MATURITY ANALYSIS OF COMPOST PRODUCED FROM CO-COMPOSTING OF VEGETABLE SOLID WASTES WITH SAWDUST.

SAMRIN AHMED KUSUM

DEPARTMENT OF CIVIL ENGINEERING

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY (BUET)

Dhaka, Bangladesh

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SAMRIN AHMED KUSUM

DEPARTMENT OF CIVIL ENGINEERING

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY (BUET)

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This thesis titled "**Maturity analysis of compost produced from co-composting of vegetable solid wastes with sawdust**", submitted by Samrin Ahmed Kusum, Roll No. 0412042132, Session: April 2012, has been accepted as satisfactory in partial fulfillment of the requirement for the degree of **Master of Science in Civil Engineering (Environmental)** on July 26, 2016.

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Samrin Ahmed Kusum

(Samrin Ahmed Kusum)

DEDICATION

This Thesis is dedicated to my parents.

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ABSTRACT

Municipal Solid Waste (MSW) consists the everyday household items that are discarded by people and with rapid growth of population and economic development, generation of such waste has also increased tremendously. In developed countries, Municipal Solid Waste (MSW) consists higher amount of inorganic wastes than in developing and low income countries. Hence management of solid wastes is different for developed and developing countries. It can be found that in developing countries, higher amount of organic wastes (food, paper, kitchen waste etc.) consists solid wastes and as a result composting is an ideal option for resource recovery from such wastes. In this research, an effort was made to convert vegetable solid waste (VSW) into fertilizer by composting and co-composting for 60 days with saw dust (SD) at three different ratios VSW : SD = 100 : 0, VSW : SD = 80 : 20, VSW : SD = 60 : 40. For a compost to be applied as fertilizer, stability (resistance for decomposition) and maturity (ready to use) should be analyzed so that the compost does not cause any adverse effect on plant growth. From the literature review, it was found that many indices are there to measure stability and maturity of compost samples. This study determined and compared few stability; maturity indices from those available ones to find out the set of most reliable tests. From the results, it was found that C/N value cannot be used to asses stability when saw dust is used because of the presence of non-compostable lignin which may cause nitrogen deficiency. Also pH, microbial activity, reduction in organic matter (ROM) values were measured, but it is concluded that each of these parameters alone cannot define stability of compost samples. On the other hand, CO_2 evolution of compost sample showed a better result to predict compost stability and it was also found that the results were very similar to the plant growth test values. For maturity evaluation, NH_4^+-N:NO_3^--N ratio and plant growth tests provided better results, however germination index (GI) and electrical conductivity (EC) measurement did not show consistent results to predict maturity. Hence those tests cannot be used alone to assess maturity. Lastly, it was suggested that only one test cannot be used to evaluate stability and maturity, rather it is wise to use a combination of these tests to get better judgment of compost stability and maturity. Apart from these tests, produced compost was compared for its effectiveness with commercially available organic and inorganic fertilizer and the result showed that compost samples proved to be better than inorganic fertilizer and commercial organic waste in most of the cases.

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CHAPTER 1: INTRODUCTION

1.1 Introduction

Solid-waste management is a major challenge in urban areas throughout the world. With rapid growth of population, urbanization and industrial revolution, waste is generating at a faster rate and until recently the inefficient management of waste is giving rise to the concern associated with waste minimization and degradation. Waste is an unavoidable by product of human activities and without an effective and efficient solid-waste management program, the waste generated can result in serious health hazards and have a negative impact on the environment. In many low income countries, a large proportion of municipal wastes are not properly disposed and municipal corporations of such countries are not able to handle increasing quantities of waste, which results in uncollected waste on roads and in other public places. There is a need to work towards a sustainable waste management system, which requires environmental, institutional, financial, economic and social sustainability.

Urban solid waste management is considered to be one of the most serious environmental problems confronting urban areas in developing countries (A. M. M. Sinha & Enayetullah, 2000) and Dhaka city in Bangladesh is not an exception. Dhaka is expanding rapidly turning it into a mega city with an enormous growth of population at a rate of around 6 percent a year. Solid wastes are being generated at a faster pace, posing a serious management threat. Rapid growth of industries, lack of financial resources, inadequate trained manpower, inappropriate technology and lack of awareness of the community are the major constraints of solid waste management for the fast growing metropolis of Dhaka. A healthy life, cleaner city and better environment are the logical demands for the city dwellers as the municipality is traditionally funded for solid waste services from municipal tax system for waste collection and disposal. Due to limited finances and organizational capacity, it has been really difficult for the municipality to ensure efficient and appropriate delivery of solid waste collection and disposal services to the entire population. Recently, solid waste generation, its disposal and impact on environment have become a major issue for this city. From April 2005 to March 2006, four priority programs were implemented by Dhaka City Corporation in collaboration with JICA for the preparation of Solid Waste Management Master Plan.

Solid waste generated can be managed in many different ways such as- incineration, landfill dumping, recycling and re-use. Among all the disposal solutions for solid waste, recycling and re-use of waste are being promoted these days to minimize the land requirement for final disposal. Recycling is a resource recovery practice that refers to the collection and reuse of waste materials by reprocessing it into a new product. Recycling and re-use of waste depends on the characteristics of generated waste. There are many options for re-use of organic waste, for example, anaerobic digestion and production of energy from it, composting and use the end product as fertilizer.

In Dhaka city, average total waste generation rate is 4634.52 tons/day and 67.65% of this urban solid waste is food and vegetable waste (JICA, 2004). Composting is one of the most favored options for municipal solid waste recycling as it can effectively reduce land requirements for solid waste disposal. Also, through composting nutrients and organic matter can be returned to soil. A JICA report published that although the compostable waste has the largest portion among generated wastes, composting contributes very little (nearly 0%) to the waste reduction.

Like other developing countries that produce higher amount of organic waste compared to the inorganic waste, Bangladesh should also concentrate on composting of such waste to reduce the requirement for landfill option. Composting defers from biological degradation as it requires control over the parameters such as temperature, moisture content, turning frequency, age etc to ensure a better quality end product that can be safely be used as soil conditioner. The soil-application of immature organic materials or compost produced from uncontrolled composting could affect both crops and the environment because of the presence of phytotoxic compounds. Unstable compost may cause reduced plant growth and damage crops by causing phytotoxicity to plants due to insufficient biodegradation of organic matter. Hence to re-use organic waste through composting, its process dynamics as well as methods to determine the quality and maturity of compost product should be studied thoroughly.

1.2 Objectives of the Research

The present research aims to characterize the vegetable solid wastes (VSW) in terms of mineral content as well as evaluate the maturity of compost materials produced from composting and co-composting of vegetable solid waste with saw dust (SD) at different ratio. The specific objectives of the present study are:

1. Chemical analysis and characterization of compost in terms of mineral contents.
2. Assessing effects of composting and co-composting of VSW with SD for the availability of nutrients and minerals.
3. Assessment of compost maturity and evaluation of phytotoxicity of VSW compost after a certain composting period (60 days).
4. Comparison of VSW compost efficiency with the available commercial inorganic fertilizers as well as organic fertilizers.

Possible outcomes of this research work are:

1. Compost maturity determination for different VSW and SD mixing ratio.
2. Variation of mineral content in VSW and SD mixture before and after composting cycle.
3. Relative assessment of different maturity indices.

1.3 Outline of Methodology

VSW will be collected from Karwan Bazar vegetable market and SD will be collected from BUET carpentry shop. Three box-type composting units will be placed in the composting site (roof top of Civil building of BUET) and will be filled with the mixture of VSW and SD in mixing ratio of 100:0, 80:20 and 60:40 v/v and aerobically composted for 60 days. After 60 days, the compost samples will be analyzed for compost maturity and mineral contents.

The outline of the methodology of this project is stated below:

1. Chemical analysis such as pH and electrical conductivity (EC) of raw solid waste as well as 60 days compost sample will be measured by using 1/10 (waste/water) extract using pH and EC meter respectively. Microbial analysis such as Total Bacteria, Helminthes egg and Clostridium will be determined from ICCDR,B.

2. Determination of different mineral such as Calcium (Ca), Magnesium (Mg) and Phosphorous (P) content of raw VSW and VSW plus SD mixture will be done by following Perchloric acid digestion (Standard Methods) method and concentrations will be measured by using Spectrophotometer.

3. For compost maturity test, carbon-nitrogen ratio (C-N), carbon-dioxide (CO_2) evolution rate, oxygen demand (O_2), ammonium-nitrate ratio (NH_4-NO_3^-), germination index (GI) and plant growth tests will be carried out on compost samples.

4. Total organic carbon will be determined by using Walkley-Black method and total nitrogen will be determined by using standard method.

5. CO_2 evolution rate will be measured by using "The Waste and Resources Action Programme (WRAP)" (Wallace, Cooper, Evans, Hollingworth, & Nichols, 2005), germination index and plant growth tests will be determined according to standard procedures.

1.4 Organization of the Thesis

The whole study is arranged in five different chapters:

Chapter 1 - Introduction: This chapter provides an overview of the whole study.

Chapter 2 - Literature Review: In this chapter, the current available knowledge as well as previous studies with findings related to this study are reviewed.

Chapter 3 - Methodologies: This chapter provides an overall description of the methodologies that were used in the laboratory to study composting and co-composting along with the tests description that were used to determine the compost maturity of the compost.

Chapter 4 - Results and Discussion: Results and relevant discussion of the study are presented in this chapter along with the test data and graphical presentation.

Chapter 5 - Conclusion and Future Recommendation: It presents the conclusion from this research study along with recommendations for future research on compost maturity analysis.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

In many developing countries as well as low income countries, waste management, specially solid waste management is not practiced properly; hence waste cannot be treated or managed and disposed to the environment safely. In Dhaka, megacity of Bangladesh, for example, with the passage of years, municipal solid waste has been predicted to increase from 3200 tons/day in 2004 to 3909 tons/day in 2010 to 4634 tons/day in 2015 (UNICEF). Also daily generation of waste is 3,500 tons, out of which only 1800 tons are collected and dumped on landfills, 400 tons are piled up on roadsides or open spaces, 400 tons are recycled and rest is dumped on the way to dumpsites (Bhuiyan, 1999).

This chapter discusses the present study on solid waste generation, processes to manage and treat solid waste and elaborates the process “composting and co-composting of solid waste” as the way of waste minimization as well as resource recovery. Also this chapter finds out the current literatures that are available to assess the maturity and stability of composted materials to be used as fertilizer.

2.2 Solid Waste Generation and Solid Waste Management Problems in Dhaka

Urban solid waste management is considered to be one of the most serious environmental problems confronting urban areas in developing countries (Pfammatter & Schertenleib, 1996) and the city of Dhaka in Bangladesh is not an exception. Inadequate collection and uncontrolled disposal of solid waste results in a serious health threat to inhabitants as well as to the environment. Solid waste disposal leads to land pollution if openly dumped, water pollution if dumped in low lands and air pollution if burnt. Dhaka city is facing serious environmental degradation and public-health risk due to uncollected disposal of waste on streets and other public areas, clogged drainage system by indiscriminately dumped wastes and by contamination of water resources near uncontrolled dumping sites. Due to the rapid urbanization and population growth of Dhaka city, waste generation has also increased markedly. The following table shows waste generation in major cities of Bangladesh.

Table 2 - 1: Total waste generation in urban areas of Bangladesh

City/town	WGR[7] (kg/cap/day)	Total Population[8] (2005)	TWG[9](ton/day)		Average TWG
			Dry Season	Wet Season	
Dhaka[1]	0.56	6728404	3767	5501	4634
Chittagong[2]	0.48	2622098	1258	1837	1547.5
Rajshahi[3]	0.3	468378	140	205	172.5
Khulna[4]	0.27	967365	261	381	321
Barisal[5]	0.25	437009	109	160	134.5
Sylhet[6]	0.3	386896	116	169	142.5

[1]Jica (2004), [2]Chittagong City Corporation, [3]Field Survey, [4]Sinha 2000, [5]Field Survey, [6]Sylhet City Corporation, [7]WGR = Waste generation rate, [8]including 10% increase for floating population, [9]TWG=Total Waste Generation Including 10% increase for floating population, which increases 46% in wet season from dry season

The issue of solid waste is not only because of the increasing quantities of waste generation but also largely because of an inadequate management system (Tınmaz & Demir, 2006). In case of the Dhaka city, Dhaka City Corporation (DCC) is responsible for solid waste management. For administrative purposes, Dhaka is divided into two distinct units– Dhaka North City Corporation (DNCC) and Dhaka South City Corporation (DSCC). These units are responsible for solid waste collection and disposal in their respective areas. In the DNCC, it is estimated that only 40–60% of waste is collected; a 2007 study estimated that approximately 42% of the entire city's (DNCC and DSCC) waste is collected (APO, 2007) . Due to the lack of resources and management plan in DNCC and DSCC, satisfactory waste management cannot be assured. Waste collection is particularly insufficient in the slum areas, which are home to approximately half of the city's poor and where government services are minimal. In order to deal with the prevailing situation in a planned way, proper study is required to analyze the urban waste management scenario of Bangladesh (Enayetullah, Sinha, & Khan, 2005). Dhaka is making improvements under its 2005 Solid Waste Master Plan, which led to a new system for regularly collecting household waste from a network of collection bins throughout the city. However, that plan is due to expire in 2015, and it is not certain that a new plan will replace it (DCC, 2005) .

