisture content (water) portion of the sludge was very high. Total volatile solids (TVS) of the biosolids after the dewatering cycles were in the range of 42 and 72% of TS which shows a high organic content. Hence, the biosolid is good to be used for co-composting with biodegradable solid waste. Considerable number of helminth eggs was found in the biosolid. The beds acted as a sieve retaining all the eggs in the sludge.

6 COMPOSTING

6.1 Solid Waste Sorting

Household waste (HW) and market waste (MW) were sorted and the biodegradable fraction co-composted with dewatered faecal sludge (DFS). Table 6-1 shows on the average the percentage of the fractions of the municipal solid waste sorted at the Buobai Co-composting pilot plant. This is derived from sorting of a total of 36.4 m^3 of solid waste.

Table 6-1 Percentage of the fractions of municipal solid waste

Solid waste	% Rejects	% Biodegradable
HW	47	53
MW	16	84

The data shows that market waste contained higher amount of biodegradable fraction than household waste. The rejects consist of inorganic materials such as plastics, textiles, glass, pieces of metal, pottery, leather and organic materials that do not decompose easily such as bones and large pieces of wood. Market waste contained fewer amounts of rejects.

It was easier to sort market waste than household waste since it contained fewer rejects. On the average, the man-hours/m^3 of solid waste sorted was 8.6 and 5.4 respectively for household and market wastes. Sorting amounts to 30% (on average) of the operation and maintenance costs of the co-composting process (see chapter economic appraisal of co-composting).

6.2 Characteristics of Starting Materials

Three co-composting cycles were carried out. The input materials were HW, MW and DFS. Table 6-2 shows the average characteristics of these starting materials (inputs) of the composts.

Each of these materials contained high microbial populations. The carbon-nitrogen ratios were high with HW registering the highest. This is an indication that the materials were good for composting to produce manure of good nutrient value. It was expected that dewatered faecal sludge would have the highest nitrogen content than the solid wastes because of the high N content of human excreta (10%). However, the values show that the N content of the faecal sludge was the lowest. This could be caused by nitrogen losses during sludge dewatering. Nitrogen dynamics in the dewatering process need to be studied further to understand the processes leading to such low values.

There were high amount of heavy metal contents in all three materials. The source of heavy metal contamination in the raw materials needs to be looked at in more detail in future research phases. The solid wastes were alkaline while the DFS was slightly acidic.

Table 6-2 Characteristics of Compost Starting Materials

Parameters	Unit	HW	MW	DFS
pH		8.7	9.0	6.6
Acidity	cmol/kg	1.4	2.2	1.3
Moisture	%	50.7	68.1	42.3
Carbon	%	27.6	32.8	11.4
Nitrogen	%	1.0	1.3	0.9
C:N		31.4	28.5	21.8
K	%	1.2	0.9	0.4
Ca	%	6.7	4.3	0.9
Mg	%	5.0	3.2	6.0
P	%	0.5	0.5	0.9
Cu	mg/kg	85.3	117.0	97.6
Pb	mg/kg	184.6	869.6	175.1
Mn	mg/kg	654.7	1077.2	583.1
Zn	mg/kg	55.2	122.1	132.5
Fe	mg/kg	3174.0	4068.5	938.4
E. Coli	CFU/g*	3.4×10^8	2.0×10^8	3.0×10^8
Total Bacteria	CFU/g	7.2×10^8	7.3×10^8	2.1×10^9
Total Fungi	CFU/g*	5.1×10^6	5.8×10^6	4.7×10^6
Clostridium	CFU/g*	5.3×10^8	4.5×10^8	4.9×10^8

- CFU = Coliform Forming Unit

6.3 Changes during composting

Temperature

For cycle 1 composting the thermophilic phase (50-70°C) lasted about three weeks and was followed by a mesophilic phase where the temperature was around 40°C for the rest of the composting period. High temperatures up to 70°C were observed during the early periods of composting. The temperature patterns (figure not shown) are typical of a well functioning composting. Figure 6-1and Figure 6-2 show the trend or variation of temperature over composting period for cycles 2 and 3 respectively. Higher temperatures were observed in cycle 2 composting than in cycle 3.

Figure 6-1 depicting trend of cycle 2 composting shows that with the exception of HW:DFS windrow, temperatures have been higher than 50°C for 4 weeks at least. Temperatures measured during cycle 2 did not reach as high levels as during the cycle 1. The general trend was that of a gradual fall in temperature with time though there were series of rise and fall in temperature. Drops in temperature may be partly due to the turning of the windrows (heaps). Total composting period was longer than during the trial (cycle 1).

The trend in Figure 6-2 for cycle 3 composting was similar to that of Figure 6-1 but the situation here was slightly different. Except heaps 5 and 6 (windrows containing PM) which registered temperatures within thermophilic phase for about 2 – 3 weeks, the rest of the windrows registered temperatures below thermophilic phase. The highest temperatures for these windrows were in the range of 40 - 50°C. The possible reason why temperatures were not high enough could be that the starting materials were lying around for quite some time and may be partly decomposed prior to composting.These temperatures were not enough for efficient pathogen inactivation since to allow inactivation of pathogens, the entire compost mass must be maintained at a minimum temperature of 65°C for 2 to 3 consecutive days (Hoornweg et al., 2000). In the later stages of the composting, temperatures were as

low as 30°C. Graphs based on composting cycle 3 were made using the average of duplicate heaps for each treatment.

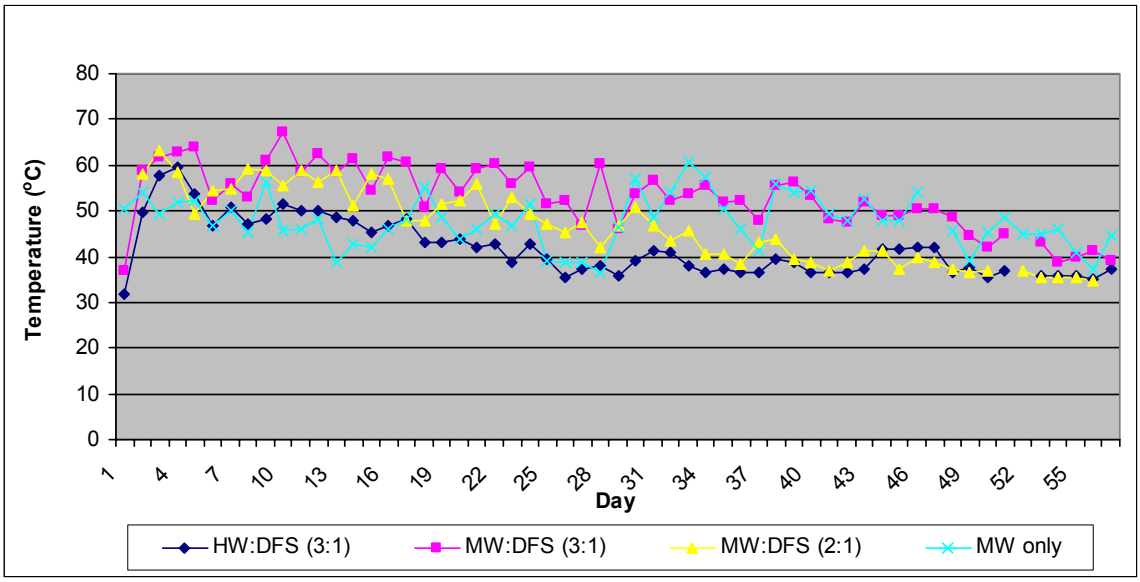


Figure 6-1 Temperature Trend for Cycle 2 Composting

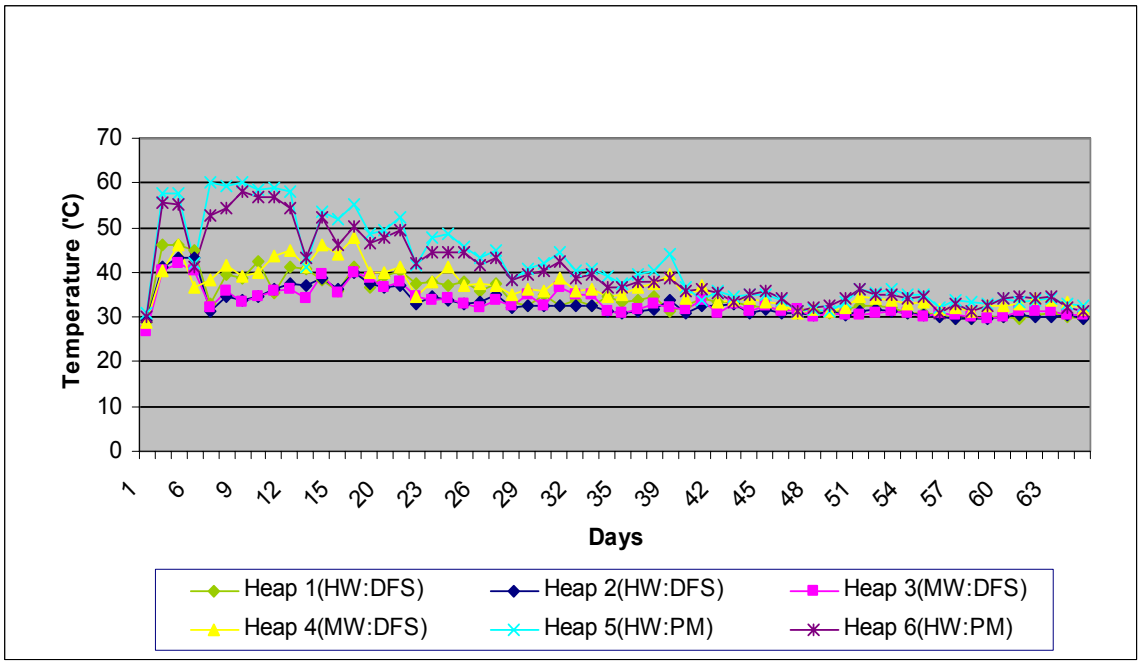


Figure 6-2 Temperature trend for cycle 3 composting

Turning and Watering

Windrows were turned at a frequency of two to three days during the thermophilic phase. The frequency was then reduced to twice weekly and finally once in a week when temperature approached the ambient conditions. The turning was done to ensure that the entire compost mass was subjected to the optimum conditions during composting. The high frequency of turning in the early stages was to enable all parts of the windrow to be heated sufficiently for efficient pathogen inactivation, and also to

aerate the windrows for the necessary aerobic conditions since consumption of oxygen is greatest during early stages of composting.

Each time the windrows were turned they were watered except when the windrows were moist enough. On the average the amount of water used per windrow during composting was 1,025 litres. For the HW:DFS compost, the water used per m^3 of initial volume of windrow was 326 litres while that of MW:DFS was 288.5 litres during composting.

The Figures 6-3 to 6-10 show the trend of some parameters during composting.

Nitrogen

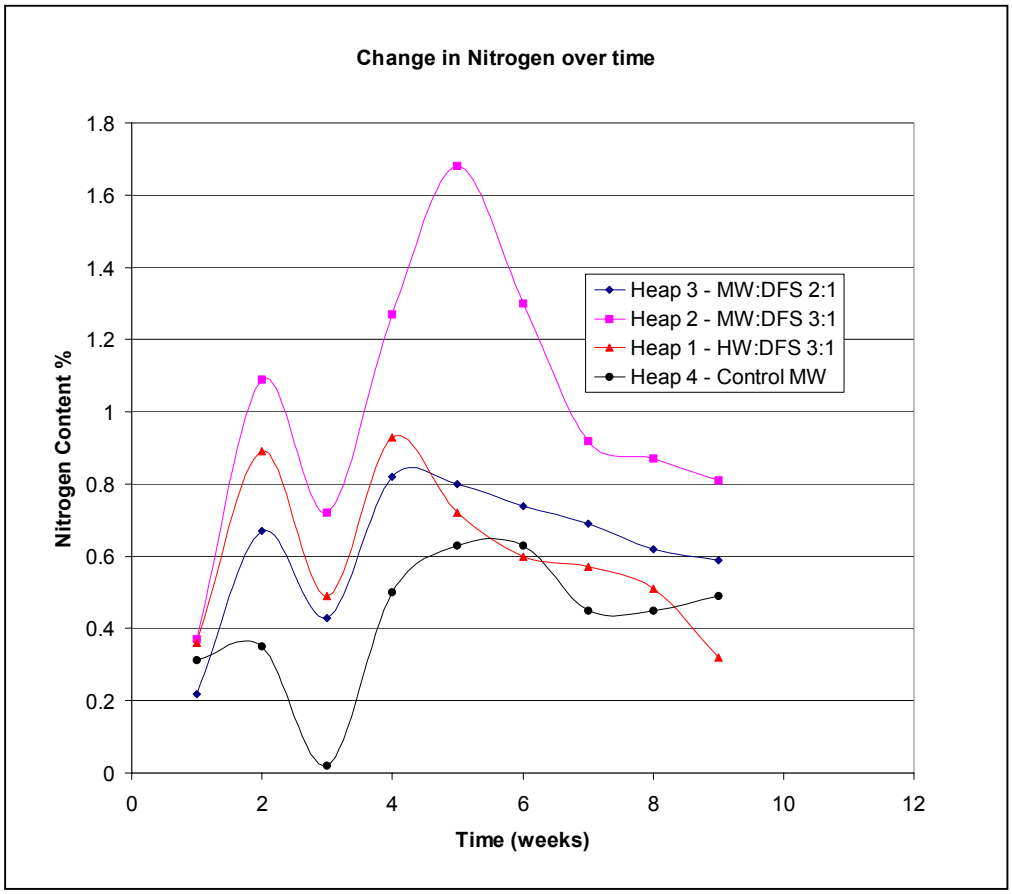


Figure 6-3 Nitrogen changes during cycle 2 composting

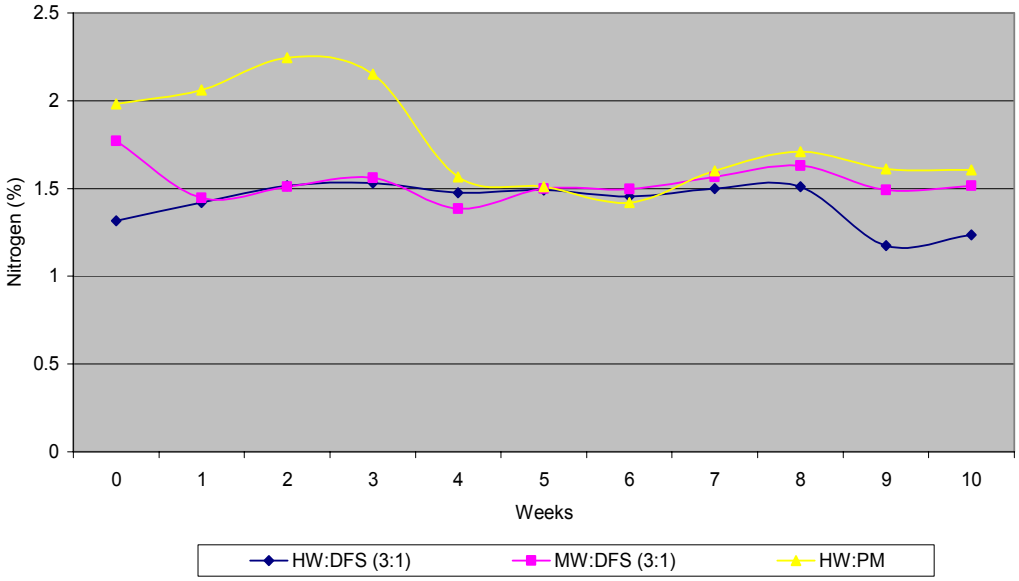


Figure 6-4 Nitrogen changes during cycle 3 composting

For cycle 2, it was expected that windrows (heaps) containing dewatered faecal sludge would have a higher N content than the control because of the high N content of human excreta (10%). However, figure 6-3 shows that the initial N contents of the 4 compost heaps were all similar. This could be caused by nitrogen losses during sludge dewatering.

Increase in nitrogen content during composting may be attributed to microbial ammonification. However, nitrogen losses, especially during the thermophilic phase as pH was high were expected to occur during composting. Thus the behaviour of nitrogen during composting was rise and fall in value. However, the nitrogen levels in the final compost products of cycle 2 were too low compared to cycle 3. Low nitrogen concentration may have an impact on the fertilising value of the compost, thus influencing crop yield, farm economics and hence farmer's livelihood.

C/N Ratio

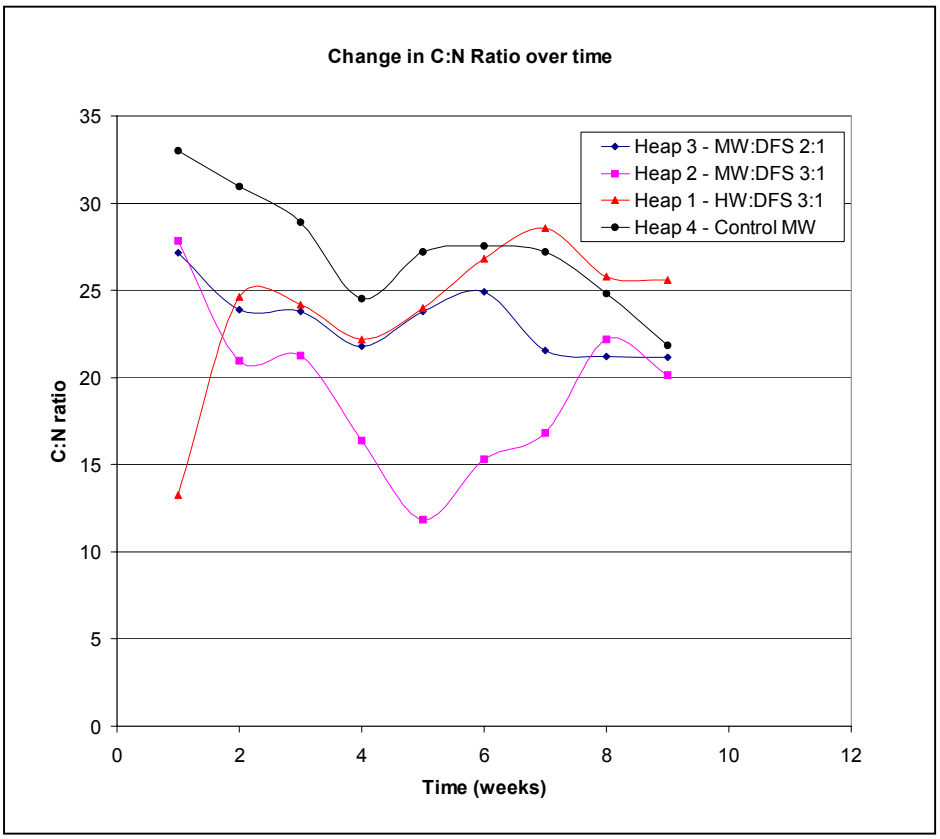


Figure 6-5 Change in C/N ratio during the second composting cycle

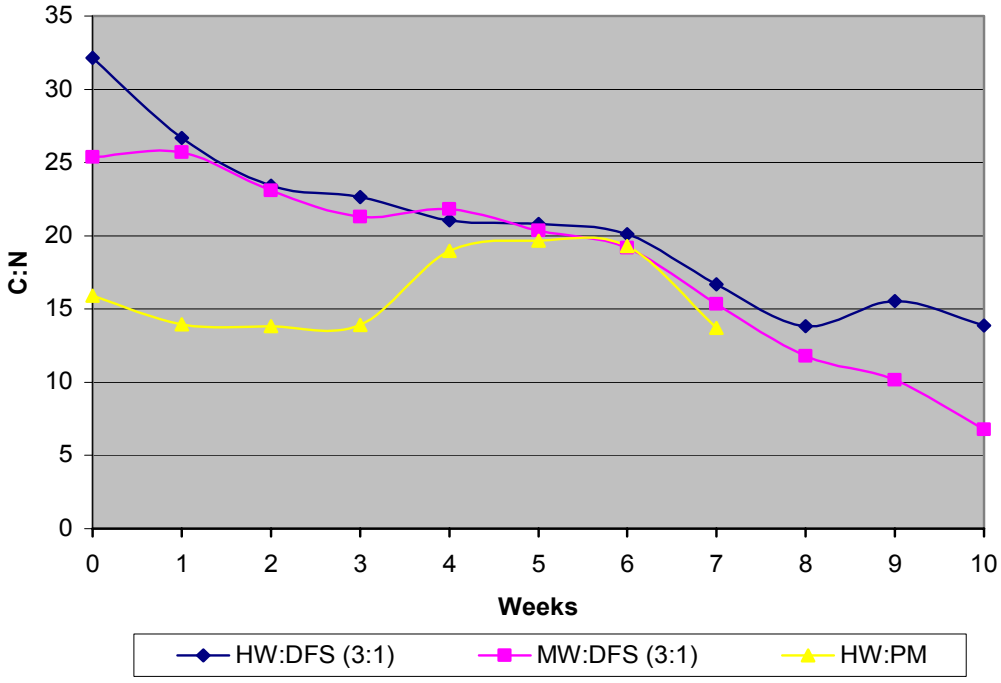


Figure 6-6 Change in C/N ratio during the third composting cycle

The decreasing trend reflects the carbon losses due to decomposition (production of CO_2). C/N ratios were in the expected range, but the values measured at the end of

cycle 2 composting were rather high. Hoornweg et al. (2000), states that the C/N ratio of the final product should be lower than 22.

