STUDY ON BIOCONVERSION OF HOUSEHOLD WASTE AND FAECAL SLUDGE THROUGH VARIOUS COMPOSTING PROCESS

by

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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering in the Department of Civil Engineering

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November 2018

Declaration

This is to certify that the thesis work entitled *"Study on bioconversion of household waste and faecal sludge through various composting process."* has been carried out by *Tonmoy Debnath* in the Department of *Civil Engineering*, Khulna University of Engineering & Technology, Khulna, Bangladesh. The above thesis work or any part of this work has not been submitted anywhere for the award of any degree or diploma.

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Abstract

This research work is concerned on the preparation, characterization, analysis and comparison of three types of compost, namely, (a) organic solid waste compost, (b) co-compost of faecal sludge and organic solid waste and (c) vermicompost of faecal sludge and organic solid waste ensuring SRDI (Soil Resource and Development Institute) standard. To this purpose, solid waste was collected from the waste management plant established in the campus of Khulna University of Engineering & Technology (KUET), while the faecal sludge was collected from the septic tank of the KUET campus. Dried faecal sludge and organic solid waste were mixed at a ratio of 1:3 to prepare co-compost using passively aeration method. For vermicompost, *Eisenia fetida*, earthworm species was used. A 56 days cycle of composting period was considered for maturation.

During composting cycle moisture and temperature plays an important role. So, temperature of different composts was monitored carefully in this period. The peak temperature of all composts was obtained within 7-8 days. Highest temperature of the composts was recorded as 51°C for organic solid waste compost, 47°C for co-compost, 38°C for faecal sludge vermicompost and 40°C for solid waste vermicompost. After that temperature starts to decrease and finally merged with the ambient temperature.

Initially all compost samples consists of 3.00 kgs of sample except faecal sludge and solid waste co-compost. To maintain the 1:3 ratio of faecal sludge nad solid waste, 1 kg dry faecal sludge was mixed with 3.00 kg solid waste sample. The mass reduction is greater for solid waste than faecal sludge. In case of solid waste compost the mass reduction is about 70% (70.26% for solid waste compost and 70.43 for solid waste vermicompost). Whereas the mass reduction of faecal sludge vermicompost and faecal sludge-solid waste co-compost is 41.53% and 58.82% respectively. Loss of moisture cintent is above 80% for solid waste compost, solid waste vermicompost and faecal sludge and faecal sludge solid waste vermicompost. But in case of faecal sludge vermicompost moisture reduction is 61.12%. Similar condition is observed for voletile solids. The fixed solid reduction percentage is 4.47%, 6.43%, 11.99% and 4.94% for solid waste compost, solid waste vermicompost, faecal sludge vermicompost and faecal sludge solid waste co-compost.

Initially composts were slight acidic except the co-compost of faecal sludge and organic solid waste (8.3). at final condition all prepared composts were a little alkaline (pH was above 7). Moisture content, total organic carbon and TVS decreased during composting process. A reverse scenario was observed in case of fixed solids and total kjeldhal nitrogen content. C/N ratio is an important indication of compost quality and maturity. According to SRDI, C/N ratio of a finely matured organic fertilizer should be within 20. In this experiment, C/N ratio of different composts were found as 10.29 for solid waste compost, 10.08 for solid waste vermicompost, 12.25 for faecal sludge vermicompost and 10.67 for co-compost of faecal sludge and organic solid waste. So, the C/N ratio values were within the SRDI recommended values. A remarkable progress was observed in case of pathogen destruction. At maturation stage the number of faecal coliform decreased by 50 times with respect to the initial condition. Phosphorus content of vermicompost (1.34% for solid awste vermicompost and 1.22% for faecal sludge vermicompost) was higher than the organic solid waste compost (0.86%) and co-compost (0.96%). Faecal sludge vermicompost was recorded to have higher potassium content than solid waste compost (0.8%), solid waste vermicompost (0.75%) and co-compost (0.76%). But according to SRDI standard the potassium content of organic fertilizer should be within 1-3%. Therefore, only faecal sludge vermicompost satisfied the SRDI standard value for total potassium content.

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Nomenclature

FSM	Faecal Sludge Management
FS	Faecal Sludge
OSW	Organic Solid Waste
SWM	Solid Waste Management
WSS	Water Supply and Sanitation
COD	Chemical Oxygen Demand
BOD	Biochemical Oxygen Demand
SVI	Sludge Volume Index
MDG	Millennium Development Goals
ADB	Asian Development Bank
DoE	Department of Environment
SRDI	Soil Research and Development Institute
TS	Total solids
VS	Volatile solids
MC	Moisture content
BARI	Bangladesh Agricultural Research Institute
EC	Electrical Conductivity
SW+W	Solid Waste Vermicompost
FS+W	Faecal Sludge Vermicompost
SW+FS	Solid Waste and Faecal Sludge Co-compost
ITM	Initial Total Mass
IMC	Initial Moisture Content
IVS	Initial Volatile Solid
IDS	Initial Dry Solid
IFS	Initial Fixed Solid
FTM	Final Total Mass
FMC	Final Moisture Content
FVS	Final Volatile Solid
FDS	Final Dry Solid

FFS	Final Fixed Solid

CHAPTER I

INTRODUCTION

1.1 BACKGROUND

The population explosion causes more and more production of different types of waste. This bang in waste production leads to inappropriate damping. Stabilization of these waste before damping is a fruitful way to reduce the health and environmental risk associated with improper damping. There is various process for the biological stabilization of solid waste products. Among those process composting, co-composting and vermicomposting are well known and effective for a large variety of waste (Domínguez & Edwards, 2010). Composting has gained its importance in municipal solid waste management process. Composting can be done both for organic solid waste and to a mixture of biodegradable fraction of solid waste with faecal sludge which is termed as co-composting (Alamin *et al.*, 2017). Vermicomposting is a special type of composting in which, biodegradable fraction of waste is converted into a better end product by using certain species of earthworm. It is quite similar to the composting process. In this process, aerobic transformation of organic by product takes place. This transformed organic product can be used in crop production without any detrimental effects (Baca *et al.*, 1992). The conventional concept of compost involves the management of decomposable organic solid waste. Sometimes it may include cow dang, saw dust etc.

The idea of co-composting faecal sludge (FS) with organic solid waste (OSW) has become a positive solution to many problems including the management of faecal sludge in an efficient and environment friendly manner. Faecal sludge contains a large content of nutrition. Co-composting of faecal sludge and organic solid waste allows recycling of nutrients into agriculture thereby closing the nutrient loop (Alamin *et al*.,2017). Among two types of composting (*i.e.* Passive aeration and forced aeration) forced aerated composting have higher oxygen levels than passively aerated composting and passive aerated composting showed better results (Alamin *et al*.,2017).

Vermicompost is a naturally rich soil conditioner. It slowly releases the nutrients into the soil to improve the physicochemical and biological characteristics of the soil. Through this process it provides beneficial impact on plants (Doube *et al.*, 1994). Similarly, composts provide nutrients in a readily available form which enhances the uptake of nutrients by plants. This improves the growth and yielding of crop products (Sreenivas *et al.*, 2000). In recent years, vermicomposts is largely used in different parts of the world. The main reason behind this is its low cost and large amount of waste conversion capacity. It is also remarkable that it can convert a variety of wastes *i.e.* sewage sludge, paper industry wastes, food and animal waste as well as residues from cultivars (reviewed in Domínguez, 2004). The final end product of vermicompost is finely divided peat like materials which shows high porosity and water holding capacity. It also contains many nutrients in a form that can be readily uptaken by plants.

Bangladesh is a developing country with a vast population. Approximately 150 million people live in an area of 147,570 km2 resulting in a population density of 964 inhabitants per km^2. Current growth rate of population in Bangladesh is 1.37% (Wikipedia, 2015). The present growth rate of waste in Bangladesh is 22.4 million tons per year or 150 kg/cap/year (Waste atlas, 2012). Within 2025 this is expected to be 47,064 tons per day (Alamgir and Ahsan, 2007). Again, Bangladesh is experiencing a rapid urbanization process as more and more people from rural areas come and settle in the cities. Urban population in Bangladesh has grown from 5 percent in 1971 to 28.1 percent in 2010, suggesting that approximately 46 million people are currently living in the urban areas (Only 20% of the population of Dhaka is served by a highly expensive sewerage network; the rest use septic tanks, pit latrines, unhygienic latrines or none at all (Hasnat, 2014). Only a small percentage of faecal sludge is managed and treated appropriately. At present there is no formal or environmentally sound faecal sludge collection and disposal system in Bangladesh (Hasina and Abdullah, 2015). The case for organic solid waste (OSW) is almost similar. A small-scale solid waste collection and dumping system may be observed in certain areas of the country. But they are limited within some of the developed regions. In case of Dhaka city, only 42% of total generated waste is collected and properly damped. Rest about 400 tons are improperly damped in open spaces and in roadsides (Bhuiya, 2007). This scenario is worse in the root areas. Today most of the local governments are facing serious problems relating waste and sanitation. Crude damping of municipal waste and faecal sludge in water bodies ad low lying areas are most common disposal system in Bangladesh. Which results in emission of Methane gas (a potential greenhouse gas). This not only adds to global warming process but also reduces quality of life due to odor and unhygienic living condition. If proper treatment systems are not in place, serious environmental degradation and associated health risk will increase (Rahman, 2009). This problem can be solved by applying innovative approaches in infrastructure, technology and resource recovery. A major holding against the development is the lake of financially viable approach for sanitation and waste management system. Creating innovative and profitable business approaches in sanitation and waste management sector is a promising solution to this problem (SDC, 2004). This business strategies may include designing environment friendly faecal sludge and waste management system with provision of adequate sanitation coverage (Murray and Ray, 2010). There are various types of resource recovery techniques regarding faecal sludge management. Among those using dry sludge as fuel for combustion, animal protein, biogas, building materials, soil conditioner etc. are considerable.

Khulna is the third largest divisional city of Bangladesh situated in the south-western part of the country and lies in the delta of the river Ganges. The city has an estimated population of 1.6 million and total number of households is 66257 (SNV, 2014). But, there is no sewerage system in Khulna City. Besides, Currently Khulna has no designated dumping sites or treatment facilities for faecal sludge (SNV, 2014). Generally, faecal sludge is stored temporarily into septic tanks. When the stored waste overflows, they are collected by local swappers and directly dumped into pits, cannels, small ponds or unplanned dumping sites. This stored waste causes bed smells, air pollution, odor and spoils the surrounding atmosphere. They also serve as the breeding zones for mosquitoes, flees, harmful bacteria. During rainy seasons those dumped sludge are carried by storm water and discharged into water sources. As a result of which rapid spreading of bacterial diseases and epidemic occurs. In case of solid waste there is a small-scale disposal site at rajbandh, but it is not adequate for the huge population of Khulna city.

The present study aims to prepare compost from organic household wastes, co-compost with faecal sludge and organic waste and vermicompost with earthworms. Analyzing the quality of produced compost, co-compost and vermicompost will be a major part of this study. This analysis will include the physical and chemical properties of the composts. This study will also focus on the comparison of the analyzed properties of prepared composts.

1.2 OBJECTIVES

The research work is carried out to attain the following key objectives

- To prepare (a) compost from organic household wastes, (b)co-compost with faecal sludge and organic waste (c) vermicompost with earthworm.
- To analyze different properties (i.e. pH, moisture content, total organic carbon, total nitrogen, total phosphorus, total potassium, TC, FC, Fixed Solids, Volatile Solids, Color and Odor) of the prepared composts.
- To compare the quality of three different types of compost [i.e. (a) compost from organic household wastes, (b)co-compost with faecal sludge and organic waste (c) vermicompost with earthworms] ensuring compost standard provided by Soil Resource and Development Institute (SRDI).

1.3 OUTLINE OF METHODOLOGY

To achieve the mentioned objectives following tasks were done-

i. To prepare composts from
   (a) organic household waste, collected wastes were sorted and separated from the inorganic part and kept in compost heap for composting process.
   (b) Co-compost from faecal sludge and organic waste the raw FS was dried and for this a simple drying bed (8 ft × 5 ft) was prepared for dewatering process. Then the dewatered FS and OSW was mixed at a ratio of 1:3.
   (c) Vermicompost with earth worm dried faecal sludge was finely grained then introduced earth worm both into grained faecal sludge and organic solid waste.
ii. To analyze different properties of the prepared composts laboratory tests were performed for color, odor, pH, moisture content, total volatile solids (TVS), fixed solids (FS), total organic carbon (TOC), total kjeldhal nitrogen (TKN), C/N ration, Total coliform (TC), faecal coliform (FC), total phosphorus, total potassium etc.
iii. The quality of three different types of composts were compared with the organic fertilizer standard provided by the Soil Resource and Development Institute (SRDI).

1.4 ORGANIZATION OF THE THESIS

The thesis consists of five chapters arranged in the following order-

Chapter 1 as discussed here provides the introduction and objectives of the thesis work

Chapter 2 presents the literature review that was performed to summarized the characteristics of faecal sludge, dewatering of faecal sludge, characteristics of organic solid waste (OSW), concept of composting, co-composting, vermicomposting, comparison of compost types, socio-economic outlook of compost, compost standards in Bangladesh.

Chapter 3 provides an overall description of the compost feedstock, process of composting, co-composting and vermicomposting, controlling temperature and moisture of compost, laboratory process of determining different parameters of prepared compost.

Chapter 4 entrails results and relative discussions of the study covering different parameters of prepared compost types with reference of Bangladesh organic compost standards provided in chapter 3.

Chapter 5 presents the conclusions for this research study with recommendation for future research.

CHAPTER II

LITERATURE REVIEW

2.1 GENERAL

People in rural and urban areas have been using the faecal sludge or human excreta for centuries to fertilize the fields and fishponds and to maintain the organic content of the soil mass. This use is quite common in China and Southeast Asia and Africa. This reuse practices have established an economic linkage between consumers and urban waste recyclers. Even the peri-urban Chinese farmers have reported that the demand of this bio fertilized vegetables are higher than that of chemically fertilized.

As well the use of organic waste in various fields is also very common in rural areas. In countries with high population density, traditional reuse practices of solid waste are very common. The production of waste product is increasing with the increase in population and development. This remarkable increase in waste production is causing serious environmental degradation leading to high risk to public health. In developing countries informal recycling of wastes are quite common. But effective treatment and recycling of wastes are still limited to some developed part of the countries. Due to devastating effect created by huge amount of waste, local and national municipal authorities are taking concern in waste management initiatives.

Vermicomposting is an innovative technology that converts various types of organic biodegradable wastes into vermicompost. Vermicompost is a finely grained, stabilized form of organic waste which is rich in nutrient content. This compost can be used as soil conditioner to reintegrate lost nutrients into the soil. A huge quantity of industrial waste covering vast land area are normally remain unutilized. These wastes are causing serious environmental and ecological damages. The organic non-toxic part of industrial waste is a potential source of raw material for vermitechnology. Vermicomposting has been applied for bioconversion of organic wastes for about two decades. These converted, stabilized end product of wastes is being used successfully for land restoration practices.

2.2 FAECAL SLUDGE

The waste generated in the pits and vaults of on-site sanitation installation, aqua privies, unsewered public and private latrines, toilets and in septic tanks through the detention of human excreta is termed as faecal sludge. These wastes contain liquid, semisolid and suspended particles. These liquids are normally several times more concentrated in suspended and dissolved solids than wastewater (Sandec Training Tool: Module 5, 2008).

According to Linda *et al.*, 2014, in case of onsite technology, faecal sludge become partially digested slurry type material. It is a combination of solid portion with black water. Pit latrines, dry toilets, public toilets, septic tanks, aqua privies etc. are the examples of onsite technology. Faecal sludge management includes the storage, collection, transport, treatment and safe end use or disposal of faecal sludge.

2.2.1 Characteristics of Faecal Sludge

The composition and other factors of faecal sludge vary through a wide range. It varies from location to location, community to community, country to country depending on the living standard, climate, socio-culture, health condition, behavior, availability of water. For example, vegetarians excrete more than non-vegetarians; rural people have a high faecal output then the urban communities. In most developing countries, on average, an adult produces 130-520 gm. feces. The characteristics of faecal sludge depends on few things like origin, quality of flashing water, collection type (on-site/off-Site) and treatment level. The raw untreated faecal sludge is normally putrid and odorous. It contains pathogens, high percentage of water with high Biochemical Oxygen Demand (BOD). But these sludges also contain essential nutrients for plants *i.e.* Nitrogen (N), Phosphorus (P), Potassium (K) etc. These are essential quality for organic fertilizer and beneficial for plants or crop production. Stabilized organic carbon content also improves the soil structure. The treatment of faecal sludge depends on the initial characteristics of raw faecal sludge and purpose of use. The main focus of treatment is to reduce the water content, pathogens, bad odors etc. There are various treatment processes like dewatering, drying, stabilization etc. (Koné *et al.*, 2010). Water content of raw faecal sludge is normally very high. It may vary from 95-98%. This high-water content makes it unsuitable for handling, transport and stabilization process. Dewatering and drying reduces water content remarkably (UNEP, 2001). Dewatering is faster than drying but requires energy for suction which makes it costly. But drying is a low-cost technique as it uses natural evaporation and gravity flow technique to drain water out.

2.2.2 Current Condition of Faecal Sludge Management

The Faecal Sludge management system is more or less same in the developing countries around the world. Everyday large quantities of sludge are collected from onsite sanitation installations, pits, ditches, septic tanks etc. They are used in agriculture fields, aquaculture with small scale pretreatment or without any treatment or disposed of indiscriminately into lanes, ditches, open space or inland waters, estuaries and the sea. This causes serious impact on the surrounding environment, harmful health hazards, air pollution.