2.3 Characteristics of Waste and Composting as an Option for Waste Minimization

Solid-waste management (SWM) has so far been the most ignored and least studied area in environmental sanitation in Bangladesh, as well as in other developing countries. But in recent years concern is growing in Bangladesh both at the governmental and other levels for the effective and economic management of solid waste (APO, 2007). Few projects like "Clean Dhaka Master Plan" funded by JICA and "National 3R (Reduce, Recycle and Reuse) Strategy of Bangladesh" under Climate Change Trust Fund were undertaken to improve the current municipal solid waste management system. However, the initiatives were not continued after the project period. It was observed that due to lack of public communication and separate collection system at the secondary collection points as well as no further use of the segregated waste especially organic part of the waste materials (DNCC, 2013).

Information about physical and chemical properties of solid waste is important in evaluating equipment needs, systems and management programs and plans, especially with respect to the implementation of disposal and resource and energy recovery options. Characterization of waste is also important to determine its possible environmental impacts (Hai, 2005). A number of studies have been conducted such as- BCAS 1998 (BCAS, 1998), Enayetullah et. al 2005 (Enayetullah et al., 2005), Hossain et al. 2000 (Hossain, Badruzzaman, & Ali, 2000) to determine the composition of solid waste generated in the city. BCAS 1998 collected solid waste samples from residential, commercial and industrial areas as well as mixed samples from the dumping locations in order to determine their composition. Enayetullah et. al 2005 determined composition of municipal solid wastes and its compostable and non-compostable amount. Hossain et al. (2000) determined composition of residential (for different income groups), commercial, industrial and hospital wastes.

Annex 1: Physical Composition of Urban Solid Waste

City / Town	Component, %												Total	Compostable, %	Non-Compostable, %
	Food & Vegetable Waste	Bones	Paper Products	Plastics	Rags, Textile, Jute	Glass	Leather, Rubber	Metals	Ceramic	Soil, Ash	Wood/ Grass/ Leaves	Medicine/ Chemical	Rocks, Dirt & Misc			
Dhaka	70.12	0.85	4.29	4.1	4.57	0.12	0.61	0.13	0.13	6.43	0.16	3.48	5.01	100	74.85	25.15
Chittagong	69.45	0.36	5.73	4.31	4.73	0.23	0.48	0.14	0.18	2.86	4.84	2.34	4.35	100	79.02	20.98
Rajshahi	62.43	0.48	6.32	7.99	3.41	1.34	0.00	0.00	0.00	2.75	11.00	0.10	4.18	100	76.84	23.16
Khulna	84.57	0.77	3.75	2.02	5.19	0.61	1.5	0.17	0.22	0	0.93	0	0.27	100	90.68	9.32
Barisal	53.55	0.55	28.65	7.16	0.81	1.38	0.28	0.04	0.00	1.30	0.33	0.05	5.89	100	54.69	45.31
Sylhet	75.77	1.65	5.22	5.34	1.64	0.89	0.64	0.24	0.65	2.59	3.87	0.12	1.38	100	81.28	18.72
Pourashava	70.70	0.90	8.96	3.58	3.37	2.02	0.39	0.63	0.33	3.32	3.33	0.46	2.02	100	77.40	22.60
Urban Center	62.93	0.31	11.25	3.47	0.75	0.06	0.13	0.02	0.02	11.25	5.74	0.44	3.62	100	69.42	30.58
Average	68.69	0.73	9.27	4.75	3.06	0.83	0.50	0.17	0.19	3.81	3.78	0.87	3.34	100	75.52	24.48

Source: Field Survey 2005

Figure 2 - 1: Table showing composition of Urban Solid Waste according to a field survey conducted by Waste Concern [9]

So, most of the proportion of urban solid wastes are composed of food and vegetable wastes, paper products and other organic wastes. In Dhaka city, average compostable content of the waste is 74% with the remaining 26% being non-compostable. Since there is a high content of compostable waste in the urban solid waste composition, composting is obviously a viable option for reducing the load on the landfill. At the same time, revenue can be earned from sale of compost as organic fertilizer, biogas and trading reduction of green house gas (GHG) emission along with reduced cost of purchasing landfill area. Furthermore with composting, valuable nutrients and organic matter can potentially be returned to the soil. So to minimize solid waste, composting is a preferred option. But a JICA report on "The Study on The Solid Waste Management in Dhaka City" says that recycling industry raises a total of 436 t/d of material recovery in Dhaka city but composting contributes very little to the waste reduction although the compostable waste has the largest portion among generated wastes. From the report, an estimated volume of recycled wastes in Dhaka city is given in the table below:

Table 2 - 2: Volume of recycled waste in Dhaka city (Source: Survey on recycle market by the JICA Study Team)

Material	a) Estimated generation of recyclable waste (ton/day)	b) Estimated recyclable waste (ton/day)	c) Recycle rate (%)	d) Contribution to waste reduction (b/3200) %
Plastic	124	103	83	3.2
Paper	260	168	65	5.3
Glass	46	24	52	0.8
Metal	27	41	*	1.3
Compostable	2211	6	0	0.2
Other	99	94	95	2.9
Total	2767	436		13.6

d) Assumed total municipal solid waste generation : 3,200 (t/d)

* Generation amount of metal is estimated by averaging 60 samples of waste composition survey, which did not contain metal factory at all. While recycled volume of metal contains imported metal from other cities in the country that did not appear in the composition survey.

The survey showed that even though the compostable waste generation was highest, recycling of such waste was minimum. Recycling of inorganic waste is common in many countries and mostly practiced by the informal sector (Furedy, 1989), (Furedy & Bubel, 1990), (M. Sinha & Amin, 1995). Composting however, is usually still not wide spread and experience has shown that in developing countries large centralized and highly mechanized composting plants have often failed to reach their target and had soon to be abandoned due to high operational, transport and maintenance costs (DoE, 2004). Although in cities of low and middle-income countries, often more than 50% of the total generated waste amount is organic and biodegradable (Dulac & Scheinberg, 2001), composting as a sustainable means of organic waste management has been doubted due to the cost and failure of marketing the produced product.

2.4 Composting and Co-Composting of Solid Waste

Once the wastes are generated and collected, the best alternative to handle them would be recycling where the materials generally undergo a chemical transformation. It is known that as much as 95% of a product’s environmental impact occurs before its discarded (Urban Development Sector Unit, 1999), most of it during its manufacturing and extraction of virgin raw materials. Thus, recycling is pivotal in reducing the overall life cycle impacts of a material on environment and public health. Solid wastes in developing countries are composed of over 50% organic materials (Hoornweg, Thomas, & Otten, 1999). Incineration of such waste is a waste of time whereas disposal in landfill will be a waste of resources. The only viable option to sustainably manage wastes in developing nations is composting because of the following advantages: lower operational cost (Taiwo, 2011) , decreased water pollution, lessened environmental pollution and beneficial use of end products (Poincelot, 1974).

2.4.1 Composting

United Nations Environment Program (UNEP) defines composting as the biological decomposition of biodegradable solid waste under predominantly aerobic conditions to a state that is sufficiently stable for nuisance-free storage and handling and is satisfactorily matured for safe use in agriculture. Composting can also be defined as human intervention or control into the natural process of decomposition as noted by Cornell Waste Management Institute. Control has the goal to enhance the efficiency of the microbiological activity, to restrict undesired environmental and health impacts and assure the targeted product quality (Strauss, Heinss, & Montangero, 1999). In its simplest form, composting is done by piling up organic materials, covering the pile regularly and then leaving it to decompose until it is suitable for distribution over fields or gardens. Almost any plant or animal waste will decompose if preservative measures are not taken. For composting purposes, the easily biodegradable fraction is of immediate interest. This includes food waste, vegetables and fruits, and garden wastes such as grass, leaves and small woody materials. Although organic waste materials such as paper and timber may also be composted, they are more resistant to microbial degradation due to their high lignin content (T. Richard, 1996). If these materials are included in the composting process, their particle sizes are often reduced beforehand through shredding to allow for quicker decomposition. Based on composition of solid waste of cities of low and middle income countries as quoted in Obeng and Wright (1987) (Obeng & Wright, 1987), easily biodegradable fractions range between 44 and 87 % (by weight). Similar average ranges (40-85 %) are also reported by Cointreau et al. (1985) (Cointreau et al., 1984) for low-income countries.

A properly managed compost operation promotes clean and readily marketable finished products, minimizes nuisance potential and is simple to operate (Bank, 1996). There is a reduction in landfill space where composting is operated as waste management technique(Awomeso, Taiwo, Gbadebo, & Arimoro, 2010; He, Traina, & Logan, 1992). As a flexible waste management, composting enhances recycling of materials, low transportation cost. In composting there is a minimal emission of greenhouse gases with subsequent effect on climate change and global warming (Seo, Aramaki, Hwang, & Hanaki, 2004). Moreover, addition of compost to soil reduces soil erosion as well as improvement of soil's structure, aeration and water retention. The use of chemical fertilizer could lead to groundwater pollution. But the use of compost discourages this water pollution.

2.4.2 Co-Composting

Co-composting is the controlled aerobic degradation of organics, using more than one feedstock for example co-composting of faecal sludge (FS) with municipal solid waste (MSW), vegetable solid waste with saw dust. Other organic materials, which can be used or subjected to co-composting comprise animal manure, sawdust, wood chips, bark, slaughterhouse waste, sludges or solid residues from food and beverage industries. The ratio of carbon to nitrogen in feedstocks is an important consideration in optimizing the composting process. Composting high nitrogen materials like animal wastes, vegetable wastes, faecal sludge etc requires the addition of a carbon source in order to provide the microbes with an energy source (Bonhotal, Harrison, & Schwarz, 2007). Carbon sources can also serve as a bulking material, that absorb the moisture, improve the aeration and the final compost quality by allowing air movement through the pile (Tremier, De Guardia, Massiani, Paul, & Martel, 2005). Although bulking agents are not believed to degrade significantly under composting conditions because of their high lignin content, some recent works have reported a certain biodegradability of wood chips (Mason, Mollah, Zhong, & Manderson, 2004). However, due to its limited degradability the major part of the wood serves as bulk material during short periods of composting, though thermophilic fungi and actinomycetes contribute to degradation of lignocellulosic material (Tuomela, Vikman, Hatakka, & Itävaara, 2000). In case of selecting the bulking agent for com-composting, it should be noted that all carbon is not created equal such as wood chips are not the same as shavings, shavings are not saw dust etc. For bulking agent, all carbon sources can be used, but which to use depends on the situation and goals of the producer.

2.5 Composting in Bangladesh

Though the production of organic wastes in developing and low income country is above 50%, the image of composting is dominated by the failed examples of oversized, over-mechanized, and centralized plants (Hoornweg et al., 1999). Small scale and decentralized approaches are more successful but often also struggle with the marketing of the compost product (Gamage, Vincent, & Outerbridge, 1998; Tuladhar & Bania, 1998; Zurbrugg &

Aristanti, 1999). In Bangladesh, Waste Concern, a research based NGO started a community-based decentralized composting project in Mirpur, Dhaka, started in 1995 with the aim of developing a low-cost technique for composting of municipal solid waste, which is well-suited to Dhaka's waste stream, climate, and socio-economic conditions along with the development of public–private–community partnerships in solid waste management and creation of job opportunities for the urban poor (Zurbrügg, Drescher, Rytz, Sinha, & Enayetullah, 2005). Waste Concern's experience in that project showed community based decentralized approach to convert waste into resource/compost/recyclables with active public-private and community partnership is possible (DoE, 2004). Government along with NGOs, CBOs and private sectors have taken the initiative to replicate Waste Concern's model of community based approach in 38 communities of 20 cities and another 28 cities are in the pipe line for replication. Recently using Clean Development Mechanism (CDM) under the Kyoto Protocol, Waste Concern along with WWR (a Dutch company) took an initiative for a 700 tons/ day capacity composting plant and land fill gas recovery project at the Matuail landfill site of Dhaka city (DoE, 2004). Waste Concern has also designed another composting plant at Khulna, the third largest city in Bangladesh. The cost of the construction was borne by the Swiss Development Cooperation (SDC). The composting plant is now being run by a local NGO in Khulna. Since August 2002 the government has replicated the model developed by Waste Concern in 14 cities of Bangladesh with support from United Nations Children's Fund (UNICEF) (Zurbrügg et al., 2005).

2.6 Compost Maturity and Stability

Composting cannot be considered a new technology, but amongst the waste management strategies it is gaining interest as a suitable option for manures with economic and environmental profits, since this process eliminates or reduces the risk of spreading of pathogens, parasites and weed seeds associated with direct land application of manure and leads to a final stabilized product which can be used to improve and maintain soil quality and fertility (Larney & Hao, 2007). Composting is one of the most favored options for municipal solid waste recycling for waste streams with high content of biodegradable materials. Compost has many uses including its use in agriculture for soil structure and fertility improvement. However, non-mature composts when applied to soils could present unfavorable phytotoxic problems to crops and the soil-application of non-stabilized organic materials could affect both crops and the environment because of the presence of phytotoxic compounds (Alburquerque, Gonzálvez, García, & Cegarra, 2006; Butler, Sikora, Steinhilber,

& Douglass, 2001; K. Chen, Lin, & Yang, 2007; Fernández, Hernández, Plaza, & Polo, 2007; Moore, Watabe, Stewart, Millar, & Rao, 2009). Unstable or immature compost may cause poor plant growth and damage crops by competing for oxygen or causing phytotoxicity to plants due to insufficient biodegradation of organic matter (Alidadi, Parvaresh, Shahmansouri, & Pourmoghadas, 2008). In addition immature compost typically immobilizes nitrogen instead of releasing it for plant growth (Blanco & Almendros, 1995). This is because immature composts continue to decompose even after application to soil, in which case, soil microbes scavenge for the nutrients that should have been made available to plants(Ofosu-Budu et al., 2010).