pH

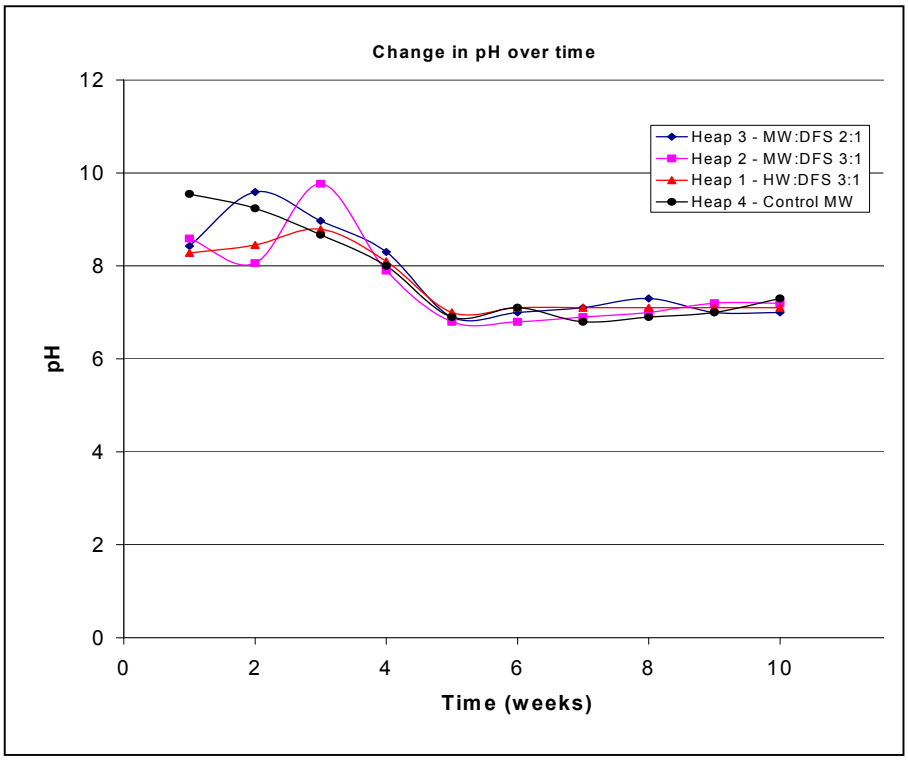


Figure 6-7 Change in pH during the second composting cycle

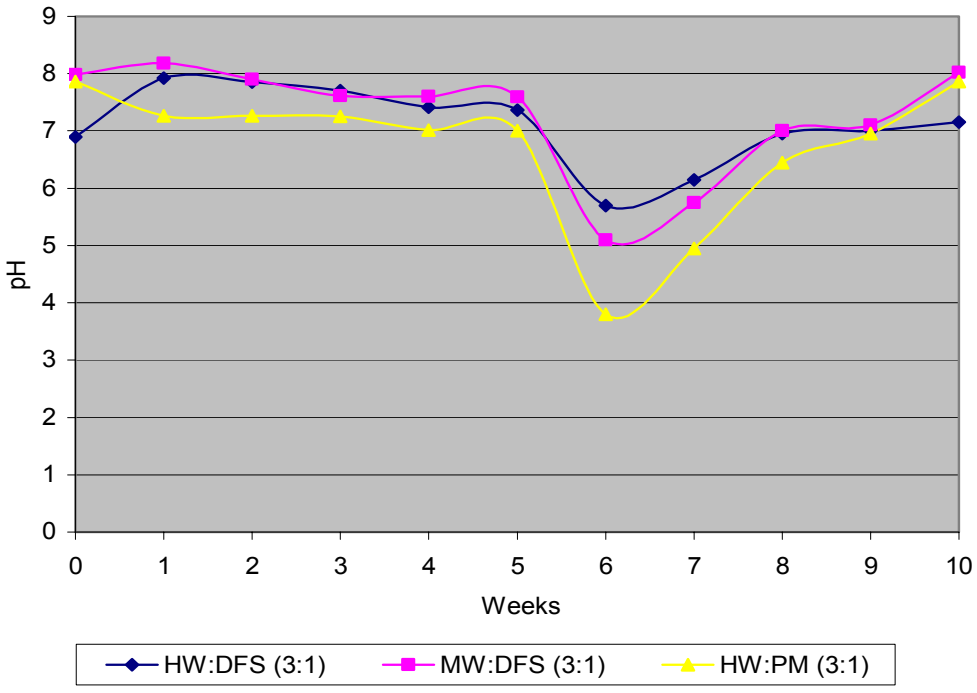


Figure 6-8 Change in pH during the third composting cycle

The high pH (especially in cycle 2) at the beginning of the composting may be due to the presence of ammonia nitrogen in the windrows. The zone at which pH sinks during the composting process may be attributed to the nitrification of ammonia compounds to nitrate or the formation of organic acids. For cycle 2, pH became

neutral and stable from the fifth week of composting, corresponding to the end of the thermophilic phase. Compost characterised by neutral pH is well tolerated by plants. For cycle 3 composting, the pH was fairly stable from the second week to the fifth week, then fall in the sixth week and then subsequently rises to the almost initial value.

E.Coli

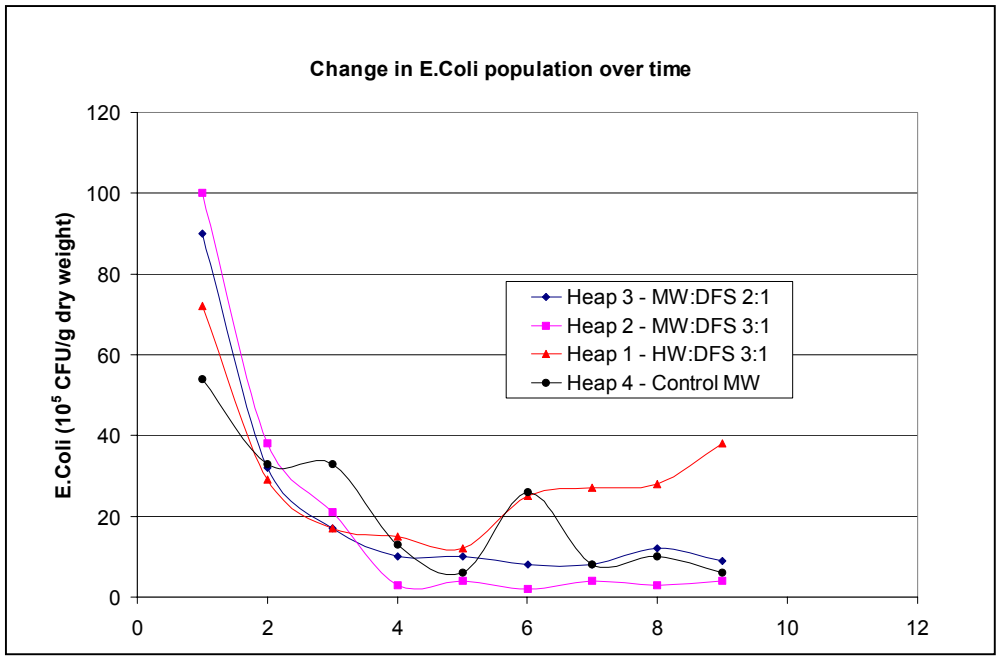


Figure 6-9 Change in E.Coli during the second composting cycle

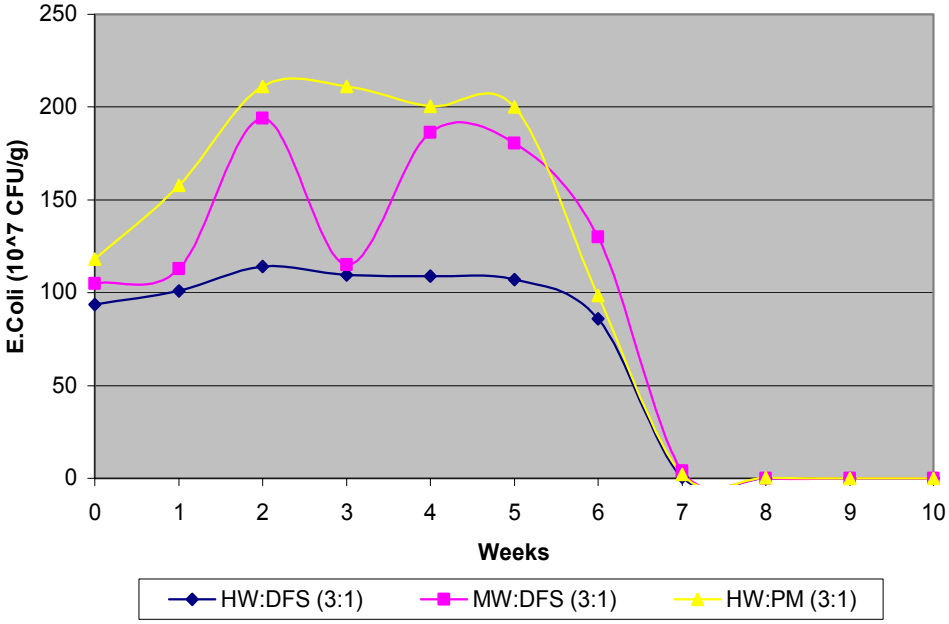


Figure 6-10 Change in E.Coli during the third composting cycle

For cycle 2 composting, the concentration decreases exponentially during the thermophilic phase then remained more or less stable. Total bacteria, fungi and clostridia were also analysed. Results indicate a similar behaviour as E.coli.

However, concentrations were surprisingly high as Escherichia coli should be inactivated within one hour at 55°C.

The trend observed in cycle 3 composting was completely different. Except MW:DFS, the windrows show an increase and a nearly stable trend in E. coli within the first five weeks and afterwards a decrease. The MW:DFS windrow shows an increase-decrease-increase trend within the first five weeks and afterwards a decrease in E. coli. The increase in E. coli value was not clear. The possible reasons could be attributed to contamination from external source or since temperatures were low in this composting process, E. coli was probably not inactivated as expected.

6.4 Quantity of Compost Produced

Table 6-3 and Table 6-4 show the material flow of the compost windrows for cycle 3 in terms of volume and weight. Each windrow was in volume ratio 3:1 of solid waste to faecal sludge/poultry manure. On the average, the volume and weight of compost at the end of composting reduced by 47.3% and 16.4% respectively. After seiving the reductions were about 64% and 49%. It can therefore be inferred from the volume changes that only about 36% of the starting volume of composting would be realised as compost.

Table 6-3 Material Flow in Volume during Composting (cycle 3)

Windrow	Volume at start of composting (m^3)	End of Composting			After Maturation			After Seiving		
		Vol.	Change in Vol.	% Reduction	Vol.	Change in Vol.	% Reduction	Vol.	Change in Vol.	% Reduction
HW:DFS	6	3.27	2.73	45.5	2.75	3.25	54.2	2.28	3.72	62.0
MW:DFS	6	3.22	2.78	46.3	2.66	3.34	55.7	2.34	3.66	61.0
HW:PM	6	3	3	50.0	2.53	3.47	57.8	1.95	4.05	67.5

Table 6-4 Material Flow in Weight during Composting (cycle 3)

Windrow	Weight at start of compostin g (kg)	End of Composting			After Maturation			After Seiving		
		Weig ht	Change in Weight	% Reductio n	Weig ht	Change in Weight	% Reduction	Weig ht	Change in Weight	% Reduction
HW:DFS	3155	2677	478	15.15	2310	845	26.78	1639	1516	48.05
MW:DFS	3172	2627	545	17.18	2213	959	30.23	1673	1499	47.26
HW:PM	2815	2339	476	16.91	2075	740	26.29	1395	1420	50.44

Compost Quality

Tables 6-5 and 6-6 show the quality characteristics of the compost windrows at start and end of composting. In most cases, composting ended on the 10th week after which the heaps were allowed to cure for 2-4 weeks. Data below show only the beginning and end (end of 10th week) of composting.

Table 6-5 Characteristics of Compost Windrows (cycle 2)

Parameter	Unit	HW:FS (3:1)		MW:FS (3:1)		MW:FS (2:1)	
		Start	End	Start	End	Start	End
pH		10.1	7.1	10.1	7.2	8.3	7.0
Acidity		0.1	0.3	0.5	0.4	0.6	0.3
Moisture	%	49.0	15.2	60.0	36.6	53	13.4
Carbon	%	3.8	8.2	9.8	16.3	3.1	12.5
Nitrogen	%	0.1	0.3	0.3	0.81	0.1	0.6
C:N		31.7	25.6	29.6	20.2	28.4	21.1
K	%	0.3	0.2	0.6	0.4	0.2	0.2
Ca	%	10.9	4.2	3.6	1.5	2.9	0.9
Mg	%	5.1	1.9	80.0	3.8	7.0	3.2
P	%	0.2	0.1	0.8	0.4	1.1	0.4
Cu	mg/kg	44.5	41.4	42.7	39.0	37.9	35.1
Pb	mg/kg	354.4	342.2	103.8	98.5	266.2	262.2
Mn	mg/kg	71.2	67.9	74.8	70.2	62.6	58.1
Zn	mg/kg	53.8	50.8	129.4	123.4	142.6	139.9
Fe	mg/kg	1050.6	1077.2	840.4	619.3	1,042	1021.2
E. Coli	CFU/g	1.5×10^9	380,000	1.6×10^9	40,000	5.2×10^8	9,000
Total Bacteria	CFU/g	1.7×10^9	4,000	1.9×10^9	700	8.0×10^8	1,100
Total Fungi	CFU/g	8.1×10^6	1,500	1.6×10^7	500	1.0×10^7	110
Clostridium	CFU/g	1.7×10^9	15,000	1.8×10^9	5,000	1.3×10^9	1,300

Table 6-6 Characteristics of Compost Windrows (cycle 3)

Parameter	Unit	HW:FS		MW:FS		HW:PM	
		Start	End	Start	End	Start	End
pH		6.9	7.2	8.0	8.0	7.9	7.9
Acidity		3.1	2.4	2.4	1.8	2.3	1.3
Moisture	%	49.9	47.0	60.8	46.5	66.5	45.4
Carbon	%	42.2	17.1	44.9	10.3	31.5	8.8
Nitrogen	%	1.3	1.2	1.8	1.5	2.0	1.6
C:N		32.2	13.9	25.4	6.8	15.9	5.5
K	%	0.5	2.3	1.0	3.2	1.5	3.6
Ca	%	0.9	1.6	0.7	1.5	13.7	2.7
Mg	%	1.6	0.7	1.3	0.7	9.3	1.2
P	%	0.8	3.9	0.7	3.3	1.9	5.5
E. Coli	CFU/g	9.3×10^8	3,650	1.1×10^9	215	1.2×10^9	1,060
Total Bacteria	CFU/g	9.9×10^8	46,500	6.9×10^8	265	1.4×10^9	210
Total Fungi	CFU/g	7.7×10^6	215	1.2×10^7	200	5.7×10^6	30
Clostridium	CFU/g	8.0×10^8	235	1.2×10^9	170	2.3×10^8	30

It can be observed from Table 6-5 and Table 6-6 that the microbial population at the end of composting was lower than at the start, but the values were still high. The pH at start and end of composting was fairly the same for cycle 3. For cycle 2, the pH has decreased to neutral state at end of composting. For the nutrients, N and P, nitrogen has decreased while phosphorus has increased at the end of composting for cycle 3, while the opposite has occured in cycle 2. The decrease in value of nitrogen for cycle 3 may be due to loss of ammonia with time. The same scenario has been observed in case of carbon. While cycle 3 has shown a decrease in carbon at the end of composting, that of cycle 2 was an increase. The carbon-nitrogen ratio in both cases was lower at end of composting than at start but those of cycle 2 were far higher. For cycle 3, the metals, K increased while Mg, Cu and Mn have decreased at the end of composting. The changes in heavy metal concentration at the beginning and end of composting need further investigation. The metal Calcium has increased for composts containing faecal sludge but decreased for poultry manure compost. For cycle 2, the same observation as was in cycle 3 was seen for Mg, Cu and Mn but

the opposite was for the rest of the metals. The conflicting observations in the two cases need to be looked at in further composting processes.

6.5 Pathogen (Helminth) inactivation during composting

The indicator usually chosen for analysis of intestinal parasites is helminth egg concentration. Viable eggs are usually considered than total egg count because many eggs are inactivated during composting process. The no-risk concentration of compost to be applied on crops should be in the range of 3 – 8 viable helminth eggs per gram of dry matter. Table 6-7 shows helminth egg inactivation during the composting process. The eggs per gram are for total egg counts.

Table 6-7 Reduction in helminth egg population

Windrow	Ratio	Composting cycle	No. of eggs at start of composting (eggs/gTS)	End of Composting		After Maturation		After Seiving	
				Eggs/ gTS	% Reduction	Eggs/ gTS	% Reduction	Eggs/ gTS	% Reduction
HW:DFS	3:1	2	42	37	12	8	81	2	95
MW:DFS			54	36	33	6	89	6	89
MW:DFS	2:1		123	72	42	12	90	6	95
HW:DFS	3:1	3	278	29	90			8	97
MW:DFS			604	86	86			59	90
HW:PM			248					9	96

It can be inferred from Table 6-7 that the helminth egg population decreased during composting. The reduction in the number of eggs could be attributed to the result of heating up of the windrows during the composting process. The inactivation of the eggs at end of composting was more pronounced in cycle 3 composting than in cycle 2. The final products obtained after sieving have shown impressive reductions in eggs, and the total egg counts (except for cycle 3 MW: DFS compost) were in the acceptable range of no-risk of 3 – 8 for viable eggs/gTS. Viable eggs for the final products would be lower than the total egg counts or negligible since most of the eggs would be inactivated. Thus the composts are good to be used for farming purposes.

6.6 Summary

Results obtained during the monitoring of three composting cycles indicate that the necessary composting time to obtain mature compost under the Kumasi conditions (climate, type of wastes, turning frequency) amounts to about 10 - 12 weeks. The thermophilic phase lasted 4 to 5 weeks. Heaps were turned every two days during the thermophilic phase, twice weekly and weekly during the subsequent phase. It is questionable whether such a high frequency is necessary. It increases the production cost (turning of the heaps) and also water and possibly also N losses. Further composting cycles should be monitored in order to determine the appropriate turning frequency under the Kumasi conditions.

It could be observed that there is no significant difference between heaps containing market waste and heaps containing household waste. The nutrient content in both types of compost is similar. However, more data is needed to determine statistical differences between the different kinds of compost. The only difference observed is the longer time needed (and hence higher cost) for household waste sorting than for market waste sorting.

Dry weight reduction at end of composting amounted to 16.4%, and by volume it was 47.3%. Total water volume added during composting corresponds to approximately 1,025 litres per compost windrow. Compost quality measured in the pilot project is in the expected range.

It was observed that there are differences in the changes that occurred during composting in cycle 2 and cycle 3. It is necessary to make more composting cycles to be able to make conclusive comments on these trends

7 SOCIO-INSTITUTIONAL ASPECT OF CO-COMPOSTING IN KUMASI

7.1 Demand and Willingness to Pay for Compost in Kumasi

The following potential compost consumers were identified in Kumasi:
[A] Urban farming systems: 1) Vegetable farmers (lettuce, cabbage, spring onions, etc.); 2) Staple crop farmers (mostly maize, cassava, rice); 3) Backyard farmers (maize, pawpaw, plantain, etc.); 4) Ornamental flower production.
[B] Peri-urban farming systems: 1) Vegetable farmers, 2) Staple crop farmers (maize, cassava, plantain, rice, coco yam, yam), 3) Fruits plantation farmers.
[C] Real estate developers and landscape designers.

7.1.1 Perception and Acceptability of Co-compost

The survey which inquired about the potential of using municipal compost made from FS and SW revealed that all actual compost users and 83% of the non-compost users perceived such a co-compost as positive or 'good' material for soil amelioration and crop growth due to (i) the resemblance to 'black soil', (ii) its fertile night-soil component, (iii) expected long-term effects on the soil, and (iv) indirect benefits (less waste, less diseases, etc. mentioned by urban backyard farmers). Only 17% of the non-actual compost users expected co-compost to be ineffective or were concerned about health/cultural or religious implications through the nightsoil component independent of any favourable fertilizer value of the product. In line with the study of Warburton and Saro-Mensah (1998), it was found that concerns and constraints in using compost are likely to be more economic or technical than cultural.