In larger cities, collection of large quantity of faecal sludge is a great challenge. Traffic congestion hindrance transportation of wastes, sometimes vehicles have no access to damping pit, poor management skills etc. are quite common. Suitable site for damping may be at a distance. In some cities faecal sludge damping sites are situated near the habitat of low-income population like slams. This threaten the health condition of locality. Especially in case of children and infants it may prove hazardous if they come to immediate contact with excreta (Ingallinella *et al.*, 2002).

According to EAWAG/SANDEC (2008), faecal sludge management comprises the following aspects.

- Legislation, policy and strategy to set objectives and criteria
- Implementation
    - Collection
    - Treatment
    - Reuse and Disposal

- Responsibilities, communication and coordination; financial arrangements, timeframe

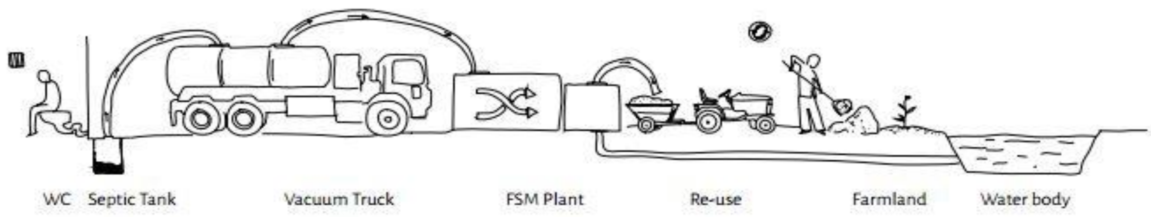

Figure 2.1: Faecal Sludge Management Service Chain, Source: (Dasgupta *et al.*, 2016)

In Bangladesh, only 58% households had onsite sanitation latrines. The rest 42% had no latrines at all (National Sanitation Survey, 2003). This scenario is quite similar to the JMP report in 2000. That report indicates 19% of open defecation rate. However, due to the special consideration of Government of Bangladesh and the development partners, the defecation system has improved considerably. Finally, open defecation rate reduced to only 3% (JMP report, 2014). But these improvements are mainly focused to the infrastructure development and construction of public or community-based latrines or toilets. Therefore, the JMP report marked the progress in sanitation as 'Not on track' towards meeting MDG target. In fact, construction of thousands of new defecations site without any consideration of proper and environmentally sound system for separation of excreta from human contact and faecal sludge management eventually led to a second-generation sanitation problem for Bangladesh. In Bangladesh about 80 metric tons of waste generates every day. Among those 24 metric tons sludges generates only in Dhaka city. Only 960 tons of sludge is being treated at Pagla treatment plant. Which is only 4% of total generation. Percentage of population that is under sewer coverage is only 22% in Dhaka city. In the areas without any sewer coverage only 55% buildings have septic tanks. The rest of the buildings directly discharges the sludge into open drains, rivers, ponds or storm drainage. This sludge mixed to the surface water bodies and causes serious environmental damage.

Even the emptying mechanism of pit or septic tanks are also poor. Normally it is done manually when the condition gets out of hand. Sometimes the tanks even get overflown, causing nuisance and foul odor. The use of mechanical suction device known as vacutug is very limited. Even when vacutug is considered as an option, collected sludges are dumped directly into the swear of DWASA or in open field. In some cases, sludges are damped into a pit then filled with earth. In both cases, faecal sludge pollute the shallow aquifers.

Now a days, different organizations including the Department of Public Health Engineering Department (DPHE) and many International/National NGOs and research organizations are showing interest in faecal sludge management systems. They are helping to establish small-scale initiatives, creating mass awareness regarding faecal sludge management, advising local authorities. They are focusing on the innovative technologies, promoting the use of organic fertilizer. They are also encouraging the entrepreneurship in the field of resource recovery technology in this sector.

2.2.3 Recovery Potential

Human excreta or faecal sludge is a reach source of organic carbon and plant nutrient (as N). Everyday a single person excrete 30 g of carbon (90 g of organic matter), 10-12 g of nitrogen, 2 g of phosphorus and 3 g of potassium. The organic matters are contained to the sludge, while the major source of nitrogen (70-80%) and potassium is urine. Phosphorus is found both in feaces and urine. Drangert (1998) shows that theoretically the fertilizer equivalent of excreta of one person is nearly enough to grow his own food (Table-2.1). In a recent study in Kumasi city of Ghana it is found that nutrients (N, P, K and organic carbon) in soil for agricultural purpose can be fully replenished by using organic soil conditioner prepared from wastes. These wastes include human waste, organic market waste, wastes from food processing industries, waste from chicken farms etc. It is considered that most of the waste should be treated accordingly (Belevi *et al.*, 2002). Following Table 2.1 shows the fertilizer equivalent of human excreta.

Table 2.1: 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 *
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)#	2.9	8.8	11.7	

*= the yearly food equivalent required for one person

#= indicative of the potential for soil conditioning, normally not designated a nutrient

Source: Drangert (1998)

The new generation requirement of faecal waste management is the effective separation of sludge form the environment and recovery of the resources form the waste. The separation system should be such convenient that recovery of nutrients from human excreta is easy (Esrey *et al.*, 1998). This type of change in sanitation system planning *i.e.* from separation of human excreta to resource recovery process is becoming popular in European countries (Otterpohl, 2000). A consequent and effective system should be developed that will allow the recycling of organic matter and nutrients into peri-urban agriculture.

Apart from using as soil conditioner faecal sludge can be used in various sectors. Table 2.2 represents the potential resource recovery options from faecal sludge.

Table 2.2: Summary of potential resource recovery options from faecal sludge

Produced Product	Treatment or Processing Technology
Soil conditioner	Sludge from drying beds Compost Pelletizing process Digestate from anaerobic digestion
Reclaimed water	Untreated liquid FS Treatment plant effluent
Protein	Black Soldier fly process
Fodder and plants	Planted drying beds
Fish and plants	Stabilisation ponds or effluent for aquaculture
Building materials	Incorporation of dried sludge
Biofuels	Biogas from anaerobic digestion Incineration/co-combustion of dried sludge Pyrolysis of FS Biodiesel from FS

(Source: Strande, L., Ronteltap, M. and Brdjanovic, D., 2014)

2.3 DEWATERING OF FAECAL SLUDGE

Dewatering of faecal sludge is done mainly by gravity flow of water through filter drying beds, and evaporation/evapotranspiration process. The dewatering ability of faecal sludge is dependent on the time period of storage and age of the sludge. Empirical evidence shows that “fresh” or “raw” FS is more difficult to dewater than older, more stabilized FS. Adding dry materials like sawdust is also effective in this respect. The addition of sawdust not only increases the liquid stream that is produced during dewatering but also increases the carbon to nitrogen (C/N) ratio.

2.4 ORGANIC SOLID WASTE

The wastes generated during the day to day activities as in form of domestic, industrial, institutional, commercial, municipal etc. are termed as solid waste (SW). Municipal solid waste does not include the medical, commercial and industrial hazardous or radioactive waste. The portion of waste that is readily biodegradable aerobically or anaerobically is called the organic solid waste (OSW). Generation of solid waste is governed by the development of the area, living standard of the people in the locality, food habit etc. From the analysis it is found that waste generation is proportional to the HDI (Human Development Index) and the GDP of the country. HDI is a comparative measure of life expectancy, literacy, education, standard of living and qualities of life of countries worldwide. Developed countries have high HDI index then the developing and under developed ones. It is evident that the waste generation in the developed area is more than the developing or under developed area. Waste generation and its maintenance has become a prime concern throughout the world. The USA alone produces approximately 254 million tons of municipal solid waste each year. This production rates in Europe and North America typically vary between 0.6 and 2.0 kg/person/day (EPA, 2008). In Bangladesh this rate is 150 kg/cap/year. In Dhaka city only 42% of generated waste are collected. The rest of the wastes remain uncollected. About 400 tons of wastes are damped in open place or on road sides (Bhuiya, 2007). These improperly damped waste cause environmental damage leading to spreading diseases. The safe, sustainable and cost-effective damping of these huge quantity of waste is the major challenge for waste management authorities. Resource recovery and composting processes are seemed to be a good measure in this purpose.

2.4.1 Characteristics of Organic Solid Waste

The solid waste consists of both biodegradable and non-biodegradable compounds. These compounds include food and vegetables, paper and paper products, polythene and plastics, textile and woods, rubber and leather, metal and tins, glass and ceramics, brick, concrete and stone, dust, ash and mud products, others (*i.e*. bone and rope). Table: 2-2 shows the solid waste generation of study area Khulna and some major cities.

Table 2.3: MSW composition in Khulna and capital cities of some developed and developing countries.

City	**Year**	**Composition (% by wet weight)**								**Reference**
		Food waste	Paper	Plastic	Textile wood	Rubber leather	Metal	Glass	Others	
Manila	1985	45.50	14.50	8.60[a]	1.30	-	4.90	2.70	31.10	A
Paris	1994	16.30	40.90	8.40[a]	4.40	-	3.20	9.40	25.80	
Vienna	1994	23.30	33.60	7.00[a]	3.10	-	3.70	10.40	25.90	
Seoul	1985	22.30	16.20	9.60[a]	3.80	-	4.10	10.60	43.00	
Mexico	1992	59.80[b]	11.90	3.50[a]	0.40	-	1.10	3.30	83.30	
Kuala Lumpur	1993	32.50	28.40	17.70	9.80	0.30	3.30	2.20	5.80	B
Kathmandu	2000	69.80	8.80	9.17	3.20	0.66	0.87	2.5	5.30	C
Yangon	2000	58.00	1.00	4.00	-	-	-	-	3.70	D
Beijing	2002	50.79	4.91	5.88	3.43	-	0.04	0.74	34.21	E
Delhi	2002	31.78	6.60	1.50	4.00	0.60	2.50	1.20	51.82	
Colombo	2002	68.15	5.99	6.69	3.02	-	1.85	1.64	10.66	
Khulna	2005	78.90	9.50	3.10	1.30	0.50	1.10	0.50	5.10	F

Notation	Details
a	Value for plastic, rubber and leather.
b	Small amounts of wood, hay and straw included.
A	Diaz L.F., Eggerth L.L., Golueke C.G., Solid waste management for economically developing country, The World Bank, Washington DC, USA, 1996.
B	Chan S.P., Estimation of solid waste generation rates and composition in Kuala Lumpur, Malaysia, M. Sci. Eng. Thesis, School of Civil Engineering, AIT, Thailand, Thesis No. EV 93-33, 1993.
C	KMC, Kathmandu Metropolitan City. A Fact Sheet, Kathmandu, Nepal, 2000.
D	YMC, Yangon Metropolitan City, A Fact Sheet, Yangon, Myanmar, 2000.
E	Visvanathan C., Trankler J., Gongming Z., Joseph K., Basnayake B.F.A., Chiemchaisri C., Kuruparan P., Norbu T., Shapkota P., Municipal solid waste management in Asia, Asian regional research program on environmental technology (ARRPET), AIT, Thailand, 2004.
F	Ahsan A., Alamgir M., Imteaz M., Shams S., Rowshon M. K., Aziz M.G., Idrus S., 2015. Municipal Solid Waste Generation, Composition and Management: Issues and Challenges. A Case Study. Environment Protection Engineering. Vol. 41., No. 3., DOI: 10.5277/epe150304.

From the analysis it is clear that the major portions of the waste generation in Asian countries are dominated by organic wastes generated from household market places etc. the major portion of these waste is food waste. But in developed cities like Paris, New York and Vienna paper waste dominates over other types of waste.

2.4.2 Solid Waste Management

The proper management of generated solid waste has become the prime concern of the current age. The countries all over the world produce millions of tons of waste in regular basis. With the rapid development, increasing urbanization and industrial growth the waste generation rate has become very high. Without an effective waste management approach, total environmental balance will collapse. There are many approaches to the management of solid waste, this could be by incineration, land filling or recycling. In developed countries there are planned collection and disposal system for solid waste. But in developing countries like Bangladesh the collection practice of waste is available at very small scale. Even in some regions there is no collection system at all. Which is causing great threat to the environment, may even cause health hazard. The present management approach of solid waste in the study area Khulna is shown below in a flow diagram:

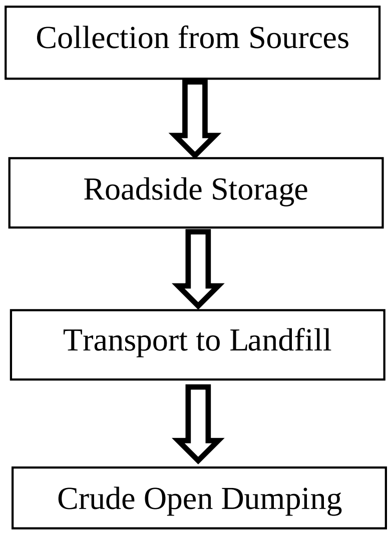

Figure 2.2: Flow diagram of waste management approach in Khulna city, Bangladesh

In open dumping procedure the wastes are not treated at all. Thus, the wastes come directly in contact with the human, animal and surrounding atmosphere. The biodegradable compound of the waste degrade under aerobic condition produces various gases (CO_2, CH_4), odor etc. Again, degradation produces leachate which percolates through the soil and gets mixed with water source (underground or surface) and causes water pollution. These adverse effects cause serious impact on the habitants of the locality. Even cause diarrheal diseases or epidemic. An efficient pretreatment can reduce these adverse effects at a large scale.

Major portion of solid waste is occupied by biodegradable wastes (food waste, vegetables, sawdust even paper and woods). These wastes are rich in carbon content, essential nutrients for plant and aquaculture. Easily biodegradable fraction of the solid wastes is suitable for composting process. Food wastes, vegetables, kitchen wastes, garden wastes, grasses, small wood pieces are some examples. Some organic materials such as paper waste, timber etc. can also be composted. But these wastes are more resistant than the others due to high lignin content (Richard, 1996). If these types of materials are present in the composting raw materials, their particle sizes are often reduced by shredding. This is done to allow quicker decomposition. Given the high amounts of biodegradable waste, organic waste recycling through composting and reuse can have considerable advantages for a city. Main potential benefits of organic waste management are reduction of harmful environmental impacts, extending landfill capacity, restoring soil texture and refueling soil nutrients (Zurbrugg and Drescher, 2002).

2.4.3 Recovery Potential

The resource potential of solid waste varies more than the faecal sludge. This potential mainly depends on the waste composition. The composition of solid waste varies city to city even within the city districts according to the income level, life standard and consumption habits. Generally due to lifestyle low income countries generate less solid waste than high income countries. According to Cointreau (1985) solid waste generation in low income countries are around 0.4 - 0.6 kg/capita/day. Where as in high income countries it varies from 0.7 - 1.8 kg/cap/day. Again, in low income countries the biodegradable portion of waste (40- 80%) is higher than the high-income country (20-50%). This is because the municipal waste in high income countries mainly consists of paper and plastics. If we consider 0.5 kg rate of per capita waste generation, it will result into300 gm/cap/day wet organic waste. It will be equivalent to 15 g/cap/day dry waste.in dry weight basis it will contain 30-40% Carbon, 1-2% of Nitrogen, 0.4-0.8% of Phosphorus and 1% of Potassium. The table-2.4 shows that generated organic waste contain high amount of organic carbon.

Table 2.4: The Fertilization Equivalent of Municipal Solid Waste (org. fraction) before waste treatment.

Nutrient	Contribution (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)[a]	16 – 22
[a] = indicative of the potential for soil conditioning, normally not designated as a nutrient	

2.5 CONCEPT OF COMPOSTING

2.5.1 General

Composting is the process of bacterial conversion of organic solid or semi-solid wastes into inert material called compost which can be handled, stored and transported without any adverse environmental impact and can be used as organic manure for improvement of soil quality and fertility. Composting is an ancient resource recovery process. There is a difference between the composting and natural decomposition. In case of natural decomposition total process is spontaneous. But composting is a completely human controlled process. By applying various controlling measures, it is possible to increase the microbial activity of microorganisms within the compost. It is also possible to avoid foul odor, unwanted environmental impacts as well as ensure product quality.

2.5.2 Process of Composting

The selection of aerobic composting process depends on certain criteria: funds available, amount and type of waste, location of the facility. Mainly two types of process are considered. These are: (a) Open System (windrows or heap, bean, trench); (b) Closed System (vessel or reactor).

a) Open System

This system is widely used in developing regions because of its economic advantage.

- **Windrow or heap**

  In this process wastes are generally piled up or gathered into heaps or elongated heaps or windrows. The heat generation is ensured by the size of the heap and aeration is controlled by periodic turning or ventilation. When the wastes are seldom turned the process is called static pile. Leachate control is done by slopping or by sealing or using impervious composting bed.

- **Bean Composting**

  Bean system is enclosed by constructed structure (wood, tin, brick or mesh compartment) all four or three sides. Main advantage of this system is the efficient use of space. Other systems (i.e. aeration, temperature control) are same as heap system.

- **Trench Composting**

  In trench system the whole system is contained under the earth surface. Aeration is done by turning. But if the trench is too deep turning operation become difficult. Leachate control is also very complicated in this process.

b) Closed System

System can be static or movable closed structures. Temperature, aeration and moisture are controlled by mechanical means. This system often requires external energy supply which results in extra costing of operation.

2.5.3 Factors Affecting Composting Process

According to Ahmed and Rahman (2007) the factors affecting the biological decomposition or composting process are described below:

- **pH Control**

  The pH of compost varies during composting process. It is also a good indicator of decomposition. The optimum pH range for most bacteria is between 6.0 and 7.5. At final stage pH values increases to about 8.5.