Hence the principal requirement of a compost for it to be safely used in soil is a high degree of stability or maturity, which implies a stable organic matter (OM) content and the absence of phytotoxic compounds and plant or animal pathogens. Maturity is associated with plant growth potential or phytotoxicity (Iannotti et al., 1993), whereas stability is often related to the compost's microbial activity. Bernal et al. (1998) (M. Bernal, Navarro, Sanchez-Monedero, Roig, & Cegarra, 1998) related stability to compost microbial activity; Hue and Liu (1995) (Hue & Liu, 1995) related stability to microbial activity and hence the potential for unpleasant odor generation. One recommended approach is to separate the available tests into categories of stability and maturity, and to then require at least one analysis to be performed from each category (Adani, Ubbiali, & Generini, 2006; Brinton, 2000; Komilis & Tziouvaras, 2009). Separation of stability and maturity tests is done because stable compost is not necessarily mature, and mature compost is not necessarily stable (Bio-Logic., 2001; Brewer & Sullivan, 2003); in some cases, mature composts may have high respiration rates, while stable composts may require additional curing to break down remaining phytotoxic compounds.

2.6.1 Compost Stability Tests

To avoid application of immature compost to soil, maturity tests on compost produced from composting is undertaken. Application of mature compost as soil conditioner is an efficient of way returning soil nutrient and improving soil. The study of the evolution of parameters of microbial activity (biomass parameters) are based, in part, on the initial hypothesis that the maturity of the compost may be assessed by the biological stability of the product (Morel, Colin, Germon, Godin, & Juste, 1985). This degree of stability may be deduced directly from the microbial biomass count and from the measurement of its metabolic activity, or indirectly, by means of the study of the easily biodegradable constituents or those susceptible to degradation (Anid, 1982). Stability can be determined using chemical (e.g., pH, C:N ratio), physical (e.g., pile temperature), or respirometric analyses, with the latter being considered the most reliable.

2.6.1.1 pH

Ammonium ($NH4^+$) is released during the rapid biodegradation of readily available substrates. This compound acts as an alkali and causes the compost pH to increase, generally to above 8. As the compost matures, this $NH4^+$ is nitrified and the pH decreases. It is thought that a high pH, therefore, may be indicative of high quantities of $NH4^+$ and hence immaturity (Fuchs, Galli, Schleiss, & Wellinger, 2001). As composting progresses, the $NH4^+$ volatilizes and organic acids form, causing pH to decrease again. Finally, organic acids become neutralized, which causes the pH to rise once more (Ko, Kim, Kim, Kim, & Umeda, 2008). Some researchers have indicated that pH should approach neutral values as compost matures (Gómez-Brandón, Lazcano, & Domínguez, 2008; Ko et al., 2008), while others have indicated that a stabilized pH (whether neutral or not) may indicate maturity (Cayuela, Mondini, Sánchez-Monedero, & Roig, 2008).

2.6.1.2 Total micro-organisms count

According to Citernesi & De Bertoldi (1979) (Citernesi & De Bertoldi, 1979), the microbial biomass of some groups of micro-organisms, specially thermophilic bacteria, decreases in the last phases of composting as the product reaches maturity, so that a total count of micro-organisms (principally bacteria) throughout the process can be a test of the state of compost maturity.

2.6.1.3 Carbon to nitrogen (C:N) ratio

A decreasing trend in the ratio of carbon to nitrogen (C:N), with eventual stabilization, can generally be observed as composting progresses due to the release of CO_2 as organic substrates are decomposed, resulting in the loss of carbon from the system (Khan et al., 2009). Though a variety of limits for compost C:N ratio have been proposed in the literature, ranging from <20:1 to <10:1 (Goyal, Dhull, & Kapoor, 2005; Mathur, Dinel, Owen, Schnitzer, & Dugan, 1993) Sullivan and Miller (2001) (Sullivan & Miller, 2001) have indicated that the limit for this parameter should be based upon that for stable soil organic matter, which is generally between 10:1 and 15:1.

2.6.1.4 Respirometric study (CO_2 evolution and O_2 uptake)

Respiration indices are commonly used in the evaluation of compost stability (Brinton, 2000). These indices provide direct or indirect measurements of the amount of biological activity in a sample, which, under optimal conditions, reflects the degree of decomposition of substrate material; the greater the degree of decomposition (i.e., the more stable the material), the lower the microbial activity and, hence, respiration rate (Wichuk & McCartney, 2010). Respiration rate is reflected in oxygen consumption or carbon dioxide production, since organisms utilize oxygen (O_2) and respire carbon dioxide (CO_2) during aerobic decomposition. Respiration rate reflects the current state of decomposition of the waste material, and is fairly consistent for stable composts, regardless of the initial state of the materials, operational conditions, and feedstock material itself (Matteson & Sullivan, 2006; D. Richard, 1995). Sullivan and Miller (2001) (Sullivan & Miller, 2001) indicated that the standard alkaline trap method of CO_2 evaluation is the simplest quantitative respiration test. This method can be used with composts produced from a wide variety of feedstocks (Brinton, 2000). Several authors have concluded that CO_2 evolution is a good indicator of stability. Brinton and Evans (2001) (Brinton & Evans, 2001) as well as Aslam and Vander Gheynst (2008) (Aslam & VanderGheynst, 2008), showed that CO_2 evolution rate tests could closely predict cress and (or) wheat growth test results and thus may be a good stability–maturity index. Goyal et al. (2005) (Goyal et al., 2005) stated that CO_2 evolution is one of the most reliable indices of compost maturity, and Switzenbaum et al. (1997) (Switzenbaum, Moss, Epstein, Pincince, & Donovan, 1997) recommended this test as the preferred respiration test for the majority of compost facilities.

2.6.1.5 Reduction of Organic Matter

Compost feedstock materials are composed of a variety of organic compounds including carbohydrates, proteins, lipids, and lignins. As composting progresses, around half of this organic material is converted to CO_2 and liberated, while the remainder is eventually converted to more stable compounds. Thus, the process of stabilization can theoretically be monitored via the reduction of readily available organic matter (OM). The OM content of compost can be estimated by evaluating volatile solids (VS) content (Bio-Logic., 2001; Fuchs et al., 2001; Sullivan & Miller, 2001; TMECC.2002c, 2002). The reduction in OM content over the course of composting is also related to the feedstock characteristics and operational conditions (D. Richard, 1995). These factors may reduce the usefulness of this evaluation. In fact, TMECC (2002*c*) (TMECC.2002c, 2002) recommends that OM measurements be combined with other stability and (or) maturity indices such as C:N ratio, pH, ammonium to nitrate ratio, etc. rather than being used as a standalone test.

2.6.2 Compost maturity tests

Maturity would be determined via plant bioassays or tests for toxic compounds (Delgado, Garcia-Morales, del Río, & Sales, 2002). Tests for toxic compounds include measurement of EC, plant bioassays involves growth test, germination index and ammonium nitrate ratio.

2.6.2.1 Electrical conductivity

Electrical conductivity (EC) provides an indication of the amount of soluble ions (i.e., salts) in a compost product and hence its potential to be phytotoxic, as salts can damage roots, affect nutrient uptake, limit plant-available soil water, or cause seed germination to be inhibited (TMECC.2002f, 2000). Though a drop in EC may be due to the leaching of salts, it may also be the result of the decomposition of organic acids, and may thus be related to the maturation process (Avnimelech, 1996). Avnimelech et al. (1996) (Avnimelech, 1996) saw a decrease in EC over time as a municipal solid waste (MSW) compost matured, and observed that EC stabilization correlated well with the achievement of maturity.

2.6.2.2 Plant growth test and germination index

Plant bioassays involve the evaluation of seed germination and (or) plant growth in compost mixtures or extracts. Tests are performed under controlled conditions, and results are presented as a percentage of germination or growth with respect to a control (Mathur et al., 1993; Sullivan & Miller, 2001). Though it may be a good idea to consider plant tests in compost maturity determinations, deciding which test to implement is a somewhat difficult task. Various methods are used throughout Europe and America; however, there are few standardized procedures (Brinton & Evans, 2001). For example, a cress test is used in Switzerland. In Germany, barley tests are done in mixtures of compost and a standard base soil mix, at concentrations of 25 and 50% compost (Brinton & Evans, 2001). In the US, a cucumber test is used; however, it has been widely criticized because cucumbers grow well in raw compost. Tomato tests have also been discarded because tomatoes will grow in just about any medium (Brinton & Evans, 2001). Aslam and Vander Gheynst (2008) (Aslam & VanderGheynst, 2008) found that the commonly used cress was more sensitive than lettuce, Chinese cabbage, and radish, while Emino and Warman (2004) (Emino & Warman, 2004) observed that cress was less sensitive than lettuce, carrot, Chinese cabbage. Komilis and

Tziouvaras (2009) (Komilis & Tziouvaras, 2009) observed that a germination index varied based on both seed type and compost type, with composts phytotoxic to one seed type sometimes enhancing the growth of a different seed. According to TMECC (2002e) (TMECC.2002e, 2002), seed germination tests are capable of indicating whether or not there are significant quantities of phytotoxins in a compost. It is important to note, however, that seed development is generally not affected unless significant amounts of NH_3 or organic compounds are present. Though some studies show the expected increase in germination with compost time (Ko et al., 2008), these tests are not particularly sensitive and may not make very good indicators of maturity (Brinton, 2000). Warman (1999) (Warman, 1999) evaluated three different seed germination tests: a direct seed test in 100% compost; a test in compost extracts; and the CCME germination test as specified in the 1996 CAN/BNQ document ‘‘Organic Soil Conditioners – Composts’’ (Environment, 1996). Three different seed varieties were tested (cress, radish, and Chinese cabbage). None of the tests were found to be sensitive enough to consistently distinguish between immature and mature composts.

2.6.2.3 Ammonium and Nitrate Ratio

The NO_3^-:NH_4^+ ratio was found by Brewer and Sullivan (2003) (Brewer & Sullivan, 2003) to be a slightly better index than either parameter on its own, but the authors recommended monitoring the ratio several times throughout the composting period (i.e., in fresh materials, after active composting is complete, and after curing), rather than relying on the final value alone. The compost products obtained by Benito et al. (2003, 2009) (Benito, Masaguer, Moliner, Arrigo, & Palma, 2003; Benito, Masaguer, Moliner, Hontoria, & Almorox, 2009) never reached the NO_3:NH_4^+ ratios deemed by others to indicate a mature product, and they concluded that to use this as an indicator of compost stability, limits would need to be established based on feedstock and initial $NH4^+$ and NO_3 values. Mathur et al. (1993) (Mathur et al., 1993) indicated that there is no fixed level for the NO_3:$NH4^+$ ratio that would consistently indicate maturity; for example, Hirai et al. (1983) (Hirai, Chamyasak, & Kubota, 1983) found that the ratio varied from approximately 33.3:1 to 0.05:1 in mature composts.

CHAPTER 3: METHODOLOGY

3.1 Introduction

This chapter discusses the procedures involved in collection of raw vegetable waste and saw dust, preparation of composting unit as well as the methodologies for collection and storage of compost produced from 60 days composting cycle. To fulfill the research objectives, observations were then made on the produced compost for the microbial analysis, chemical analysis and compost maturity analysis.

This chapter has been arranged in such a way so that it can firstly provide the detail description of the construction methodology of the box composting unit. Later a brief discussion has been made on the procedures that were used for microbial analysis of the raw waste as well as the produced compost by determining the population size of the Total Bacteria, Escherichia Coli and Clostridium Perfringens. Then few methodologies have been described for the chemical analysis of raw VSW and final compost materials to measure the mineral content (Potassium, Calcium, Magnesium and Phosphorous). To measure the compost maturity many parameters like pH, electrical conductivity, carbon-di-oxide evolution, germination index, reduction of organic matter (ROM), total organic carbon (TOC), ammonium-nitrate ratio (NH_4-NO_3^-), carbon-nitrogen ratio (C/N), seedling emergence and relative growth are measured and the methodologies that were followed to measure these parameters have been discussed in this chapter.

3.2 Sample Collection, Preparation and Construction of Composting Unit

3.2.1 Collection of vegetable solid waste (VSW) and saw dust (SD)

Vegetable solid waste collection point was Karwan Bazar, the largest wholesale vegetable market of Dhaka. The waste was collected very early in the morning to ensure that only fresh VSW were collected and to avoid contamination of the waste with other inorganic or organic materials. It was carefully monitored that the collected wastes were only composed of vegetable leftovers and no inorganic such as polyethylene, plastic materials etc or other organic wastes such as paper, animal flesh, mud etc were mixed with that. Also the freshness of the waste was a prerequisite as this study deals with the composting of the wastes and already degraded wastes will provide different values during composting procedure.

For the co-composting purpose, saw dust (SD) was used which was collected from the "Carpentry Shop" of Bangladesh University of Engineering and Technology (BUET). SD was mixed with VSW as bulking agent instead of other agents like lime, ash etc. because VSW is rich in nitrogen content and it needs additional carbon source like saw dust. There were various types of saw dust texture and size available at that shop, but the very finer dust was collected and used in this study. The collected SD was mostly composed of Gamar, Boom and Partex wood.