The 83% of the farmers who were positive about co-compost stressed their particular interest in "organic" fertilizer and indicated that if well composted it would be both less health hazardous and less expensive compared to inorganic fertilizers, which can also result in skin irritation during application.
However, some of those farmers who were skeptical about co-compost pointed to the night soil component as being capable of spreading infections and mentioned other reasons as given above. These farmers assumed that consumers would avoid crops on which co-compost had been used for fear of infections. Other reasons stated by the farmers were: 1) the bulky nature of compost making transportation cost too high, 2) application of compost to the soil would require the employment of more farm hands due to its bulky nature. Farmers who perceived compost to be expensive also associated it to the cost components such as actual cost of the plant, collection of raw materials, the packaging and transport to the field, cost of labour to transport and incorporate the compost.

7.1.2 Willingness-to-Pay (WTP) for Compost

The majority of farmers with positive perception were willing to pay for municipal compost (70%) while 30% were unwilling though the importance of soil amelioration was acknowledged. Those farmers who did not express WTP argued e.g. that they first have to test the product to know its effectiveness (in terms of yield and returns). Other reasons were financial constraints. Farmers argued that it is government responsibility to subsidise or supply inputs free to farmers. They complained also about land insecurity. Some stressed that the current soil ameliorants (mostly poultry manure) they use give hem high yield and therefore no need to replace or try new ones. Ten percent out of those who were willing to pay could not express any bid (amount) and suggested that they would accept the market price if it is not too high.

Monetary Willingness to Pay Response Analysis

During the study, urban vegetable farmers in Kumasi expressed the lowest mean WTP, US$0.1, although their system was found to be most profitable with annual profit up to US$ 600 to 1000. Peri-urban vegetable farmers showed the largest mean WTP (US$3), with values of the other farming systems in between (Table 7-1). The probit analysis helped to explain the difference and revealed that farmers' WTP depends besides their income highly on the type, availability, acquisition, and effectiveness of current soil ameliorants use. Peri-urban vegetables farmers, on the other hand, expressed higher bid because they use chemical fertilizer (US$14 per bag of 50kg) largely due to limited access to poultry manure.

Backyard farmers in Kumasi were willing to pay US$ 1.5 for 50kg of compost, even though the quantity demanded per garden per year is low as most of them have very small sizes (less than 400m^2).

Table 7-1 Mean WTP and Standard (SD) of Potential Compost Users Identified

Clients	Mean WTP $US	Std. Dev. $US
Vegetable farming, urban	0.1	0.1
Vegetable farming, peri-urban	3.0	1.9
Staple crops, urban	2.0	1.6
Staple crops, peri-urban	2.7	1.0
Backyard, urban	1.4	0.9
Ornamentals	0.6	0.4

Source: Danso *et al* (2002).

Hypothetical Demand Analysis for Compost in Kumasi

From the theoretical point of view, the study revealed that there is a demand for compost in Kumasi by different interested groups. It was estimated that about 11,000 t of compost could be demanded per year by the different farming systems identified (Table 7-2 Farmers' WTP and Theoretical Demand Estimate for Compost in Kumasi.

).

Table 7-2 Farmers' WTP and Theoretical Demand Estimate for Compost in Kumasi.

Potential Clients (Kumasi)	Estimated number of farming households in and around the city (total)	Average farm size per farmer ha	Number of farmers willing to pay (extrapolated from sample size)	Average WTP (US$)	Qty/year in 50 kg-bags per farming household	Total theoretical demand of compost in tons per year *	Total demand with assumed compost cost of $3/50kg[1]
Vegetable (urban)	200	0.1	126	0.1	214	1348	0
Vegetable (peri-urban)	280	0.8	260	3.0	28	364	157
Staple crops (urban)	115	0.2	67	2.0	5	17	7
Staple crops (peri-urban)	15000	0.8	5550	2.7	14	3885	1166
Urban backyards	85000	0.04	71000	1.4	3	5325	1225
Urban ornamentals	50	0.04	40	0.6	33	66	0
Total	**100645**		**72294**		**297**	**11005**	**2555**

Source: Danso *et al* (2002)

- Calculation example: (urban vegetable farming) 214 kg y^{-1} x 50kg ÷1000 = 10.7t y^{-1} x 10.7 x 126 farmers willing to pay = 1348t y^{-1}. Compost application was assumed to be twice a year for vegetable farmers (urban and peri-urban) and at least once a year for the other farming systems. Although 8 of 10 backyard owners were willing to pay for compost it is assumed that only 50% would actually use compost for their specific crops.

[1]Total demand calculated based on the actual WTP (not on the average) of all the farmers in Kumasi

7.1.3 Scenarios with marketing of co-compost

Taking into consideration compost production and transport costs as well as the theoretical demand and WTP for compost, different scenarios can be calculated to analyse how many farmers could actually benefit from compost or how high is the likely compost demand. This figure is crucial for the planning of the capacity of the compost station(s). For this analysis case, two basic scenarios were selected:
[1]. It is assumed that the compost production is completely subsidized, i.e. farmers only pay for transport of compost to their farms.
[2]. It is assumed a 50kg sack of compost costs 3USD (based on coverage of running costs only)

In both scenarios we look at two farming systems as examples: Urban vegetable farmers and peri-urban vegetable farmers, and imply that co-compost has more benefits including availability than poultry manure, which is de facto free of charge except transport.

Scenario 1 and 2:
Urban Vegetable Farmers
With subsidies, it would be possible for all urban vegetable farmers living **at** the plant to use compost. Although their mean WTP is very low which makes further transport impossible (i.e. <$1per 50kg), it still allows those close to the plant to benefit. If the price per bag of compost is $3 for 50kg, no urban vegetable farmers would be willing to buy co-compost, given the low WTP range as discussed earlier on.

Peri-urban Vegetable Farmers
In the case of scenario 1, i.e. with subsidies, peri-urban farmers would only need to pay for transportation. If we transform the WTP for compost into transportation costs, the study reveals that 14% of these farmers could pay $1-2 for transportation, 5% could pay $3 and 38% could pay about $5 or 6 (Fig. 7-1). According to the illustration, it implies farmers within 35km radius could come for the co-compost.

On the other hand, when there are no subsidies, the result indicates that only 26% of the last group with WTP of 3 USD could afford the price but have little or nothing left for transport (Fig 7-2)

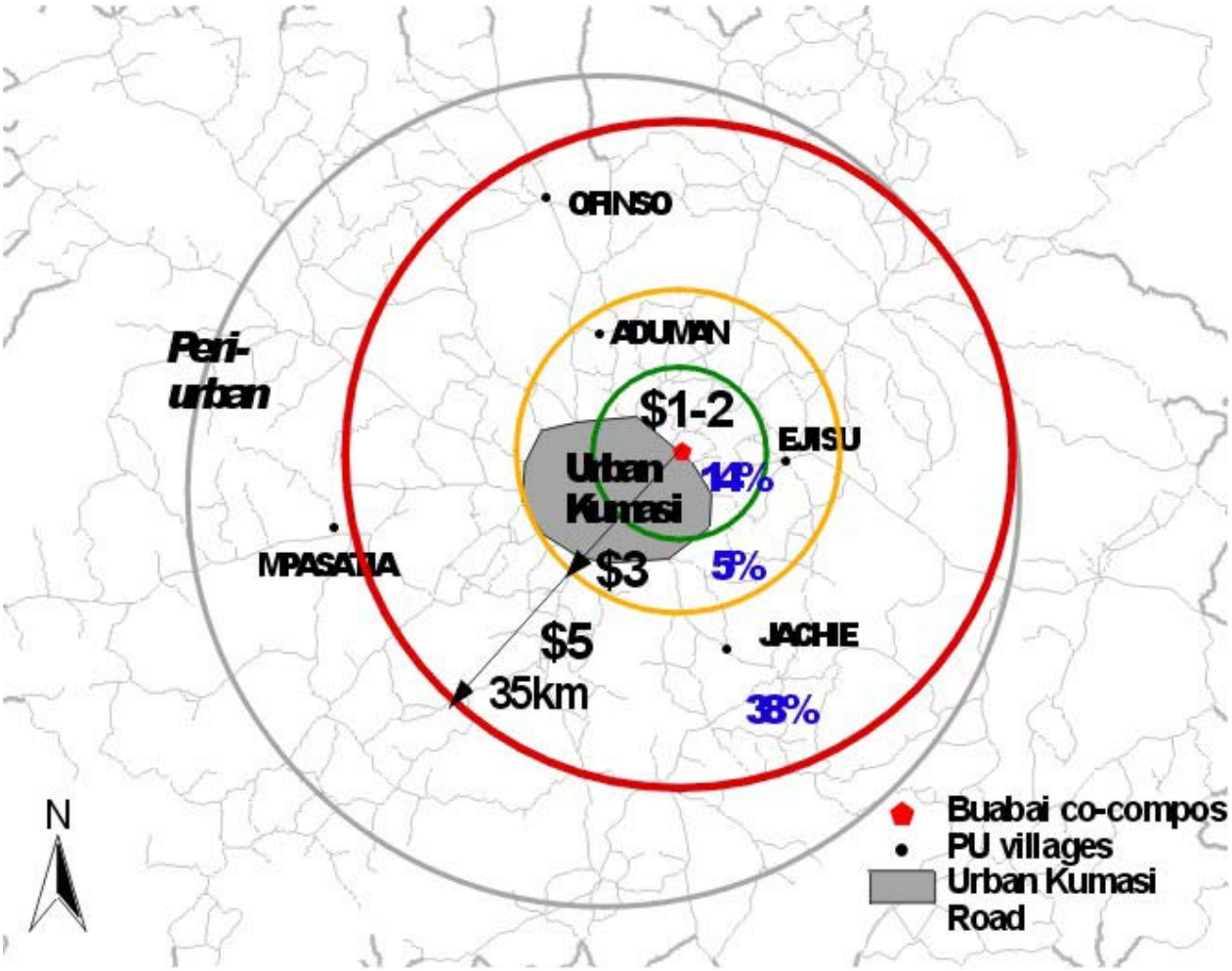


Figure 7-1 Peri-urban marketing of co-compost with subsidy

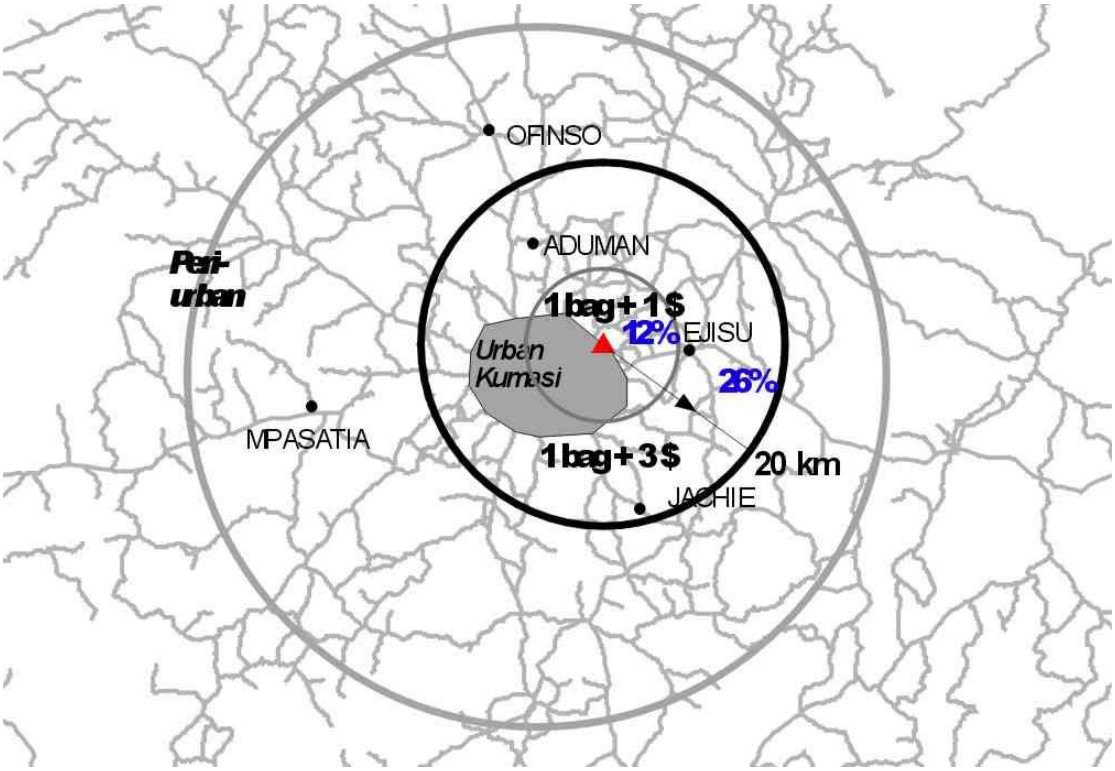


Figure 7-2 Peri-urban marketing of co-compost without subsidy

Conclusions on user's perception

The study revealed that there is a demand for compost in and around Kumasi by different groups. The most potent ones are peri-urban vegetable and staple crop farmers, backyard and estate companies, which represent the largest market for urban compost users.

In Kumasi, a theoretical compost demand by farmers of about 11000 t y^{-1} was estimated

The mean WTP, however, ranged between 0.1 and 3.0 US$ per 50 kg sack while compost production costs (based on running costs of the station) is estimated to be 3US$ for the same quantity. Thus only those farmers with this (higher than average) WTP could afford the product if there are no subsidies. This would reduce the marketable compost volume to about 23% of the total compost demand of 11000 t yr^{-1}.

Another important result is that those farmers who can afford the compost are all located in the peri-urban area (except ornamentals/flower growers) and not among urban farmers. Thus, compost stations have to be located in the peri-urban fringe and not in the city itself. To reduce transport costs several stations around the city are recommended, with a larger station at the landfill site to produce large amounts for landscape designers.

Farmers with experience in compost expressed concerns because of tedious labour involvement if self prepared, and low market demand for "organically" fertilized crops. However, this group with firsthand experience is small. On the other hand, majority indicated that they would use it if they first try it to be assured of its effectiveness. In

fact, 90% of farmers without compost experience asked for compost samples for field trials to be able to really assess its effectiveness.

For efficient marketing of co-compost under the assumption of perfect competition (e.g. versus poultry manure), several conditions are to be met for adequate marketing.

- The farmers or gardeners are located near the source of compost;
- The entity producing compost is willing to assist the user with transport and the compost is highly subsidised
- Marketing is ensured for larger number of people if the quality is very good

7.1.4 Proposed Compost Distribution Pathway: From Plant to End User

In the perception studies, it was gathered from the farmers that the means of assess to compost or poultry manure is through direct contact with the supplier. Individual farms or farmers' groups arrange to transport the compost or manure from the source to the farmer. They see this as the practicable way they will get the compost in Kumasi.

Further investigations were made from our study visit to nine composting facilities in West Africa. It was observed that cases where marketing and sales are done through the WMD do gave the worst performance in compost sale as WMD are institutions with no direct relationship with compost users. Their area of expertise is limited to collection and disposal of waste. The cases where the compost producer is in charge of sales show best performance (see Table 7-3 below). Better yet is the case where an institution with a strong relationship to farmers and with expertise in information dissemination is involved (like the Ministry of Agriculture), as is the case in the Bodija plant in Ibadan.and also in Dhaka, Bangladesh where, marketing has been transferred to a private fertilizer company, which proved very successful.

Table 7-3 Compost Distribution Channels and Sales Performance

Plant / Marketing channel	Through WMD	Direct sales	MOFA and fertilizer company	Sales Performance
AKCPP, Accra				Compost remains unsold at the plant
Teshie, Accra				All production sold, but farmers have no access to the product; costs not covered
GOAN / KNRMP, Kumasi				Compost used by producers on farm
AJVD, Cotonou				Product sold, but sales do not cover running costs
DCAM, Cotonou				Product sold, but not to farmers
ITRA, Lomé				Good prospects. Sales ready to begin. Farmers interested
ITRA, Tsévié				Good prospects. Sales ready to begin. Farmers interested
Bodija, Ibadan				All production sold, mainly to farmers at market
Wogodogo, Ouagadogou				Product sold to urban farmers and gardeners, but sales do not cover running costs
Total	**2**	**6**	**1**	

Source: Fink (2002)

In the case of Kumasi, it is recommended that compost be distributed as:

- Direct sales on the station- Individual farmers and farmers' groups collecting from compost station or through
- MoFA or any interested NGO and fertilizer company/distributor(s). Such NGO is yet to be identified.

Recommendation for further studies

It is important to assess farmer's perception and willingness to pay after they have tried the compost produced at the Kumasi plant as the discussion on perception reported here was done without the farmers testing our product. Many indicated they want to 'try' the compost first to know its effectiveness. It is likely that their WTP may change after using the compost. However, to do this requires a longer time because compost effect is not so evident until many years of application. If funding is available for a longer period e.g 3-4 years, it would be possible to produce more compost, possibly enrich it with more nutrients from other sources and try it out with a larger number of farmers for a longer period for field response. Then we can have a better recommendation for decision support.

7.2 Institutional Perception and framework for composting

The results of the survey showed that many institutions have both positive and negative perception of composting. However, they expressed their supportiveness and willingness to participate in the case a project was to be initiated.

The survey revealed a constellation of stakeholders' roles to play in project implementation based on the expertise and abilities of each organisation.

From the institutions listed in the perceptions survey, it is possible to group them into four general clusters: 1) Regulators: are institutions in power to draft by-laws, legal instruments, and policies; 2) Organisation & Management: institutions in charge of running composting plants; 3) Supporters of initiatives: institutions providing external support (financial, material, knowledge); 4) Beneficiaries: users of sanitation services (households and markets), communities and workers receiving income through composting (composting producers), and farmers (users of compost). Beneficiaries coincide with the groups representing each of the stages in the rural-urban nutrient cycle. Some of the institutions fall into more than one cluster; they are in the position to work as inter-cluster channels of linkage facilitating the flow and exchange of information. A model integrating the waste recycling and the clustering of institutions is proposed in Figure 7-3

Figure 7-3.

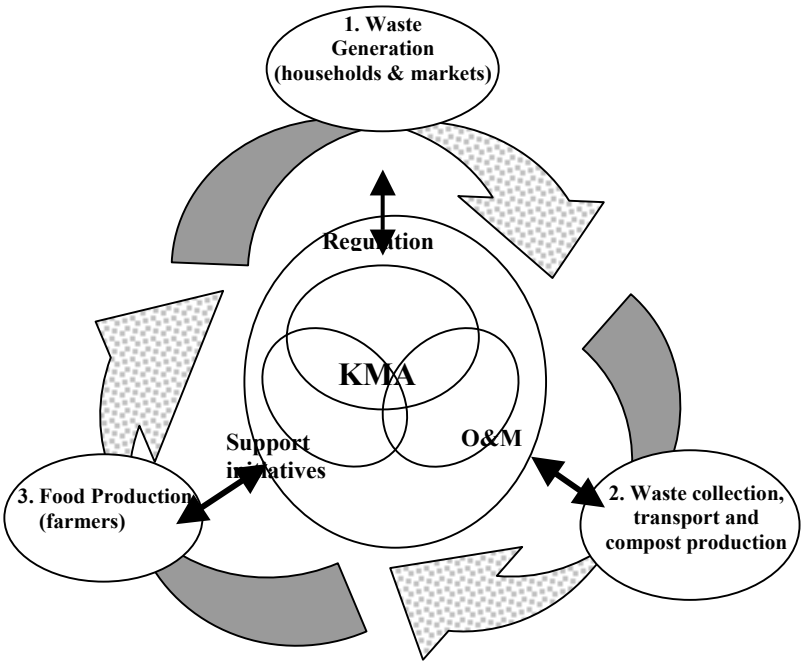


Figure 7-3 Proposed Institutional Platform for Supporting Co-composting in Kumasi.