- **Moisture Control**

  Moisture content should be in the range of 50-60% during the composting process, the optimum being about 55%. At moisture level above 65% water begins to fill the interstices between the particles of the wastes, reducing the interstitial oxygen and causing anaerobic condition. Thus, result in rapid fall of temperature and at the same time production of offensive odors. When the moisture contents drop below 50% the composting process become slow.

- **Carbon-Nitrogen Ratio**

An optimum balance between carbon (C) and nitrogen (N) is necessary because the bacteria need a minimum supply of nutrients to survive. Nitrogen is an important constituent of bacteria cell. On the other hand, carbon is the source of energy for bacteria. The speed of decomposition process largely depends on the initial carbon nitrogen ratio.

- **Oxygen Requirement**

The availability of air is a key to the aerobic composting procedure. But it is very difficult to determine the exact requirement of the oxygen because of its dependence on many variables such as temperature, moisture content and available nutrients. An approximate method of monitoring the sufficient oxygen supply is to check the compost for foul odors. Presence of foul odor indicates insufficient supply of oxygen.

- **Temperature**

Temperature is also a key factor affecting biological activity. At first a rapid rise in temperature is necessary for microorganisms to participate in the composting process. This high temperature is the result of thermophilic bacterial action. This high temperature is necessary for the complete destruction of diseases causing microorganisms. Higher temperatures, e.g. 60-70ºC for about 24 hours should be maintained for pathogen destruction.

2.5.4 Quality of Compost

From various experimental analysis Gotaas (1956) prepared a list of ranges of different main constituents. Table 2.5 represents the list provided by him. It is remarkable that values of different constituents largely depend on the initial feedstock quality.

Table 2.5: 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

Dry compost is dusty and may cause irritation during handling process. That’s why the compost should be sufficiently wet. Compost with less than 35% moisture is considered dry. Again, compost with high moisture is clampy and may cause some odor. After considering all these effects The Composting Council (2000) recommends 40% moisture content for composts.

As in case of Bangladesh a government organization named Soil Resource Development Institute (SRDI) has established a standard for compost or organic fertilizer. Table 2.6 shows the standard values of organic fertilizer established by SRDI.

Table 2.6: Standard Values of the Parameters of Organic Fertilizer by SRDI

Parameter	Content
Physical:	
Color	Dark Gray to Black
Physical Condition	Non-granular Form
Odor	Absence from foul odor
Moisture Content	15-20%
Chemical:	
pH	6.0 - 8.5
Organic Carbon	10 - 25%
Total Nitrogen (N)	0.5 – 4.0%
C/N Ratio	Maximum 20
Phosphorus (P)	0.5 – 1.5%
Potassium (K)	1.0 – 3.0%

Source: Fertilizer (Management) Act 2006 and Compost Standards of Ministry of Agriculture, Government of Bangladesh for use in the agricultural purposes.

2.5.5 Benefits of Using Compost

The Composting Council (2000) summarizes 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 stabilizes soil pH.
- Can bind and degrade specific pollutants.

2.6 CO-COMPOSTING

2.6.1 General

Preparing compost by mixing two different types of material at same condition is termed as co-composting. In this experiment faecal sludge and organic solid waste are used together to produce co-compost. Co-composting of FS and OSW is advantageous as these two materials complement each other. Faecal sludge is relatively high in nitrogen content on the other hand solid waste is high in organic (Carbon) content. The high temperature during the action of thermophilic bacteria is very much effective in the destruction of pathogens present in the faecal sludge. This is also a mandatory stage for full maturation of a hygienically safe and environment friendly soil conditioner.

2.6.2 Co-composting of Faecal Sludge

Composting is the process of preparing organic soil conditioner by the action of various microorganisms preferably in aerobic condition (Strande *et al.,* 2014). It is a controlled process where thermophilic microorganisms decompose the organic matters present in the compost. The resulting compost is a stabilized organic product produced by the above-mentioned biological decomposition process 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" (Strauss *et al*, 2003).

Co-composting is the controlled aerobic degradation of organics, using more than one feedstock (faecal sludge and organic solid waste) (Tilley *et al*., 2014). Faecal sludge has a high moisture and nitrogen content, while biodegradable solid waste is high in organic carbon and has good bulking properties (i.e., it allows air to flow and circulate) (Eawag and ENPHO, 2014) In co-composting, two or more raw materials are composted together –for instance, faecal sludge and organic solid waste whereby the biologically generated waste heat is sufficient to raise the temperature of the composting mass to the thermophilic range (50 to 65ºC). The final product of composting is a stable humus-like material known as compost (Hafiz *et al.,* 2017).

Figure 2.3: Compost piles in Demo Compost Plant, Source: (Alamgir, 2009)

Temperature and Moisture Control

Temperature Control

The microbial activity within the compost results in a temperature increase to 45-50ºC within 5 days. Temperature above 70ºC should be avoided as they are too high for most soil micro-organisms and the process comes to a halt. A temperature around 65ºC is necessary for rapid composting. This will ensure the destruction of weed seeds, insect larvae and potential human or plant pathogens. Therefore, it is preferable for the temperature of the composting pile to stay around 65ºC for some time period. After the first week the temperature gradually decreases to 30-40ºC. During this time (mesospheric phase) other micro-organisms take over the process until the feedstocks transformed into finished compost. At final stage of compost, the temperature coincides with the atmospheric temperature. If this condition is not satisfied the then the compost is not fully matured.

Measuring Temperature

The method of measuring temperature:

- An alcohol thermometer was used to measure the temperature.
- At first a small pen size diameter hole was pushed into the compost pile with a thin stick
- Then carefully lowered the thermometer into the hole.
- After about one minute the thermometer was pulled out of the compost and immediately recorded the temperature reading.
- In this process temperature of compost at the top, middle and bottom were determined and the average of those temperatures was taken as the actual temperature.
- The ambient temperature was also recorded.

Moisture Content Control

Microorganisms consumes nutrients only as the dissolve ion condition on a film of water. Thus, the moisture content of water plays an important role. To ensure rapid decomposition the moisture content must be maintained at a level between 40-60%. Often the temperature of compost pile decreased though the process is not finished. It may be because of the low water content. Addition of farther water rises the temperature and the decomposition process continues. If the moisture content of the compost is too high, the pile tends to become anaerobic and produces unpleasant odor. Moisture content should be maintained above 40% till the start of mesospheric phase. Then the moisture content decreases and for finished compost it should be between 15-20%.

The moisture content of the compost (at field) was determined according to the USCC compost operations:

- At first grab a handful of composting material from the middle portion.
- Then squeeze the material hard.
- If water squeezes out of the compost, then it is too wet and the moisture content is above 60%.
- If only a few drops of water appear but do not release and the compost remain compacted, then the moisture content is in optimal range.
- If the compost does not release water but crumbles upon release, then the moisture content below 40% and not satisfactory.

It is advisable to use protective gloves during this test for personal hygiene. In case of less moisture water should be added until optimum moisture content is not obtained.

2.6.3 Organic Solid Waste Management with Faecal Sludge

The urban area of Bangladesh generates approximately 18,015 tons of waste per day, which adds up to over 6.58 million tons annually. It is projected that this amount will grow up to 49,000 tons/day and close to 19.16 million tons per year by 2025 (Ahsan, 2005). In Bangladesh, city authority is responsible for overall management of MSW in urban areas as per the Municipality Act. The ultimate goal of waste management is the absence of waste, i.e. to get rid of it, to use it as a resource, or not to have it in the first place (Alamgir & Ahsan, 2007).

Public authorities in developing countries spend 20-50% of their annual budget on solid waste management, but services covered less than 50% of the population in the cities

(Nzeadibe & Ajaero, 2010). However, in the developing countries, even though about 60% of the municipal solid waste stream compositions are compostable material composting is not formally integrated in urban solid waste management (Harir *et al.,* 2015). So biological treatment is a very economical natural treatment process for organic solid wastes in a country like Bangaldesh. So reducing the burden of both FS and MSW, co-composting is the best solution not only to solve the country's sanitation issues but also to lessen poor management of solid waste. Municipal solid waste after sorting into several piles of organic waste to which dried fecal sludge is added in a process known as co-composting. Different raw material including saw dust, Eppawala Rock Phosphate (ERP), rice husk and fecal sludge are then added in varying proportions to develop value- added organic fertilizer (Raj, 2015).

2.6.4 Nutrient Content Obtained by Co-composting Human Waste

Nutrient contents of composts, which have been produced from co-composting human waste (faecal or sewage treatment plant sludge) are shown in Table 2.7. However, the data show that nutrient, notably N, contents do not range particularly high which were collated from many references and for composts produced from many different raw materials, including human waste. 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. 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 (Cofie, 2003).

Table 2.7: 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, 1981)[2]
	0.45	(Byrde, 2001)[3]
Phosphorus (as P_2O_5)	0.6 – 0.7	(Shuval *et al.*, 1981)
	0.9	(Obeng and Wright, 1987)[1]
		(Kim, 1981)[2]
Potassium (K_2O)	---	(Shuval *et al.*, 1981)
	1.0	(Obeng and Wright, 1987)[1]
Organic matter (% TVS)	12 - 30	(Kim, 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

2.7 VERMICOMPOST

2.7.1 General

Vermicomposting, through earthworms, is an eco-biotechnological process that transforms energy rich and complex organic substances into a stabilized end-product "vermicompost" (Benitez *et al*., 2000). Vermicomposting is stabilization of organic material involving the joint action of earthworms and microorganisms. Although microbes are responsible for the biochemical degradation of organic matter, earthworms are the important drivers of the process, conditioning the substrate and altering the biological activity (Aira *et al*., 2002).

By the turn of the century, earthworms' potential as a biological tool should be much better understood to make organic farming and sustainable development a reality with the use of selected species of earthworm.

2.7.2 Vermiworm/Earthworms

2.7.2.1 History of Earthworms

Earthworms have a long past history. They were named as "the intestines of the soil" by Greek philosopher Aristotle in 330 BC. He suggested that the earthworm plays a vital role in maintaining soil life. But during 4^{th} quarter of 19^{th} century there was a belief among the general people that the earthworms are harmful for plants and corps. They thought that earthworms eat the plant roots and cause gradual death of corps. During that period elimination of earthworms from the crop fields were very common. This false idea had been confronted by Darwin. In 1881 Darwin published a book named 'The Formation of Vegetable Molds through the Action of Worms with Observations on Their Habits'. In that book Darwin indicated earthworms as 'ploughs of the earth'. It was due to their ability to transform soil into worm casting. According to his theory the top most rich soil layer is the result of casting action of earthworms. He also claimed that earthworms are the most important creature in the ecosystem.

2.7.2.2 Earthworm species suitable for vermicomposting

Earthworms are major biomass in the terrestrial ecosystem. There are more than 8300 species of earthworms (Reynolds & Wetzel, 2010). There are very little information on the lifecycle, biology of a vast majority of those species depending on different life history, feeding and borrowing technique, the earthworms are broadly classified into three major ecological categories *i.e.* (1) epigeic, (2) anecic and (3) endogeic.

Endogeic species are normally known as soil feeders. They make horizontal borrow lines immediately below the surface soil in search of foods. In this process they take up high amount of mineral soil.

Anecic species formerly known as borrowers live into the deeper layer of soil. They form vertical borrow lines and ingest only moderate amount of mineral soil.

Epigeic earthworms are known as litter dwellers and litter transformers. They live in the organic portion of soil layer normally near the surface soil. They eat the organic manure of the soil. They are also found in the fresh organic compound in the forest. They may also find near the human habitat in the organic manure like cattle dugs. These worms show high consumption of organic matter. They show high tolerance to the environmental factors. They have a short lifecycle with high productive rate. They show good potential for vermitechnology (Domínguez & Edwards, 2010). Only a few epigeic earthworm species are extensively used for vermicomposting. Four of them are quite well known. They are: *Eisenia andrei*, *Eisenia fetida*, *Perionyx excavatus* and *Eudrilus eugeniae* (Figure 2).

Figure 2.4: Earthworm species *Eisenia andrei* (top left), *Eisenia fetida* (top right), *Eudrilus eugeniae* (bottom left) and *Perionyx excavatus* (bottom right).

The most widely employed epigeic earthworm for successful management of wastes is *Eisenia foetida* (Garg *et al*., 2004). Vermicomposting of different kind of organic wastes through various species of earthworms has been examined by many researchers (Ranganathan, 2006; Kaur *et al*., 2010). It has been recommended by several researchers that the epigeic earthworms can be utilized for disposal and management of organic wastes (Suthar, 2006; Sinha *et al.*, 2010). Some researchers have shown that the food and kitchen wastes, mixed with other waste stuffs and cattle dung, are suitable for vermicomposting (Chauhan *et al.*, 2010; Degefe *et al.*, 2012).

2.7.3 Mechanisms

According to Aira *et al*., 2007 there are two distinctive stages of earthworm activity:

1) Active phase: in this phase earthworms processes the organic compounds by modifying physical and microbial composition and

2) Maturation phase: during this phase earthworms moves towards the fresh organic compound layer. The microorganisms take over the decomposition process of digested organic matter.

The period of maturation phase normally depends on the active phase. Again, the active phase largely depends on the type and number of earthworms (Domínguez *et al*., 2010). It is also dependent on the rate of residue application (Aira & Domínguez, 2008).

During the decomposing process the decomposition of the organic compounds effected by the Gut Associated Process (GAPs) (Figure 3). It includes ingestion, digestion and assimilation of organic matter, available microorganisms in the gut and finally casting (Gómez-Brandón *et al*., 2011). The gut atmosphere activates some specific microbial groups. For example, during process through gut some specific bacteria activated while others remain

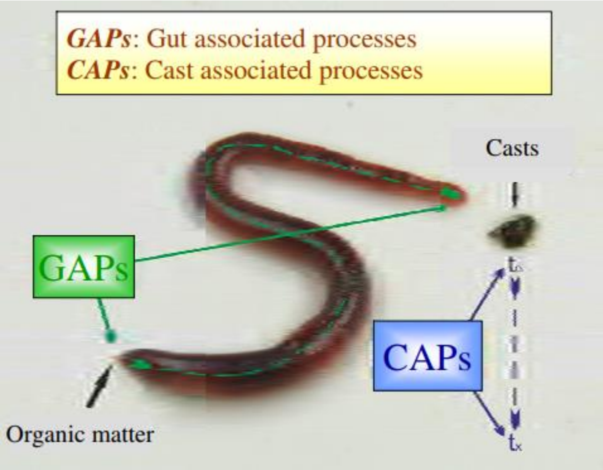

Figure 2.5: Earthworms affect the decomposition of organic matter during vermicomposting through ingestion, digestion and assimilation in the gut and then casting (*gut associated processes*); and *cast associated processes,* which are more closely related with ageing processes.

Unaffected. Some other organisms get digested (Monroy *et al.*, 2009). This effect on microorganism community during gut associated process alters the decomposition pathways during the vermicomposting process. This change cause modification of microbs involved in decomposition. Microbs form guts released in faecal material and continue decomposition. Earthworms crest contains different microbs then the parent materials (Domínguez *et al*., 2010). It is expected that the microbs in the fresh compost material promotes modifications quite similar to those present earthworms. They alter the activity level and modify the functional diversity of the microbs during the process (Aira & Domínguez, 2011).

After completion of gut associated process (GAPs) the earthworms crest commences to Crest Associated Process (CAPs; Figure 3) Also during this process vermicompost reach to the maturation phase. This compost helps in plant growth and suppress the diseases (Domínguez *et al*., 2010). However, little is yet known about when this "optimum" is achieved, how we can determine it in each case and if this "optimum" has some kind of expiration date.

Transforming wastes into vermicompost serves in two ways. In one direction, it converts wastes into a value-added product. On the other hand, it reduces solid waste pollution which is a result of population growth, unplanned urbanization and industrialization. An important advantage of vermicomposting is its scale of application. It may be applied for a small scale *i.e.* household waste to a large scale *i.e.* city scale composting (Edwards and Lofty 1972). The steps associated to waste digestion during vermicomposting are listed below.

- Ingestion of organic waste material.
- Softening of organic waste material by the saliva in the mouth of the earthworms.
- Softening of organic waste and neutralization by calcium (excreted by the inner walls of oesophagus) and passed on to the gizzard for further action in oesophagus region of worm body.
- Waste is finely ground into small particles in the muscular gizzard.

- Digestion of organic waste by a proteolytic enzyme in stomach.
- Decomposition of pulped waste material components by various enzymes including proteases, lipases, amylases, cellulases, chitinases etc. secreted in intestine and then the digested material is absorbed in the epithelium of intestine.
- Excretion of undigested food material from worm castings.

2.7.4 Factors controlling vermicomposting process

There are a number of factors that control the success of vermicomposting process. They are broadly divided into two categories *i.e.* Abiotic factors and Biotic factors

2.7.4.1 Abiotic Factors

Moisture content, pH, temperature, aeration, feed quality, light, C:N ratio etc. are important abiotic factors

- **Moisture Content**

Moisture content is very important for vermicomposting process. Proper moisture content is necessary for the action of earthworms and microorganisms in the compost. Earthworms breath through their skin and microorganisms take up nutrients through a thin film of water. 60-80% of moisture at initial period is considered a good moisture rang for the process (Neuhauser *et al*. 1988). Physical and chemical condition of the feedstock may induce some variation. According to Reinecke and Venter (1985) even 5% variation in moisture content may cause variation in clitellum development of *Eisenia fetida* worm species.