VSW and SD were collected carefully in separate jute bags by using sanitary gloves to avoid any kind of contamination or alteration of the collected samples. Samples were then carried back to the roof top of BUET where final sorting of VSW was done. Finally before placing the VSW and VSW-SD mixture into the composting unit, homogenization was also done by cutting the VSW into smaller and equal pieces.

Figure 3 - 1: Collection of Vegetable Solid Waste (VSW) from Karwan Bazar Vegetable Market and Saw Dust (SD) from BUET Carpentry Shop.

3.2.2 Composting unit construction

In this study, composting was done in an aerobic condition. Hence the composting unit was a perforated basket of 60 liters capacity. To allow continuous air flow from top to bottom when the basket is full with test samples, few PVC pipes were inserted as shown in the Figure 3-2. The pipes were perforated by using "Gang Drill" machine from the Machine Lab of BUET.

After preparing the composting unit by using perforated basket and PVC pipe, 3 such units were filled up with the prepared VSW and SD mixture. In one unit 100% VSW was placed and that basket was marked as W1 (100:0), in the second unit a mixture of 80% VSW and 20% SD was placed by marking it W2 (80:20) and in the last unit a mixture of 60% VSW and 40% SD was placed by marking it W3 (60:40). All the measurements were volumetric basis. After placing the waste sample inside, a jute bag was wrapped around the composting unit as shown in Figure 3-3 to avoid the loss of samples while watering during the composting period.

Figure 3 - 2: Composting unit with perforated PVC pipe to allow aerobic condition throughout the composting period

Figure 3 - 3: Composting unit with Jute bag wrapped around to restrict loss of finer partilcles throughout the composting period

When the composting units were placed properly, test samples were collected two times- on the very first day of composting; that is the raw waste and on the last day of composting (60 days) from all three units to conduct pH, electrical conductivity (EC), germination index (GI), total organic carbon (TOC), ammonium-nitrogen and nitrate-nitrogen, mineral content etc tests.

3.3 Test Methodologies

3.3.1 Test for microbial analysis of waste

The collected raw waste samples as well as the 60 days compost samples from the three composting units titled W1, W2, W3 were analyzed for microbial content and the total Bacteria, Escherichia Coli and Clostridium Perfringens were measured from International Centre for Diarrhoeal Disease Research, Bangladesh (ICDDR, B). The waste samples were collected in a zip-lock bag and was transferred to the ICDDR, B immediately for testing. In ICDDR, B they used drop plate method to estimate the number of total Bacteria, E.Coli and Clostridium Perfringens.

3.3.2 Physicochemical analysis of waste

3.3.2.1 pH and electrical conductivity (EC) Test

pH and electrical conductivity were measured for 1:10 (compost : water) volumetric extract of waste and water by using pH and EC meters respectively.

3.3.2.2 Total volatile solids and reduction of organic matters determination

Total volatile solids of waste samples were determined and from the difference of TVS of raw samples and composted samples, reduction of organic matters (ROM) was measured. ROM is an indicator for the determination of compost maturity. To determine TVS, a clean and dried crucible was weighted and recorded as W_{dish}. A small amount of wet sample was oven dried at 105°C for 24 hrs and the dried sample was then placed into that crucible. The total weight of crucible and dried waste was recorded as W_{total}. Then the crucible with the dried waste sample was placed into an oven heated at a temperature 550°C and ignite it for 2 hours in MLSS machine. Cool the residue in a desiccator to balance the temperature. After balancing the temperature the crucible with the residue was weighed and the weight was indicated as $W_{volatile}$. After taking all the weights, TVS can be measured by using the following formula:

$$\text{\% volatile solids} = \frac{\text{Wtotal} - \text{Wvolatile}}{\text{Wtotal} - \text{Wdish}} \text{ X } 100$$

Where: W_{dish} =Weight of dish (mg), W_{total} =Weight of dried residue and dish (mg), $W_{volatile}$ =Weight of residue and dish after ignition (mg).

TVS of raw waste sample and 60 days composted samples were measured. Then the ROM was measured by determining the difference between TVS_{raw} and $TVS_{60\ days}$.

3.3.2.3 Total organic carbon (TOC)

Total organic carbon (TOC) was determined by modified Walkley Black chromic acid wet oxidation method. At first the moisture content of the air-dry soil was determined, which has been ground to pass a 0.42 mm sieve. Then accurately enough soil (between 0.01 to 0.02 gm) to contain between 10 mg and 20 mg of carbon into a dry 250 ml conical flask was weighed. Then 10 ml of 1N $K_2Cr_2O_7$ was added and the flask was swirled gently to disperse the sample in the solution and 20 ml concentrated H_2SO_4 was added, directing the stream into the suspension. Then the flask was stirred immediately until the soil and the reagent were mixed and inserted a 200°C thermometer while swirling the flask on a hot plate until the temperature reaches 135 °C. Then the flask was set aside to cool slowly on an asbestos sheet in a fume cupboard and 10 ml phosphoric acid was added. One blank (without soil) had been processed in the same way to standardize the $FeSO_4$ solution. When the flask was cooled to room temperature, it was diluted to 200 ml with deionized water. After cooling the sample was titrated with the $FeSO_4$ using the "ferroin" indicator. Firstly 3 or 4 drops of ferroin indicator were added and titrated with 0.4 N $FeSO_4$. As the end point was approached, the solution takes on a greenish color and then changes to a dark green. At this point, the ferrous sulphate solution was added drop-by-drop until the color changes sharply from blue-green to reddish-grey. If the end point was overshot, 0.5 or 1.0 ml of 1 N $K_2Cr_2O_7$ can be added and the end point was re approached drop-by-drop. Correction must be applied for the extra volume added. If over 8 ml of the 10 ml dichromate have been consumed, the determination must be repeated with a smaller sample. Finally the percentage of organic carbon present in the sample was calculated using following formula.

$$\text{Total Organic Carbon (\%)} = \frac{3(1-\frac{T}{S})}{W}$$

Where: T = Volume of $FeSO_4$ used in sample titration (mL), S = Volume of $FeSO_4$ used in blank titration (mL), W = Oven-dry sample weight (g)

3.3.2.4 Ammonium nitrogen and organic nitrogen determination

In solid waste, nitrogen occurs in nitrate, nitrite, ammonia, and organic nitrogen state. In Kjeldahl Digestion method, waste sample is distillated first to remove the ammonia nitrogen and the distillates are used to measure NH_3-N of that waste sample by titrimetric method. Again the digested waste sample is further digested by heating and from the distillates Total Kjeldahl Nitrogen (TKN) is calculated. Once TKN and NH_3-N is known, Norg-N can be easily determined from their differences as TKN is the summation of these two parameters.

3.3.2.5 Ammonium nitrogen (NH_3-N) determination by titrimetric method:

The waste sample was first thoroughly homogenized and then wet sample (equivalent to 1 gm dry sample) was weighed and transferred to a 500 ml Kjeldahl flask. The sample was then diluted to 300 mL by using distilled water. A neutral pH 7 was attained by using dilute acid or base. Then 25 ml borate buffer solution was added and pH was adjusted to 9.5 with the help of 6N NaOH. The sample was then heated and 100 ml distillates were collected in a 500 ml Erlenmeyer flask containing 50 ml indicating boric acid. Collected distillates were then titrated for ammonia with standard 0.02 N H_2SO_4 until indicator turns a pale lavender. A blank was carried through all the steps and necessary corrections were applied.

Ammonia-Nitrogen (NH_3-N) (mg/kg) = ――――――――

where, A= Volume of H_2SO_4 titrated for sample, ml, B= Volume of H_2SO_4 titrated for blank, ml.

Figure 3 - 4: Kjeldahl Digestion Apparatus

3.3.2.6 Organic nitrogen (N_{org}) determination

After N-NH_3 collection by distillation of waste sample in the Kjeldahl digestion apparatus, 50 ml of Kjeldahl digestion reagent was added to the digested waste sample for further digestion. Few glass beads were also added and after mixing, the digested waste sample was then placed under a hood to remove acid fumes while heating. Boiled until the volume is greatly reduced to 25 ml to 50 ml and copious fumes were observed. Then digestion was continued for an additional 30 minutes. As digestion continued, colored or turbid samples became transparent and pale green. After finishing digestion, the solution was cooled to room temperature and another 300 ml of water was added. Then carefully 50 ml $NaOH\text{-}Na_2S_2O_3.5H_2O$ reagent was added to form an alkaline layer at the bottom of the flask. The contents were distilled and 200 ml distillate was collected. 50 ml indicating boric acid was used as absorbent solution. The titrimetric method then proceeded with the addition of 0.02N H_2SO_4 as titrant to the distillate flask until the distillate became pale lavender in color. The amount of H_2SO_4 needed to change the distillate color was recorded and used in calculating Total Kjeldahl Nitrogen (TKN) for the sample. Organic nitrogen was then calculated by the difference of TKN and previously determined NH_3-N. A blank was carried through all the steps and necessary corrections were applied.

Figure 3 - 5: Collection of distillates in conical flask from Kjeldahl Apparatus (Left) and determination of Total Kjeldahl Nitrogen from the distillates by titrimetric method (Right).

$$\text{Total Kjeldahl Nitrogen (TKN) (mg/kg)} = \frac{(A-B)x\ 280}{gm\ dry\ wt\ of\ sample}$$

where, A= Volume (ml) of H_2SO_4 titrated for sample, B= Volume (ml) of H_2SO_4 titrated for blank.

3.3.2.7 NO_3-N, NO_2-N and NH_4-N determination

Measurement of NO_3-N, NO_2-N and NH_4-N nitrogen was carried out in the laboratory of the Dhaka University Soil Science Department. Samples were collected in a zip-lock bag and immediately transferred to that laboratory for conducting the tests.

3.3.2.8 Test for mineral content

Analytic tests were carried out on the raw waste as well as 60 days composted waste to determine and compare the mineral content of the raw and composted solid waste. Using Perchloric Acid digestion method Calcium (Ca), Magnesium (Mg) and Phosphorus (P) content of waste were measured.

Approximately 2 grams of oven-dried sample was taken in a volumetric flask and 100 ml of distilled water was added, then 25 ml of nitric acid was added to the sample and kept overnight. After keeping the mixture for 24 hrs, the flask was then heated to boiling for two hours. After cooling the sample, 10 ml of perchloric acid was added to the flask and heated again for one hour to boiling. At this time water was added whenever needed. If the color of the sample turns yellow, the digestion process is assumed to be completed; if the color of the sample turns dark, 2 to 3 ml of nitric acid is added to the flask and heat is applied; the process is repeated until the sample color turns yellow. Finally distilled water was added up to the 200 ml graduation mark of the volumetric flask. The content of the flask was stirred for 5 minutes, then cooled and finally filtered using a filter paper (0.45 micron). The filtrate was used to find the mineral content of solid waste samples by atomic absorption spectrophotometry using an AAS (Shimadzu, AA6800).

3.3.3 Compost maturity tests

For the determination of compost maturity of the 60 days compost materials, along with the C/N ratio, CO_2 evolution test, Germination Index (GI) and plant growth test were conducted. Detail procedures for conducting these tests are given below:

3.3.3.1 CO_2 evolution test

CO_2 evolution test was done by following "The Waste and Resources Action Programme (WRAP)" (Wallace et al., 2005) .Transfer 100 gm ± 2 gm of the test sample weighed to the nearest 0.1 gm to the incubation vessel. Transfer approximately 250 ml of sodium hydroxide solution to the carbon dioxide scrubbing vessel and add 50.0 ml of water into the carbon dioxide collecting vessel. Attach and seal all lids and stoppers. Ensure the air inlet diffuser of the carbon dioxide scrubbing vessel reaches the bottom of the vessel. Ensure the air inlet tube of the incubation vessel reaches the bottom of the vessel. Ensure that the air inlet diffuser of the carbon dioxide collecting vessel reaches the bottom of the vessel. Switch on the air pump and adjust the airflow rate to approximately 25-75 ml/min. Equilibrate at 30^{o}C for 72 hours. After 72 hrs equilibration remove the collecting vessel containing water and connect a collecting tube containing 50.0 ml of 1 M sodium hydroxide. Change the collecting tube with another containing a fresh 50.0 ml of 1 M sodium hydroxide every 24 hours over a 4-day period. Do not turn off the air pump at any time or back-pressure may cause NaOH to siphon back to the pump. Maintain the temperature of the incubation units at 30^{o}C at all times.

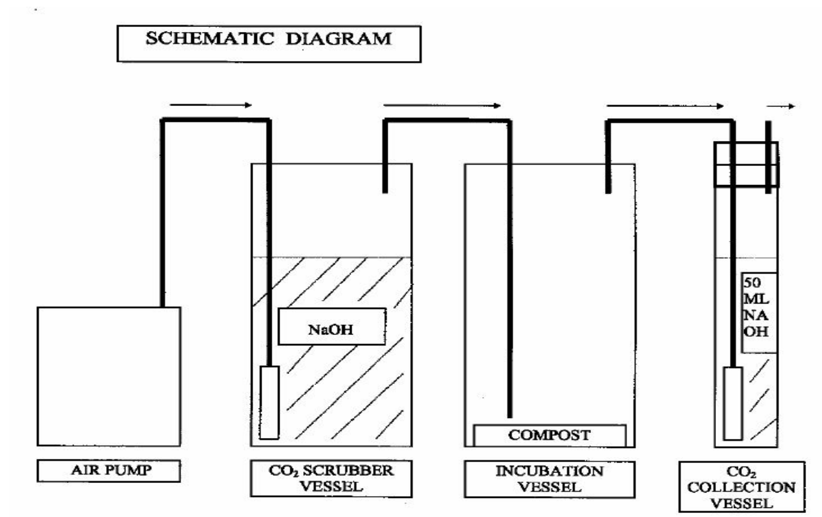

Figure 3 - 6: Schematic diagram of CO_2 evolution test.