Source: Vázquez, *et al.* (2002)

At the very centre of the institutional platform is the Kumasi Metropolitan Assembly (KMA), this institution plays a role as regulator, a manager, a supporter of initiatives and as a beneficiary due to municipal savings; its central role doesn't mean it should be the chief institution or the one in charge, but it should be the main facilitator. Bi-directional arrows link the cycle to the institutional platform, meaning that the relationship may not be characterised as patron-client relationship, but as a mutual benefit relationship

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8 AGRONOMIC EFFECT OF CO-COMPOST IN KUMASI

8.1 Effect of Compost on Germination and Early Growth of Seedlings

Eight vegetables, selected for the germination experiment are presented in Table 8-1

Table 8-1 Vegetables Used in the Germination Test

Common Name	Latin Name	Cultivar Variety
Tomato	*Lycopersicon esculentum*	Petomech
Sweet Pepper	*Capsicum annuum*	C. wonder
Okra	*Hibiscus sabdariffa / esculentus*	Local variety
Garden Egg (Egg Plant)	*Solanum melongena*	Local variety
Lettuce	*Lactuca sativa*	Great Lakes
Cabbage	*Brassica oleracea capitata alba*	Oxylus
Spring onion	*Allium cepa*	Texas
Carrot	*Daucus carota*	Tokita

The result shows that germination percentage vary from 70-100% for all vegetables except for okra and garden egg which averaged below 30%. The seeds of these vegetables were consumed by red ants. The inhibition of germination was greater in certain vegetables than others. Many of the vegetables were not significantly affected by the compost treatments. The highest difference in germination observed between compost treatments during the experiment was 3 days with the average for most vegetables being below 2 days. Analysis of the regression lines of the different growth parameters indicates a wide variation between the different vegetables. Two groups of vegetables could be clearly distinguished based on their reactions to increasing compost percent; carrot, onion and okra in one group and the rest in another group. The seeds of the first group vegetables showed greater sensitivity to increasing compost concentrations than the other vegetables. This indicates that the vegetables in the second group do not have clear benefits or negative effects from the compost treatments. In the second group, lettuce was the most sensitive of the vegetables, but did not show the same number of significant trends as the vegetables of the first group.

The greatest benefits of fertilisation and the least negative effects of phytotoxicity as shown by plant weight and plant height were obtained for the compost concentrations of between 0% and 25%. Nursery bed topsoil amended to these rates may result in some greater production advantages. Applications of over 25% compost resulted in more phytotoxic effects than positive ones. With cumulative applications in quick succession, a greater amount of negative effects may become apparent since the soil ecosystem might not have time to break down the phytotoxins before an additional amount is applied. Compost applications of 12.5%-25% of the topsoil (20 cm) are equivalent to application rates of approximately 200-400 t/ha. These are very high, and more importantly, costly treatments. Such high and cumulative application rates will make future crops unsafe to eat, may significantly affect the growth of plants, may contaminate and poison the soil ecosystem, and decrease the quality of the land.

In the interest of keeping costs low for the farmers, and to maintain non-phytotoxic, yet growth promoting healthy nursery beds, it was recommended to farmers to keep

compost applications to a minimum. Application rates not exceeding 40 t/ha per crop is recommended for nursery beds

It is proposed that an experiment be conducted comparing two transplanted vegetable production systems, one with a compost fertilised nursery bed and one without. This will help to determine whether a set amount of compost should be split between nursery and planting beds or used exclusively on the planting bed.

8.2 Suppression of Soil-Borne Pathogens with Compost Amendments

Lettuce and tomato were chosen as the test crops because they are typical crops in the urban and peri-urban areas of Kumasi and also both crops suffer significant damage from soil-borne fungal pathogens and root knot nematodes. Moreover, disease symptoms on these plants can be observed in a short period and are relatively easy to determine. Root galls caused by nematodes on both tomato and lettuce roots can be observed in a short time after inoculation. *Scelortium rolfsii*, which has a wide host selection, causes discolouration along the tap root and stem base. *Fusarium* wilt, a common tomato disease, causes discolouration of the vascular tissue along the tap root and the stem base as well as yellowing of lower leaves. In these diseases the infected plant ultimately wilts and dies. These symptoms are easy to determine and scored.

8.2.1 Disease suppression under Tomato

The result indicates that positive and negative effects of compost occured within well-defined ranges. Upon closer observation of the plants it was observed that at the 100% compost treatment all surviving plants were on the verge of death. In both series infected with fungal pathogens the incidence of infection was zero or close to zero. Cutting plant shoot and roots did not indicate any infection by either pathogen except for one plant that contracted *Fusarium* on the 8th day after inoculation and died two days later. The incidence of root galls was observed for most plants inoculated with root knot nematodes either all died or dying at the time of harvest. Plants that died before harvest were uprooted before they began to rot. Severe galling was observed on all of these plants. A significant reduction in root galling was observed from just a 6.25% compost application as shown in Figure 8-1.

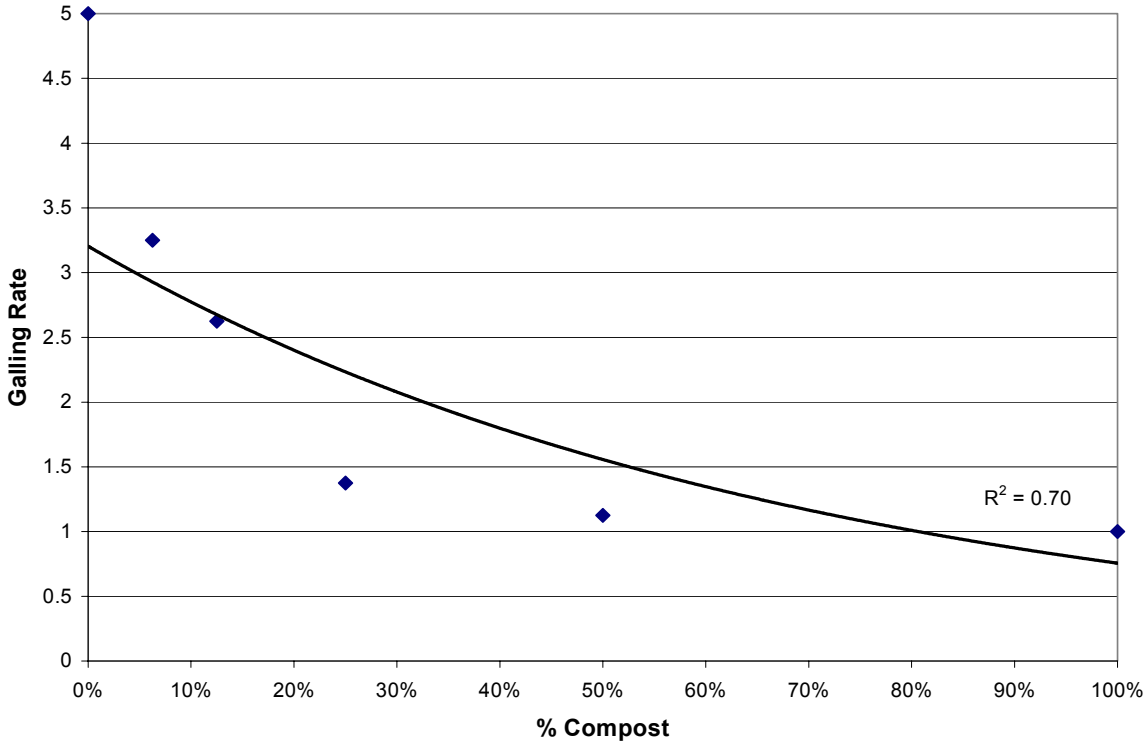


Figure 8-1 Root Knot Nematode Galling on Tomato Plants

Further reductions were observed as the concentration of compost increased. However, the higher compost concentrations were also very toxic to the plants.

8.2.2 Disease suppression under Lettuce

Large reductions in plant survival under compost concentrations of 25% or greater were observed for all pathogen treatments. The level of necrosis due to toxic burns at the base of the plants increased dramatically when lettuce was planted in 50% compost. Almost all lettuce plants died at the 100% compost treatment.

Infection by S*clerotium rolfsii* was not observed on the outer stem of the lettuce seedlings during the course of the experiment, nor was any infection observed when shoot bases and taproots were cut open.

The incidence of root galls was observed for most plants inoculated with root knot nematodes. The severity of infection measured on the 5-point galling scale is presented in

Figure 8-2. The plants planted without compost (0% treatment) were all dead between the 4th and 5th week. ANOVA of the dry weight of lettuce for the two pathogens shows that there is a significant difference in the effect of inoculation on the dry weight of lettuce for all compost treatments

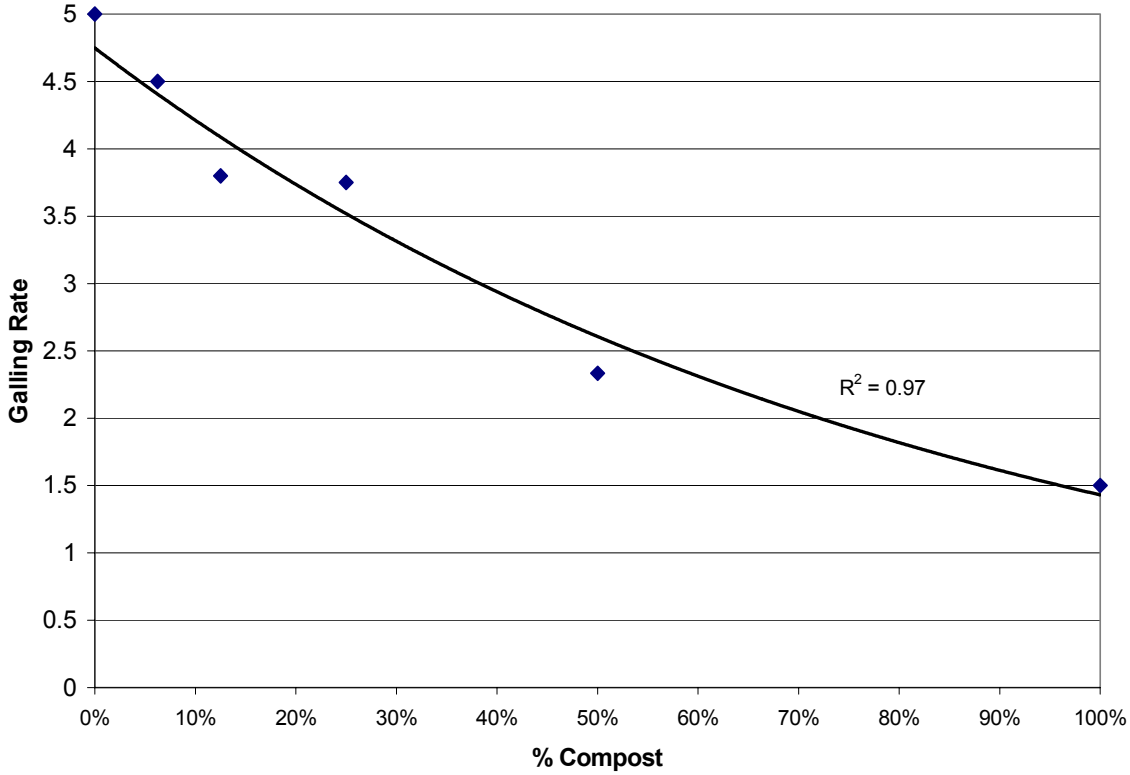


Figure 8-2 Root Knot Nematode Galling Rate on Lettuce Plants

Qualitative observations made on the plants show that, at 0% compost treatment the nematodes killed all eight plants while all eight plants survived in the 6.25% treatment. At the 6.25% compost treatment there is no significant difference between the two pathogen treatments. This indicates that the damage to the lettuce plants is not significant in the 6.25% treatment, but is significant in the 0% treatment. However, this relationship is not consistent for all compost treatments. The 12.5% and 50% compost treatments show significant differences between the yields of lettuce under the two pathogen treatments, while the difference is not significant at 25% compost.

Table 8-2 Lettuce Dry Weight (g/pot) for Different Compost Treatments[1]

Treatment	0%	6.25%	12.50%	25%	50%	100%
Control	0.60	0.94 a	1.08 a	0.56 a	0.22 a	0.00
Nematode	0.00	0.88 a	0.37 b	0.45 a	0.09 b	0.12

[1] values followed by the same letter in the same column are not significantly different

For both pathogen treatments the dry weight of lettuce was greatest for the 6.25%-12.5% compost treatments. At these compost treatments the plants appeared to derive benefit most from the fertilisation effect of the compost, and in the case of the nematode series, from the suppresiveness of the nematodes. In both cases the addition of 6.25% compost led to greater growth than the 0% compost treatment. At the higher levels of compost, 50% and 100%, the toxic effects are the most likely reason to explain the large decrease in both dry weight and plant survival for both pathogen treatments.

8.2.3 Implications for Field Level Compost Applications

Plant diseases and their difficult control by chemical pesticides are important factors keeping yields, quality and economic profit of farms in tropical conditions at low levels. Most research, so far conducted into the management and control of both foliar and soil-borne plant diseases in the humid sub-tropics of West Africa, has focussed mainly on diseases affecting cash or staple crops, using an array of various chemical pesticides. The potential use of compost extracts as an organic method of controlling foliar diseases and nematode damage in lettuce, tomato and manioc was attempted in Togo (Somana, 2001). The extracts obtained from compost produced from MSW of Lome, the capital city of Togo, were prepared using different compost to water ratios and different soaking times. The results indicate the stronger extracts, those with higher amounts of compost and longer soaking times, were able to suppress disease incidence of *Alternaria sp*. and *Cercospora sp.* and nematode populations in lettuce and tomato. Limited suppression was observed for *Cercospora sp.* on manios leaves, while there was no significant effect to herbivorous caterpillars and acari. This study indicates that there is a potential for the use of composts as organic pesticides for foliar disease control, but does not establish the role of composts for soil-borne disease control.

This present experiment attempted to show the ability of compost to suppress soil-borne pathogens in urban vegetable farming systems. It is concluded that in lettuce and tomato plants the incidence and severity of nematode root galling was reduced with increasing compost concentration. There was a significant improvement in plant performance, and decrease in galling severity, in both lettuce and tomato plants, with an increase from 0% to 6.25% compost. The exact mechanism explaining the suppression of nematode damage at the 6.25% level is not known. However, it is suggested that either antagonists or compost toxicity may be responsible.

Based on the low compost concentrations required to suppress nematode damage, the optimal application rate to maximise disease suppression and fertilisation benefits, and to minimise the phytotoxic effects and economic costs is a compost percentage between 6.25% - 12.5%. This is equivalent to a field application rate of approximately 100-200 t/ha. However, these application rates are much too high and unpractical for field wide applications. To achieve the benefits of nematode suppression at low levels it is suggested to increase the compost concentration in direct contact with the plants by mixing compost mixtures directly into the planting holes of each seedling during the transplanting phase. Although much more time consuming, the effective concentrations of compost may be achieved.

The implications of these conclusions on field level applications by farmers are important and should be adapted to site specific conditions. High application rates on sandy soils may lead to high leaching of nutrients but may be necessary to increase the organic matter content of these soils to prevent nutrient leaching. The long-term effects of applying high loads of compost may lead to an accumulation of

phytotoxic compounds and addresses the need for such research. It is most probable that over the long term, small applications of compost will allow for a better break down of toxic compounds by the soil ecosystem. Moreover, regular long-term applications of compost at low rates will increase both the organic matter and the plethora of beneficial biological organisms in the soil ecosystem. This will lead to greater stability and a healthier soil with lower incidences of soil-borne pathogens.

It is thus recommended that regular compost applications of 20-40 t/ha may help to reduce the severity of nematode damage in both tomato and lettuce, while maintaining some benefits of fertilisation and keeping costs low. It is further assumed that other commonly grown urban vegetables may benefit from the suppression of nematode damage from amendments of this compost.

8.3 Participatory On-Farm Trials with Compost in Lettuce-Based Urban Agriculture

The field trials were conducted with lettuce farmers selected from Gyenyasi Urban Farmers Association, located in Gyenyasi close to KNUST campus. This farmer association work closel y with IWMI

Nine different treatments and one control (no application) were chosen with each treatment having three replicate plots (total of 30 plots). In the field trial, compost (from composting cycle 2) was compared with poultry manure which tbe farmers usually use as source of nutrients. The quantities and time of application for each treatment are presented in Table 8-3. The chemical analyses of these inputs are presented in Table 8-4. Details of experimental design and data collection are highlighted in the Annex.

Table 8-3 Quantities and Time of Application of Different Fertiliser Treatments

Treatment Type	Code	Quantity (t/ha)	Time of application
Control	CON	0	n.a.
Poultry Manure Litter	PM10	10	Every crop
Poultry Manure Litter	PM20	20	Every crop
Poultry Manure Litter	PM40	40	Every crop
Co-compost	C10	10	Every crop
Co-compost	C20	20	Every crop
Co-compost	C40	40	Every crop
Co-compost	SC25	25	Single application on first crop
Co-compost	SC50	50	Single application on first crop

Co-compost	SC100	100	Single application on first crop

Table 8-4 Chemical Analysis of Fertiliser Treatments

Treatment	TKN (%)	Org C (%)	Org M. (%)	P (%)	K (%)	pH	EC (ms/cm)
Poultry manure litter	1.14	4.91	8.5	n.a.	n.a	7.4	7.86
Co-compost	1.06	6.75	11.64	1.84	3.22	7.3	n.a.

8.3.1 Performance of Compost and Poultry Manure Fertiliser Treatments

The mean yield of poultry manure treatments was greater than the compost treatments of equivalent weight although this difference is not significant. The differences can be easily distinguished by simple observation, but high variation between replicate plots makes this difference statistically not significant.

Table 8-5 Lettuce Yield (kg/m^2) for the Compost and Poultry Manure Treatments

Treatment	**Crop**			**Mean of all crops**
	1st	**2nd**	**3rd**	
Control	0.90	0.97	0.82	**0.89**
Compost (10t/ha)	1.37	1.18	1.27	**1.27**
Compost (20t/ha)	1.22	0.93	1.41	**1.19**
Compost (40t/ha)	2.35	1.68	1.58	**1.87**
Poultry Manure (10t/ha)	1.95	1.73	2.17	**1.95**
Poultry Manure (20t/ha)	1.77	1.28	1.85	**1.63**
Poultry Manure (40t/ha)	2.45	2.28	2.02	**2.23**

With a few exceptions in the third crop, and the problems encountered with high nematode damage in the 20 t/ha treatment, both the compost and poultry manure series showed an increasing yield obtained from an increase in fertiliser treatment. As opposed to the single application treatments, which indicated a decrease in yield with successive crops, the compost and poultry manure treatments applied to every crop result in quite constant yields over the three crops.

The nitrogen content of poultry manure was slightly higher than compost (Table 8-6). This may explain the greater yields obtained using poultry manure. Although fertiliser treatment, and not variation in field conditions, is the most important variable influencing lettuce performance, variation in field conditions does however create problems for accurate statistical analysis.

For single compost application only the application of 100 t/ha, may be used to provide nutrients to successive crops, and then there appears to be only enough for two crops before the nutrients are either leached away or removed with the crop. The other two treatments (25 t/ha and 50 t/ha) barely achieved the “market” yield threshold on the second crop and by the third crop all treatments performed similar to the control treatment.

Among the three compost treatments applied to every crop only the 40 t/ha compost treatment can achieve the yields required by farmers for every crop. The 10 t/ha treatment barely achieved the "market" threshold, while the 20 t/ha compost treatment does occasionally reach the "economic" threshold.

Third, since the farmers regularly use poultry manure as a fertiliser, the trials involving poultry manure could be appropriately compared to the farmers' usual practices. The results from the trials indicate that all three poultry manure treatments may achieve the "economic" threshold, and that they occasionally break the 2.0 kg/m^2 yield mark. These results correlate well with the relationship between the farmers' usual practice and the resulting performance. Farmers usually fertilise with between 10-40 t/ha of poultry manure and achieve yields greater than 1.6 kg/m^2 for all crops; similar results were obtained from this field trial.

Fourth, a pairwise comparison between the compost and poultry manure treatments indicates that greater yields are obtained from the poultry manure than from the compost treatments of equal weight.

8.3.2 Lettuce Tissue Nutrient Content

A comparison between the compost and poultry manure treatments indicates that there is a small significant difference between the nitrogen (p=0.07) and phosphorus (p=0.06) contents of the lettuce under these two treatments. This relationship was backed by the farmers. Their observations in the field was that the lettuce under the poultry manure treatments was greener and more lush than under the compost treatments. This would indicate a difference in nutrients, particularly nitrogen.

Soumare *et al.*(2003) found significant increases in phosphorus and potassium concentrations in tissue of rye grass in a pot experiment with applications of 50 t/ha of a MSW compost on two different tropical soils from Mali. In general very high applications of compost may be required to observe significant increases in nutrient content in plant tissues.

8.3.3 Changes in Soil Properties Following Compost Application

The percent change in various chemical and physical soil parameters measured two months after the start of the field trials are presented for the different treatments in Table 8-6. A wide range in changes was observed for some parameters, especially available P which recorded an increase of 162% and a decrease of 21% in different treatments.