- **pH**

Another important controlling factor of vermicomposting process is pH. 5.5-8.5 is the optimal pH range for vermicomposting. However optimum pH is near 7. During composting process, a considerable change in pH may be observed. At initial period a low pH is often observed. The formation of carbon dioxide and volatile fatty acid is the main reason behind this lower value. The evolution of this carbon dioxide and utilization of fatty acids leads to a considerable rise in pH with progression of project (Kaushik and Garg 2004).

- **Temperature**

The optimal temperature range for vermicomposting is 12-28°C. The earthworms get inactivated at temperature below 10°C and dies at temperature greater than 48°C. So, the temperature of vermicompost should not be lower than 10°C and not upper than 40°C. the best temperature for vermicomposting is around 35°C (Ismail 1997). At very low temperature earthworms do not consume foods and at very high temperature reproduction rate declines. This may lead to the mortality of worms. Tolerances and preferences for temperature vary from species to species.

- **Aeration**

Earthworms are aerobic organisms. So, aeration is an important factor for vermicomposting process. Oxygen consumption of worms depends on the microbial activity. Excessive moisture during composting process may cause a non-aerobic environment, which will affect the oxygen supply.

- **Feed Quality**

Feed materials for earthworms are the basic need for the vermicomposting process. Normally a worm takes 100-300 mg/g body weight/day (Edwards, 1988). The quantity of food requirement depends on some specific factors *i.e.* particle size of food, C/N ratio, salt content, state of decomposition etc. Small size particle food is easier to consume by earthworms. Those also increase the aeration through waste piles. Earthworms derive their nutrition from organic materials, living microorganisms and by decomposing macro-fauna.

- **Light**

Earthworms are photophobic in nature (Edwards and Lofty 1972). So, they should be kept away from light.

- **C/N Ratio**

C/N ratio is a controlling factor for earthworm growth rate and reproduction. If the C/N ratio of feed material is high then the consumption rate is also high. It also accelerates the growth and reproduction rate of earthworms. If the C/N ratio is very high or very low then it inversely affects the growth rate and reproduction. C/N ratio of food material should be within 15-25 range.

2.7.4.2 Biotic Factors

Earthworms stocking density, Microorganisms, enzymes etc. are some biotic factors for vermicomposting

- **Earthworms stocking density**

The quantity of earthworms in vermicomposting system affects the process from various directions like borrowing activities, feeding rate etc. According to Uvarov and Scheu (2004) with high population density of earthworms the mortality rate also increases. Frederickson *et al*. (1997) also indicated significant decrease in growth and reproduction of *Eisenia Andrei* with increase in stocking density. High stocking density of worms results in the rapid turnover of organic matter into worm casts (Aira *et al*. 2002). So, while establishing the vermicomposting system the stocking density should be maintained strictly. Normally 200-250 numbers of earthworms are sufficient for 1.5-2 kg of waste materials. 1 kg of earthworms normally contains about 1000 earthworms.

- **Microorganisms**

During vermicomposting process the stabilization of waste materials obtained by mutual interaction of earthworms and microorganisms (Edwards and Fletcher, 1988). Microorganisms normally inhabitant into the waste materials. These organisms help in breaking down the waste particles. The types of microorganism community depend on the materials undergoing the composting process. The earthworms consume fungi to fulfill their protein. The fungal population in earthworms' casts are same to the waste materials initially (Edwards and Bohlen 1996). Microorganisms mineralize complex food materials. Pramanik (2010) reported that during gut associated process earthworms consumes microorganisms. But all microorganisms are not killed. Under favorable condition of earthworm guts, spore germination is facilitated (Tiunov and Scheu 2004).

- **Enzymes**

Enzymes actions are required for complete stabilization of complex structured waste compound. The worms secrete enzymes in their gizzard and intestine. This secretion is responsible for rapid conversion of cellulosic and proteinaceous materials (Hand *et al*.

1988). Cellulases, b-glucosidases, amidohydrolase, proteases, urease and phosphatases etc. are some important enzymes involved in the vermicomposting process. The actions of different enzymes are listed below:

- Cellulases depolymerize cellulose
- B-glucosidases hydrolyze glucosides
- Amidohydrolase, proteases and ureases are involved in Nitrogen mineralization
- Phosphatases remove phosphate groups from the organic matter

Enzyme activities are useful in interpreting intensity of microbial metabolism in soil. Enzymes act as catalysts for decomposition and detoxification of contaminants (Nannipieri and Bollag 1991).

2.7.5 Quality of Compost

Vermicompost shows a hormone like activity. This activity alters the plant morphology. This change increases the soil quality, root instigation, biomass quality and overall plant growth. Subler *et al*. (1998) shows that incorporation of small amount (about 10 mg of volume) of vermicompost (pig manure) into commercial bedding of tomato plant, results in significant increase in total biomass.

Atiyeh *et al*. (2000) reported that a small incorporation of vermicompost have a remarkable beneficial impact on the chickpea plant growth. So, it is clear that vermicompost have a good impact on plant growth.

Vermicompost stimulating the root growth increasing proliferation of root hairs. Applications of vermicompost to field soils have also been reported to increase crop growth and yields (Arancon *et al*., 2004).

Vermicompost is reported to have favorable impact on every growth parameters of various crops *i.e.* sugarcane, paddy and wheat (Ismail, 2005). Ahmed *et al*. (2010) mentioned the plant height, total dry weight and leaf area significantly increases on the application of biofertilizers. Also, found that plant height of wheat increased by inoculation with Azospirillum sp. Experiments have shown that composts have a favorable impact on plant growth by better rooting, improving soil textures, improving nutrients condition of soil (Arancon *et al*., 2004).

The observation regarding the increased biomass agreed with several experimental findings that application of biofertilizer and rhizobacteria increase plant height by 40%. It is also found that the biomass increases the leaf area by 24% for Soya beans and 41% root nodules for *Vicia sativa.* A number of other studies also pointed out that the application of biofertilizers increased the plant height in rice and Senna, number of leaves in piper beetle, leaf area in maize, total number of root nodules in mung bean and green gram (Ramaroorthy *et al*., 2003).

According to Shanmugam and Veeraputhran (2000), application biofertilizer stimulates the growth of plants with a greater number of tillers and broader leaves in rice. Ghoshal and Singh (1995) reported that the total crop biomass enhancements of 33, 36 and 67% in rice over control inbiofertilizers treatments. Singh *et al*. (2008) reported that the increase in dry weight of straw berry (Fragaria × anunassa Duch.) leaves in 7.5 t/ha vermicompost concentration.

Vermicompost amend soils also increase growth and yield of cowpea, banana and straw berries (Arancon *et al*., 2004). Venktesh *et al*. (1998) reported that yields of Thompson seedling grapes increased significantly in response to vermicompost application. According to several researchers vermicompost enhances seed germination, seedling growth and yield (Edwards and Burrows, 1988). Ravindran *et al*. (2007) observed the helophytic compost and rhizobacteria increased the plant growth, number of leaves, leaf area, root nodules, fresh weight and dry weight in Arachis hypogaea L.

According to Xie and Mackenzie (1986) there were a negative impact of excess vermicompost (30%) on the cucumber seedlings. Excess vermicompost results into salt stress which reduces the crop production.

2.7.6 Advantages of Vermicompost

There are many advantages of using vermicompost. Some of them are outlined below:

- If vermicompost are applied on farmlands, the quality of organic matters in the soil increases. As a result, the quality of soil improves and in turn crop yield increases.
- Uses of chemical fertilizer can be reduced by 50% if vermicompost is used instead.
- Producing vermicompost takes lesser effort and capitals. Women can easily do this job at home beside their chores.
- Organic components in soil are reducing day by day due to over use of chemical fertilizers. The reduction of organic substances can be compensated by the use of vermicompost.
- Vermicompost supplies to the soil, the nutrients needed by the crops. It increases the fertility of the soil. It retains water and temperature balance.
- Different types of tiny organisms that live in the soil that increases the soil fertility. They are called microorganisms. Vermicompost increases the capability of these organisms to work better.
- A piece of land where vermicompost is used, required the least amount of chemical fertilizers. In many cases farmers do not need chemical fertilizers, if vermicompost is used.

2.8 COMPOST STANDARDS IN BANGLADESH

2.8.1 Legal and Regulatory Framework for Fertilizer

The following Acts, Rules, Ordinances and guidelines provided the legal and regulatory framework for production, storage, marketing, sales and use of Fertilizers:

- Fertilizer (Control) Ordinance, 1999
- Fertilizer (Management)Act,2006
- Fertilizer (Management) Guidelines, 2007
- Fertilizer (Management) Guidelines, 2007 Amendment
- Fertilizer (Management) (Amendment) Ordinance, 2008
- Fertilizer (Management) (Amendment) Act, 2009
- Fertilizer Dealer Appointment and

- Fertilizer Distribution Integrated Policy 2009

Amendment/Supplement/Clarification of Fertilizer Dealer Appointment and Fertilizer Distribution Integrated Policy (From 2009-2011)

2.8.2 Terms and Conditions Pertaining Registration of Organic Fertilizer

1) Any organic Fertilizer must be manufactured from organic sources and shall not be allowed to manufacture from inorganic sources like plastic materials, toxic waste or hospital waste etc. The name and sources of raw materials used in the organic Fertilizer shall be clearly mentioned in application form submitted for standardization (or, setting standard).

2) Under the Fertilizer (Management) Act 2006, two members from BARI/BINA/SRDI nominated by the chair of Technical Sub-Committee along with representative(s) from DAE shall inspect physically and collect random sample on-spot during physical inspection of the production facility and procedure of the organic Fertilizer hereby applied for standardization on behalf of Fertilizer Technical Sub-Committee and shall arrange laboratory test to at least three nominated laboratory in due course of standardization process.

3) To determine the amount of Organic Carbon Tyurin's Method (1931/1936) shall be used as unified method by the laboratories of five (5) Government nominated Institutions (BARI/BINA/SRDI/BSTI/Dhaka University).

4) All details about the production process (e.g. aerobic/anaerobic/semi-aerobic technologies etc.) shall be clearly mentioned in the application form for Specification/Registration.

5) Organic Fertilizer production after receiving registration shall come under verification through examining the random samples by the specified laboratories collected from open market by DAE representative(s). Legal action shall be solicited under country's existing laws in case any form of discrimination of the set specification.

6) Import/marketing/distribution /use of any organic Fertilizer produced in abroad is prohibited in Bangladesh
7) To verify the effectiveness of the organic Fertilizers economic analysis shall be undertaken following the methods of Integrated Plant Nutrient System (IPNS).

Source: Mondol (2017)

CHAPTER III

MATERIALS AND METHODS

3.1 GENERAL

This chapter discusses the overall procedures involved in this research starting from the collection and preparation of Faecal Sludge (FS) sample, the co-composting system, vermicomposting system and the procedures used for determination of the compost parameters.

Total process is mainly divided into two different stages *i.e.* field work and laboratory testing. This chapter deals in details, the process of collection of FS, and Organic Solid Waste (OSW) and earthworms for vermicomposting. Then a short discussion on how the sample was stored for composting process. Then presented the methodology involved in determination of physicochemical parameters and other parameters of the compost at initial and matured condition. The procedures are accompanied with necessary figures and formulae whenever deemed appropriate.

3.2 STUDY AREA

The research work was conducted in Khulna University of Engineering & Technology (KUET). The sludge samples were collected from a septic tank located in the premises of KUET. So, it can be said that the study area for this research is KUET campus. KUET is situated in Khulna district, the third largest city in the southern area of Bangladesh in Ganges delta (Bayes, 2011). KUET is in the northwest part of Khulna city. The campus is about 15 kilometers from the zero point of Khulna City. Khulna is humid during summer and pleasant in winter. Khulna has an annual average temperature of 26.3 °C (79.3 °F) and monthly means varying between 12.4 °C (54.3 °F) in January and 34.3 °C (93.7 °F) in May (Wikipedia, 2015). Annual average rainfall of Khulna is 1,809.4 millimeters (71.24 in). Approximately 87% of the annual average rainfall occurs between May and October (Wikipedia, 2015). The KUET campus covers 101 acres (Wikipedia, 2015). From the study, it has been observed that the total number of septic tanks in the KUET premises is around 70. Among them, one septic tank was selected which graphically lies at 22''50' north latitude and 89''50' east longitudes (Google Earth). Its mean elevation is 7 feet above Mean Sea Level (Bayes, 2011). The location is beside the employee building number 19 in KUET. A 10 feet boundary wall is to the north of the location, waste treatment plant is to the west, a residential building is to the south and a blank space is to the east. The location of the study area is presented in the Figure 3.1 and Figure 3.2.

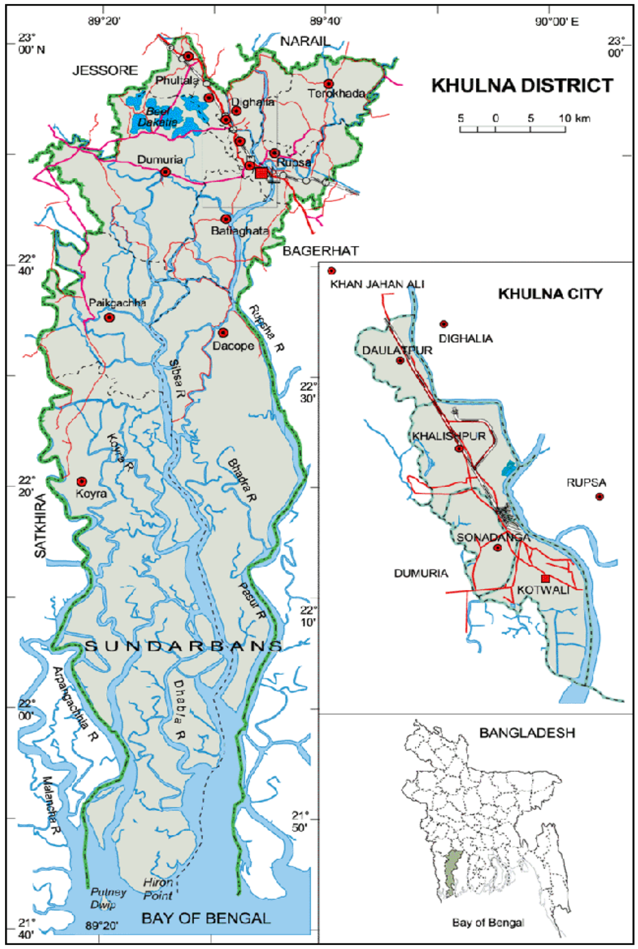

Figure 3.1: Location of the study area in map

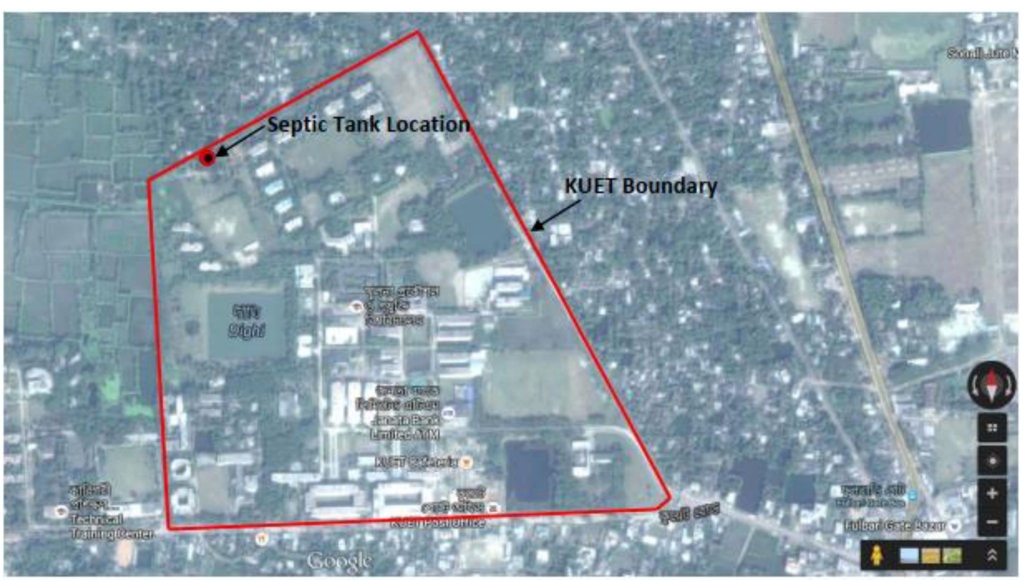

Figure 3.2: Location of the study area in aerial view

3.3 EXPERIMENTAL EQUIPMENTS

A number of equipment were required and used during the various stages of the study. These are listed below:

- **Field Equipment**

  - **Drying Bed**
    A drying bed (in Figure 3.3) was prepared for dewatering the raw sludge. The bed is of 12.5X12.5 size having a sloppy bed surface with maximum depuration at the middle. The least depth of the bed 6in. was at the edges of the bed and maximum depth was at the middle 8in.