Figure 3 - 7: CO_2 evolution test by using air tight unit to capture the evolved CO_2 gas in NaOH base solution.

The mass of carbon dioxide evolved over 4 days is given by the following equations:

$$\text{mg } CO_2 \text{ evolved per 24 h time period} = \{[B_{vol} - S_{vol}] \times 44.2\}/2$$

$$\text{Total mg } CO_2 = \text{sum of mg } CO_2 \text{ evolved over 4 days}$$

$$\text{mg } CO_2\text{/g VS/d} = [\text{Total mg } CO_2] / [\text{dry weight of compost x VS x t}]$$

where, B_{vol} is the volume in ml M HCl for the blank and S_{vol} is the volume in ml M HCl for the sample. VS is the mass of volatile solids / g of compost and t is the time in days.

3.3.3.2 Germination index (GI) test

A modified phytotoxicity test using seed germination was used to estimate compost maturity. Germination index for the waste samples collected at 0, 10, 20, 30, 40, 50 and 60 days were measured by using three types of seeds- Tomato, Carrot and Lettuce. Twenty seeds each of Carrot, Lettuce and Tomato were obtained and the seeds were placed on a filter paper in a petri-dish. Water extracts of each of the composts (W1, W2 and W3) were prepared by mechanically shaking 20 gm of the compost with 40 ml of distilled water. The aqueous solutions were then filtered through a 0.45 μm membrane to get the extract. 20 ml of the water extracts was used to soak the seeds and kept in the dark at ambient room temperature (27°C). Distilled water was then used to soak seeds as control treatment. Seeds were monitored over 5 days until there was adequate germination in the control plates. Un-germinated seeds were defined as being zero (0) cm long. The germination indices which combined seed germination and root growth were both expressed relative to the control (Rajbanshi, Endo, Sakamoto, & Inubushi, 1998). Germination index (GI) was calculated as follows:

Germination Index = (% Germination) × (% Radicle Length) / 100

$$\% \text{ Germination} = \frac{\text{No of Seed germinated in compost extract}}{\text{No of Seed germinated in water}} \times 100\ \%$$

$$\text{Radicle Length} = \frac{\text{Mean Root Length in Compost Extract}}{\text{Mean Root Length in Control}} \times 100$$

Figure 3 - 8: Germination Index test for raw waste samples of W1, W2, W3 and Blank for 20 Lettuce, Tomato and Carrot seeds.

3.3.3.3 Cress test

The plant growth test was conducted by following or cress test was conducted in a 500 ml flower pot using 1:1 compost/control mixture as the growth medium. Each compost and control medium is tested in 2 replicates. At the start of the test, each flower pot is filled with 250 ml compost and 250 ml reference soil mixture. Distilled water is used to assure the optimum moisture content for seed plantation. 100 seeds of each type (Tomato, Carrot and Lettuce) are placed on the top of the flower pot and covered with a thin layer of soil mixture. Finally an extra amount of water can be applied to maintain required moisture level. Then the pots are placed in a dark place to allow germination. Once germinated, pots are tranferred to an open place for sun light and necessary watering is done by using distilled water. In each pot same amount of watering is done to avoid error while comparing the results. The test is finished after 14 ± 2 days after 50% of the control seedlings have emerged. At the end of the test, total fresh and dry weight of the plants is measured for each flower pot separately.

Figure 3 - 9: Plant growth result for Carrot, Tomato and Lettuce seeds after 10 days of plantation.

Cress test result = (WC/WR) x 100%

Where, WC = weight of plants in compost and WR = weight of plants in reference soil.

CHAPTER 4: RESULTS AND DISCUSSIONS

4.1 General

This research studies on characterization of vegetable solid waste in terms of mineral content as well as evaluate the maturity of compost materials produced from composting and co-composting of vegetable solid waste with saw dust (SD) at different ratio. In this chapter, all the results that are found by conducting different tests on raw vegetable waste and 60 days old compost materials will be presented. Apart from the test results, explanations for any kind of anomalies will be provided too. Since this study greatly deals with the determination of compost maturity so that the waste can finally be applied to the soil to return the nutrients effectively for agricultural purpose, many methodologies have been used to determine the compost maturity and a comparison will be made to find out the most effective methods.

Vegetable waste was mixed with saw dust at two different ratios and three waste samples W1 (VSW:SD = 100:0), W2 (VSW:SD = 80:20), W3 (VSW:SD = 60:40) were analyzed throughout this study. Hence an effort was made to find out the effect of saw dust on compost maturity by observing whether the addition of saw dust was beneficial or not. In addition to this, 60 days compost materials was also compared for its maturity and effectiveness as a fertilizer with available compost fertilizer and inorganic fertilizer in the market.

4.2 Physicochemical Parameters and Microbial Characteristics of Raw Vegetable Solid Waste (VSW) and 60 days Compost

Physicochemical parameters i.e, pH, electrical conductivity (EC), total volatile solids (TVS), total organic carbon (TOC), amonia-nitrogen (NH_3-N), nitrate nitrogen (NO_3-N), nitrite nitrogen (NO_2-N), organic nitrogen (N_{org}-N), Mineral content such as Phosphorus (P), Magnesium (Mg), Calcium (Ca) and Potassium (K) and microbial characteristics of raw VSW and 60 days composted waste are presented in the Table 4-1:

Table 4 - 1: Physicochemical Parameters and Microbial Characteristics of Raw Vegetable Solid Waste and 60 days Compost for the W1 (VSW:SD=100:0), W2 (VSW:SD=80:20) and W3 (VSW:SD=60:40)

Parameters	Units	W1		W2		W3	
		Raw	60 Days	Raw	60 Days	Raw	60 Days
pH		7.67	8.16	8.26	8.34	8.22	8.1
Electrical Conductivity	[1]µS/cm	836	5890	760	457	581	145
Total Volatile Solids	%	75.93	46.02	86.67	86.3	91.18	96.3
Reduction of Organic Matter	%	+ 29.91		+ 0.37		- 5.12	
Total Organic Carbon	%	56.79	20.92	51.52	35.91	25.08	52.43
Phosphorus (P)	mg/l	0.14	0.63	0	0.21	0.01	0.16
Calcium (Ca)	[2]ppm	1248.7	1462.5	149.19	1188	206.6	190.03
Magnesium (Mg)	ppm	902.61	30.37	14.07	40.38	24.87	9.39
Total Bacteria	[3]CFU/gm	6.4×10^9	1.4×10^7	1.88×10^9	1.36×10^5	1.76×10^9	1×10^5
Escherichia Coli	CFU/gm	1.6×10^6	0	8×10^5	0	4×10^5	0
Clostridium Perfringens	CFU/gm	0	30	10	7	0	4

[1]Electrical Conductivity, EC was measured in micro Siemens per centimeter unit (µS/cm). [2]Calcium and Magnesium content were measured in terms of parts per million (ppm) unit. [3]Microbial characteristics were measured in terms of Colony Forming Unit per gram (CFU/gm).

4.2.1 Variation of pH

pH can be used as an indicator of compost maturity. In this study it has been found that the initial pH value increased after 60 days of composting for W1 and W2 waste samples whereas for W3, the same decreased. Initially pH increases due to the degradation of waste by releasing NH_4^+ and when this ammonia starts to form acids, pH value decreases. Since the pH of W1 and W2 waste samples are greater than the initial value, it can be assumed that the NH_4^+ ions have not volatilized completely after 60 days of composting. Studies found that during the early stages of composting, the pH decreases slightly to values of about 5, and later rises as materials gradually decompose and stabilize. The pH finally stays at values between 6 and 8 (Cardenas Jr & Wang, 1980; Chiang, Yoi, Lin, & Wang, 2001; Fernández et al., 2007).

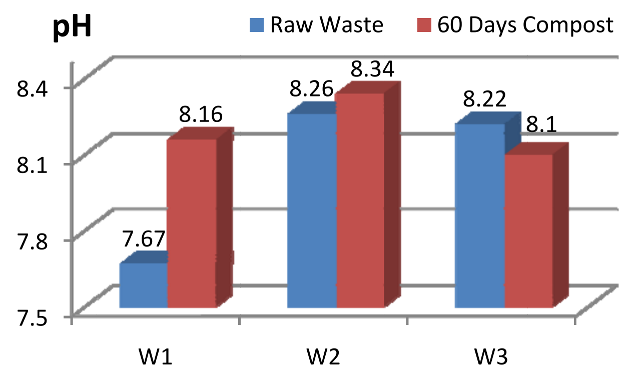

Figure 4 - 1: Changes in pH after composting and co-composting [W1 (VSW:SD=100:0), W2 (VSW:SD=80:20) and W3 (VSW:SD=60:40)].

4.2.2 Variation of EC

From the above figure it can be seen that for both W2 and W3 waste sample, a drop in EC value can be identified whereas W1 acts just opposite. A drop in EC may occur due to the leaching of salts as well as it may occur as the result of decomposition of organic acids which is related to maturation of composting process (Avnimelech, 1996). Hence it can be stated that W2 and W3 have reached maturation whereas W1 has not. Due to high EC, W1 cannot be used for soil application.

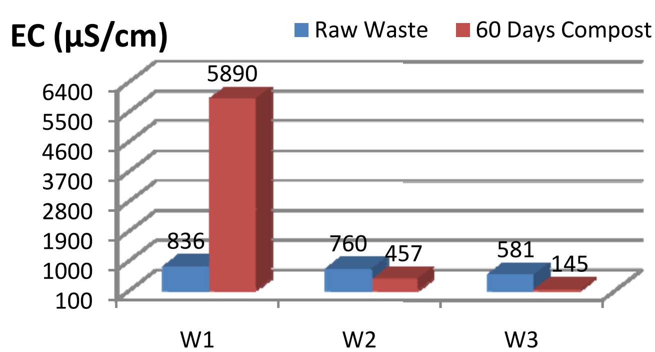

Figure 4 - 2: Changes in Electrical Conductivity, EC (μS/cm) after composting and co-composting [W1 (VSW:SD=100:0), W2 (VSW:SD=80:20) and W3 (VSW:SD=60:40)]

However, Wu et al. (2000) (Wu, Ma, & Martinez, 2000) have suggested that EC may be of use in evaluating the maturity of products produced from consistent feedstocks but Benito et al. (2003) (Benito et al., 2003), Khan et al. (2009) (Khan et al., 2009) and Cooperband et al. (2003) (Cooperband, Stone, Fryda, & Ravet, 2003) found that EC was a poor indicator of maturity and stability for pruning waste, paper pulp, sawdust-amended manure and vegetable waste, and green tea and rice bran composts, respectively. Thus it can be considered that EC may not be a useful maturity parameter for this study.

4.2.3 Variation of TVS and ROM

From the following Figure 4-3, it is visible that the TVS decreased for waste samples W1 and W2 whereas increased for W3 sample. The ROM in W1 and W2 are 29.91% and 0.37% respectively indicating faster degradation of organic matter in raw waste (W1) where no saw dust was used. In W2, due to the presence of saw dust containing lignin, changes in volatile solids were very low as lignin conserved even after the composting.

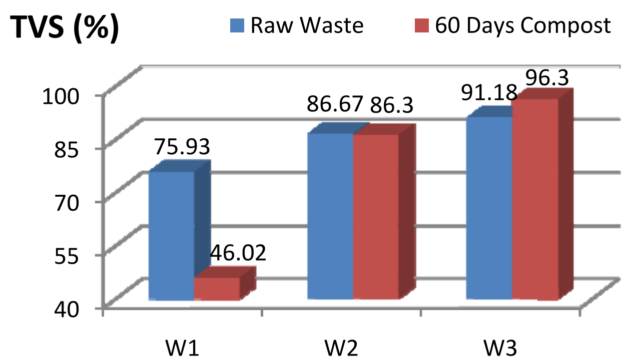

Figure 4 - 3: Changes in Total Volatile Solids (TVS) after composting and co-composting [W1 (VSW:SD=100:0), W2 (VSW:SD=80:20) and W3 (VSW:SD=60:40)]

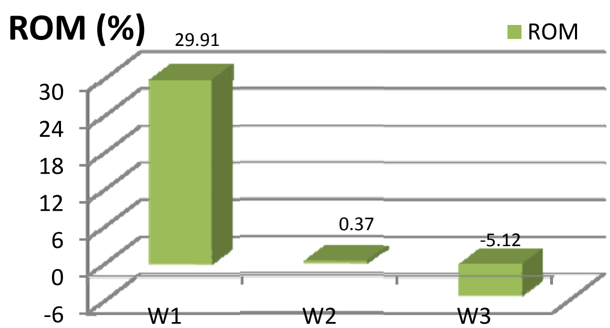

Figure 4 - 4: Reduction in Organic Matter (ROM) due to the 60 days co-composting of W1 (VSW:SD=100:0), W2 (VSW:SD=80:20) and W3 (VSW:SD=60:40).