Table 8-6 Percent Change in Soil Properties under Different Fertiliser Treatments

Treatment	pH	OM (%)	TKN	Available P	Available K	Bulk Density (g/cm^3)	Porosity (%)
Control	7.4	-24.7	-11.3	91.2	10.9	-5.0	4.6
SC25	10.6	3.2	-6.2	-20.9	3.4	n.a.	n.a.
SC50	12.0	-2.0	21.2	17.9	43.8	n.a.	n.a.
SC100	16.9	-10.5	2.4	135	51.6	0.4	-9.1
C10	9.5	-22.7	21.2	71.4	-2.2	-0.8	-3.7
C20	10.1	-9.7	2.4	101.3	50.2	-0.1	-0.8
C40	11.6	-3.4	2.4	87.1	96.3	-0.8	1.5
PM10	12.1	0.9	9.5	161.7	21.3	3.0	-11.1
PM20	10.5	-7.5	-5.4	66.0	55.9	-5.7	9.1

PM40	10.0	-5.1	21.2	115.8	152.3	1.6	-7.7

After two months of treatments no significant effects on soil conditions are apparent from the different treatments. It is assumed that changes in soil conditions may be observed from compost application on the long term (1+ years).

8.4 Conclusions

The field trial involving consecutive crops grown following a single compost application have indicated that there is a large loss of nutrients following the first crop. After two crops the yield of lettuce under all three compost treatments (25 t/ha, 50 t/ha & 100 t/ha) was reduced to similar levels as the control. It is proposed that the sandy soils of the Gyenyasi farms leached out the majority of the available nutrients provided by the compost after two harvests. Even after one harvest the available nutrients of the highest compost treatment (100 t/ha) were greatly decreased to uneconomical yields. It is concluded that for these sandy soils, it is unreliable to depend on residual nutrients from previous compost applications. It is recommended that compost applications should be made for each crop, otherwise very large compost applications greater than 200 t/ha will be required.

The nutrient content in lettuce tissue amended with various compost and poultry manure treatments did not show many significant differences. The contrast between the compost applications and the poultry manure applications did show a significant difference on the first and second crop only. All other effects of treatment type and farmer were not significant. It is assumed that the duration of the experiment (three months) was not long enough to observe any noticeable changes. Any changes in tissue nutrient content might be reflected in soil properties. However, no noticeable changes to soil properties were observed due to wrong assumptions of initial soil conditions. Long-term applications of compost on sandy soils might lead to significant changes, especially in organic matter content.

The comparative experiment between compost and poultry manure indicated that lettuce yields were always greater for poultry manure treatments than equal weight compost treatments. At all application levels (10, 20, & 40 t/ha), the poultry manure treatments obtained economic lettuce yields, while for the 10 & 20 t/ha compost treatments low uneconomic yields were obtained. Since poultry manure litter is in excess in the Kumasi region, it is very inexpensive and easy to buy and transport. Furthermore, the density of poultry manure is much lower than the compost. As a result farmers complain about the quantity and weight of compost required to achieve economic yields. A 10-kg bag of poultry manure is much easier to carry than a 40-kg bag of compost! These reasons help to conclude that the current input use of the Gyenyasi farmers, poultry manure, is the preferred option due to its superior field performance, low and competitive cost, and easier farmer usability.

Under different farming conditions where availability or cost of poultry manure makes it unusable, the compost may be used as a suitable fertiliser. An application rate of 40t/ha per crop is recommended for nutrient intensive vegetables such as lettuce grown on very sandy soils.

The quality of the produced compost is one of its most important constraints. The low organic matter content of the compost is probably due to the quality of the inputs.

The market waste and sludge contributed large amounts of silt and sand particles which are not conducive to a good quality compost. Lowering the amount of sand and increasing the amount of organic matter, through selection of appropriate inputs, may decrease the compost weight, heavy metal content, and electrical conductivity, and increase the overall quality of the compost. Without high organic matter content, the long term benefits of compost application will not be realised.

Various regression equations (not shown) have been developed between yield and other growth parameters. Near-accurate estimations of yield from easier to measure growth parameters will be possible. This may help researchers in making assessments of lettuce bed performance in a shorter time.

The design of the present experiment was made with very limited resources of time, labour and compost. The experiment had a few weak aspects that should be avoided if resources allow. The most important aspect concerns the variation between farmers and field conditions. It is recommended that in order to avoid high variation that might lead to insignificant results, a minimum of five replicates per treatment be employed. Either as five farmers or five plots under one farmer.

9 ECONOMIC APPRAISAL OF THE CO-COMPOSTING PILOT PLANT

9.1 Costs Streams

Only direct costs, which are made up of investment capital, operational and maintenance costs, are considered in this report. Indirect or hidden social costs, such as those from anthropogenic gaseous emissions and leachate pollution, are not considered because they are extremely difficult to estimate.

9.1.1 Investment Capital Costs

The investment capital costs of the Buobai Co-composting Pilot Project are presented in
Table 9-1 below. These costs are made up of construction of site office and store, ramp for vacuum trucks, a 15m^3 sludge storage tank, a solid waste handling area, two parallel drying beds, a composting area and a percolate storage tank. The clearance of the site and the purchase of general items make up the rest of capital items. In this analysis, the cost of land was not included because Kumasi Metropolitan Assembly donated it free for the project. The total amount spent as investment capital costs was US$ 21,753. The higher expenditure over what was proposed in the project proposal has arisen because the costs of general items, sludge storage tank, pipe-work, splitting chamber, sludge drying beds, composting area, sludge storage area and roofing materials needed to accomplish the task. The actual amount spent was also more than given in the contract document for construction because some of the items were under-estimated. The amount spent on general items was about 28% of the actual cost of the project's capital items. An important expense under general item constitutes the establishment of the site office and store room that amounts to US$ 5,825. The cost of constructing the composting area was also high due to extra concrete and reinforcement steel. An important outlay for the roofing material to cover the composting area was necessary to protect windrows during the rainy season.

Table 9-1 Investment Capital Costs of the Buobai Co-composting Pilot Plant, Kumasi (2002)

No.	Cost Item	Contract Amount in US$[1]	Actual Amount in US$[1]	% of Contract Value	% Total Cost
1	GENERAL ITEMS	3,227	6,159	191	28
2	SITE CLEARANCE	55	55	100	40.3
3	DISCHARGE BAY	703	703	100	13
4	SLUDGE STORAGE	1,217	1,489	122	7
5	PIPEWORK	215	954	444	4
6	SPLITTING CHAMBER	123	249	203	1
7	SLUDGE DRYING BEDS	2,206	2,572	117	12
8	Solid waste handling area	1,020	1,071	105	5
9	COMPOSTING AREA	3,447	3,840	112	18
10	SLUDGE STORAGE AREA	47	508	1,081	2
11	ROOFING MATERIALS	2,609	3,359	129	15
12	PERCOLATE STORAGE TANK	1,294	794	61	4
13	DAYWORK	1,135	0	0	0
14	10% CONTINGENCY	1,730	0	0	0
15	**TOTAL**	**19,028**	**21,753**	**114**	**100**

[1] Original costs in cedis; but converted here using the average (while construction works last) exchange rate of 7,500 cedis to 1 US$

In all, US$ 6,315 was spent on faecal sludge and percolate handling facilities, accounting for 29% of the actual amount spent on capital items. Comparatively, an amount of US$ 8,270 was attributed to composting capital items, which is 38% of the amount spent on the project. The analysis also shows that 67% of the capital costs were imputed to the co-composting processes (biosolid production, waste sorting and processing of the matrix).

9.1.2 Operational and Maintenance Costs

In addition to investment costs, operation and maintenance (O+M) of the co-composting plant in 2002 caused expenditures, which occur regularly. Table 9-2 shows yearly general O+M cost in the pilot plant. These recurrent costs are obtained from time observations made during field monitoring and collation of financial data in 2002. Kumasi Metropolitan Assembly undertook transportation of the municipal solid waste, faecal sludge so the costs of these activities have not been included in this report. The real cost of research works, sampling and laboratory analysis carried out on the project has also not been included.

Table 9-2 Yearly Running Costs for the Buobai Co-composting Pilot Project, Kumasi (2002)

NUMBER	COST ITEM	AMOUNT IN US$/yr	PERCETAGE (%) OF TOTAL
1	COMMUNICATION	167	9
2	FINANCIAL EMOLUMENTS	1,064	59
3	TRANSPORTATION	140	8
4	OCCUPATIONAL THERAPY	100	7
5	CONSUMABLES	60	3
6	WATER SUPPLY	40	2
7	MAINTENANCE AND REPAIRS	209	12
8	**TOTAL**	**1,800**	**100**

The total running cost incurred on the pilot project during the base year (2002) was US$ 1,800. In terms of average cost per ton of compost produced (max. 37 tons), the value works out to be US$49 per ton. For pure solid waste composting of similar capacity, the average cost per ton in America is US$32 (Kashmanian and Spencer, 1993). This figure ($32), however, does not consider such activities of the co-composting processes undertaken on feacal sludge in the pre-composting phase. Considering the fact that the project is research-oriented, the highest running cost was incurred in meeting personal emoluments, including salaries and wages of the plant manager and two fulltime workmen. Payment of emoluments alone was US$1,064, representing 59% of the total running cost incurred in managing the pilot project. The cost of water was extremely low, because KMA provides the water tanker while the project paid for the water itself so total cost is partially subsidised.

Table 9-3 below categorises the running costs into various activity areas, namely: sludge removal, sand replenishment, compost turning, waste sorting, and compost screening and bagging. The rationale behind categorising the costs according to the various activities is to determine those with high values in order that they can be adjusted. About 11% of the total running costs is classified as contingent expenditures.

Table 9-3 Categorised Running Costs of the Buobai Co-composting Pilot Plant based on man-hour monitoring in 2002

NUMBER	COST ITEM	AMOUNT IN US$	PERCENTAGE (%) OF TOTAL
1	SLUDGE REMOVAL	100	6
2	REPLENISHMENT OF SAND	75	4
3	COMPOST TURNING	300	17
4	WASTE SORTING	525	29
5	COMPOST SCREENING AND BAGGING	100	6
6	CONTINGENCIES*	700	39
	TOTAL	**1,800**	**100**

*Other costs including the salary of plant manager not charged to the various activities

The result shows that sorting of solid waste is the most costly activity undertaken by the Buobai plant. Its value is about 29% of the total operational and maintenance costs, or US$3.3 per m^3 of sorted organic waste on the average. The operations of the plant are labour-cost intensive. To reduce the cost of sorting it is prudent to sort the organic material at source and this will require elaborate public education in selected pilot areas.

9.2 Benefit Streams

Benefits of the co-composting method are classified into direct revenues and indirect economic gain made from the operations of the project. Direct revenues may arise from the sale of the compost produced, and from household and commercial waste removal taxes. Indirect economic benefits of the co-composting method may be derived from averted transport and landfill space costs, and from reduced municipal's health wage bill. Public health benefits arising from co-composting are of three categories: averted health treatment costs, productivity gain due to lower morbidity, and productivity gain due to lower mortality (Steiner, 2002; World Health Organisation, 2001).

Total economic benefit is the sum of direct revenues from the co-composting operations and social benefits derived thereof. The total economic benefit is calculated based on the following simple mathematical relationship:

$$B_{ET} = Q_{pi} + W_{ri} + (\alpha + \beta + \lambda)Q_i \qquad (1)$$

Where Q_{pi} = sales revenue of compost;

W_{ri} = revenues from waste removal services provided by the KMA

α = benefit derived, per ton of waste handled, from averted cost of waste transportation from source of generation to landfill sites;

β = benefit derived, per ton of waste handled, from landfill space saved;

λ = indirect heath benefit derived, per ton of waste handled, from the co-composting; and Q_i = the quantity of waste handled in the plant.

The economic price of good quality compost in Ghana is US$121 per ton of compost. This is an average derived from assessment of many compost samples in Ghana including the imported ones. The realistic capacity of the Buobai plant is 37 tons of compost per annum from a total of 180 m^3 of municipal solid waste and 360m^3 of raw feacal sludge. Therefore, the yearly sales revenue works out to be US$4,477. The project has coverage area of 800 people of the high-income group, which is equivalent to 100 households. But, in economic terms, each household in Kumasi paid US$2.50 per week (or US$130 per annum) for waste services (average of household waste and septage) in the year 2002. Consequently, the total revenue that accrued to the Kumasi Metropolitan Assembly from waste services in 2002 was US$13,000. The average values of α and β in equation (1) are estimated for the Kumasi Metropolitan Area as US$8 and US$ 41.30 respectively. The value for λ for tropical countries including Ghana is US $50 for solid faecal sludge (Esrey (2002); WHO, 2002). This standard figure is used in this analysis as a proxy to compute the health economic benefits for co-composting. In calculating the direct benefit stream, the value of sorted recyclable materials has been excluded because the scale of operation of the pilot plant is so small as to generate any significant amount of recyclables. The benefits arising from soil improvement as a result of compost application, from reduction in environmental pollution and from research results are difficult to quantify and these components are also excluded. Table 9-4 gives a summary of the economic benefits derived from the co-composting operations of the Buobai plant.

Table 9-4 Economic Benefits derived from The Buobai Co-composting Pilot Plant (at 2002 Shadow prices)

Direct Revenues (US$)		**Indirect Benefits (US$)**			**Total Benefits (in US$)**	**Average Benefit/ton Compost Produced**
Sale of Compost	Waste Removal Charges	Transportation Cost Saved	Landfill Space Cost Saved	Public Health Bill Saved		
4,477	**13,000**	**600**	**3,100**	**3,750**	**24,927**	**674**

From the analysis, the benefit derived from waste removal charges represents the highest potential economic benefit to the Buobai Co-composting pilot project. Its value is over 52% of the total economic benefits derived from the project. As the project is still in the pilot stage, it has been deemed prudent by Management not to exploit this aspect of its operation to advantage until the scheme's potential has been established. However, it should be noted that this benefit currently accrues to the Kumasi Metropolitan Assembly, which is used for societal welfare. It is essential that the Metopolitan Assembly religiously maintain this aspect of the plant's operations. The sale value of compost is 18% of the total benefit derived from the project's operations, while the total indirect benefits derived from the operation of the project is US$7,450(or 30%). It makes economic sense, therefore, to continue to operate the plant with slight improvements in volume reduction of waste, which currently stands 55%.

9.3 Economic Analysis

The rationale behind conducting the economic analysis is to determine the economic viability over the life of the project. As opposed to financial analysis, economic appraisal attempts to assess how the operations will affect society as a whole. The

economic analysis of the project is calculated on the basis of incremental costs and incremental output. The economic rate of return (i.e. discount rate which makes discounted net costs equal to discounted net benefits, or the net present value of the project equal to zero) has been estimated using the following assumptions. Project life was assumed to be 15 years (equivalent to the minimum expected life of a compost plant) including a two-year investment period during which the developing activities would be completed. Costs of inputs are rising at a rate equal to the average rate of depreciation of the Ghanaian currency (15%) during the 2002 fiscal year. Prices of compost are increasing by 10% per annum. Being a smalls-scale pilot station, the Buobai compost plant is discounted of taxation. In calculating the economic prices, which are expressed in constant 2002 prices, a distinction has been made between internationally traded and non-traded commodities. Compost is not traded internationally. Since local prices of organic soil ameliorants are reasonably efficient and integrated into the national marketing system, market prices are used as the basis of the economic values. All market prices are deflated by the foreign exchange premium (12%) to obtain economic (shadow) prices. Thus, the standard conversion factor of 0.93 is applied to all costs to covert them to economic values. Regularly, partial recapitalisation of the project for the maintenance and repairs of project's facilities is expected to take place after every 5 years. The sensitivity of the economic rate of return to changes in cost/benefit streams was tested for (a) delay in one year in the benefits with no delay in costs; (b) an increase in 10% of costs; (c) increase in 10% of benefits and (c) fall of 10% and 20% in benefits. The results of the economic analysis are presented in Table 9-5 below.

Table 9-5 Sensitivity Analysis on Economic Rate of Return of the Buobai Co-composting Pilot Plant

NUMBER	ASSUMPTION	ECONOMIC RATE OF RETURN (ERR)
1	BASE CASE	**44**
2	ONE YEAR LAG IN BENEFITS	**30**
3	10% INCREASE IN COSTS	**30**
4	10% INCREASE IN BENEFITS	**55**
5	10% FALL IN BENEFITS	**29**
6	20% FALL IN BENEFITS	**9**

The analysis of the plant's economic viability shows that the economic rate of return on the investment is 44%. This represents the return of the resources engaged in the plant over its economic life and is higher than the opportunity cost of capital, which has been approximated as the average interest rate of borrowed capital (35%; Bank of Ghana, 2002) in Ghana during the 2002 fiscal year. The net present value of the investment at a discount rate of 35% is US$2,338. This means that the Buobai project is economically viable, *ceteris paribus*. It also means that if money were borrowed from a financial institution in Ghana to under take the operation, it will benefit society as a whole by US$2,338. The sensitivity analysis indicates that, the plant is highly sensitive to changes in economic parameters. However, the plant is more sensitive to changes in benefits than changes in costs. While the plant can tolerate a degree of latitude in the values of economic parameters estimated, it is important that major divergences in costs, outputs and timing be avoided. While divergences in input and output prices are outside the control of plant, the analysis underscores the need for sound project management, regular and timely financing and orderly flow of inputs for which the production component depends. The major economic risks are on the marketing of the compost produced. There is a need for a good marketing strategy for the compost.

9.4 Economy of Scale

There might be considerable economy of scale when the plant capacity is increased, because costs do not necessarily rise in the same proportion as the capacity of the plant. For instance, even when more faecal sludge and solid waste are treated, one discharge bay and one site office will still be sufficient. The paradox is whether management should reduce or increase the volume of compost produced per annum. The costs of production of the co-composting venture are made up of fixed costs and variable costs. While fixed costs do not depend on the volume of compost produced, variable costs very much depend on the output of the plant. So it is possible that the cost per unit weight of compost produced by a smaller plant can be higher than that for a larger plant. However, very large capacity plants have the disadvantage of generating very high transport costs from increased waste collection coverage area, larger capital investment costs, and a backlog of unsold compost. In this case, production of compost will experience what economists usually call the *zone of diseconomy*. For an activity with much social bias, such as co-composting, all the economic benefits will be skimmed plus society's financial resources to finance the plant. A solution to the problem of choosing the right capacity of production lies on the determination of a break-even volume, based on practical financial data collected over the one year of operation. For this purpose, the costs and benefits of various capacities of co-composting were calculated (as presented in Table 9-6) and plotted on a graph (as in Figure 9-1 below).

Table 9-6 Cost-Benefit Analysis of the Buobai Co-composting Pilot Plant (At 2002 Constant Prices)

COMPOST OUTPUT	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150
DIRECT COSTS (in US$ x10^2)	10	18	27	50	67	88	98	120	131	150	162	178	197	215	234
DIRECT BENEFITS (in US$ x10^2)	13	26	39	52	65	78	91	104	117	130	143	156	169	182	195

The break-even analysis shows that the ideal range of operation of the Buobai pilot plant is from 10-45 tons of compost per annum. The break-even weight is estimated at 45 tons per annum. This is the practical point at which direct costs and direct benefits are equal. This weight is equivalent to about 90 tons of total solid (dewatered sludge and solid waste). Based on the practical data, the respective weights required to process the 45 tons of compost are 30 and 60 tons of dewatered faecal sludge and municipal organic solid waste.