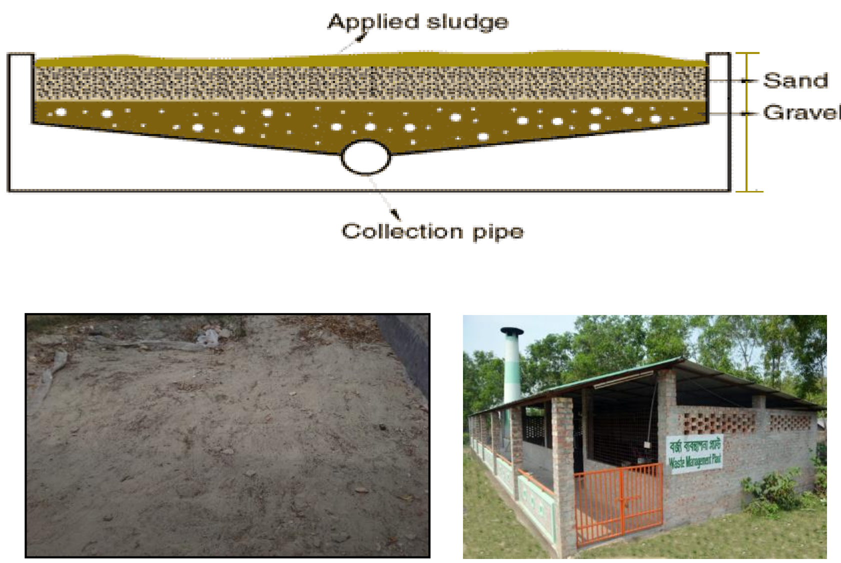

Figure 3.3: Prepared faecal sludge drying bed (inside KUET waste management plant)

  - **Compost Heap**
    A compost heap or windrow was made with wooden frame and wire mesh as side walls. Heap is 6ft long and 4ft wide with six chambers each having a dimension of 2ftX2ft. Total height of the heap is 2ft. Feagure 3.4 shows the prepared compost heap.

Figure 3.4: Compost Heap

- **Laboratory Equipment**

  - **pH Meter**
    A pH measuring meter of company called “**HACH”** was used to measure the pH of the sample. It was a Sension 2 type. The Figure 3.5 presents the pH meter used for the experimental purpose.

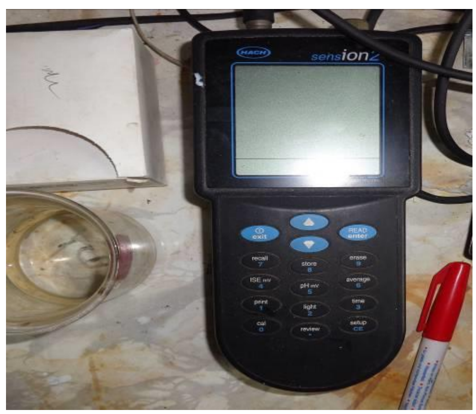

Figure 3.5: HACH pH meter (Sension 2)

  - **Oven**
    An oven of “Heraeus” company was used to measure the moisture content of the sample at various stages. The oven has the power of 0.81kw with 220volt.

  - **Muffle Furnace**
    Muffle furnace capable of increasing the temperature to 650ºC was used to evaluate the total carbon (C). The Figure 3.6 shows the muffle furnace.

Figure 3.6: Muffle Furnace

- **Kjeldhal Apparatus**
  Automatic Kjeldhal apparatus UDK 129 was used to determine total Kjeldhal nitrogen content of sample composts. Figure 3.7 shows distillation and digestion units of automatic Kjeldhal apparatus UDK 129.

Figure 3.7: Automatic Kjeldhal apparatus UDK 129 (Distillation and Digestion Unit)

- **Thermometer**
  A standard laboratory thermometer was used to measure the temperature of compost at various stages.

- **Measuring Balance**
  Measuring balance with an accuracy of 0.001 was used to measure the weight of sample.

- **Others**

Beakers, pipette, crucible, funnels, filter papers, steering rod etc.

3.4 EXPERIMENTAL PROCESS

Total process involved in this research work is presented by a flow chart given in Figure 3.8

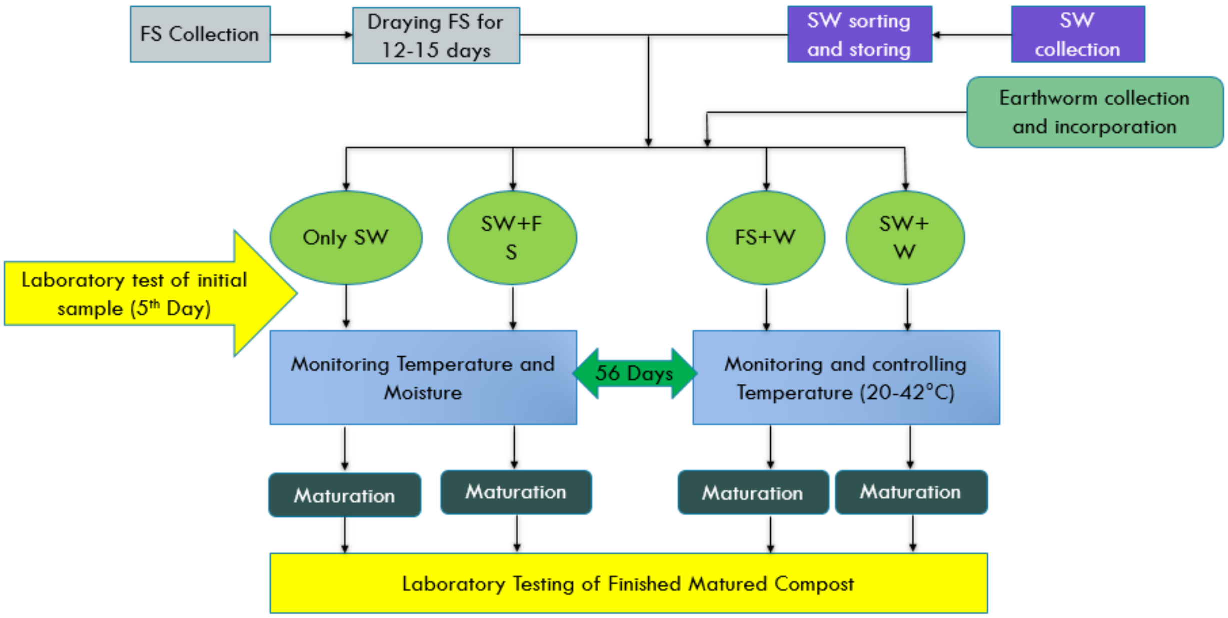

Figure 3.8: Experimental Process Flow Chart

Here, SW= Solid Waste
SW+FS= Solid Waste + Faecal Sludge Co-compost
FS+W= Faecal Sludge + Earthworm
SW+W= Solid Waste + Earthworm

At first raw faecal sludge samples were collected from the septic tanks of the KUET campus. Then they were dewatered for 12-15 days in the prepared drying bed. At the same time solid waste samples were collected from the waste management plant of KUET campus. The collected solid waste samples were sorted for inorganic, harmful and toxic elements. Than the composting process was started. For vermicomposting the earthworms were collected with the help of a private collector and immediately incorporated into the compost sample. During composting cycle, the temperature and moisture content was monitored carefully. In case of vermicompost the temperature was kept within 42°C. The laboratory testing of compost was performed at two stages. For initial testing the 5th day samples were collected (Hafiz *et. al.*,2017). The final stage testing of composting was performed at 56th day.

3.5 FFEEDSTOCK

3.5.1 Collection of Faecal Sludge

The faecal sludge sample was collected on 2nd January, 2018. Before collecting the sample, hand gloves and face mask were used in hand and mouth to ensure personal hygiene and safety. Normal buckets were used for the collection. After collecting a bucket full of waste, it was immediately transferred to the drying bed. Figure 3.9 shows raw faecal sludge immediately after collection.

Figure 3.9: Collection of Faecal Sludge

3.5.2 Dewatering of Faecal Sludge

Raw faecal sludge contains large quantity of waste water (known as dark water) with it. Normally solid content of sludge is very low compared to waste water flow. This makes raw sludge unsuitable for composting process. If proper waste water treatment facility is not present then it is necessary to dewater the raw sludge (EAWAG/SANDEC, 2008). The drying process is done on the prepared drying bed. Dried faecal sludge (Figure 3.10) is collected from the drying bed after it became separable (after 12 days). Then it was stored for co-composting and vermicomposting process.

Figure 3.10: Dried Faecal Sludge

3.5.3 Collection and Sorting of Solid Waste

Solid wastes were collected from the waste management plant of KUET campus. This management plant collects waste from the 7 residential halls and all the teachers and officer quarters daily basis. The solid wastes were collected at the same date of faecal sludge collection.

Co-compost quality mainly depends on the quality of input raw materials. So, the input material should be chosen carefully. The input solid waste must be separated from the nonbiodegradable portion of the waste. During sorting there should be no compromise in case of hazardous waste. The sorting operation of solid waste is presented in the Figure 3.11.

Figure 3.11: Sorting Operation

3.5.4 Collection of Vermicompost

Two kinds of earthworms can be used to produce vermicompost. In this case red worms or *Eisenia foetida.* They are typically 2.5-3inch long. July-August are their breeding time. But at favorable condition they can breed throughout the year. The earthworms were collected with the help of some local collector. Generally, one kilogram of worm contains approximately 1000 number of worms. Worms can be collected into a damp or wet plastic container or box. Around 500 numbers of worms can be collected in one-liter container. Worms should be applied within 5-6 hours of the collection. In this experiment the collected worms were applied immediately after collection. Figure 3.12 shows vermiworms immediately after collection.

Figure 3.12: Collected vermiworms

3.6 FAECAL SLUDGE AND SOLID WASTE MIXING RATIO

For the better quality of co-compost, the faecal sludge and solid waste mixing ratio should be carefully maintained. In this case the ratio was kept 1:3. In previously conducted research work Hafiz *et. al.*,2017 this ratio shows the better result than others. Based on that in this research 1:3 ratio is taken. Faecal sludge and sloid waste should be mixed thoroughly.

3.7 CO-COMPOSTING PROCESS

Mixed wastes were transferred in to the compost heap. The compost heap helps to ensure the required temperature rise of the compost to reduce the harmful bacteria. Within 3 days temperature rises to 63ºC. This condition remains for about 1.5-2 days. Then it decreases to 50ºC. Decrease in temperature continues till the average temperature reaches to room temperature. The turning operation of the compost was done at every 10 days interval. This was done to maintain proper aeration throughout the composting mass.

3.8 VERMICOMPOSTING PROCESS

Vermicomposting process is slightly more complicated than the other types of composting process due to the presence of vermiworms. Vermiworms are very much sensitive to the heat, temperature and light. So, the whole process was done in a cold and damp place. Temperature was maintained very carefully. In this experiment, the highest temperature of solid waste vermicompost was recorded as 40°C. Then the temperature decreased and merges with the ambient. In case of faecal sludge vermicompost highest temperature was 38°C. The compost heap was covered with a piece of black cloth to avoid the effect of light. This also produce a damp condition inside the heap chamber.

3.9 MATURATION

Total composting operation continued about 50 days. During this time the compost mass turned into soil type color. The absence of foul odor is also an indication of compost maturation.

Vermicomposting is a continuous process. It also depends on the amount and type of feedstock. The first cycle of maturation takes longer time then the next cycles. It takes roughly about 50-55 day to mature the first cycle.

3.10 LABORATORY TESTING

Laboratory tests of various samples is the most important part of the research work. It involves from collection to sampling for various parameters as per standard methods. Different types of tests (physiochemical, microbial) have been performed for different samples that were collected. The whole experiment was carried out in the Environmental Laboratory in KUET campus, except total Phosphorus (P) and total Potassium (K) tests. Total Phosphorus (P) and total Potassium (K) parameters were experimented at Soil Research and Development Institute (SRDI) in Dhaka. The following Table 3.1 represents the laboratory tests of various samples.

Table 3.1: Laboratory tests performed for different kind of samples

Raw Faecal Sludge	Compost
pH	pH
Biochemical Oxygen Demand (BOD_5)	Color
Chemical Oxygen Demand (COD)	Odor
Dissolve Oxygen (DO)	Temperature
Nitrate-Nitrogen	Moisture (%)
(Ortho) Phosphate	Total Volatile Solids (TVS)
Sludge Volume Index (SVI)	Fixed Solids (FS)
Alkalinity	Total Organic Carbon (TOC)
Total Solids (TS)	Total Kjeldahl Nitrogen
Total Suspended Solids (TSS)	C/N Ratio
Total Volatile Suspended Solids (VSS)	Total Coliform (T.C)
Fixed Solids (FS)	Faecal Coliform (F.C)
Total Dissolved Solids (TDS)	Phosphorus
Electrical Conductivity (EC)	Potassium
Total Organic Carbon (TOC)	
Total Coliform (T.C)	
Temperature	
Moisture (%)	
Faecal Coliform (F.C)	

a) Physiochemical parameters

Laboratory tests were performed by practicing standard lab procedures. Minimizing errors more than once test was experimented for each parameter. The following Table 3.2 represents the list of physiochemical parameters with their standards manual.

Table 3.2: List of Physiochemical Parameters

Serial No.	Name of the Test	Standard Methods (SM) of Analysis***
01	pH	SM 4500-H* B
02	Total Volatile Solids (TVS)	SM 2540 E
03	Fixed Solids (FS)	SM 2540 E
04	Temperature	SM 2550 B
05	Color	physically**
06	Odor	physically**
07	Total Kjeldahl Nitrogen	
08	Phosphorus	Spectrophotometric moylbdo-vanadate method
09	Potassium	Flame photometric method
10	Chemical Oxygen Demand (COD)	SM 5220 C
11	Biochemical Oxygen Demand (BOD_5)	SM 5210 B

12	Dissolve Oxygen (DO)	SM 5210 B
13	Sludge Volume Index (ml/gm)	SM 2710 D
14	Total Solids (TS)	SM 2540 B
15	Total Suspended Solids (TSS)	SM 2540 D
16	Phosphate (PO_4)	SM 4500-P E
17	Total Alkalinity (as $CaCO_3$)	SM 2320 B
18	Temperature	SM 2550 B
19	Electrical Conductivity (Ms/cm)	SM 2510 B
20	Nitrate nitrogen (mg/L)	SM 4500 NO_3-N

(***All tests were performed from source of Standard Methods for the Examination of Water and Wastewater, 20th edition, Clesceri, 1999)

(**Color and odor test have been performed on basis of practical judgment) [Hafiz *et al.*,2017]

b) Microbial parameters

The pathogenic microorganism coliforms spreads diseases. Faecal coliforms are the major pathogenic microorganisms. These are found in the feces of worm bodied animals. They are carried by storm runoff or other animals and get mixed with the river water. These are main reason behind different waterborne diseases (Flint River GREEN, 2011). If pathogens are present in both wastewater and compost it can cause serious harm to compost users. That's why in FS it is important to consider the pathogen activation. So, some microbial parameters were also tested to justify the possible presence of fecal contamination. The following Table 3.3 represents the list of microbial parameters that were tested for compost and raw faecal sludge.

Table 3.3: List of Microbial parameters

Serial No.	Name of the Test	Standard Methods (SM) of Analysis***
01	Total Coliform	SM 9222 B
02	E. Coli (Faecal Coliform)	SM 9222 D

(***All tests were performed from source of Standard Methods for the Examination of Water and Wastewater, 20th edition)

CHAPTER IV

RESULT AND DISCUSSION

4.1 GENERAL

The results obtained from the research work including the comparative analysis of the quality of different types of prepared compost are discussed in this chapter. In addition, it has been attempted to explain whether the change in the values of the parameters or concentration of the constituents be beneficial or harmful in context of application to agricultural soil. Moreover, an effort is made to decide on the quality of the compost based on the parameters and constituent concentration as determined by the test procedures.

4.2 CHARACTERISTICS OF RAW FAECAL SLUDGE

After the collection of any sample, it is prior to test the samples through standard laboratory tests for its characterisation. Same process was also applied to after collection of raw FS from different locations. Parameters that should be considered for the characterization of FS include solids concentration, chemical oxygen demand (COD), biochemical oxygen demand (BOD), nutrients, pathogens, Total solids (TS) with other solids, Electrical conductivity etc. the results of different tests on raw faecal sludge is attached with the report as Annex-1

These parameters are normally used for domestic waste water analysis. It should be noted that, domestic waste water analysis is different than faecal sludge. Annex-1 represents the characteristics of the collected samples from the septic tanks of KUET campus. From the result it can be said that, FS from septic tank is high strength type (Montanegro & Strauss, 2002) High strength means highly concentrated, mostly fresh FS; stored for days or weeks only where as low-strength means FS of low concentration; usually stored for several years; more stabilized than high strength type.

Again, on the basis of Suspended Solids (SS) the sample is high-strength because of their higher concentration (≥ 30000). There will be always variability in determining the FS concentration and characteristics. Time, performance of pit latrine or septic tank, temperature, location of ground water table, salinity, tank location, emptying process, no of users, rainfall etc. always influence the overall characteristics of raw FS. Moreover, from the characteristics, it can be known the concentration of nutrient content in the FS which has an influence in end-use option.

4.3 QUALITY OF PREPARED COMPOST

Using FS as a soil amendment has many benefits over using chemical fertilizers alone (Strauss, 2000). Organic matter in FS can increase soil water holding capacity, build structure, reduce erosion and provide a source of slowly released nutrients. As mentioned above, when using FS as a soil conditioner, the fate of and exposure to pathogens needs to be taken into consideration. Co-composting and vermicomposting are two secondary treatment procedure for faecal sludge nad organic wate. These processess considerably reduce the amount of pathogens present in the faecal sludge and waste products. Social acceptance is also closely linked to potential commercial value. For all consideration and proof, laboratory valid result and decision is needed.

Mass Balance

The composting process reduces the amount of waste considerabily. Reduction of moisture and voletile solids is the main reason behind this mass reduce. Table 4.1 represents the initial and final mass of prepared compost.

Table 4.1: Initial and Final Mass of Prepared Composts

Compost Type	Mass of Feedstock (gm)	Mass of compost after 56 days (gm)
Solid Waste Compost (SW)	3000	892
Solid waste Vermicompost (SW+W)	3000	887
Faecal Sludge Vermicompost (FS+W)	3000	1754
Faecal Sludge and Solid Waste Co-compost (FS+SW)	4000	1647

The change in total mass, moisture content (MC), voletile solids (VS) and fixed solids (FS) at initial and final stage of composting is shown in the Table 4.2.