TMECC (2002*c*) (TMECC.2002c, 2002) recommends that ROM measurements be combined with other stability and (or) maturity indices such as C:N ratio, respirometry, pH, ammonium to nitrate ratio, etc., rather than being used as a standalone test. Wu et al. (2000) (Wu et al., 2000) concurred that ROM makes a poor indicator for compost maturity, as the changes in TVS was not consistent for composting. In this study, in W3 waste sample, ROM value shows a negative quantity. Which might be the reason of sampling error or error might have occurred while taking readings for test results.

4.2.4 Variation of TOC

The changes in TOC due to composting of solid waste exhibited the similar behavior as TVS showing decrease in volatile solids content for W1 and W2 samples; whereas an increase in W3 sample. The main reason for decreasing TOC from 56.79% to 20.92% of W1 and from 51.52% to 35.91% of W2 is due to decomposition of the waste by transforming organic matter into carbon dioxide.

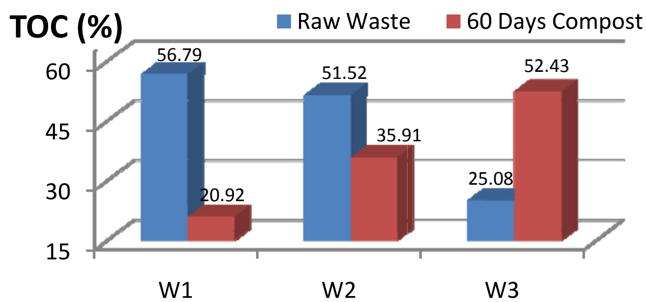

Figure 4 - 5: Changes in Total Organic Carbon (TOC) after composting and co-composting [W1 (VSW:SD=100:0), W2 (VSW:SD=80:20) and W3 (VSW:SD=60:40)]

4.2.5 Chemical analysis of compost for mineral content

To examine the variation of nutrients like phosphorus, calcium and magnesium due to composting and co-composting of vegetable solid waste with saw dust over the 60 days composting period, both the raw waste samples and the composted samples were analyzed.

Table 4 - 2: Effect of composting and co-composting on Phosphorus, Calcium and Magnesium content of vegetable waste.

Minerals	Waste Sample	Before Composting	After 60 Days Composting	% Loss of Minerals [a]
Phosphorus (P)	W1 (VSW:SD=100:0)	0.14	0.63	(350)
	W2 (VSW:SD=80:20)	0.04	0.21	(425)
	W3 (VSW:SD=60:40)	0.01	0.16	(1500)
Calcium (Ca)	W1 (VSW:SD=100:0)	1248.69	1462.5	(17)
	W2 (VSW:SD=80:20)	149.19	1188	(696)
	W3 (VSW:SD=60:40)	206.6	190.03	8
Magnesium (Mg)	W1 (VSW:SD=100:0)	902.16	30.37	97
	W2 (VSW:SD=80:20)	14.07	40.38	(187)
	W3 (VSW:SD=60:40)	24.87	9.39	62

[a] Percentage loss of minerals in terms of initial mineral content. The values in parenthesis represents the percent gain instead of percent loss.

It is evident from Table 4-2 that Phosphorus content increased over the composting period in all waste samples. Whereas, Mg content reduced due to composting except for W2 waste sample. In case of Calcium content, except W3, W1 and W2 calcium content increased due to composting over 60 days.

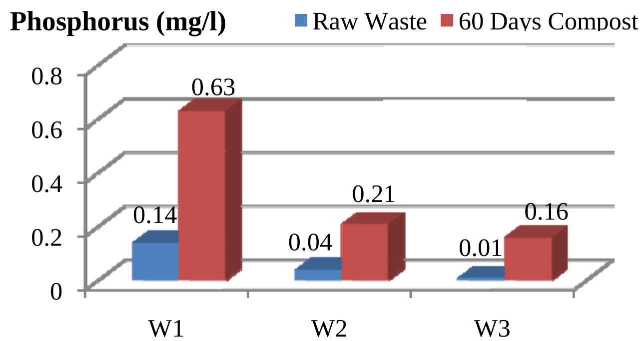

Figure 4 - 6: Changes in Phosphorus content after composting and co-composting [W1 (VSW:SD=100:0), W2 (VSW:SD=80:20) and W3 (VSW:SD=60:40)]

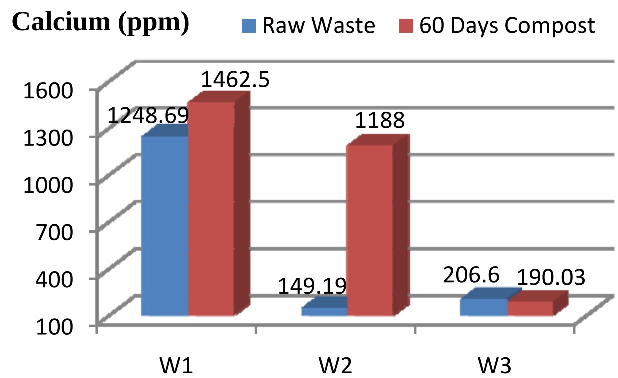

Figure 4 - 7: Changes in Calcium content after composting and co-composting [W1 (VSW:SD=100:0), W2 (VSW:SD=80:20) and W3 (VSW:SD=60:40)]

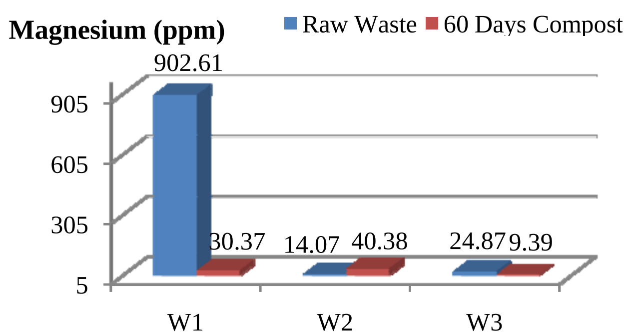

Figure 4 - 8: Changes in Magnesium content after composting and co-composting [W1 (VSW:SD=100:0), W2 (VSW:SD=80:20) and W3 (VSW:SD=60:40)]

Due to the use of jute sack and addition of finer particle saw dust, leaching from the composting unit was reduced significantly. Hence it can be assumed that the concentration of P increased during composting is the consequence of the low losses of P and a reduction in the amount of waste. The lower leaching losses from these heaps were probably a consequence of a lower infiltration of water into the heap (Sommer, 2001). Again, the presence of earthworms may give rise to the calcium content. In waste sample W3, Ca was lost slightly, and it was noted during sampling that this composting unit had generated the lowest amount of vermin. Mg has lost significantly and since all these minerals are not volatile, the only reason for loss may be stated as leaching loss (Tiquia, Richard, & Honeyman, 2002).

4.2.6 Microbiological changes occurred during composting

Microbial analysis such as Total Bacteria, Escherichia Coli and Clostridium Perfringens of the raw waste samples as well as 60 days composted samples were done in ICDDR,B microbiology laboratory to examine the changes occurred due to composting of waste. From table 4-1, it can be observed that initially waste samples contained total bacteria and E. Coli, whereas only W2 sample contained Clostridium Perfringens. Analyzing the changes in the number of bacteria in the composted materials (Table 4-1), it was found that the composting process contributed to a significant reduction in the number of the discussed microorganisms, except for Clotridium Perfringens. In raw waste sample, the highest number of total bacteria was recorded in sample W1 which is 6.4×10^{9} CFU/gm, while in composted sample the highest amount of total bacteria was recorded in sample W1 which is 1.6×10^{6} CFU/gm. According to Mckinley and Vestal (McKINLEY & Vestal, 1984), the thermophilic phase of composting has a significant effect on the change and succession of microorganism population. Such high temperature of thermophilic stage of composting causes an inactivation or reduction of mesophilous (not spore-forming) microorganisms (e.g. E. coli). Hence in this study, it was found that the amount of E. Coli reached to a value of zero after composting and total bacterial count also decreased. Contrarily to this, a gradual increase of Clostridium Perfringens in W1 and W3 composted masses was recorded. The increase in the number of discussed types of bacteria was, however, more visible in compost W1, where it reached the maximal value 30 CFU/gm. This can be explained by its higher optimal growth temperature of 43-47°C which was not attained during this composting.

4.3 Compost Maturity Analysis

Maturity is the degree or level of completeness of composting and implies improved qualities resulting from ‘ageing’ or ‘curing’ of a product (M. P. Bernal, Alburquerque, & Moral, 2009). The California Compost Quality Council (CCQC, 2001) (CCQC, 2001) defined maturity as ‘the degree or level of completeness of composting’, and the UK Composting Association (2001) (UK Composting Association, 2001) defined maturity simply as ‘the degree to which a compost has matured’, and mature compost as ‘compost that does not have a negative effect on seed germination or plant growth’. Bernal et al. (1998a) (M.

Bernal et al., 1998) described maturity as implying "a stable OM content and the absence of phytotoxic compounds and plant or animal pathogens". Similar definitions were used by Chen and Inbar (1993), Iannotti et al. (1993) and Hue and Liu (1995) (Y. Chen & Inbar, 1993; Hue & Liu, 1995; Iannotti et al., 1993).

A variety of methods for evaluating stability and maturity are available. According to California Compost Quality Council (CCQC), a maturity index characterization requires that the compost producer provide the C:N ratio of the finished product and reports at least one parameter from each of the following group A and B:

Group A:

Carbon Di-Oxide Evolution or Respiration

Oxygen Demand

Dewar Self Heating Test

Group B:

Ammonium : Nitrate Ratio

Ammonia Concentration

Volatile Organic Acids Concentration

Plant Test- **a)** Germination Index

b) Plant Growth Test

The following Table 4-3 provides the standard values for the tests to measure compost stability and maturity according to CCQC:

Table 4 - 3: Maturity assessment according to CCQC guidelines (TMECC, 2002)

C/N ratio ≤ 25				
Group A (Stability Test)	**Units**	**Very Stable**	**Stable**	**Unstable**
CO_2 Evolution rate	mg CO_2/gm/d	<2	2-4	>4
Dewar Self Heating	Dewar Index	V	V	<V
Specific oxygen uptake rate	mg O_2/gm/d	<3	3-10	>10
Group B (Maturity Test)	**Units**	**Very Mature**	**Mature**	**Immature**
NH_4-N : NO_3-N		<0.5	0.5-3.0	>3.0
NH_4-N	mg/kg dry weight	<75	75-500	>500
Volatile organic acid concentration	mmol/gm dry weight	<200	200-1000	>1000
Germination Index	% of control	>90	80-90	<80
Seedling Emergence	% of control	>90	80-90	<80

In addition to these tests, the Association of Swiss Compost Plants (ASCP) 2001 (Fuchs et al., 2001) guidelines also suggests few other maturity test indices such as: pH, reduction of organic matter (ROM), open and closed cress test etc. Buchanan (2002) (Buchanan, 2002) reported that the CCQC's Maturity Index was a useful tool for evaluating the quality of a variety of compost materials, as it enabled detection of immature composts which may have been deemed mature by a single test. In this study, Carbon-Di-Oxide (CO_2) Evolution, Germination Index (GI), Cress Test, Carbon-Nitrogen ratio (C:N), Ammonium-Nitrate Ratio ($NH4^+$-NO_3^-), Reduction of Organic Matter (ROM) indices have been analyzed to assess the compost maturity.

4.3.1 Carbon : Nitrogen ratio (C/N)

A maturity rating is applied based on the results of a series of tests; in order for compost to be considered mature or very mature, it must have a C:N ratio of no more than 25:1. Then the compost can be tested for other maturity indices from group A and group B to confirm the maturity. In this study, three waste samples were tested for this ratio before and after the composting procedure. The result is as follows:

Table 4 - 4: C/N ratio of waste samples before and after composting and co-composting

Waste Sample	Carbon : Nitrogen Ratio (C/N)	
	Raw	**60 days Compost**
W1 (VSW:SD=100:0)	78.46	23.02
W2 (VSW:SD=80:20)	407.49	335.63
W3 (VSW:SD=60:40)	135.63	376.77

A decreasing trend in the ratio of carbon to nitrogen (C:N), with eventual stabilization, is visible from the table for both W1 and W2 waste sample. As composting progresses, it releases CO_2 due to the decomposition of organic substrates, resulting in the loss of carbon from the system, hence with age of composting, C/N ratio decreases. However, in this study C/N ratio has increased in case of W3, such an increase may be the result of NH_3 volatilization. Also the resulting ratio of W2 and W3 waste sample do not comply with the CQCC standard. According to Wu et al. 2000 (Wu et al., 2000); Cooperband et al. 2003 (Cooperband et al., 2003), C/N ratio may not provide a good indication of compost maturity. Changes in C/N ratio also depend upon other properties of the compost, such as pH; for example, at basic pHs (>7.5), carbon loss as CO_2 and nitrogen loss as NH_3 are concurrent, and as a result the C:N ratio may even remain stable throughout composting (Sullivan & Miller, 2001). Hence Mathur et al. 1993 (Mathur et al., 1993); Namkoong et al. 1999 (Namkoong, Hwang, Cheong, & Choi, 1999) and Boulter-Bitzer et al. 2006 (Boulter-Bitzer, Trevors, & Boland, 2006) suggested that C/N should not be used as a sole test of maturity.