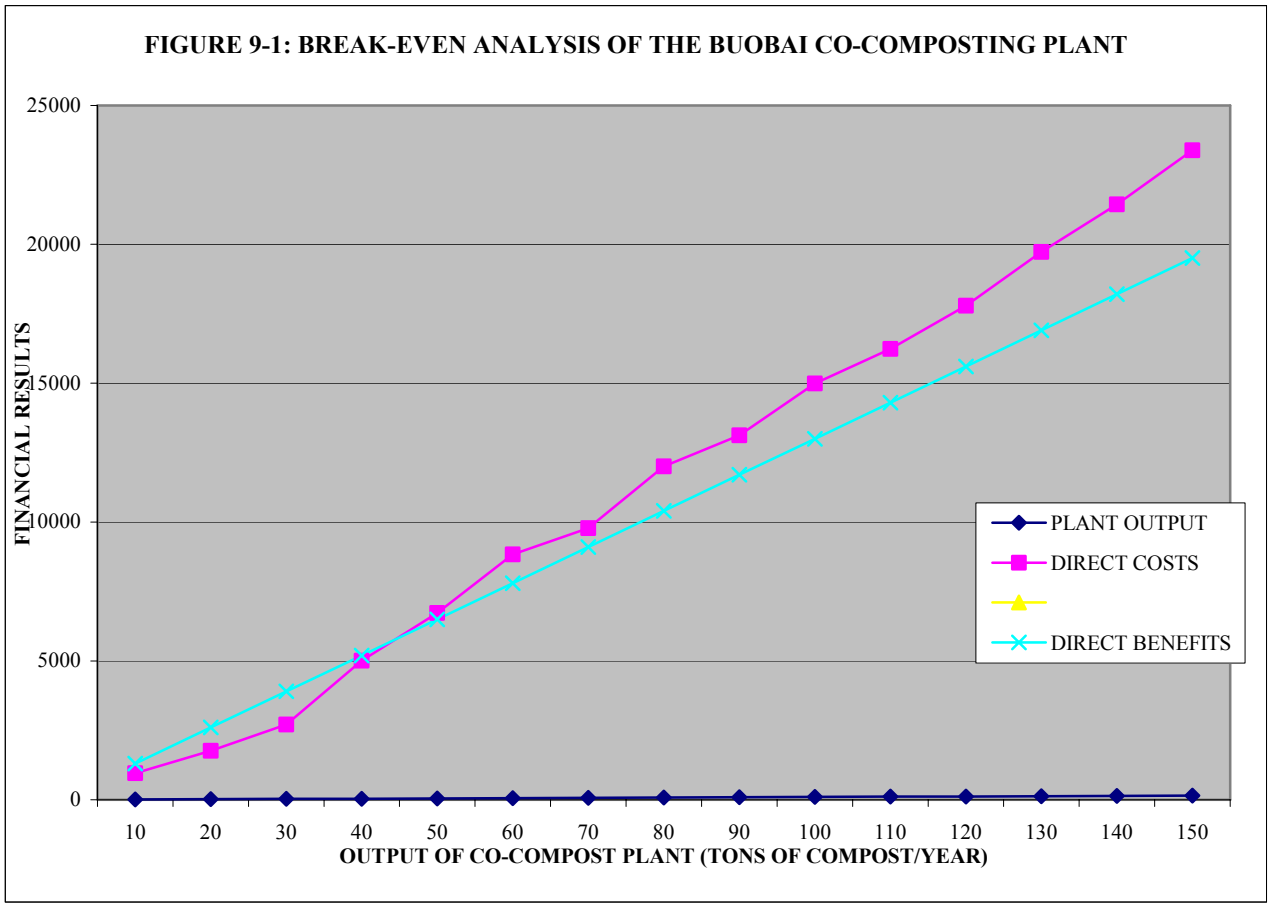


Figure 9-1 Break-even Analysis of Buobai Co-composting Plant

Working backwards, a volume 135 m^3 of organic waste is needed to combine with 43 m^3 of dewatered sludge to produce the break-even volume. Furthermore, 224 m^3 and 430 m^3 of raw solid waste (unsorted) and raw faecal sludge (un-dewatered) respectively will be needed to operate the plant at the break-even point. From the financial point of view, where the individual entrepreneur's objective is to maximise financial profits, operations of the plant is cost beneficial at 30 tons per annum. However, the Buobai pilot plant is so far research-oriented, which has a double-agreeable purpose of removing waste from society and providing plant nutrients to urban and peri-urban agriculture. Thus, the net economic benefits are very important in every decision taken on the plant. It is therefore recommended that the plant be operated at the capacity very close to 45 tons of compost per annum, while steps are taken to address the extremely long dewatering period. If operated at the recommended level, the opportunity costs of establishing the plant during the start-up year will be US$23,553. These economic costs are made up of investment capital and co-composting running costs, which could have been put at its best alternative use elsewhere. The economic benefits derived from operating at this level sum up to be US$ 38,250. The net economic benefits are, therefore, US$14,697, which is sufficient to build and operate a health clinic for the residents of the Buobai suburb in Kumasi.

9.5 Conclusions

The current coverage for waste collection service is about 70%, which is mainly provided by the private sector under temporary arrangements. Notwithstanding this

high coverage of waste collection, there is still a problem of managing it from the collection stage up to its final disposal point. The Buobai Co-composting Pilot Plant was established as a satellite scheme to remove both municipal solid waste and faecal sludge from the system and turn them into plant nutrients. The plant is research-oriented whose outputs will include prepared guidelines for co-composting in Ghana and the creation of a pool of knowledge for technical advice to waste managers, engineers and planners on the subject. The economic appraisal of the plant has shown that the cost of producing a ton of compost is US$ 49/ton. The analysis also shows that the plant is economically viable, though financially it might not be. However, we are more concerned with its contribution to society's welfare. The optimal level of operating the plant has been estimated at 45 metric tons of compost. This will require 224 m^3 of municipal solid waste and 430 m^3 of raw faecal sludge to produce it. At 2002 constant prices, this volume of compost is expected to yield a net economic benefit of US$ 14,697.

However, the plant is confronted with a number of constraints that also border on its economic sustainability. Sorting of the waste at the plant represents one of the most costly activities confronting the plant. Being a purely labour scheme, the plant requires the employment of casual labour to carry out the sorting exercise. Dewatering of the faecal sludge also constitutes an area of concern to the survival of the plant. It is the activity that determines the rate of compost production by the plant, as it takes a very long time to be achieved and the sand has to be changed frequently. Based on these, the following recommendations are hereby made:

1. There should be a pilot scheme of source separation of waste that should specifically serve the Buobai co-composting pilot plant. In this way, about 60% of the current costs of sorting the solid waste would have been saved. In this case, it is better to start with the medium- and high-income dwellers that are well-organised and easily amendable to changes.
2. Instead of waiting for the faecal sludge to dewater completely before the composting processes takes place, the sludge could be directly mixed with organic waste while monitoring pathogen level
3. The research component should be intensified and possibly extended to cover waste routing models and cost-effective source separation strategies as well as quality improvement. The rationale is to reduce all variable costs to the lowest possible levels.
4. The major risk associated with the co-composting plant is on the marketing of the compost. Quality standards must be assured. Pilot demonstration schemes need to be established in the urban and peri-urban areas immediately as one of the means of experiential learning.

10 CAPACITY BUILDING AND AWARENESS CREATION

10.1 Capacity Building

- Many M.Sc students worked on various aspects.
- Two project assistants were trained on the job
- Training course on helminthes analysis organized for the participating project students
- Four scientific staff of the local university and two engineers of the Kumasi Municipal Authority's Waste Department were involved in project activities

10.2 Awareness Creation

- Initial results were presented at the 1st international solid waste management in Kumasi in December 2002
- Awareness was created among farmer groups in Kumasi
- Results to be presented at an IWMI workshop on waste recycling in the second half of 2003

10.3 List of Products from the Project

1. An operational co-composting plant in Kumasi
2. Mid –term report
3. 4 M.Sc dissertations; three submitted and passed. The fourth one is under review

11 FINANCIAL REPORT

During the course of the project, many expenses were incurred. Most of these went into the construction of the pilot station. With the realisation of the fact that the construction of pilot station cost more than the amount allocated in the proposal, matching funds were secured from other sources so as to be able to cover all expenses. Table 11-1 shows the breakdown of expenditure as charged to the French funds.

Table: 11-1 Budget and expenditure

Category	French Funds(FF)	FF in Dollars ($)	Exp to Dec 2003	Current Balance
Personnel Costs	**67,000.00**	**9,383.75**	**8,648.72**	**735.04**
Salaries	52,000.00	7,282.91	6,306.41	976.51
Fees(Operations & Staff)	15,000.00	2,100.84	2,342.31	(241.47)
Operating Costs	**162,700.00**	**22,787.11**	**8,497.86**	**14,289.26**
Office Supplies	3,700.00	518.21	18.28	499.93
Travel	90,000.00	12,605.04	1,270.03	11,335.01
Mail/Telecommunications	3,000.00	420.17	21.92	398.25
External Services	19,000.00	2,661.06	2,000.00	661.06
Monitoring	32,000.00	4,481.79	3,131.90	1,349.89
Operation and Maintenance of pilot plant	15,000.00	2,100.84	2,055.73	45.11
Equipment (construction works, Various small tools)	24,900.00	3,487.39	22,053.57	(18,566.17)
Sub-total	254,600.00	35,658.26	39,200.14	(3,541.88)
Overheads (8%)	20,368.00	2,852.66	2,852.66	0.00
Grand Total	**274,968.00**	**38,510.92**	**42,052.80**	**(3,541.88)**

This table does not include additional related expenses which were charged to other sources. These include:

1. The time spent by the project leader during the course of this project was partially covered by IWMI fund
2. The Swiss partners spent considerable time but the cost was not charged to the project but rather completely paid for by SANDEC/EAWAG. In addition to this they also bore the cost of travel to Ghana and living expenses while in Ghana throughout the course of the project. This accounts for the high positive balance with respect to travel allocation.
3. The user and institutional perception studies was partly incorporated and covered in a related IWMI project.
4. The agronomic studies was partly funded by scholarship award (AGROPOLIS) given to the student involved.

This fund leverage has enabled us to cover more grounds which would have been otherwise difficult.

12 **CONCLUSIONS AND FOLLOW UP PLAN OF ACTIVITIES**

12.1 CONCLUSIONS AND RECOMMENDATIONS

Sludge dewatering

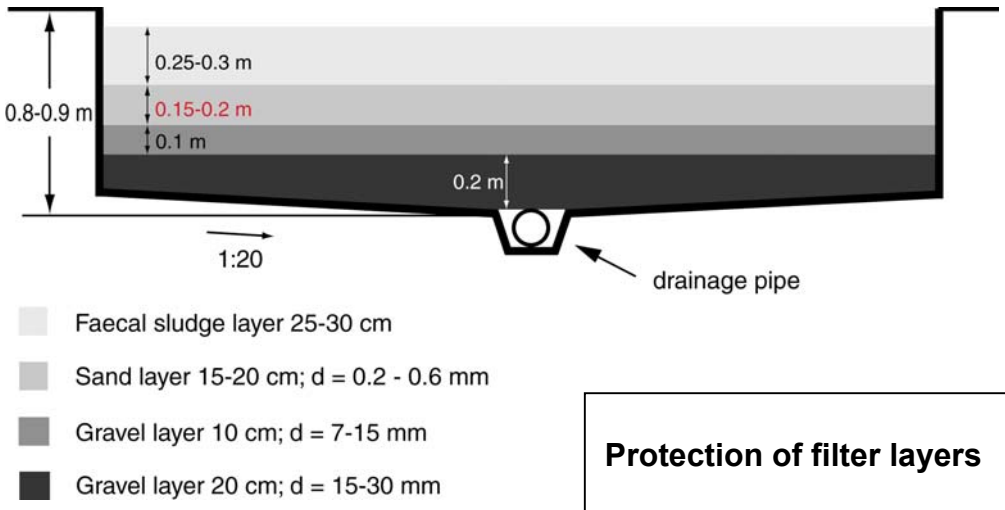
The study shows that drying beds retain suspended solids very efficiently; SS concentration in the percolate is reduced by 97%. The concentration of organic matter is also considerably reduced (90%) as it is mainly in the solids fraction. However, factors such as rain, type of filter layer and sludge strength can reduce the rate of dewaterability. Moreover, the organic concentrations in the percolate are still high: 5,885 mg/l TS, 4,684 mg/l COD. The quality of the percolate can be compared with that of (concentrated) tropical wastewater. Percolate could be co-treated with wastewater. If co-treatment is not feasible (for example, if there is no wastewater or no wastewater treatment facility), a percolate treatment system may need to be designed according to the design guidelines developed for wastewater treatment in the tropics.

Particular care must be given to sand quality. Sand particles should have a diameter of 0.2-06 mm and should not crumble. Crumbling of the sand particles would lead to a rapid clogging of the filter, making sludge dewatering ineffective. If an adequate type of sand is not available within a reasonable distance from the treatment site, another treatment option should be chosen. Another option for sludge dewatering consists of settling/thickening tanks or ponds.

It is necessary to dissipate the energy when loading sludge onto the beds. If the energy is not sufficiently reduced, filter layers can be damaged considerably. It is not necessary to construct a storage tank as used in this pilot project. The storage tank allowed for easier monitoring; it allowed the determination of the raw FS characteristics however, the construction of such a tank in a full-scale, non-experimental plant would increase construction costs and operational requirements for the management of the solids settled in the tank.

Box recommendations for dewatering

Drying bed profile



Raw sludge characteristics

⇒ Partly stabilised (septage or mixture septage/public toilet sludge with a low amount of public toilet sludge)

Sand characteristics

⇒ Sand particles do not crumble
⇒ Sand easily available locally

Reduction pressure flow

⇒ Stilling chamber, inlet channel and splash plates

Sizing of the beds

⇒ 15 days drying cycle
⇒ 25-30 cm sludge layer on beds
⇒ 100-200 kg TS/m2*y
⇒ 0.08 m2/cap

Drying bed removal efficiency

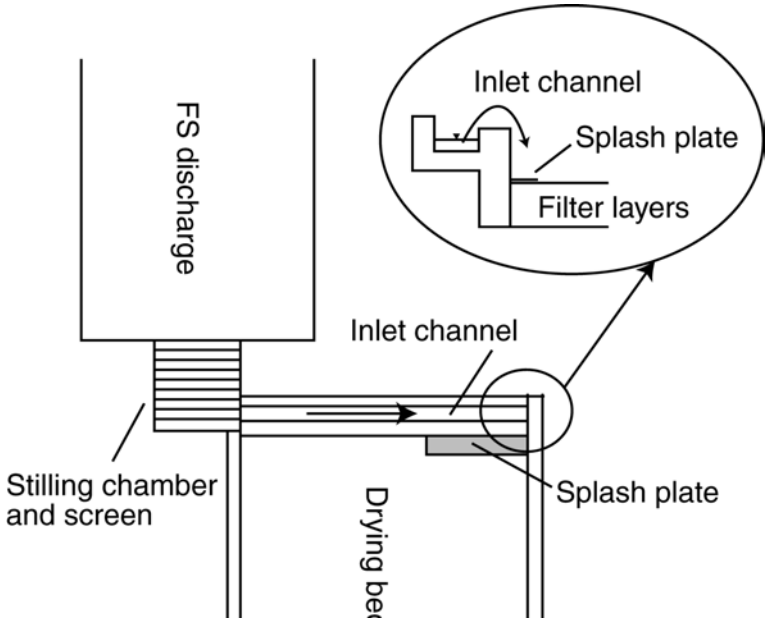
⇒ 97% SS, 90% COD, 100% HE, 40% NH4 (Accra)

Costs (full-scale plant)

⇒ Construction: 16 US$/t TS*y
⇒ O&M: 31 US$/t TS*y

Protection of filter layers

Stilling chamber, inlet channel and splash plate



Biosolids

⇒ 0.1m3 biosolids/m3 fresh FS
⇒ Biosolids hygienisation necessary prior to reuse in agriculture (co-composting, sun drying or storage)

Percolate

⇒ 50-80% of raw FS volume
⇒ Quality comparable to tropical wastewater
⇒ Salinity too high for irrigation
⇒ Percolate treatment: e.g. waste stabilisation ponds or combination sand filter and wsp

Co-composting

Results obtained during the monitoring of three composting cycles indicate that the necessary composting time to obtain mature compost under the Kumasi conditions (climate, type of wastes, turning frequency) amounts to about 12 weeks. The thermophilic phase lasts 4 to 5 weeks. Heaps were turned every two days during the thermophilic phase, twice weekly and weekly during the subsequent phase. It is questionable whether such a high frequency is necessary. It increases the production cost (turning of the heaps) and also water and possibly also N losses. Further composting cycles should be monitored in order to determine the appropriate turning frequency under the Kumasi conditions. Temperature patterns indicate that all parts of the heaps have been exposed to high temperatures during a sufficient long period so as to guarantee pathogens inactivation except for the third cycle where temperature was not high enough.

It was observed that there are differences in the changes that occurred during composting in cycle 2 and cycle 3. It is necessary to conduct more composting cycles to be able to make conclusive comments on these trends.

Planting trials

The short term trials with the compost produced show that it may be used at small rates on nursery beds without any significant delay or damage to seedlings. The long-term use may provide increased suppression to nematode damage in tomato and lettuce. If farming conditions exist whereby poulty manure is not accessible or unusable, then compost may be suitably used as an organic fertiliser. The compost quality needs improvement. Increasing its organic matter content is imperative for any long-term benefits to be realised. .

In conclusion, the co-compost market still needs to be developed. If compared on a nutrient yield basis, the price of compost considerably exceeds the one of chemical fertilizers. Given the relatively low willingness-to-pay by the farmers, the cost of co-compost production still needs to be considerably reduced. A means to the end is the shortening of haulage distances, hence, the placing of decentralised co-compost stations closer to the farmland.

To be able to arrive at meaningful recommendations on the constraints, opportunities and impacts of recycling human and municipal organic waste back into agriculture through co-composting, a period of 3-4 years of investigations would be required. Farmers' response to planting trials using co-compost vs. other sources of soil ameliorants are of particular importance. Further to this, the marketing and use of soil conditioners and fertilizers within urban and peri-urban agriculture needs to be assessed in an integral manner and strategic approaches for co-compost marketing be tried out. This constitutes a process demanding considerable periods of field and action research. The KMA also shares similar concern (Box 2) particularly with regards to the eventual taking over and operation of the plant.

Box 2 KMA'S PERSPECTIVE ON INSTITUTIONAL ARRANGEMENTS FOR TAKING OVER BUOBAI PILOT CO-COMPOSTING PROJECT

By

Anthony Mensah, Sanitary Engineer, KMA. January 2003

The Kumasi Metropolitan Assembly very much appreciates the implementation of the Pilot Co-composting Project, which fits well into the Assembly's strategic plan for waste management in Kumasi city. The collaborative roles played by the various stakeholders especially the sponsors are worthy for commendation.

As the host and future operator of the station the KMA has over the period played its collaborative role in the areas of:

- Supervision of Composting Station construction;
- Collection and transportation of faecal sludge and organic solid waste to station;

and is expected to assume responsibility for:

- Management of the station after the study period; and
- Promotion/Marketing of compost.

In the view of KMA the following observations have been made:

5. The length of time for research activities has not been adequate particularly in respect of compost trials.

   Over the period, considerable amount of compost has been produced, however, authentic and reliable results from trials have yet to be obtained. To acquire results that can be confidently presented, defended and utilized, a longer time frame of not less than 2 years would be required. This will facilitate the trial of compost of varying composition with wider scope of crops varieties.

6. Lack of adequate information for effective marketing and promotion of compost.

   Effective marketing and promotion of compost requires adequate information based on results from compost trials if prospective compost users could be effectively sensitized.

The above two very important roles in the research activity have been the responsibility of IWMI, which has the requisite capacity to handle them.

In conclusion, there is no denying the fact that a number of questions need to be answered, and which answers will represent a marked proportion of the success of the project. Where as KMA would be prepared to take over and manage the facility beyond the piloting phase, we would appreciate if the funding could be extended by at least **Two Years** within which those gaps could be filled. KMA will continue to play its assigned roles to help ensure a completed project that all stakeholders could be proud of.