Table 4.2: Change in Total Mass, Moisture Content (MC), Voletile Solids (VS) and Fixed Solids (FS) at Initial and Final Stage of Composting

Type	Total mass initial (gm)	Total mass final (gm)	Loss (%)	MC initial (gm)	MC final (gm)	Loss (%)	VS initial (gm)	VS final (gm)	Loss (%)	Fixed Solids initial (gm)	Fixed Solids final (gm)	Loss (%)
SW	3000	892	70.26	1581.9	191.96	87.87	884.90	190.71	78.45	533.21	509.35	4.47
SW+W	3000	887	70.43	1670.1	176.16	89.45	745.81	164.28	77.97	584.10	546.57	6.43
FS+W	3000	1754	41.53	839.1	326.24	61.12	869.11	290.83	66.54	1291.8	1136.92	11.99
FS+SW	4000	1647	58.82	1763.6	312.60	82.24	1187.08	336.94	71.62	1049.32	997.46	4.94

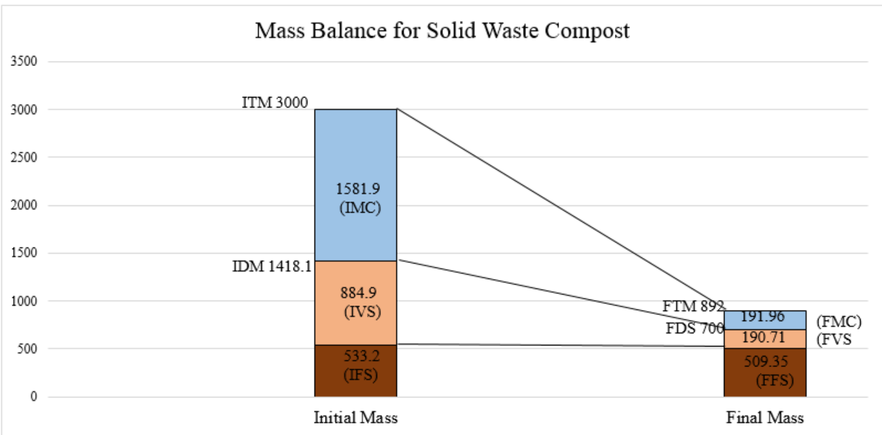

Figure 4.1: Massbalance for Solid Waste Compost

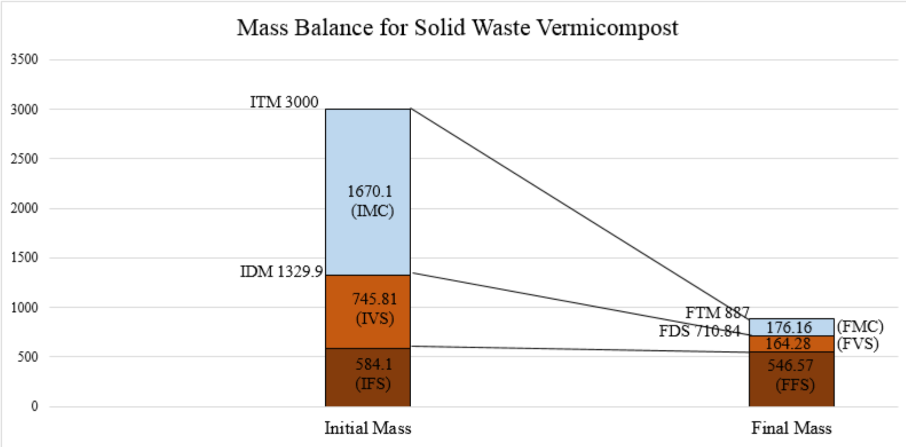

Figure 4.2: Massbalance for Solid Waste Vermicompost

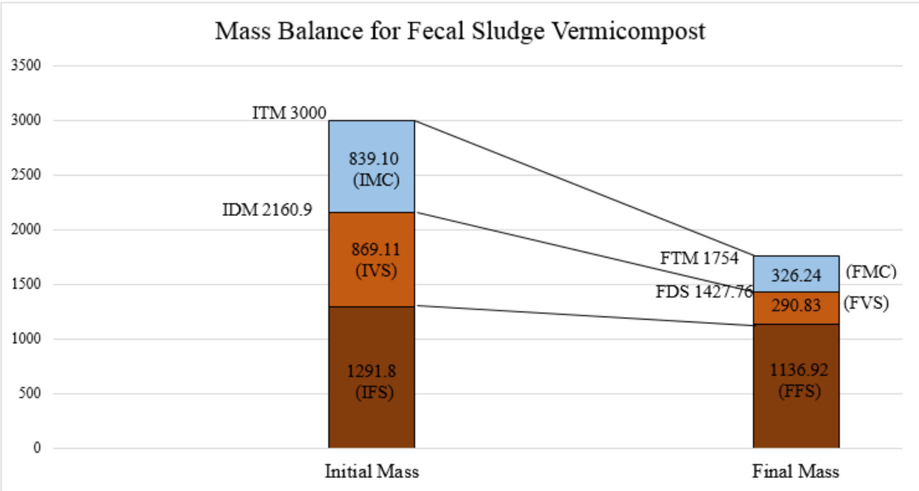

Figure 4.3: Massbalance for Faecal Sludge Vermicompost

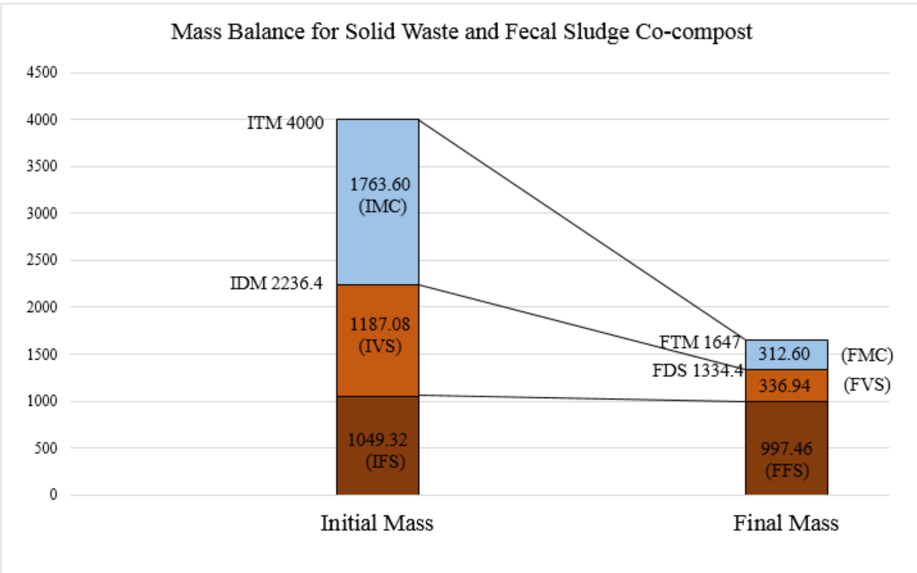

Figure 4.4: Massbalance for Solid Waste Faecal Sludge Co-compost

Here, ITM= Initial Total Mass, IMC= Initial Moisture Content IDM= Initial Dry Mass, IVS= Initial Volatile Solid, IFS= Initial Fixed Solid, FTM= Final Total Mass, FDM= Final Dry Mass, FMC=

Final Moisture Content, FVS= Final Volatile Solid, FFS= Final Fixed Solid. All Mass values are in gram unit.

Figure 4.1, 4.2, 4.3 and 4.4 shows the massbalances for the solidwaste compost (SW), solidwaste vermicompost (SW+W), faecal sludge vermicompost (FS+W) and solidwaste faecal sludge co-compost (SW+FS) Initially all compost samples consists of 3.00 kgs of sample except faecal sludge and solid waste co-compost. To maintain the 1:3 ratio of faecal sludge nad solid waste, 1 kg dry faecal sludge was mixed with 3.00 kg solid waste sample. The mass reduction is greater for solid waste than faecal sludge. In case of solid waste compost the mass reduction is about 70% (70.26% for solid waste compost and 70.43 for solid waste vermicompost). Whereas the mass reduction of faecal sludge vermicompost and faecal sludge-solid waste co-compost is 41.53% and 58.82% respectively. Loss of moisture cintent is above 80% for solid waste compost, solid waste vermicompost and faecal sludge and faecal sludge solid waste vermicompost. But in case of faecal sludge vermicompost moisture reduction is 61.12%. Similar condition is observed for voletile solids. The fixed solid reduction percentage is 4.47%, 6.43%, 11.99% and 4.94% for solid waste compost, solid waste vermicompost, faecal sludge vermicompost and faecal sludge solid waste co-compost.

The laboratory testing of prepared compost was performed in two stages. The initial samples were collected at 5th day. The results of initial testing is attached with the report as Annex-2. The final testing was done after 56 days. After 56 days of beginning of composting process, the samples were collected for necessary to determine properties at the final condition/maturation stage. The final test results are attached with the report as Annex-3. The initial samples were not tested for potassium and phosphorus content.

A comparison and discussion on the initial and final condition of composts with supporting graphs is preseted below. In the charts, prepared composts are designated by specific letters *i.e.*, SW= Solid awste compost, SW+W= Solid waste Vermicompost, FS+W= Faecal Sludge Vermicompost and FS+SW= Faecal Sludge and Solid Waste Co-compost.

Color and Odor

From the final condition result it is seen that, color, odor and moisture that was observed is satisfactory which depend on the local climate, constituents of the OSW, local human nature, etc. prototype compost was dark gray in color, absence of foul odor, and dry in combination. Physically there is no significant difference between three types of co-compost. Although particle size analysis was not carried out, there was no significant difference in texture of finished compost.

pH

pH is an important indication of compost maturity. It can be seen that the pH values are within the recommended values 3-11 for compostable substance (De Bertoldi *et al*., 1983). Figure 4.5 shows the variation of pH value at initial and final condition.

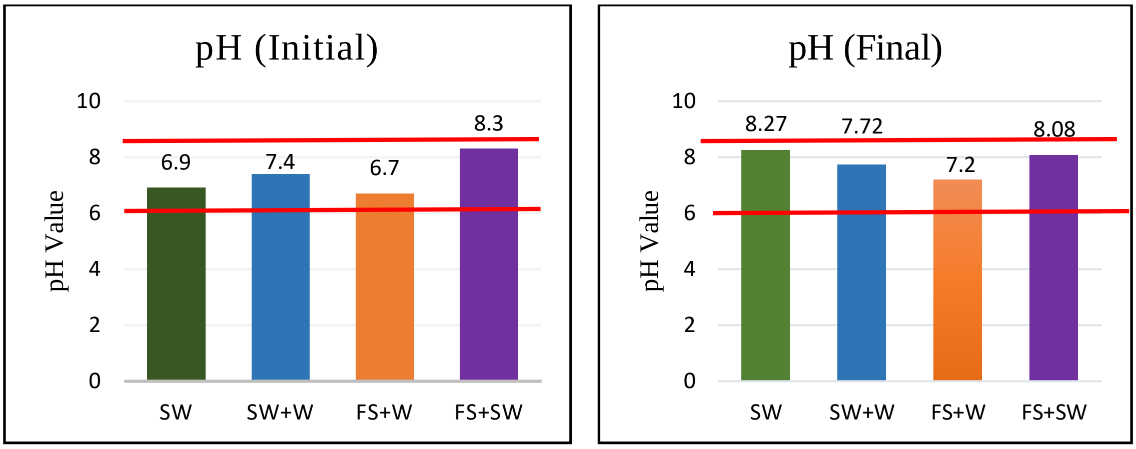

Figure 4.5: pH content at initial and final stage of composting

In this experiment initially, pH values of different composts were. 6.9 for solid waste sample, 7.4 for solid waste vermicompost, 6.7 for vermiculture of faecal sludge and 8.3 for faecal sludge and solid waste co-compost. Finally, these values were found as 8.27, 7.72, 7.2 and 8.08 respectively. At finished condition pH values for the prepared composts are within the pH range of 7.1-8.6 reported by Bernal *et al.*,1998 for composts of various organic waste sources like sewage sludge, animal manure, city refuse, industrial and plant refuses. Earthworms and microorganisms are able to change the soil pH (Suthar *et al.*, 2015). Low pH at initial period is due to the formation of carbon dioxide and volatile fatty acids. But in case of co-compost of faecal sludge and organic solid waste initially the pH value was high. It can be explained by solubilization of ammonia leading to ammonium formation (Omrani *et al.*, 2005, Suthar *et al.*, 2015). In later stages of the experiment, the action of aerobic microorganisms increases the decomposition. Which leads to formation of alkaline materials in presence of sufficient moisture (Yousefi *et al.*, 2012, Parvaresh *et al.*, 2004). If compost is highly alkaline or acidic then it will harm the soil condition and even adversely affect the fertility of soil resulting in a decrease in crop production. It may also cause immature destruction of crops. Thus the pH of compost should be within the desirable level for the soil. According to the SRDI standard the pH of compost should be within 6 to 8.5. The marked red lines show the SRDI standard range.

Moisture Content

Moisture content is an important indication of maturation. In normal and co-compost, the microorganisms take up nutrients in a thin film of water. In case of vermicompost it is essential to maintain a certain moisture in the compost to provide favourable condition for the vermiworms to breed. Also to maintain the temperature level in vermicompost the moisture content can be modified. The moisture contents in the composts were initially high *i.e.* 52.73% for solid waste sample, 55.67% for vermiculture of solid waste, 27.97% for vermiculture of faecal sludge and 44.09% for faecal sludge and solid waste co-compost. At final stage the moisture content dropped to the following 21.52%, 19.86%, 18.60% and 18.98% respectively. The marked red lines show the SRDI standard range. Figure 4.6 shows moisture content at initial and final condition.

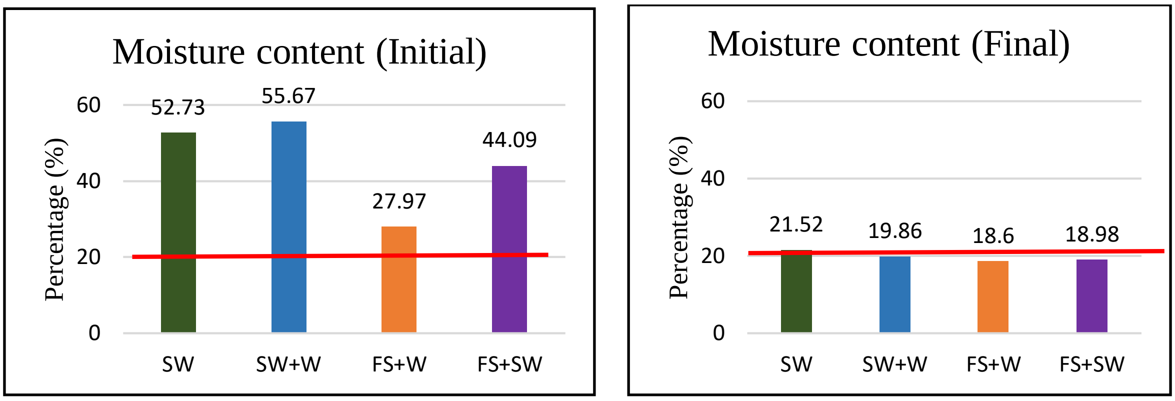

Figure 4.6: Moisture content at initial and final stage of composting

Total Volatile Solids (TVS) and Fixed Solids (FS)

At initial condition total volatile solid content was found as 62.4% for solid waste sample, 56.08% for vermiculture of solid waste, 40.22% for vermiculture of faecal sludge and 53.08% for faecal sludge and solid waste co-compost. As in final condition these values decrease to 27.24%, 23.11%, 20.37% and 25.25% respectively. The degradation of organic material is the reason behind this drop in TVS value (Bernal *et al*., 1998). Figure 4.7 shows TVS at initial and final condition.

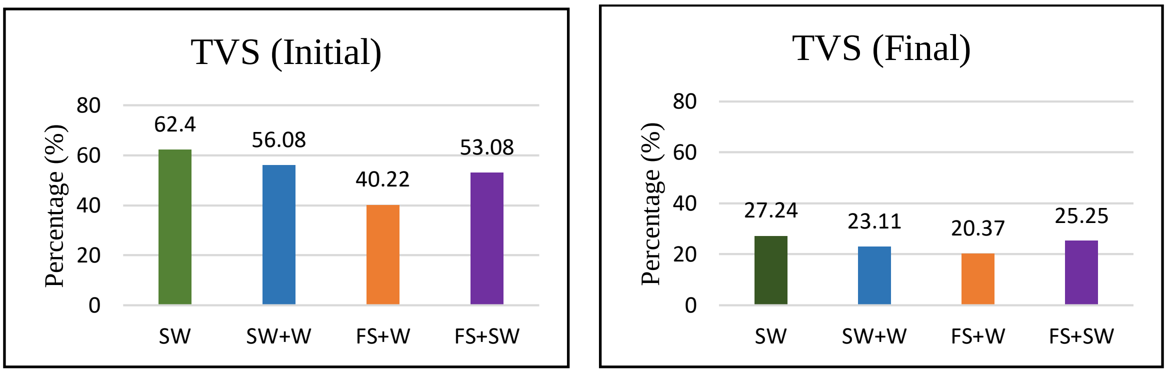

Figure 4.7: Total Volatile Solid (TVS) content at initial and final stage of composting

In case of fixed solids (Figure 4.8) at initial condition obtained values were 37.6% for solid waste sample, 43.92% for vermiculture of solid waste, 59.78% for vermiculture of faecal sludge and 46.92% for faecal sludge and solid waste co-compost. At final conditions these values increased considerably and found as 72.76%, 76.89%, 79.63% and 74.75% respectively. This increase in fixed solids content is due to the moisture decrease in the composting process. The marked red lines show the SRDI standard range.