4.3.2 Ammonium : Nitrate Ratio

According to ASCP (2001), the NH_4^+ : NO_3 ratio is very useful in evaluating compost quality, a ratio below 0.5 indicates a very mature compost. Bernal et al. (1998) (M. Bernal et al., 1998) recommended an $NH4^+$:NO_3^- ratio of 0.16 or less as an appropriate cut-off between mature and immature composts, while Ko et al. (2008) (Ko et al., 2008) employed a threshold of 1:1 for the NH_4^+ : NO_3^- ratio and indicated that this ratio is more useful than the C:N ratio for evaluating the state of compost. According to CCQC, a compost is considered "very mature" if this ratio is less than 0.5 and "mature" is the ratio lies between 0.5 to 3.0. In this study, both W2 and W3 waste samples had a NH_4^+:NO_3^- ratio between 0.5 to 3.0, hence considered matured. While W1 sample had a ratio less than 0.5, meaning "very mature" compost.

Table 4 - 5: Ammonium-Nitrate ratio of 60 days compost sample

Tests	**Waste Sample**	**Value**	**Maturity based on CCQC standard values**		
			Very Mature	**Mature**	**Immature**
Ammonium : Nitrate (NH_4^+ : NO_3^-)	W1 (VSW:SD=100:0)	0.357	√		
	W2 (VSW:SD=80:20)	0.816		√	
	W3 (VSW:SD=60:40)	0.962		√	

4.3.3 CO_2 Evolution

Compost stability can be assessed by its microbial activity. Microbial activity can be measured by determining the aerobic respiration rate. In aerobic conditions, bacteria uses oxygen in the presence of sunlight to produce CO_2 along with energy and heat by degrading organic matter, a metabolism process of bacteria which is known as bacterial catabolism. Therefore, compost stability can be measured my measuring this microbial activity- such as by measuring carbon dioxide evolution, oxygen consumption and self-heating, which are indicative of the amount of degradable organic matter still present and which are related inversely to stabilization (F. d. Zucconi & De Bertoldi, 1987).

Table 4 - 6: CO_2 evolution test results on 60 days compost samples.

Tests	**Waste Sample**	**Value**	**Stability based on CCQC standard values**		
			Very Stable	**Stable**	**Unstable**
CO_2 Evolution (mg CO_2/gm/d)	W1 (VSW:SD=100:0)	1.371	√		
	W2 (VSW:SD=80:20)	0.847	√		
	W3 (VSW:SD=60:40)	0.839	√		

In this study, CO_2 evolution was measured to observe the stability of test waste samples. From the study, the respiration rate of W1, W2 and W3 samples were found to be 1.371 mg CO_2/gm/d, 0.847 mg CO_2/gm/d and 0.839 mg CO_2/gm/d respectively. According to the CCQC guidelines for compost stability, a compost with respiration rate less than 2 mg

CO_2/gm/d is considered to be "very stable". So from this study, it can be observed that all those waste samples were composted as "very stable". Again, Hue and Liu (1995) (Hue & Liu, 1995) indicated that a compost is considered stable if it has CO_2 evolution rate less than 2.8 mg CO_2/gm/d. So studied composts were marked "stable" based on his research as well.

4.3.4 Germination Index

Seed germination test helps to evaluate the efficiency of the composting process for plant growth and seed germination. The germination index is also a measure of compost maturity. According to Zucconi et. al (1981) (F. Zucconi, Monaco, & Debertoldi, 1981), the compost is considered immature when the germination index is lower than 50% compared to the control with distilled water. According to CCQC guidelines, a compost is considered matured if the germination index is higher than 80% compared to the control with distilled water.

Table 4 - 7: Summary of germination index tests on 60 days compost sample

Tests	Waste Sample	Value	Based on CCQC guidelines			Based on Zucconi et. al 1981	
			Very Mature	Mature	Immature	Mature	Immature
Germination Index (% Control)	W1 (Lettuce)	171	√			√	
	W1 (Tomato)	100	√			√	
	W1 (Carrot)	15			√		√
	W2 (Lettuce)	0			√		√
	W2 (Tomato)	296	√			√	
	W2 (Carrot)	44			√		√
	W3 (Lettuce)	612	√			√	
	W3 (Tomato)	204	√			√	
	W3 (Carrot)	13			√		√

Table 4-7 compares germination index (GI) of 60 days compost samples W1, W2 and W3 for three different plant types- carrot, tomato, lettuce and shows the maturity level based on CCQC standard values as well as Zuconni et. al 1981. According to CCQC, GI lower than 80% is considered immature. Hence, W2 waste sample was found to be very mature for tomato seeds and immature for both carrot and lettuce seeds. On the other hand, W1 and W3 samples both were marked as "very mature" for lettuce and tomato, but for carrot seeds, they were marked as "immature". When GI values were compared to Zuconni et. al, the results were same.

Table 4 - 8: Variation of germination index over the 60 days composting cycle

Age of compost	W1 (VSW:SD = 100:0)			W1 (VSW:SD = 100:0)			W1 (VSW:SD = 100:0)		
	Lettuce	**Tomato**	**Carrot**	**Lettuce**	**Tomato**	**Carrot**	**Lettuce**	**Tomato**	**Carrot**
0 days	0	44	0	0	0	98	0	145	0
10 days	0	23	0	0	0	0	0	51	0
20 days	0	12	0	0	0	0	0	5	0
30 days	0	4	0	0	2	0	10	31	0
40 days	30	29	8	0	358	8	540	287	8
50 days	144	77	13	0	322	15	600	281	10
60 days	171	100	15	0	296	44	612	204	13

Above table shows the changes in GI values over the 60 days composting and co-composting process. To visualize the changes that occurred during this process, the following graphs were prepared:

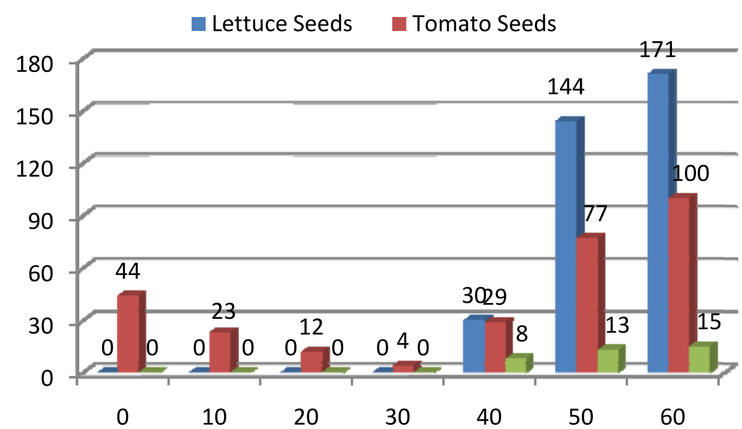

Figure 4 - 9: Changes of GI values for lettuce, tomato and carrot seeds over the 60 days composting of W1 (VSW:SD = 100:0) waste sample

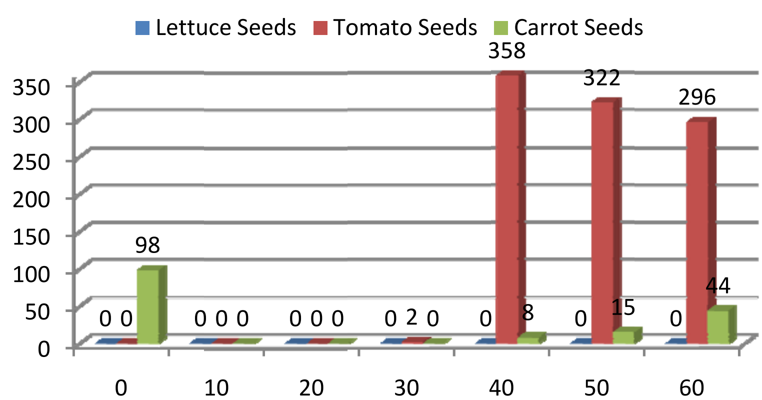

Figure 4 - 10: Changes of GI values for lettuce, tomato and carrot seeds over the 60 days composting of W2 (VSW:SD = 80:20) waste sample.

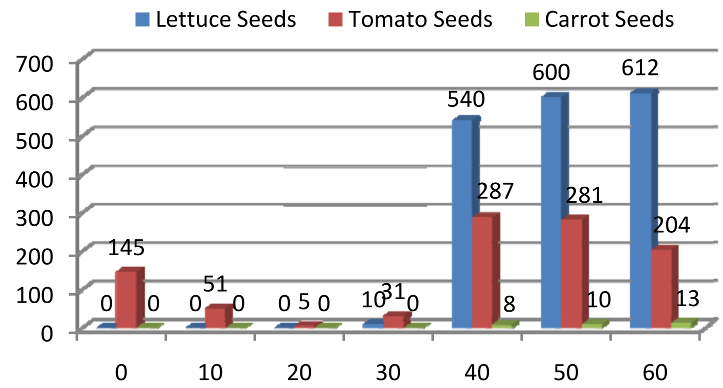

Figure 4 - 11: Changes of GI values for lettuce, tomato and carrot seeds over the 60 days composting of W3 (VSW:SD = 60:40) waste sample.

As it is shown in the above three figures, it can be generalized that the initial GI values for the three different seeds were very low, in most of the cases it was zero. In W1 and W3 samples, tomato seed showed initial high value of GI and then it also decreased. In case of W2 sample, GI values of carrot seeds were initially high other than tomato and lettuce, which were zero. The initial high value for tomato in case of W1 and W3, and for carrot in case of W2 can be explained by the non toxicity of raw vegetable waste and synthetic characteristics of wastes. These GI values then decreased as the composting process began and reached thermophilic stage where toxic compounds such as phenolic acids, organic acids and alcohols were formed. But this decrease lasted only for first 30 days. For the later period of composting, all the GI values increased with composting time, except for tomato seeds in W2 compost extracts. To assess whether a compost is matured or not, only GI test cannot be considered to be the only test. Additional tests are required and cress test or plant growth test is one of those.

4.3.5 Cress Test

Cress test was done in a 500 ml flower pot with test compost and control soil poured in an equal amount by volumetric basis. The test set up is shown in the table below:

Table 4 - 9: Test set up for cress test of produced compost sample

Sample	Volume (ml/pot)		Weight of (gm/pot)	
	Control Soil	Compost	Control soil	Compost
2 x Reference or Control Soil	500	0	566.57	0
[a]2 x W1 Sample : Control (1:1)	250	250	283.29	187.18
[b]2 x W2 Sample : Control (1:1)	250	250	283.29	154.76
[c]2 x W3 Sample : Control (1:1)	250	250	283.29	129.59

[a]W1 = 60 days composted sample = 100% VSW, 0% SD. [b]W2 = 60 days composted sample = 80% VSW, 20% SD. [c]W3 = 60 days composted sample = 60% VSW, 40% SD

The test was stopped after 14 days as 50% of the control seedlings have emerged. Table 4-5 shows the test result:

Table 4 - 10: Cress test result for lettuce, tomato and carrot in 60 days compost samples.

Test Sample		**Fresh air dry weight of yield (gm)**	**% relative to control soil**	**Maturity according to CCQC guidelines**
Control Soil	Lettuce	2.05675	-	-
	Tomato	2.5615	-	-
	Carrot	0.39725	-	-
[a]W1 : Control Soil	Lettuce	3.3363	162	Very Mature
	Tomato	6.5447	256	Very Mature
	Carrot	1.07825	271	Very Mature
[b]W2: Control Soil	Lettuce	3.64655	177	Very Mature
	Tomato	6.84265	267	Very Mature
	Carrot	0.79985	201	Very Mature
[c]W3 : Control Soil	Lettuce	1.87465	91	Very Mature
	Tomato	3.9117	153	Very Mature
	Carrot	0.49575	125	Very Mature

[a]W1 = 60 days composted sample = 100% VSW, 0% SD. [b]W2 = 60 days composted sample = 80% VSW, 20% SD. [c]W3 = 60 days composted sample = 60% VSW, 40% SD

So it is evident from the table that all the three types of seeds were sensitive to the compost phytotoxicity and the compost mixture aided in plant growth. It can also be noted that the highest plant growth relative to control soil was 271 for carrot seeds in W1 compost and soil mixture. Whereas the lowest was 91 for lettuce seeds planted in W3 sample and soil mixture. The following figures were taken during the plant growth test that can show the comparative growth of seeds in different compost sample and control media mixture:

7 days plant growth in W1 and control soil mixture

10 days plant grwoth in W1 and control soil mixture

7 days plant growth in W2 and control soil mixture

10 days plant growth in W2 and control soil mixture


7 days plant growth in W3 and control mixture


10 days plant growth in W3 and control mixure


7 days plant growth in control soil


10 days plant growth in control soil

Figure 4 - 12: Overview of cress test (top to bottom: seed growth test comparison after 7 days and 10 days for i) W1 and control soil mixture, ii) W2 and control soil mixture, iii) W3 and iv) control soil, v) harvesting and air drying of harvested plant samples)

4.4 Comparison Among Produced Compost, Commercially Available Compost Fertilizer and Commercially Available Inorganic Fertilizer for Plant Growth

In this study, cress tests were conducted on inorganic as well as commercially available compost fertilizers to assess the efficiency of the produced compost material for the selected three types of seeds. For inorganic fertilizer, urea was selected and "waste Concern Fertilizer" was used for commercially available compost fertilizer. In inorganic fertilizer test, three different mixing ratios were used to consider the adverse effect of excess fertilizer. The test set up is shown in the table below:

Table 4 - 11: Test set up for measuring the efficiency of produced compost over available inorganic and organic compost fertilizer.