12.2 FOLLOW-UP ACTIVITIES

The results of the project collated to date allow making first inferences as to the performance of the process and the achievable compost quality. However, the database is as yet insufficient to formulate guidance for planners, operators and engineers. The major causes of nitrogen loss and potential counter measures need to be reliably assessed. Investigations with urban and peri-urban farmers have revealed that conditional willingness-to-buy compost prepared from faecal sludge (FS) and municipal solid waste (MSW) exists. The farmers demand that planting trials using co-compost and comparing this with other soil/nutrient amendments be conducted to be able to judge the potential benefits of the co-compost. Such trials, which constitute a crucial element in establishing the potential compost market, would have to last several years to be able to make meaningful observations on soil and plant response. In view of the above, future field research would seek to comply with the following objectives, issues and activities:

Issue	Objective, output	Activities required
A. **Producing a marketable co-compost from FS and MSW**	**Guidance** for planners, engineers and operators on the **design, construction, operation, and costing of FS / MSW co-composting schemes** are at hand	• FS dewatering on sludge drying beds: Monitoring filter dynamics and bed performance under varying FS loading regimes and rainfall conditions; investigating nitrogen dynamics; developing suitable options for percolate treatment and use or disposal • Co-composting dewatered FS and MSW: Investigating nitrogen behaviour and testing nitrogen conservation measures; testing maximum admixing ratios of dewatered FS; testing suitable additives to co-compost and identifying their impact on co-compost quality; identifying / eliminating sources of heavy metals in the source materials; assessing the impact on compost quality from windrow watering with drying bed percolate; assuring hygienically safe compost quality using helminth eggs as an indicator
B. **Marketing co-compost**	A **strategy** is devised which assures **long-term marketability** of co-compost produced from FS and MSW under **competitive market**	• Conducting planting trials with a selected number of urban and peri-urban farmers, applying co-compost and promising enriched variants • Conducting perception and willingness-to-pay studies with various potential co-compost users, viz. vegetable and staple food farmers, plantation farmers, estate/landscape developers, backyard farmers, and identifying actual demand for

	conditions	co-compost • Identifying suitable outlet and distribution structure/pathways for co-compost products • Developing and testing strategies for rendering co-compost and enriched variants competitive on the soil conditioner/fertilizer market • Raising the awareness of policy and decision makers for treating urban waste and recycling it into urban agriculture • Monetarising the benefits of using co-compost in urban agriculture and conducting financial and economic investigations to justify the subsidizing of co-compost production • Devising jointly with the stakeholders the strategy for a stepwise implementing of sustainable marketing of co-compost
C. Institutional set-up and jurisdictional framework	Recommendations for an **enabling institutional and regulatory framework** pertinent to and facilitating sustainable co-compost production and marketing are at hand	• Conducting focus group discussions, advocacy and promotional campaigning with relevant actors, viz. municipal and national authorities; FS and MSW collectors/haulers; co-compost producers/sellers; farmers • Formulating the institutional and regulatory framework jointly with the concerned authorities as part of an overall framework enabling sustainable urban waste management and recycling of organic fertilizer
D. Dissemination	**Knowledge, recommendations and guidance** on co-composting are effectively **transferred / rendered accessible to stakeholders** in Ghana, other West African countries and elsewhere	• Convening a suitable number of national and regional workshop/seminars involving various stakeholder groups, issuing concomitant background documents, proceedings and guidance material • Setting up and continuously updating a project website, and make use of other electronic media to disseminate knowledge gained in the project and enable discussions • Producing guidance documents on co-compost production and marketing for decision makers, planners and engineers • Setting up collaboration with other institutions wishing to build capacity in R+D of co-composting

Proposed duration of project: 3 years

Principal investigator:

- Dr. Olufunke Cofie, IWMI – Ghana

Field research partners:

- EAWAG/SANDEC, Dubendorf, Switzerland
- Kwame Nkrumah University of Science & Technology (KNUST), Kumasi
- Kumasi Metropolitan Assembly / Waste Management Department

- **Funds sought (tentative)**: US $ 80,000

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ANNEX

ANALYTICAL AND EXPERIMENTAL PROCEDURES

1. SLUDGE AND PERCOLATE

1.1 Field Evaluation.

Sludge depth in the drying bed was measured daily. The volume of percolate produced from the drying beds was measured every 24hrs.

1.2 Sampling for laboratory Analysis

1.2.1 *Sludge Sampling*

Faecal sludge samples were taken at the initial, intermediate and final stages during the dewatering period. For the initial sample, faecal sludge discharged into the tank was thoroughly stirred and samples taken from different points and mixed together for analysis. Subsequent samples were taken in the drying bed every forty-eight hours. The following procedure was used for each sampling:

- Three points on each bed were selected.
- The sludge at each selected point was stirred till it becomes homogenous.
- An equal volume was taken from each point using a measuring jug.
- These were mixed together and a portion taken for analysis.

The initial and final samples were analysed for all parameters while only moisture content was determined in the intermediate samples.

1.2.2 ***Percolate Sampling***

- Over every twenty-four hours throughout each dewatering cycle, the volume of percolate produced is measured, stirred and an equal daily volume was taken and stored in a refrigerator.
- Samples were taken from the first and last twenty-four hours of a dewatering cycle for analysis.
- At the end of a dewatering cycle, a composite, consisting of volumes by ratio of percolate collected was taken for analysis and for laboratory scale anaerobic treatment.

1.3 Laboratory Analysis

All laboratory analysis followed the procedure outlined in ''Standard Methods for the Examination of Water and Wastewater' and were carried out in the Dept of Civil Engineering, water supply and environmental sanitation laboratory, KNUST

1.3.1 pH

A digital pH measuring kit with a probe (WTW pH 323-B / Set-2) was used. The percolate sample under test was well shaken, and the probe inserted. There was a digital read-out when the probe was inserted in the sample.

1.3.2 Temperature

A digital pH measuring kit with a probe (WTW pH 323-B / Set-2) was used. The kit measures both the pH and temperature of the sample. The sample under test was well shaken, and the probe inserted. There was a digital read-out of the temperature when the probe was inserted in the sample.

1.3.3 Total Solids (TS)

The apparatus used in the analysis are:

- Evaporating dish; Dessicator; Oven; Steam bath; Analytical Weighing Balance

The evaporating dish was cleaned and heated in the oven at a temperature of 105^{o}C for one (1) hour. It was then removed and cooled in the dessicator to room temperature. The empty dish was then weighed using the weighing balance and its weight in grams recorded. The percolate sample was well shaken and a volume of 100ml was measured and poured into the weighed dish. The sample was then evaporated to dryness on the steam bath, and then transferred into the oven for drying at 105^{o}C to a constant weight for one to two hours. The dish was removed from the oven, cooled in the dessicator to room temperature, and then weighed.

The Total Solids was then calculated as:

$$TS\ (mg/l) = \frac{(A - B)}{V} \times 1{,}000{,}000$$

A = Weight of dish + Residue in grams.
B = Weight of empty dish in grams.
V = Volume of Sample in ml (100ml).

1.3.4 Suspended Solids (SS)

The materials and apparatus used in the analysis are:

- Distilled water; Glass fibre filter; Membrane filter apparatus; Glass dish; Analytical Weighing Balance; Vacuum pump; Oven

The glass fibre filter was placed on the membrane filter apparatus. The filter flask was connected to the vacuum pump and a vacuum was applied. Three successive 20ml portion of distilled water was passed through the filter by suction to wash the filter. The filter was removed from the membrane and transferred to the glass dish. It was dried in the oven at 105^{o}C for 1hour. The filter was then cooled in the dessicator.

The glass dish with the filter was weighed using the weighing balance and the weight recorded. The filter was then placed on the membrane filter apparatus. The percolate sample was well shaken and a 20ml portion taken. This portion was then diluted with distilled water to 1litre. The diluted sample was well shaken and a volume of 100ml of it was passed through the filter with the aid of the vacuum created by the vacuum pump. The suspended solids in the sample were retained on the filter as residue. The filter was carefully removed from the membrane apparatus and transferred to the glass dish. The dish with the filter was dried in

the oven at 105^{o}C for one hour. The dish was removed from the oven, cooled in the dessicator and then weighed.

The Suspended Solids is then calculated as:

$$SS\ (mg/l) = \left[\frac{(A - B)}{V} \times 1{,}000{,}000 \quad F \right]$$

A = Weight of dish + Filter + Residue in grams.
B = Weight of dish + Filter in grams.
V = Volume of diluted sample in ml = 100ml.
F = Dilution factor = 50

1.3.5 Total volatile solid

For TVS, The dried samples used for TS analysis were ignited in the oven at 800^{o}C and The TVS content was calculated using equation below.

$$TVS\ (mg/l = \frac{(C - D)}{V} \times 1{,}000{,}000$$

Where:
C = weight (g) of residue + dish before ignition.
D = weight (g) of residue + dish after ignition

1.3.6 Turbidity

Attenuated Radiation Method (Direct reading)

Apparatus

HACH DR/2010 Portable Datalogging Spectrophotometer

Procedure

The spectrophotometer is switched on and the stored programme number 750 is entered by pressing the Enter button (or key). The wavelength dial is rotated until the display showed 860nm, and the display quickly showed zero sample and then FAU TURBIDITY.

The sample is well shaken and a portion of it is filtered using the filter paper. 25ml of the filtered portion of the sample (the blank) is poured into a sample cell (bottle). The blank is placed into the cell holder and the light shield closed. The Zero button is pressed and the display showed Zeroing then 0. FAU TURBIDITY. The sample is well mixed and 25ml of it is poured into another sample cell and immediately placed into the cell holder and the light shield closed. The Read button is pressed and the display showed Reading then the turbidity result in Formazin Attenuation Units (FAU).

1.3.7 Conductivity (EC)

A digital conductivity measuring kit (WTW LF 323-B / Set) was used. The kit has a probe connected to it. The sample under test was well shaken, and the probe inserted. There was a digital read-out when the probe was inserted in the sample.

1.3.8 Biological Oxygen Demand (BOD)

(Dilution Method)

Principle
By this method, the dissolved oxygen (DO) content of the sample is determined by the Azide modification of Winkler method before and after incubation for five days at 20^{o}C. Two 300ml BOD bottles are filled with sample till they overflow and tightly closed. The content of one bottle is analysed for initial DO concentration, and the other incubated for five days at 20^{o}C after which DO concentration is analysed. The difference in DO gives the BOD of the sample after allowance has been made for the dilution, if any, of the sample.

Chemical and apparatus

- Distilled water
- Magnesium sulphate solution (MgSO4)
- Phosphate buffer
- Calcium chloride solution (CaCl2)
- Iron (III) chloride solution (FeCl3)
- Manganese (II) sulphate solution (MnSO4)
- Alkali-iodide-azide reagent
- Conc. sulphuric acid (H2SO4)
- 0.025 M Sodium thiosulphate solution (Na2S2O3)
- Starch solution
- Volumetric flask (1000ml)
- BOD bottle (300ml)
- Conical flask (250ml)
- Burette (50ml)
- Pipettes (2ml, 5ml)
- Vacuum pump
- Glass container (11 litres)
- Incubator (thermostatically controlled at 20^{o}C)

Procedure
In preparing the dilution water, a pre-determined volume of distilled water is poured into the 11 litres capacity glass container. For each 1 litre of distilled water in the glass container, 1ml MgSO4, 1ml Phosphate buffer, 1ml CaCl2 and 1ml FeCl3 are added. The vacuum pump is applied and the distilled water is aerated for 2 hours. The sample is well shaken and 2ml (and 5ml) of it are pipette into volumetric flasks, and diluted to 1 litre with the dilution water. For each dilution, two 300ml BOD bottles are carefully filled with the diluted sample excluding air bubbles. For one of the bottled samples, the dissolved oxygen content is determined immediately. The other is incubated at 20^{o}C for 5 days after which the dissolved oxygen content is determined. In determining the dissolved oxygen content, 1ml MnSO4 followed by 1ml alkali-iodide-azide reagent are added to the diluted sample in the BOD bottle and closed carefully to exclude air bubbles. The bottle is inverted several times for the manganese hydroxide precipitate formed to mix evenly, and then allowed to settle. When the precipitate has settled to approximately half the bottle volume, 1ml conc. H2SO4 is added and the bottle closed. The bottle is inverted several times for complete dissolution of the precipitate, which gives intense yellow colour. 200ml of the solution is decanted into a conical flask. This is titrated with the 0.025 M Na2S2O3 to a pale yellow colour. 1ml of starch solution is added and the titration continued to the first disappearance of the blue colour.

Calculation

$$BOD5\ (mg/l) = (Di - Df)/ P$$

where:
Di = volume of 0.025 M Na2S2O3 used for 200ml of the original dilution (ml)
Df = volume of 0.025 M Na2S2O3 used for 200ml of the incubated dilution (ml)
P = decimal volumetric fraction of sample used = 1/ dilution factor

1.3.9 Chemical Oxygen Demand (COD)

Principle
The sample, with the organic matter to be measured, is oxidised under reflux with a known amount of dichromate in concentrated sulphuric acid with silver sulphate as a catalyst. Part of

the dichromate is reduced by organic matter and the remainder is determined by titration with ferrous ammonium sulphate using ferroin as indicator.

Chemical and apparatus

- Distilled water
- 0.25N Potassium dichromate
- Mercury (II) sulphate
- Silver sulphate solution
- Conc. H2SO4
- Ferroin indicator
- Ferrous ammonium sulphate
- Measuring cylinder (100ml)
- Volumetric flask (1000ml)
- Reflux flask
- Burette (50ml)
- Pipettes (10ml, 20ml)
- Heater
- Condenser

Procedure

About 1g mercury (II) sulphate is placed in the reflux flask. The leachate sample is well shaken and a 100ml portion taken. This portion is then diluted with distilled water to 1litre. The diluted sample is well shaken and a volume of 10ml of it is pipette into the flask. 10ml of 0.25N Potassium dichromate followed by 20ml of concentrated sulphuric acid are added to the flask. The flask is then cooled under running water, and 1ml of silver sulphate solution is added. The process is repeated using 10ml of distilled water instead of sample as blank. The content of the flasks is mixed well and the flasks fitted to the condenser. The heaters are switched on and the mixture boiled under open reflux for 2 hours. Flasks are allowed to cool and condenser is washed down with distilled water. Flasks are removed and 45ml of distilled water is added to each flask. Flasks are cooled under running water and 3 drops of ferroin indicator are added producing a light blue-green colour. The residual solution is then titrated with ferrous ammonium sulphate to a reddish-brown end-point.

Calculation

$$COD\ (mg/l) = [(A–B) \times N \times 8000/ V] \times F$$

where:
A = volume of ferrous ammonium sulphate used for the blank titration (ml)
B = volume of ferrous ammonium sulphate used for the sample titration (ml)
V = volume of diluted sample used (10ml)
N = normality of ferrous ammonium sulphate
F = dilution factor (10)

Standardisation of ferrous ammonium sulphate

The normality of ferrous ammonium sulphate is not stable; it changes with time. Thus for a COD test on any particular day, the normality is checked as illustrated below:
10ml of the standard Potassium dichromate solution is diluted with distilled water to about 100ml. 30ml of conc. sulphuric acid is added and cooled under running water. 3 drops of ferroin indicator is added and titrated with the ferrous ammonium sulphate to reddish-brown end-point.
Normality = (C x 0.25)/ D
where:
C = volume of Potassium dichromate (10ml)
D = volume of ferrous ammonium sulphate (ml)
0.25 = normality of the standard Potassium dichromate

1.3.10 Dissolved Oxygen (DO)

A digital oximeter kit (WTW OXI 323-B / Set) is used. The kit has a probe connected to it. The sample under test is well shaken, and the probe inserted. There is a digital read-out when the probe is inserted in the sample.

1.3.11 Ammonia-nitrogen (NH_3-N)

Principle

Chemical and apparatus

- Distilled water
- Borate buffer
- Indicating boric acid
- 6N Sodium hydroxide solution
- 0.02N Sulphuric acid
- pH meter
- Volumetric flask (300ml)
- Distillation flask
- Burette (50ml)
- Pipettes (25ml, 50ml)
- Conical flask (500ml)
- Heater
- Condenser

Procedure

The sample is well shaken and a 50ml portion taken. This portion is diluted with distilled water to 300ml and poured into the distillation flask. 25ml borate buffer is added and the pH of the solution is altered to about 9.5 using 6N Sodium hydroxide solution. The process is repeated using 300ml of distilled water instead of sample as blank. 50ml indicating boric acid is pipette into the conical flasks. The content of the distillation flasks is mixed well, and the flasks put on the heaters and connected to the condenser. The conical flasks with the boric acid are placed at the lower end of the condenser. The heaters are switched on and at least 200ml of distillate containing ammonia is distilled into the boric acid. The presence of ammonia in the distillate changes the blue-black colour of the boric acid to green. The distillate is then titrated against standard 0.02N Sulphuric acid to a pale lavender end-point.

Calculation

$$NH3–N\ (mg/l) = [(A - B) \times 280] / V$$

where:
A = volume of sulphuric acid titrated for sample (ml)
B = volume of sulphuric acid titrated for blank (ml)
V = volume of sample used (ml)

1.3.12 Total Kjeldahl Nitrogen (TKN)

The Total Kjeldahl Nitrogen is obtained by the sum of ammonia-nitrogen (NH3-N) and organic-nitrogen. Thus

$$TKN\ (mg/l) = NH3\text{-}N\ (mg/l) + Organic\text{-}nitrogen\ (mg/l)$$

The organic-nitrogen is determined as follows:
The residual solution in the distillation flasks after the ammonia determination is allowed to cool. One Kjeldahl catalyst tablet followed by 10ml concentrated sulphuric acid are added to each flask. The solutions are heated (or digested) under hook until copious white fumes are seen. The heating continues until the solutions become clear or pale straw and the volume of liquid in the flasks is about 25–50ml. The flasks and their contents are allowed to cool. The residual solutions are diluted with distilled water to 300ml. 50ml sodium hydroxide-sodium thiosulphate solution is added gently to the solution in each distillation flask, and the pH

checked to ensure that the solutions are alkaline. 50ml indicating boric acid is pipette into the conical flasks, and at least 200ml distillate is distilled into the boric acid. The distillate is then titrated against standard 0.02N Sulphuric acid to a pale lavender end-point.

Calculation

Organic-nitrogen (mg/l) = [(C - D) x 280] / V

where:
C = volume of sulphuric acid titrated for sample (ml)
D = volume of sulphuric acid titrated for blank (ml)
V = volume of sample used (ml)

1.3.13 Nitrate-nitrogen (NO_3-N)

Cadmium Reduction Method using Powder Pillows

Apparatus
HACH DR/2010 Portable Datalogging Spectrophotometer

Procedure
The spectrophotometer is switched on and the stored programme number 355 is entered by pressing the Enter button (or key). The wavelength dial is rotated until the display showed 500nm, and the display quickly showed zero sample and then mg/l NO3-N HR.

The sample is well shaken and a 10ml portion of it taken and diluted with distilled water to 1 litre. 25ml of the diluted sample is poured into a 25ml sample cell. The contents of one Nitra Ver 5 nitrate reagent powder pillow is added to the prepared sample in the cell and then covered. The Shift Timer button is pressed and the cell is vigorously shaken until the timer beeps in one minute. When the timer beeps, the shaking is stopped and the Shift Timer pressed again for a five-minute reaction period to begin. A second 25ml sample cell is filled with the diluted sample, which is the blank and covered. When the five-minute period is over, the timer beeps and the display showed mg/l NO3-N HR. The blank is placed into the cell holder and the light shield closed. The Zero button is pressed and the display showed Zeroing then 0.00 mg/l NO3-N HR. The blank is removed and the prepared sample is then placed into the cell holder and the light shield closed. The Read button is pressed and the display showed Reading then NO3-N result in mg/l is displayed.
A reagent blank is run for this test using demineralised water in place of the sample. The result obtained is substrated from all test results run for the sample.

1.3.14 *Phosphorus*

Phos Ver 3 (Ascorbic Acid) Method using Powder Pillows
Apparatus
HACH DR/2010 Portable Datalogging Spectrophotometer
Procedure
The spectrophotometer is switched on and the stored programme number 490 is entered by pressing the Enter button (or key). The wavelength dial is rotated until the display showed 890nm, and the display quickly showed zero sample and then mg/l $PO4^{3-}$ PV.

A 10ml Cell Riser is inserted into the cell compartment. The sample is well shaken and a 10ml portion of it taken and diluted with distilled water to 1 litre. 10ml of the diluted sample is poured into a 10ml sample cell. The contents of one Phos Ver 3 phosphate powder pillow is added to the sample in the cell and immediately swirled to mix. A blue colour forms if phosphate is present. The Shift Timer button is pressed and a two-minute reaction period begins. A second 10ml sample cell is filled with the diluted sample, which is the blank. When the two-minute period is over, the timer beeps and the display showed mg/l $PO4^{3-}$ PV. The blank is placed into the cell holder and the light shield closed. The Zero button is pressed and the display showed Zeroing then 0.00 mg/l $PO4^{3-}$ PV. The blank is removed and the prepared sample is then placed into the cell holder and the light shield closed. The Read button is

pressed and the display showed Reading then the orthophosphate ($PO4^{3-}$) result in mg/l is displayed. Other forms of phosphorus, P and polyphosphate (P2O5), can be obtained by pressing the arrow buttons in turn.
A reagent blank is run for this test using demineralised water in place of the sample. The result obtained is substrated from all test results run for the sample.

1.3.15 Faecal Coliforms (FC)

(Membrane filtration method)

Principle

In the membrane filtration method a measured volume of wastewater sample is filtered through a membrane composed of cellulose esters. The pore size is such that the organisms to be enumerated are retained on the surface of the membrane, which is then placed, normally face-upwards, on a differential medium selective for the indicator organisms sought. This may be either an agar or an absorbent pad saturated with broth. On incubation at a specified temperature for a given time, it is assumed that the indicator organisms retained by the membrane will form colonies of characteristic morphology and collier depending on the medium used. The other organisms are either inhibited or can be distinguished by their colonial appearance. The colonies of the organism sought are counted and the result is expressed as the number per 100ml of the sample.

Chemical and apparatus

- Sulphate Lauryl broth culture medium
- Sterile water
- Sterile pipettes (1ml)
- Filtration apparatus
- Burner
- Tweezers
- Petri dishes
- Membrane filters
- Absorbent pads
- Incubator
- Vacuum pump

Procedure

Serial dilution is made by transferring 1ml of a well-mixed sample into 99ml sterile water using sterile pipette. The mixture is well shaken and 1ml of it is transferred into another 99ml sterile water using a different sterile pipette and so on. The dilutions of 10^{-2} up to 10^{-10} are prepared for analysis.