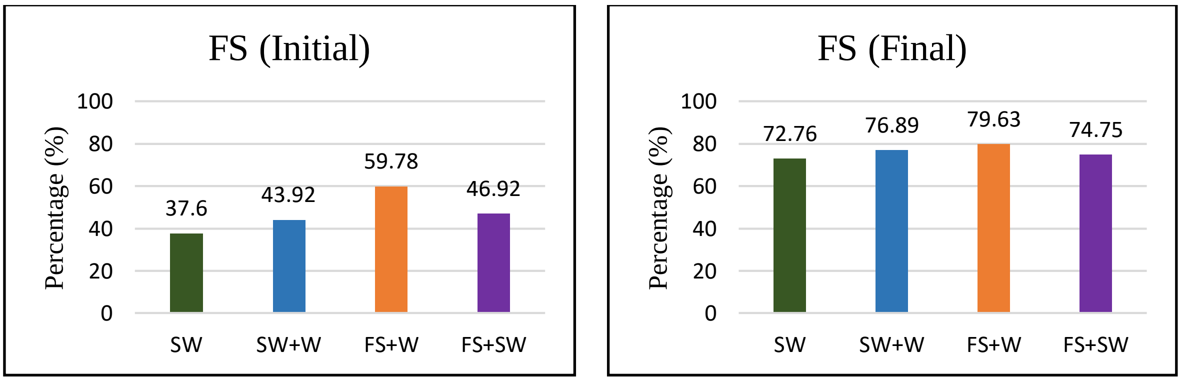

Figure 4.8: Fixed solid (FS) content at initial and final stage of composting

Total Organic Carbon

Total carbon content (%) of co-compost was determined as a direct function of total volatile solid (TVS) (Adams *et al*., 1951). Figure 4.9 shows total carbon content at initial and final condition.

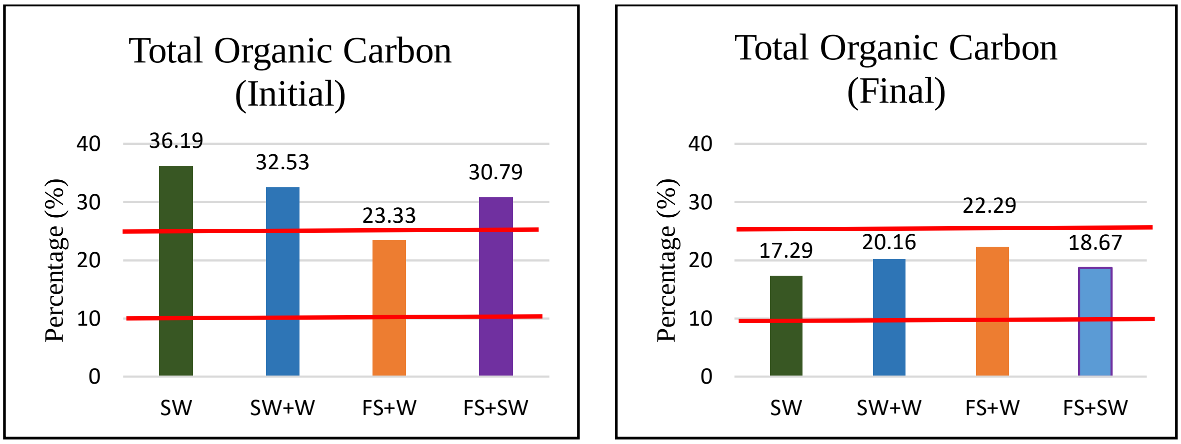

Figure 4.9: Total Organic Carbon content at initial and final stage of composting

Total carbon content values for the final stage of compost falls within the standard range of the SRDI compost standard. It also falls within the value range provided by Gotaas (1956). A decrease in total carbon content was observed in the initial and final values of co-compost. This may be explained as the decomposition of starting material and mainly transformation into carbon dioxide. The marked red lines show the SRDI standard range.

In case of vermicompost, the earthworms mineralize and decomposes the organic compounds into substrate material. Carbon compounds are lost in the form of CO_2. The number of earthworms also decreases slightly with the decrease of C/N ratio. this decrease in C/N ratio increases the oxidation of organic matter and thus total organic carbon.

Total Kjeldahl Nitrogen

An increase is observed of the values of nitrogen content. From the Figure 4.10 it is seen that initially total kjeldahl nitrogen content was 1.75% for solid waste sample, 1.49% for vermiculture of solid waste, 1.60% for vermiculture of faecal sludge and 1.65% for faecal sludge and solid waste co-compost. Finally, these value increases as 1.68%, 2.1%, 1.82% and 1.75% respectively. The marked red lines show the SRDI standard range.

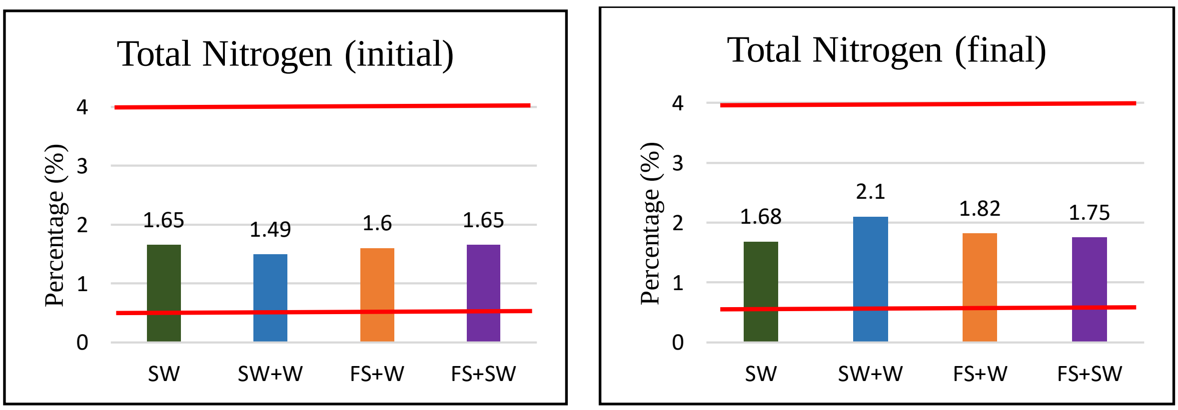

Figure 4.10: Total Kjeldahl Nitrogen content at initial and final stage of composting

From the analysis it is evident that the nitrogen content of composts rises at maturation. This is due to the concentration effect caused by the decomposition of organic compound which leads to weight loss (Bernal *et al*.,1998; Sa´nchez-Monedero *et al*., 2001). In case of vermicompost, the nitrogen level increases due to the secretion of enzyme by earthworms.

Carbon to Nitrogen (C/N) Ratio

Carbon to nitrogen ratio (C/N) is an important indication of compost maturity. It represents the decomposition of organic matter and the stability obtained during composting period. C/N ratio decreases in every sample with time. The C/N ratio during composting is shown in Figure 4.11.

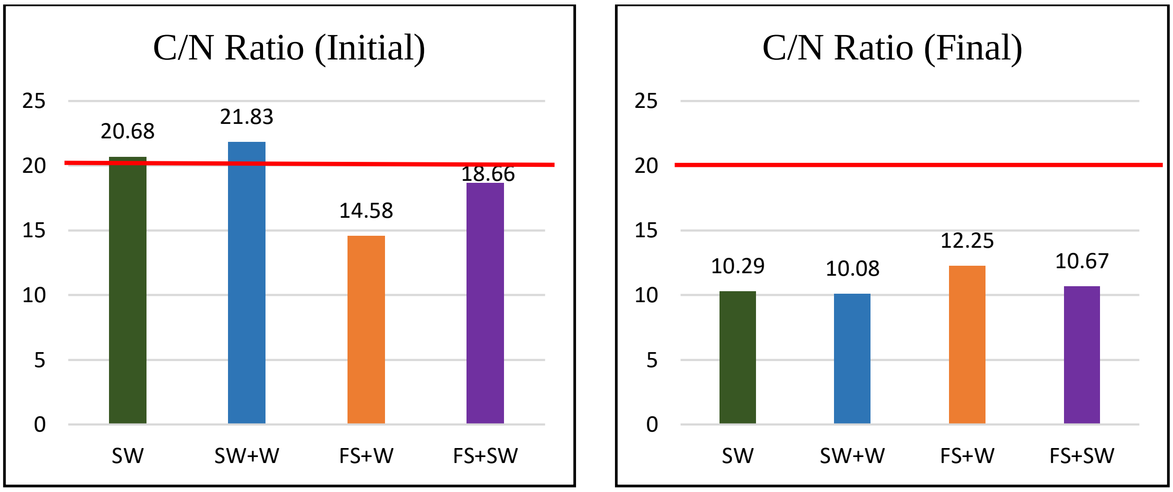

Figure 4.11: Carbon to Nitrogen Ratio (C/N) at initial and final stage of composting

Many authors have used C/N ratio as an indicator of compost maturity. But due to its large variation and dependency on input material it cannot be used as absolute standard. However, a value below 20 may be considered as satisfactory (Wong *et al*, 2001). According to Fuchs *et al.*, (2001) a value around 16 is satisfactory. It also ensures compost to avoid nitrogen blockade. Allison (1973) recommended that, for a well humified compost C/N ratio value should be around 10. In case of mixed material, he recommended the value to be below 15. This value will not alter the microbial equilibrium of soil. From the above results and discussions, it is clear that the vermiculture of faecal sludge shows better result (C/N ratio 12.25) than others. The marked red lines show the SRDI standard range.

Total Coliform (TC), Faecal Coliform (FC)

While implementing resource recovery technique it should be ensured that the system is not harmful for the users. For this purpose the amount of pathogens should be monitored carefully. Figure 4.12 shows total coliform content.

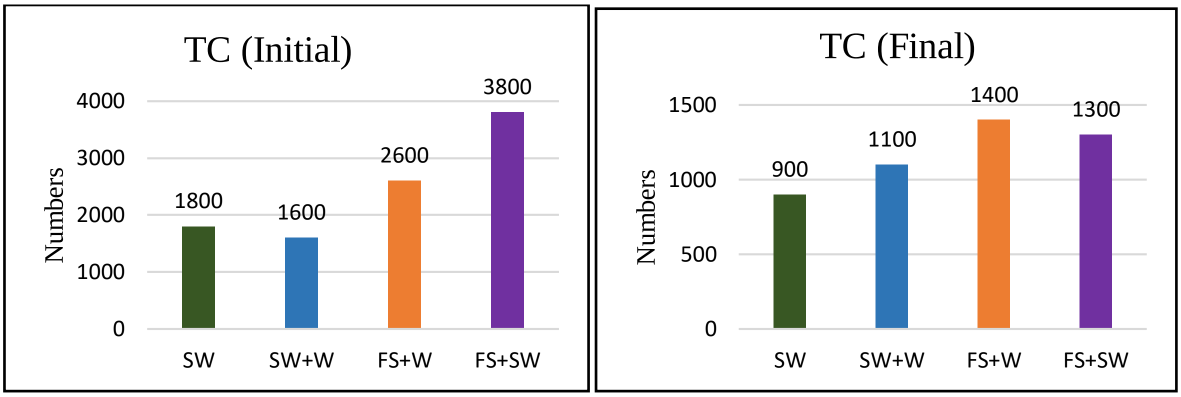

Figure 4.12: Total Coliform (TC) content at initial and final condition of composting

presence of faecal coliform in compost indicates pathogenic contamination, which is harmful for the user and the environment. Raw faecal sludge contains considerable amount of faecal coliform. It is important to ensure that compost prepared from faecal sludge contains FC within standard. In this case, maturated compost sample of all type contains less faecal sludge then the WHO guideline provided standard. The marked red lines show the SRDI standard range. Figure 4.13 shows faecal coliform content at initial and final condition.

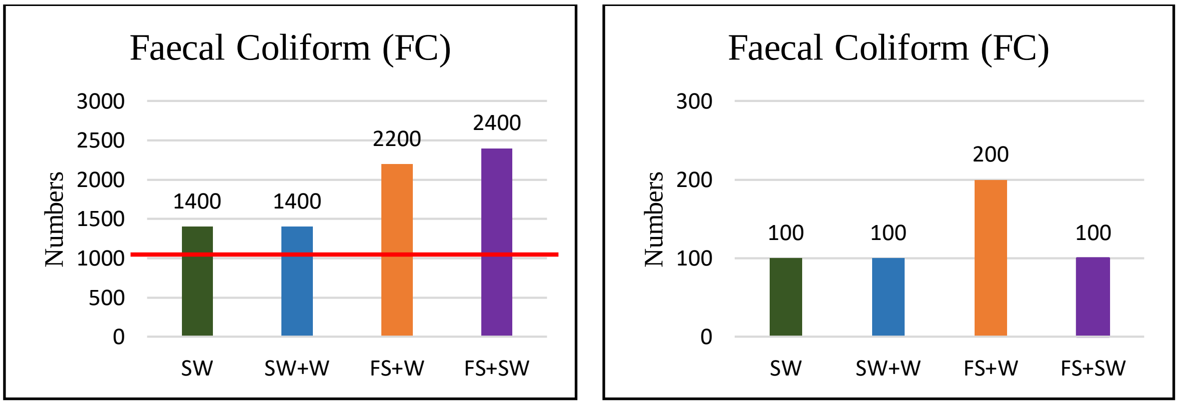

Figure 4.13: Faecal Coliform (FC) content at initial and final condition of composting

Phosphorus (P)

Phosphorus is an important constituent of organic fertilizer. During composting period phosphorus content increases. The enzymes in the intestines of the earthworms and action of microorganisms mineralize and mobilize the amount of phosphorus. This is the reason behind the increase in phosphorus content (Suthar & Singh, 2008). In different experiment, it has been found that the phosphorus content normally increases during composting period (Jadia *et al.*, 2008). The following Figure 4.14 shows the Phosphorus content of prepared compost.

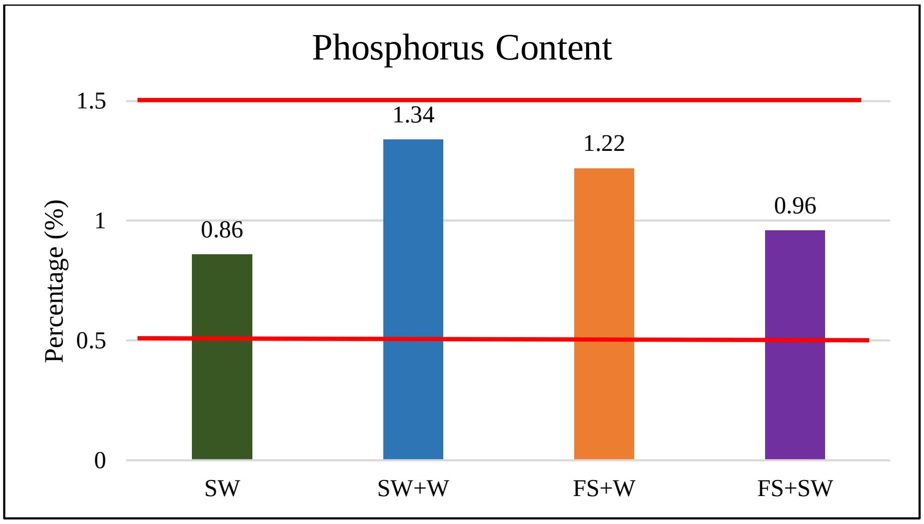

Figure 4.14: Total Phosphorus content of different types of compost at final condition

In this experiment, total phosphorus content is found as 0.86% for solid waste compost 1.34% for vermiculture of solid waste, 1.22% for vermiculture of faecal sludge and 0.96% for faecal sludge and solid waste co-compost. These values are within the standard (0.5-1.5%) provided by the Soil Resource and Development Institute (SRDI). The marked red lines show the SRDI standard range.

Potassium (K)

Potassium is also an important constituent of organic fertilizer. It is essential for proper growth of plants and essential nutrient for crops. In this experiment, total phosphorus content (shown in Figure 4.15) is found as 0.86% for solid waste compost 1.34% for vermiculture of solid waste, 1.22% for vermiculture of faecal sludge and 0.96% for faecal sludge and solid waste co-compost. These values are within the standard (0.5-1.5%) provided by the Soil Resource and Development Institute (SRDI). The marked red lines show the SRDI standard range.

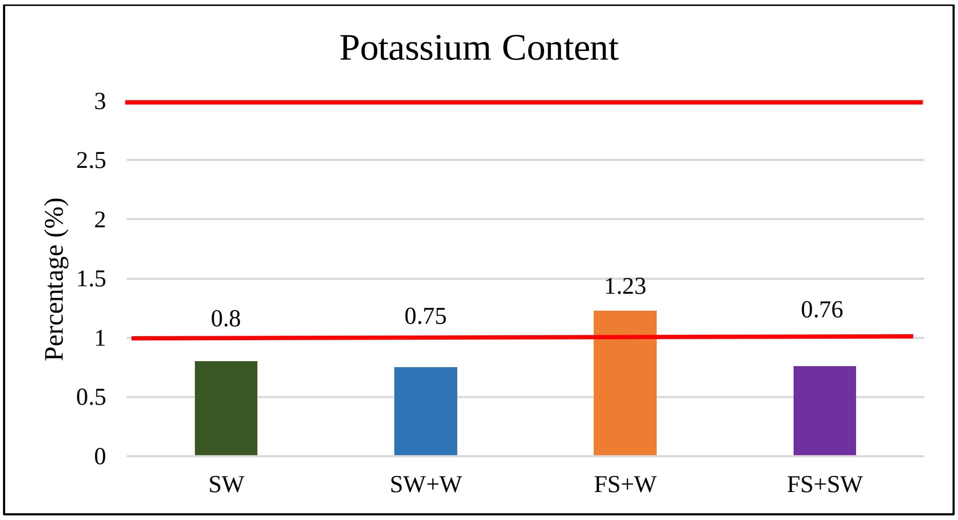

Figure 4.15: Total Potassium content of different types of compost final condition

Acid production during organic matter decomposition by the microorganisms is the major mechanism for solubilisation of insoluble phosphorus and potassium. Also, the presence of large number of microflorae in the gut of earthworm might play an important role in increasing P and K content in the process of vermicomposting (Pramanik *et al.,* 2006).