Sample	Volume (ml/pot)		Weight of (gm/pot)	
	Control Soil	Compost	Control soil	Compost
2 x Reference or Control Soil	500	0	566.57	0
[a]2 x WC : Control (1:1)	250	250	283.29	198.645
Sample	**Volume of control soil (ml)**		**Weight of Urea (mg)**	
[b]1 x U1 : Control (1:1)	500		10	
[c]1 x U2 Sample : Control (1:1)	500		20	
[c]1 x U3 Sample : Control (1:1)	500		25	

[a]WC= Waste Concern Compost Fertilizer : Control soil = 1 : 1 [b]U1= Urea fertilizer 10 mg/500 ml control soil. [c]U2= Urea fertilizer 20 mg/500 ml control soil. [d]U3= Urea fertilizer 25 mg/500 ml control soil.

Figure 4 - 13: Plantation of carrot, lettuce and tomato seeds in three different ratio of urea fertilizer mixed with control soil.

Figure 4 - 14: Emergence of plants after 14 days of plantation in control soil mixed with inorganic fertilizer.

Figure 4 - 15: Plant growth after 7 and 10 days of plantation in a mixture of waste concern fertilizer and control soil.

From the cress test on these two commercial fertilizer, the following results were found:

Table 4 - 12: Test result for measuring efficiency of produced compost with commercially available inorganic and organic fertilizer.

Test sample		Fresh air dry weight of yield (gm)	% relative to control soil
W1 : Control Soil	Lettuce	3.3363	162
	Tomato	6.5447	256
	Carrot	1.07825	**271**
W2: Control Soil	Lettuce	3.64655	177
	Tomato	6.84265	**267**
	Carrot	0.79985	201
W3 : Control Soil	Lettuce	1.87465	91
	Tomato	3.9117	153
	Carrot	0.49575	125
[b]U1 : Control Soil	Lettuce	0.41	20
	Tomato	0.56	22
	Carrot	0.165	42
[c]U2 : Control Soil	Lettuce	0.39	19
	Tomato	0.41	16
	Carrot	0.194	49
[d]U3 : Control Soil	Lettuce	0	0
	Tomato	0.0112	0
	Carrot	0.01	3
[a]WC : Control Soil	Lettuce	5.17065	**251**
	Tomato	5.33125	208
	Carrot	0.82195	207

[a]WC= Waste Concern Compost Fertilizer : Control soil = 1 : 1 [b]U1= Urea fertilizer 10 mg/500 ml control soil. [c]U2= Urea fertilizer 20 mg/500 ml control soil. [d]U3= Urea fertilizer 25 mg/500 ml control soil.

From the above table, it can be noted that for carrot, W1 compost mixture resulted best, whereas for tomato W2 compost mixture resulted better than any other combination of samples and control media. Interestingly, only for lettuce, it can be seen that waste concerns' compost fertilizer produced more plants than any other combination. However, in no cases the inorganic fertilizer worked better, in fact it showed the lowest relative production of plant with respect to control media.

CHAPTER 5: CONCLUSIONS AND FUTURE RECOMMENDATIONS

5.1 Conclusions

This research was conducted to find out the maturity of compost produced from composting of vegetable solid waste and the results were compared with two other composts produced from co-composting of vegetable solid wastes with saw dust mixture. Vegetable solid waste is rich in nitrogen and saw dust is rich in carbon. Hence while co-composting, saw dust was added to vegetable solid waste as bulking agent to provide necessary carbon source to be used by microorganisms to degrade or stabilize the solid waste. In addition of supplying carbon, saw dust also acted as bulking material that allowed air circulation. Due to the addition of saw dust, the decomposable part composted with vegetable solid waste during the co-composting period. But saw dust has also lignin and lignin protected cellulose which was conserved during the co-composting period and may have caused nitrogen immobilization, hence nitrogen deficiency in compost materials giving a higher C/N ratio of compost materials. The conclusions that can be drawn from this study are listed below:

Compost Stability:

1. **Microbial Analysis-** T.Bacteria and E.Coli reduced significantly which indicates stability of compost product. However, Clostridium Perfringens increased in W1 and W3 by a slight amount which might be caused by some external contamination or by formation of an anaerobic region in the composting unit since the compost was not turned during the whole time.

2. **pH-** pH value was above 8 for all samples. From last 30 days value, a stable pH condition was observed which refers to compost stability.

3. **CO_2 Evolution-** Literature confirms that CO_2 evolution test gives the best result for stability test. This study also confirmed that statement by showing values that also co-related well with plant growth test for maturity analysis. CO_2 evolution result classified all test samples W1, W2 and W3 as stable compost.

4. **Reduction of Organic Matter (OM)-** Over the 60 days composting, OM reduced significantly for W1. Reduction in OM for W2 was almost negligible. But for W3, ROM increased slightly, which may be due to a sampling error or testing error.

Compost Maturity:

1. **C/N Ratio-** In this study C/N of W1 sample satisfy the requirement for maturity. And a decreasing trend in C/N ratio was found in W2 sample as well. However the C/N value for W3 did not satisfy the guideline.

2. **EC-** EC increased for W1 sample, while for W2 and W3, EC decreased. Decrease in EC value indicates maturity as it occurs due to the decomposition of phytotoxic organic acids.

3. **NH_4-N : NO_3-N Ratio-** This study shows if compost is classified based on this index, 60 days compost would be classified as mature compost. This index shows a good co-relation with CO_2 evolution test for stability index.

4. **Germination Index (GI)-** GI shows slight irregularity in assessing compost maturity. According to this index, carrot seeds showed no sensitivity and tomato germinated in all media. Whereas lettuce germinated well in W1 and W3 media, meaning a mature compost. But W2 was marked immature with GI index.

5. **Plant growth test-** Plant grew well in compost and soil mixture than in soil alone. Also the values indicated "very mature" compost from this test. Test result also co-related well with CO_2 evolution test for stability measurement.

Finally, it was found that-

- Studied compost sample proved to be **better** for plant growth than the available inorganic market fertilizer and organic compost fertilizer (produced by "waste concern") tested in this study.
- CO_2 evolution, NH_4-N : NO_3-N and Plant growth test- these three tests co-related very well and these results indicate the studied compost samples to be "stable" and "mature".
- ROM, C/N ratio, CO_2 evolution, NH_4-N : NO_3-N and Plant growth tests co-related well with each other to indicate that W1 is comparatively matured than other two compost samples.

5.2 Recommendations

Composting was done for only 60 days. In future studies composting could be done for a longer period to observe the selected parameters of this study.

1. In this study only 2 mixing ratios for co-composting were used and only one type of waste (vegetable solid waste) with one type of bulking agent (saw dust) was used. Future studies may be carried out by varying the co-composting ratios as well as by varying the bulking agent by using ash, lime etc. Instead of using only one type of bulking agent, several types of bulking agents can be used in different ratios to better assess the factors affecting composting process and the end compost products' effectiveness as fertilizer.
2. Waste samples were not turned during the whole composting period to allow better air circulation and ensure aerobic decomposition. Hence, it can be recommended that this study can be conducted in future to evaluate the effect of turning frequency on the quality of compost produced from composting.
3. Many stability tests and maturity indices were determined in this study for the 60 days compost samples produced from composting and co-composting by measuring different parameters of the raw waste and final compost samples. But is has been advised by many authors that these parameters should be monitored at different stages of composting process to find better explanation. In case of ammonium : nitrate ratio, Brewer and Sullivan (2003) (Brewer & Sullivan, 2003) suggested to monitor the ratio several times throughout the composting period (i.e., in fresh materials, after active composting is complete, and after curing), rather than relying on the final value alone. So in future studies, this can be incorporated.
4. Only three types of seeds and one mixing ratio of compost : control were used to determine the efficiency of the produced compost samples to be used as fertilizers. Different types of seeds with different mixing ratios of compost and control can be studied to find out the efficiency of compost materials.
5. Only effectiveness of compost materials as fertilizers were measured. Given the effectiveness as fertilizer, an economic evaluation of the produced compost should be conducted as well to see if the product is marketable and profitable.

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APPENDIX

Table A - 1: Raw data for plant growth test for carrot, lettuce and tomato in W1, W2 and W3 waste samples mixed with control soil, inorganic fertilizer and organic compost fertilizer.

Waste Samples	Lettuce				Tomato				Carrot			
	Number of plants in each pot	Average Number	Air dry weight (gm)	Average air dry weight (gm)	Number of plants in each pot	Average Number	Air Dry Weight (gm)	Average air dry weight (gm)	Number of plants in each pot	Average Number	Air Dry Weight (gm)	Average air dry weight (gm)
W1-1	78	76	3.5307	3.336	89	85	6.0380	6.545	66	68	1.0462	1.078
W1-2	74		3.1419		80		7.0514		69		1.1103	
W2-1	81	76	3.7794	3.647	81	88	5.3056	6.843	63	63	0.8427	0.800
W2-2	70		3.5137		95		8.3797		62		0.757	
W3-1	78	73	2.0984	1.875	79	80	4.3426	3.912	63	54	0.6289	0.496
W3-2	68		1.6509		80		3.4808		44		0.3626	
U1	49	49	0.41	0.41	68	68	0.56	0.56	14	14	0.165	0.165
U2	40	40	0.39	0.39	49	49	0.41	0.41	35	35	0.194	0.194
U3	0	0	0	0	8	8	0.0112	0.0112	1	1	0.01	0.01
WC-1	89	80	4.8769	5.171	91	89	5.7536	5.331	70	65	1.0864	0.822
WC-2	71		5.4644		87		4.9089		60		0.5575	
S1	85	77	1.9875	2.057	65	64	2.5773	2.562	37	41	0.3307	0.397
S2	69		2.126		62		2.5457		44		0.4638	

W1 = 60 days composted sample = 100% VSW, 0% SD. W2 = 60 days composted sample = 80% VSW, 20% SD. W3 = 60 days composted sample = 60% VSW, 40% SD. WC-1 and WC-2= Waste Concern Compost Fertilizer : Control soil = 1:1. U1= Urea fertilizer 10 mg/500 ml control soil. U2= Urea fertilizer 20 mg/500 ml control soil. U3= Urea fertilizer 25 mg/500 ml control soil. S1 and S2 = Control soil (500 ml)

Table A - 2: Values for pH, EC, Phosphorus (P), Calcium (Ca) and Magnesium (Mg) for raw waste samples and compost samples.

Sample Designation		pH	EC (µS/cm)	P (ppm)	Ca (ppm)	Mg(ppm)
Raw Waste	W1	7.67	836	0.14	1248.69	902.61
	W2	8.26	760	0.04	149.19	14.07
	W3	8.22	581	0.01	206.6	24.87
Compost Sample	w1	8.16	5890	0.63	1462.5	30.37
	w2	8.34	457	0.21	1188	40.38
	w3	8.1	145	0.16	190.03	9.39

Table A - 3: Calculation of different parameters of raw waste sample as well as compost samples for W1, W2 and W3.

Parameters	Unit	W1	W2	W3
TVS raw sample	%	75.93	86.67	91.18
TVS Compost sample	%	46.02	86.3	96.3
Reduction in organic matter	%	29.91	0.37	-5.12
Total CO_2 Evolution	mg/day	44.7525	49.725	52.4875
Total CO_2 per day	gm VS/day unit	1.37112	0.846982	0.839183
Ammonium nitrogen (NH_4-N) of Raw sample	%	0.01691	0.01143	0.01421
Nitrate nitrogen (NO_3-N) of Raw Sample	%	0.652	0.0496	0.078
Ammonium Nitrate Ratio of Raw sample	-	0.025936	0.230444	0.182179
Ammonium nitrogen (NH_4-N) of Compost sample	%	0.005692	0.007116	0.007116
Nitrate nitrogen (NO_3-N) of Compost Sample	%	0.015939	0.008723	0.0074
Ammonium Nitrate Ratio of Raw sample	-	0.357111	0.815774	0.961622
Total organic carbon of Raw sample	%	56.79	51.52	25.08
Total organic carbon of Compost sample	%	20.92	35.91	52.43
Total nitrogen of Raw sample	%	0.72381	0.12643	0.18491
Total nitrogen of Compost sample	%	0.908671	0.106992	0.139156
C/N Ratio for raw sample	-	78.45982	407.4982	135.6336
C/N Ratio for Compost sample	-	23.02263	335.6326	376.7714

Table A - 4: Properties of garden soil used in this study as control media

Liquid Limit	Plastic Limit (%)	Plasticity Index (%)	Specific Gravity	Organic Content (%)	Silt (%)	Clay (%)
49	18	31	2.7	0	58	17

Table A - 5: Measured weather parameters of test area (Dhaka) during the plant growth test period (24th November, 2015 to 7th December, 2015)

Day	Date	Temperature (^oC)		Rainfall (mm)	Humidity (%)		Wind Speed (kmph)	
		Max	Min		Max	Min	Max	Min
01	24/11/2015	29	20	No	96	34	4	0
02	25/11/2015	28	21	No	90	44	0	0
03	26/11/2015	27	18	No	88	41	4	0
04	27/11/2015	27	18	No	87	41	0	0
05	28/11/2015	28	20	No	90	36	0	0
06	29/11/2015	29	18	No	93	35	0	0
07	30/11/2015	29	19	No	96	40	0	0
08	01/12/2015	30	20	No	91	44	4	0
09	02/12/2015	28	21	No	87	44	0	0
10	03/12/2015	29	22	No	96	55	7	4
11	04/12/2015	30	22	No	94	45	4	0
12	05/12/2015	26	18	No	89	52	0	0
13	06/12/2015	25	18	No	90	54	0	0
14	07/12/2015	26	20	No	87	55	0	0