The sterile tweezers is used to place one absorbent pad into each Petri dish and covered with the lid. About 2.5ml of the culture medium is poured onto the absorbent pad in the Petri dish to soak the pad and the excess is poured out but leaving slight excess. This excess prevents the pad drying out during incubation. The tweezers is also used to carefully removed a sterile membrane filter from its pack and place it in the sterile filtration apparatus. 100ml of the diluted sample is poured into the filtration funnel and a vacuum is applied to draw all the liquid through the membrane filter. The membrane filter is removed from the filtration apparatus by holding it by the edge using the sterile tweezers, and placing the grid side of the filter uppermost onto the pad soaked in the culture medium. The lid of the Petri dish is replaced and the dish placed in the incubator with the lid uppermost and incubated at $44.5^{o}C$ for 18–24 hours. After the incubation period, the Petri dish is removed and with the help of a lens, the yellow colonies developed are counted.

Calculation

Faecal coliforms (no/100ml) = number of colonies x dilution factor

1.3.16 Helminth Eggs (HE)

Instruments and Laboratory Equipment:

- Blender
- Gauze
- Round Bottomed Flasks
- Rubber Tubing
- Centrifuge
- Spatula
- Pasteur Pipette
- Whitlock McMaster Worm Egg Counting Chamber
- Seive
- Centrifuge Tubes

Reagents

- Zinc Sulphate ($ZnSO_4$)
- Sulphuric Acid (H_2SO_4)
- Acid/alcohol
- Ethyl acetate

Procedure

Sample was homogenized for 30secs using a blender and screened through gauze folded into 4 layers (for compost, samples are sieved with coarse and fine sieves to remove stones, rubble and other large particles. Tap water was added to dewatered or dried samples to give an approximate volume of 400ml, liquid sludges were blended undiluted.) with 2l of water. The filtrate was collected in 2l round bottom flasks and allowed to settle overnight or for 3hours. (for leachate sample this was the start point)

The supernatant was sucked up using a rubber tube until 400ml of the filtrate was left (the flask had been marked at this level). The sediments are then placed in 15ml centrifuge tubes, the flask is then rinsed 2 to 3 times with 50ml distilled water to give a total sediment volume of 450ml. The sediments are then centrifuged at 400g for 3 mins.

The supernatant was then discarded and the deposit resuspended with 5 volumes of $ZnSO_4$ (d = 1.2) the solution was then homogenized with a spatula and centrifuged at 400g for 3mins. The $ZnSO_4$ supernatant was then poured into a 2-litre round bottom flask and diluted with 1.5l of water. The diluted sample was then allowed to stand for 3 hours.

The supernatant was again sucked up using a rubber tube leaving a deposit of 250ml (previously marked) which was then resuspended by shaking, placed in 15ml centrifuge tubes and centrifuged at 480g for 3 mins. The 2-litre flask is rinsed with 50ml distilled water this is also added to the sample for centrifugation giving a total product of 300ml.

The pellets are then regrouped in two 15ml test tubes and recentrifuged at 480g for 3 mins. The deposits were then resuspended with 5ml acid/alcohol (H_2SO_4 + C_2H_5OH) and 5ml ethyl acetate. The product was homogenized by shaking and occasionally it was opened to let out gas. The mixture was centrifuged at 660g for 3min.

The supernatant was sucked up with a Pasteur pipette to leave 1ml of liquid.

The deposit is the read using a Whitlock McMaster worm egg counting chamber and number of eggs identified and counted at 100X magnification are recorded. If need be the deposit is further diluted with $ZnSO_4$*or distilled water and number of eggs counted multiplied by dilution factor.

For Viability, residual ethyl acetate is removed by washing with 10ml 0.1 N H_2SO_4 and centrifuged at 400g for 8 mins. The supernatant was discarded and the remaining deposit diluted with 4ml 0.1N H_2SO_4. The product was then incubated at 37^0C for 1week. The deposit

was then read on a Whitlock McMaster worm egg counting chamber and number of eggs identified and counted at 100X magnification are recorded. If need be the deposit is further diluted with $ZnSO_4$ or distilled water and number of eggs counted multiplied by dilution factor.

* Where $ZnSO_4$ is added, the upper 2ml of sample is taken for examination also, dilution factor is not considered.

The concentration of number of eggs per litre was computed according to the formula: -

$N = Y/C \times M/V \times 1000$ (Stein and Schwartzbrod, 1989), where

N = number of eggs per litre of sample
Y = number of eggs in the McMaster dish
M = estimated volume of product at final centrifugation
C = volume of the McMaster dish
V = sample volume.

2. COMPOST

2.1 Field evaluation

Temperature measurements were taken in the heaps with a thermistor (thermometer with a probe), at 15 points on each heap including the center of the heap and the average recorded in ^{o}C for the heap in general. Measurements were taken at least once a day. In the morning and /or evening

2.2 Sampling for laboratory Analysis

Compost samples are taken weekly. From each heap, portions of the compost are taken from the inner, outer, top, bottom and middle of the heap, mixed thoroughly before a sample is taken. Out of this, a portion was taken and blended to ensure homogeneous mixture.

Chemical and microbiological analysis were carried out following standard procedures of laboratories in Soil Research Institute, Kumasi

2.2.1 Chemical Analysis

2.2.1.1 Organic Carbon

The Walkley-Black Procedure (wet combustion) was used to determine organic carbon content in each sample. Samples were air-dried and grinded using a grinding machine. The mixture was sieved through a 2mm wire mesh and 1g of the sample was weighed into a 500ml Erlemeyer flask. 10ml of 1N Potassium dichromate (K_2CrO_7) was added followed by 75ml concentrated sulphuric acid. The flask was shaken for one minute and allowed to stand for 30minutes to cool.

200ml of distilled water was added then 5ml orthophosphoric acid (to aid sharp end-point). The solution was tittrated against 1N Ferrous Sulphate using Diphenyl as indicator until a colour change from purple to green was observed. The percentage organic carbon was calculated from

$$\% C = \frac{[(10.5 - X \times N) \times Factor] \times 0.39}{W}$$

X = Titre Value of $FeSO_4$
N = Normality of K_2CrO_7
W= Weight of sample
Factor= ml of N Dichromate / ml of $FeSO_4$ required

2.2.1.2 Nitrogen

The Kjeldahl method (wet digestion) was used to determine the nitrogen content. Samples were air-dried and grinded using a grinding machine. The mixture was sieved through a 2mm wire mesh and 0.2g of the sample was weighed into a digestion tube. 0.25g of selenium powder was added followed by addition of about 5ml concentrated sulphuric acid. The mixture was placed on a digester and heated at a temperature of $200^{0}C$ for 1 hour. The temperature was increased to about $420^{0}c$ and the heating continued until a clear solution was obtained. It was made to cool and 200ml distilled water was added. The solution was transferred into a distillation tube followed by addition of 20ml 40% sodium hydroxide. Distillation was done for about four minutes using the Kjeltel equipment. The distillate was collected into a 250ml cornical flask containing 25ml boric acid and PT5 indicator (PT5 – bromo cresol green and methyl red).

The solution was titrated with 0.02N hydrochloric acid until solution was changed to pink colour.

% Nitrogen was calculated by the formulae:

$$\% \text{ Nitrogen} = \frac{T \times N \times 14.07 \times 100}{W \times 1000}$$

T= Titre Volume
N= Normality of HCL
W= Weight of sample

2.2.1.3 Potassium and Phosphorus

1g of the sample was weighed into crucibles followed by placing item in a furnace. The materials were ashed for 3hours at 450^0c. The ashed sample was removed to cool. A few drops of distilled water were added. 10ml of diluted HNO_3 (1:2 HNO_3) was also added to the sample and placed on water bath to digest. After observing the first sign of boiling, the sample was removed and allowed to cool after which it was filtered into a 100ml flask and made to the mark. This was divided into two (50ml each).

To one part (of the two, 50ml samples), 10ml of ammonium vanadate solution was added followed by 10ml of ammonium molybdenum and filled to the 100ml mark. This was left for the development of yellowish colouration. Phosphorous concentration in the sample was read on spectrophotometer at 420nM. The same sample was then analysed by flame photometer for potassium concentration. The energy emitted by the photometer is proportional to the concentration of potassium in the sample. The concentration is expressed as ppm.

2.2.1.4 Calcium and Magnesium

From the second 50ml sample obtained from previous test 2.3.1.3, two 20ml aliquots were measured into two separate cornical flasks. To one of the 20ml aliquots, 1ml hydroxylamine was added to eliminate interference followed by 5ml buffer solution of $NH_4CL + NH_3$ Solution and 1ml KCN. 2 drops of Erichrome Black T indicator was added and titrated against 0.02N EDTA solution until a blue colour change was observed. The titre volume was noted.

For the aliquot measuring calcium, 5ml 0f KOH, 1ml KCN, and 0.1g murexide indicator were added to the other 20ml aliquot solution. It was then titrated against 0.02N EDTA solution until colour change was observed. This was subtracted from the composite titre value of Ca and Mg above.

$$\% \text{ Ca} = \frac{Tx\ 0.02 \times 40.08 \times 100}{\text{Wt of Sample} \times 1000}$$

$$\% \text{ Mg} = \frac{Tx\ 0.02 \times 24.31 \times 100}{\text{Wt of Sample} \times 1000}$$

2.2.1.5 Heavy Metals (Pb, Mn, Cu, Zn, Fe)

0.5g was weighed into crucibles and kept in a Muffle furnace for three hours. They were allowed to cool followed by addition of a drop of distilled water to each.

10ml of 1:2 HNO_3 solution was added to digest the ash and kept in a water bath. After observing samples till boiling took place on the water bath, they were removed and made to the mark. An aliquot each was taken to determine the heavy metals using the Atomic Absorption Spectrometer at their respective wavelength.

Concentration of metal/kg^{-1}soil = concentration in solution x dilution factor $\frac{100}{}$ (0.5)

2.2.1.6 pH

From each sample, 25g was weighed followed by addition of 25ml distilled water. The mixture was stirred for 30minutes. The pH probe was immersed into the mixture to about 4cm and the pH value was read on the pH metre.

2.2.1.7 Moisture

A known quantity (W g) of sample material (trash) was weighed into a previously weighed aluminum dish. This was then dried in an oven at 105^0c overnight. It was removed from the oven and allowed to cool for 30minutes and weighed (W_1 g). Percentage moisture content was calculated from the following formula:

$$\% \text{ Moisture} = \frac{W - W_1}{W} \times 100\%$$

W = Initial fresh weight
W_1= Dry weight

2.2.2 Microbiological Analysis

2.2.2.1 Fungal Populations

10g of fine compost was weighed using Adams Electronic Balance. This was transferred into a 90ml sterilized distilled water as diluent in 250ml, Erlemeyer flask and shaken for 10minutes with whirlmixer. From this stock suspension, the serial decimal technique up to $1:10^5$ was employed; and the spores raised on sabouraud's maltose agar. This was incubated at 28^OC for 3 days. The fungal species appearing were countered using a colony counter. The major species were identified using morphological and cultural characteristics.

2.2.2.2 Total Bacterial Populations

The procedures followed were same as that for fungal enumeration (2.3.2.1). However, bacterial colonies were raised on plate count agar and incubated at 28^OC overnight.

2.2.2.3 E. Coli Populations

Similar procedures were followed as indicated for fungi and bacteria. E-coli spores were raised on LB medium overnight at 37^OC.

2.2.2.4 Chlostridial Populations

The sample preparation employed the same procedures as above. Also a serial dilution up to $1:10^5$ was used. 1ml of the diluted organisms was transferred into sterilized petri plates into which modified Winogradskys's Medium was poured. They were incubated at 37^OC for 24hours and colonies that appeared were counted.

3. Methodology and Experimental Design for Agronomic investigations

3.1. Germination Experiment

Five soil treatments were prepared with potting mixture and compost according to the following fresh weight percentages of compost: 0%, 12.5%, 25%, 50%, 100%. Twenty circular seedling trays (25 cm diametre and 7cm deep) were filled with the five soil treatments at four trays per treatment.

The potting mixture was prepared with 50% river sand and 50% black soil obtained from the Department of Crop Sciences at KNUST. Both were sterilised by heat treatment and mixed thoroughly.
Thirty seeds of each vegetable were planted onto one half of a plate for each soil treatment. Since most of the seeds were very small, they were loosely placed on the surface and lightly covered with the respective soil treatments. Okra seeds, being the largest seeds used, were soaked in water overnight (16h) before planting.

Seedling trays were placed in a screenhouse for three weeks in a random order. The temperature in the screenhouse ranged from 25-30°C, and the photoperiod was 12h per day. Germinated seeds were counted every day for 15 days. Germination was considered successful when the seed radicle protruded from the surface of the soil. The average time of germination (ATG) was calculated at the end of the experiment according to the following method: ATG = sum of (number of germinated seeds on i^{th} day x i^{th} day) / sum of germinated seeds on last day.

Seedlings trays were watered daily with 50 ml of tap water to maintain sufficient moisture. After three weeks seedlings were harvested. The root soil was completely dissolved in water, and the length of the primary taproot and shoot were measured. Fresh weights were also measured.

3.2. Suppression of Soil-Borne Pathogens with Compost Amendments and Pathogen isolation and greenhouse experiment

3.2.1 Plant Pathogen Isolation

Sclerotium rolfsii and *Fusarium oxysporum* f.sp. *lycopersici*, both causing wilt in tomato were isolated from stems and roots of diseased tomato plants collected from a farm at Akumadan, a major tomato growing centre in Ghana located less than 100 km north of Kumasi. The roots were washed under tap water for 5 min to remove soil particles and main roots with typical disease symptoms cut into tiny pieces. They were plated on chloramphenicol (500 ppm) potato-dextrose agar (CPDA; five pieces/plate) and incubated on a laboratory bench at 30 $\pm$ 4 ^{O}C for five days. Fungal colonies emerging from the plated tissue pieces were sub-cultured on CPDA. When isolation was attempted from diseased stems (especially for *F. oxysporum* f. sp. *lycopersici*) tissue pieces were obtained from the internal necrotic tissue and the fungus isolated as before. Pure cultures of the two fungi were maintained on CPDA plates on a laboratory bench until needed for soil infestation.

The nematode eggs used as inoculum were extracted from plant house cultures of *Meloidogyne incognita* built on tomato seedlings using the Sodium hypochlorite (NaOCl) method (Taylor and Sasser, 1978). Infested tomato plants were carefully uprooted and washed under running tap water to remove soil particles. The roots were then cut into one centimeter long pieces using a sharp knife and a clean board. About 100g of the macerated roots was placed in a jar and enough 0.5% NaOCl solution added to cover the roots. The jar was tightly covered and vigorously shaken for 3-4 minutes. The sodium hypochlorite solution containing root knot nematode eggs and root debris was poured through a 500μm sieve. The residual NaOCl in the sieves was rinsed several times by placing them under slow running tap water. The eggs collected from the sieve were put into the 200ml beaker. The egg suspension obtained was allowed to sit for 24 hours to allow the eggs in the suspension to settle to the bottom of the beaker by gravitational force. The supernatant was carefully poured off leaving a concentrated egg suspension, which was topped with distilled water to the 200ml mark for easy determination of the number of eggs in suspension.

The suspension was continually stirred and a pipette used to draw a 1ml aliquot from the concentrated egg suspension for determination of the number of eggs per unit volume. The 1ml aliquot egg suspension was transferred into a Doncaster (1962) counting tray. To ensure uniform distribution of eggs in the counting dish, enough distilled water was added and the end point of a pipette was used to spread the eggs evenly in the dish. The eggs in all the 10 channels of the counting dish were counted. The counts were repeated three times, each time the suspension was well stirred to ensure uniform distribution of eggs before an aliquot was taken for counting. The counting was done under a dissecting microscope at magnification 100x using a tally counter to ensure accuracy. The egg density of the 200ml suspension was determined by taking the average of the three counts.

3.2.2 Tomato Pathogen Inoculation

A 1x4x6 factorial design was used for the experiment with one vegetable (tomato), four pathogens at six soil treatments with four replicates per treatment. The four pathogen treatments were; the control, *Sclerotium rolfsii*, *Fusarium oxysporum* f.sp *lycospersici* and *Meloidogyne incognita*. The six soil treatments were prepared with potting mixture and compost according to the following weight percentages of compost, 0%, 6.25%, 12.5%, 25%, 50%, and 100%. The potting mixture was prepared with 50% river sand and 50% black soil obtained from the Department of Crop Sciences at KNUST. Both were sterilised by heat treatment and mixed thoroughly. The chemical characteristics of the potting mixture were as shown in Table 4.

The control inoculum was made by cutting out eight plates of only PDA and homogenizing in a blender with 200 ml of water at low speed for thirty seconds. Fungal pathogen inoculum was prepared by cutting out eight plates of each fungi and homogenizing in a blender with 200 ml of water at low speed for thirty seconds. Another 500 ml of water was added to each solution and hand stirred. On day of use the *Sclerotium rolfsii* was nine days old and the *Fusarium oxysporum* f.sp *lycospersici* was twelve days old.

For each pathogen treatment, 100ml of inoculum solution and 200ml of water was added to a mixing bucket with two litres of one soil treatment and thoroughly mixed by hand for 5 minutes. The contents of the mixing bucket was divided equally into four half-litre plastic pots and two three-week old tomato seedlings were transplanted into each pot and watered. This was repeated for each soil treatment.

For pots to be inoculated with nematodes, each soil treatment was evenly distributed among four half-litre pots and two three-week old seedlings were transplanted into each pot. A one ml aliquot of the nematode egg suspension was removed with a pipette and injected into the soil one cm away from the tomato seedlings.

Pots were kept in a screenhouse with temperatures ranging between 25-30C and a photoperiod of 12h. Plants were watered every two days with 50ml to maintain sufficient moisture. The test plants were monitored for incidence of pathogens every two days.

3.2.3 Lettuce Pathogen Inoculation

The lettuce pot experiment followed the same procedure as the tomato pot experiment except that only *Sclerotium rolfsii* inoculum was used since the *Fusarium* pathogen was specific to tomatoes. The *Sclerotium rolfsii* inoculum was ten days old when the lettuce plants were inoculated. All lettuce plants that were transplanted were eighteen days old.

For pots to be inoculated with nematodes, each soil treatment was evenly distributed among four half-litre pots and two three-week old seedlings were transplanted into each pot. A one ml aliquot of the nematode egg suspension was removed with a pipette and injected into the soil one cm away from the lettuce seedlings.

Pots were kept in a screenhouse with temperatures ranging between 25-30C and a photoperiod of 12h. Plants were watered every two days with 50ml to maintain sufficient moisture. The test plants were monitored for disease incidence every two days.

3.3. Field trials.

The area is composed of raised beds of an average size of $20m^2$. Three farmers were selected for their ability and willingness to participate in the experiment. Fourteen raised beds, available at the commencement of the experiment, belonging to the three farmers were selected and subsequently divided into thirty plots with an average size 10 m^2. The three farmers and their respective group of plots are all located on similar soils.

Daily irrigation of the lettuce plots was done by hand watering cans unless there was a significant rainfall event in which case the farmers did not water their crops. The quantity of irrigation water was controlled at approximately 6 lm^3/m^2/day for each plot. The irrigation water was obtained from shallow wells within the same area of each other. The nutrient content in the irrigation water was on average about 8mg/L NH_3-N and 20 mg/L NO_3-N (Keraita, 2002). This is equivalent to about 14 kg NH_3-N / ha /month and 36 kg NO_3-N /ha/month.

The farmers removed weeds using a hand-held weeding fork on a weekly basis. All plots were monitored to ensure that weeding occurred on the same day each week for all plots. No pesticides were applied on the first crop. However, septoria leaf spot (*Septoria lactucae* Pass.) was rampant and reduced the quality of the lettuce crop therefore causing huge financial loss. On the second and third crops the fungicide Dithene was used for two or three applications per cropping season. Applications

were done within 24h of each other for all plots when the farmers deemed it necessary.

3.3.1 Soil Analysis

Soil was analysed before and after second cropping. All chemical and physical analysis of soil and composts were completed at the Soil Research Institute (SRI) in Kumasi. Method used is described in the Annex.

3.3.2 Field Measurements

Field measurements were collected 30 days after transplanting. A one square metre grid was randomly demarcated in the centre of each plot and all of the lettuce plants within it harvested whole. Parameters measured include fresh yield The leaf count was measured by counting the number of open leafs of each of these five plants. The length of the three largest leaves of each of these five plants were recorded to obtain the average longest leaf for each plot. The fresh weight of these five plants was then measured on a more accurate lab scale and compared to the field scale measurements.