4.4 TEMPERATURE VARIATION DURING COMPOSTING PROCESS

To ensure the compost quality monitoring and maintaining temperature is very important. Because the rates of organic degradation are temperature dependent and increases at wormer temperature. Composting is a controlled process of biodegradation of organic waste. The microorganisms involved in this process are same as responsible for the organic degradation of soil. The resulting end product is a dark, rich, humus-like matter that can be used as a soil amendment. That's why, during composting period, regular temperature was monitored and recorded.

Considering a 55 days cycle of composting a temperature vs days graph has been prepared for each type of sample. The graph for normal organic compost and co-compost of faecal sludge and solid waste are more or less similar. This is due to the same type of biodegradation process. The microorganisms of compost rapidly go through a series of bioreaction with the biodegradable organic compound and raise temperature at a considerable level. The temperature variation of solidwaste compost is shown in the Figure 4.16.

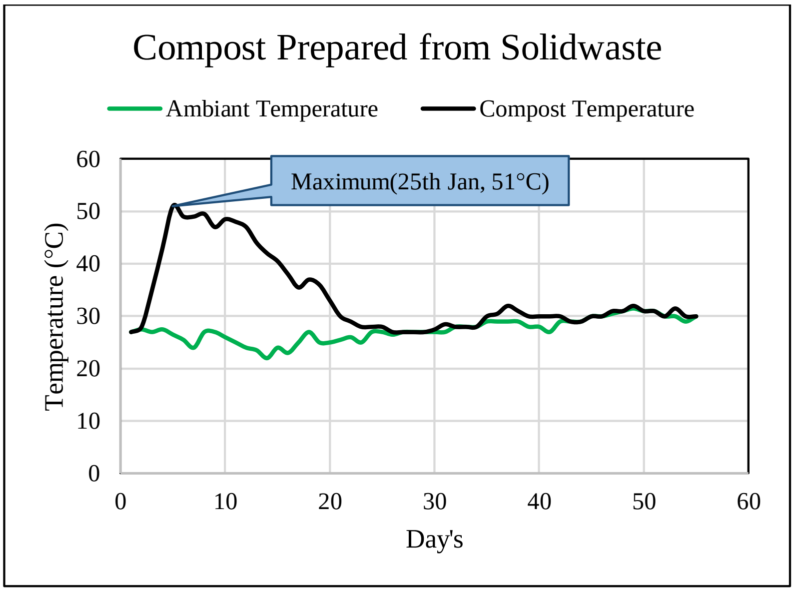

Figure 4.16: Temperature Curve of Compost prepared from Solid waste

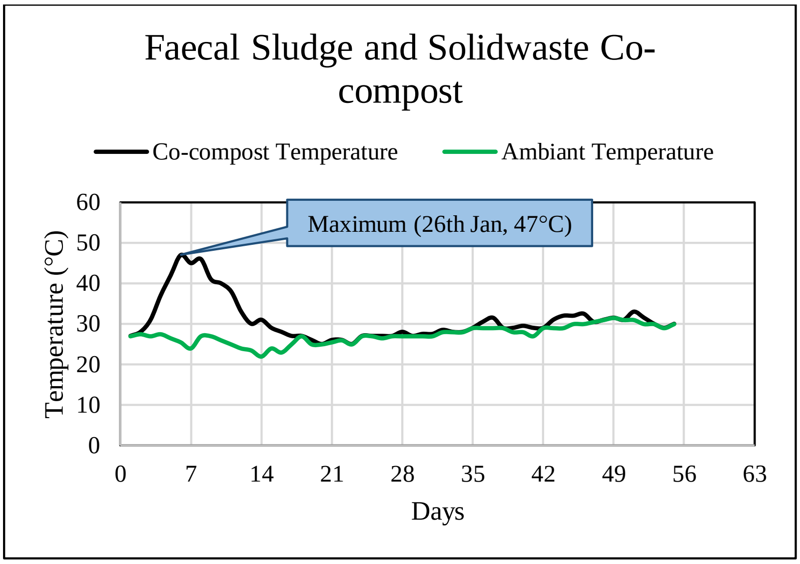

Figure 4.17: Temperature Curve of Faecal Sludge and Solid waste Co-compost

Highest temperature for normal organic compost was observed 51°C at the 6th day (25th January, 2018). Then it started to decrease and gradually nearly coincide with the ambient temperature. Same type of fluctuation was observed in the case of co-compost (shown in Figure 4.17). The temperature of co-compost was highest at 7th day of composting cycle (26th January, 2018) and it was 47°C. This temperature also decreases with time and finally come near to the ambient temperature.

But in case of verminculture samples *i.e.* vermicompost of organic solid waste and vermicompost of faecal sludge, the temperature variation is different. This is because of the use of vermiworms or earthworms. The earthworms cannot sustain higher temperature above 45°C. Temperature below 20°C is also unsuitable for their breeding. The best temperature for earthworm is 35-20°C. But for the reaction of microorganism compost temperature may increase. That's why certain temperature controlling measures (*i.e.* turning of compost, using water sprinkle etc.) were adapted. The variation of temperature of vermicompost is represented graphically in the Figure 4.18 for faecal sludge vermicompost and in Figure 4.19 for solid waste vermicompost.

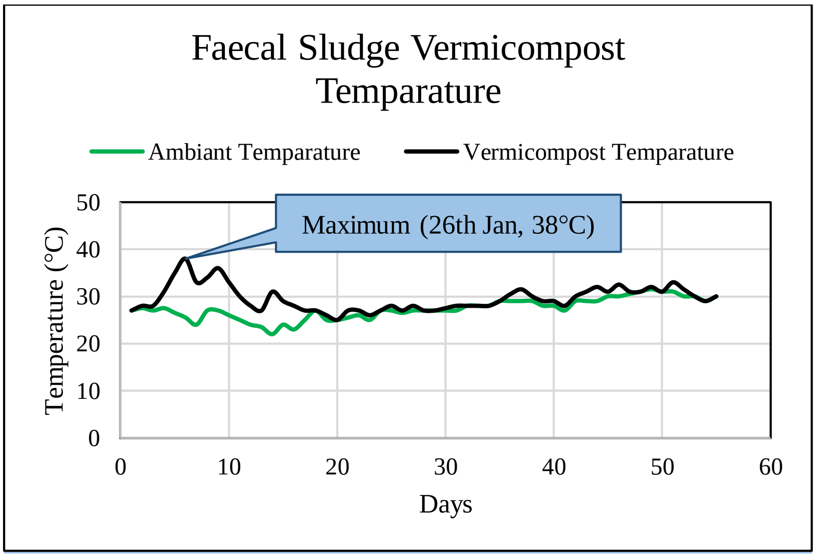

Figure 4.18: Temperature Curve of Faecal Sludge Vermicompost

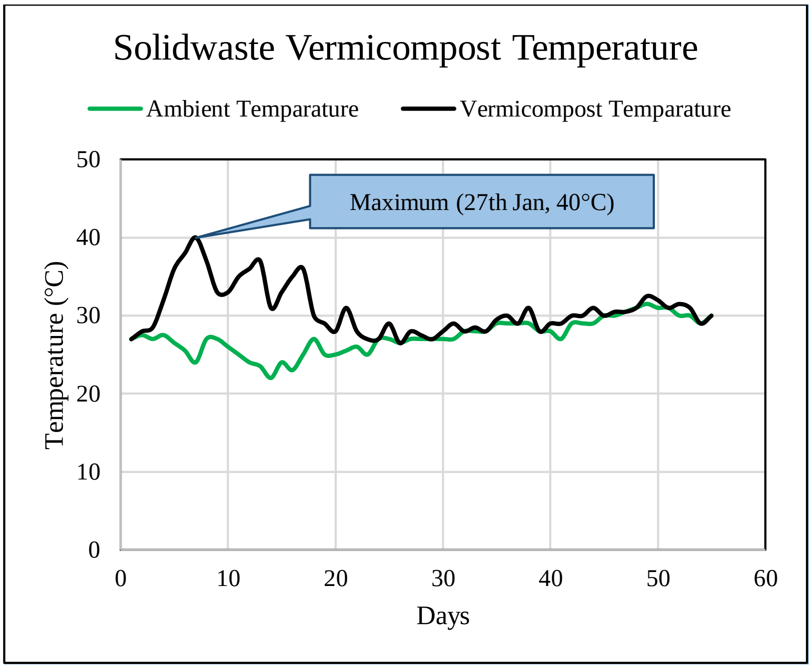

Figure 4.19: Temperature Curve of Solid Waste Vermicompost

4.5 COMPARISON OF COMPOST QUALITY

Table 4.3: Compost status at finished state

SL. No.	Characteristics	Units	Results				SRDI Standards	Status
			SW	SW+W	FS+W	SW+FS		
01	pH		8.27	7.72	7.20	8.05	6.0 –8.5	Alkaline
02	Moisture content	%	21.52	19.86	18.60	18.98	Maximum 20 %	Decreased and within limit
03	Total Organic Carbon	%	17.29	20.16	22.29	18.67	10-25 %	Decreased and within limit
04	Total Kjheldhal Nitrogen	%	1.68	2.10	1.82	1.75	0.5 – 4.0 %	Increased and within limit
05	C/N		10.29	10.08	12.25	10.67	20:1 (maximum)	Decreased and within limit
06	Faecal Coliform (FC)	Nos.	100	100	200	100	≤1000, WHO guideline 1989	Decreased About 50 times
07	Phosphprus	%	0.86	1.34	1.22	0.96	0.5-1.5	Within limit
08	Potassium	%	0.80	0.75	1.23	0.76	1.0-3.0	Only FS+W is within range

Note: SW: Solid Waste Compost, SW+W: Solid Waste Vermicompost, FS+W: Faecal Sludge Vermicompost, SW+FS: Solid Waste and Faecal Sludge Co-compost

Mainly three types of composts were prepared in this research work. These were compost from organic solid waste, co-compost of faecal sludge and organic solid waste and vermicompost with *Eisenia foetida* earthworm. Prepared vermicompost were of two kinds *i.e.* faecal sludge vermicompost and organic solid waste vermicompost. The compost status at final stage of composting is shown in Table 4.3. The physical condition of all types of composts were more or less same. Color of composts varied from dark grey to black. Absence of odor was an indication of good maturation. From the pH values it is evident that the composts were slightly alkaline in nature. This may be due to the formation of alkaline compound during composting process. The pH values were within the recommended standard of SRDI. The moisture content of solid waste compost was a little higher than the SRDI recommended value. In other composts moisture content was within the standard. The percentage of total organic carbon considerably decreased during composting process. At maturation stage the final carbon content were within the SRDI standard value. But the carbon content of vermicomposts were little higher than the solid waste compost and co-compost. This may be due to the reduction of microorganisms by earthworm's guts action. Similar scenario was observed in case of nitrogen content. Although the nitrogen content of all composts was within the standard range, the nitrogen percentage of vermicomposts were slightly higher than the solid waste compost and co-compost. The C/N ratio for all composts were within the recommended value. So, the proportion of raw materials at initial period was optimum. The number of pathogenic microorganisms decreased considerably during composting process. The number of faecal coliforms decreased by 50 times with respect to the initial condition. This indicates that the prepared composts were safe for handling, transport and processing. The percentage of Phosphorus content was within the standard limit. But in case of Potassium only faecal sludge vermicompost satisfies the standard limit.

CHAPTER V

CONCLUSION AND RECOMMENDATION

5.1 GENERAL

This chapter includes the overall conclusions of the entire research work as well as some recommendation for further studies in future. In the conclusion section, the findings are concluded based on the objectives of this thesis as stated in Chapter One. While, in the recommendation section, some points are listed which deems to be the relevant research works in future for further progress of research in this area.

5.2 CONCLUTION

The findings of the conducted research works can be concluded as the followings:

1. The physical condition of all prepared compost was more or less same. The color of the composts varies from black to dark gray. Absence of bad odor represents the acceptable stage of maturation.
2. All parameters of the prepared composts satisfied the SRDI provided standard values except potassium. However, only the vermicompost prepared from faecal sludge satisfied the potassium standard value.
3. The values of moisture content, volatile solids, total organic carbon and C/N ratio have decreased during composting process.
4. The pH, fixed solids and total Kjheldhal nitrogen increased during composting process.
5. The number of pathogenic microorganisms decreased considerably during composting process. The number of faecal coliforms decreased by 50 times with respect to the initial condition.

5.3 RECOMMENDATION

For the future study or research purpose the following recommendations are in order-

1. Helminth egg content and germination index can be tested during different stages of composting
2. A comparative analysis of time period required for full maturation of vermicompost and normal compost can be done.
3. An analysis on the NPKS (Nitrogen, Phosphorus, Potassium, Sulphur) content can be carried out.
4. A study on the efficiency of vermicomposting in converting waste into compost can be carried out.

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ANNEX-1

Characteristics of Collected FS from Septic Tank

Serial No.	Characteristics	Septic Tank sample	Standard Methods (SM) of Analysis***
1	pH	7.51	SM 4500-H* B
2	COD (mg/L)	20400	SM 5220 C
3	DO (mg/L)	0.21	SM 5210 B
4	BOD_5(mg/L)	677	SM 5210 B
5	Sludge Volume Index (ml/gm)	1.655	SM 2710 D
6	Phosphate (mg/L)	501	SM 4500-P E
7	Alkalinity (mg/L)	8650	SM 2320 B
8	TDS (mg/L)	3890	SM 2540 D
9	TS (mg/L)	42780	SM 2540 B
10	TSS (mg/L)	41750	SM 2540 D
11	Total Volatile Suspended Solids (%)	60.79	SM 2540 E
12	Fixed Solids (%)	39.21	SM 2540 E
13	Total Organic Carbon (%)	35.26	
14	Temperature	27.2	SM 2550 B
15	Total Coliform (nos/100ml) DF=200	92000	SM 9222 B
16	Faecal Coliform (nos/100ml) DF=200	65000	SM 9222 D
17	Electrical Conductivity (Ms/cm)	4.78	SM 2510 B
18	Moisture (%)	95.19	
19	Nitrate nitrogen (mg/L)	1.2	SM 4500 NO_3-N

(***All tests were performed from source of Standard Methods for the Examination of Water and Wastewater, 20th edition, Clesceri, 1999).

ANNEX-2

Characteristics of prepared compost at initial condition

SL. No.	Characteristics	Units	Results				SRDI standard*
			SW	SW+W	FS+W	FS+SW	
01	Color		Brown	Black gray	gray	Brown	Dark gray to black
02	Odor		Odorous	Odorous	Absence of Odor	Odorous	Absence of foul odor
03	pH		6.9	7.4	6.7	8.3	6.0 –8.5
04	Moisture content	%	52.73	55.67	27.97	44.09	Maximum 20 %
05	Total Volatile Solids (TVS)	%	62.4	56.08	40.22	53.08	
06	Fixed Solids (FS)	%	37.60	43.92	59.78	46.92	
07	Total Organic Carbon	%	36.19	32.53	23.33	30.79	10-25 %
08	Total Kjheldhal Nitrogen	%	1.65	1.49	1.60	1.65	0.5 – 4.0 %
09	C/N Ratio		20.68	21.83	14.58	18.66	20 (maximum)
10	Total Coliform (TC)	Nos.	1800	1600	2600	3800	
11	Faecal Coliform (FC)	Nos.	1400	1400	2200	2400	≤1000, WHO (1989)

(*compost standards, ministry of Agriculture, Bangladesh)

ANNEX-3

Characteristics of prepared compost at finial condition

SL. No.	Characteristics	Units	Results				SRDI Standards
			SW	SW+W	FS+W	FS+SW	
01	Color		Black	Black	Dark gray	Black	Dark gray to black
02	Odor		Absence of Odor	Absence of Odor	Absence of Odor	Absence of Odor	Absence of foul odor
03	pH		8.27	7.72	7.20	8.05	6.0 –8.5
04	Moisture content	%	21.52	19.86	18.60	18.98	Maximum 20 %
05	Total Volatile Solids (TVS)	%	27.24	23.11	20.37	25.25	
06	Fixed Solids (FS)	%	72.76	76.89	79.63	74.75	
07	Total Organic Carbon	%	17.29	20.16	22.29	18.67	10-25 %
08	Total Kjheldhal Nitrogen	%	1.68	2.10	1.82	1.75	0.5 – 4.0 %
09	C/N Ratio		10.29	10.08	12.25	10.67	20 (maximum)
10	Total Coliform (TC)	Nos.	900	1100	1400	1300	
11	Faecal Coliform (FC)	Nos.	100	100	200	100	≤1000, WHO (1989)
12	Phosphorus	%	0.86	1.34	1.22	0.96	0.5-1.5
13	Potassium	%	0.80	0.75	1.23	0.76	1.0-3.0

(*compost standards, ministry of Agriculture, Bangladesh)