USE OF GRASS CLIPPINGS ENHANCES THE MATURITY AND STABILITY OF MUNICIPAL SOLID WASTE INTO COMPOST

MD. MAHMUDUL HASAN LIKHON

DEPARTMENT OF AGROFORESTRY AND ENVIRONMENTAL SCIENCE
SHER-E-BANGLA AGRICULTURAL UNIVERSITY
DHAKA-1207

JUNE, 2018

USE OF GRASS CLIPPINGS ENHANCES THE MATURITY AND STABILITY OF MUNICIPAL SOLID WASTE INTO COMPOST

BY
MD. MAHMUDUL HASAN LIKHON

REGISTRATION NO. 11-04502

A Thesis

Submitted to the Faculty of Agriculture,

Sher-e-Bangla Agricultural University, Dhaka

in partial fulfillment of the requirements

for the degree of

MASTER OF SCIENCE (MS)
IN
AGROFORESTRY & ENVIRONMENTAL SCIENCE
SEMESTER: Jan- June, 2018

APPROVED BY:

Dr. Md. Kausar Hossain **Professor** **Supervisor**	**Dr. Jubayer-Al-Mahmud** **Associate Professor** **Co-Supervisor**

Professor Dr. Nazmun Naher
Chairman
Examination Committee

DEPARTMENT OF AGROFORESTRY AND ENVIRONMENTAL SCIENCE
Sher-e-Bangla Agricultural University
Sher-e-Bangla Nagar, Dhaka-1207

CERTIFICATE

This is to certify that the thesis entitled "**USE OF GRASS CLIPPINGS ENHANCES THE MATURITY AND STABILITY OF MUNICIPAL SOLID WASTE INTO COMPOST**" submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of **Master of Science in Agroforestry and Environmental Science**, embodies the result of a piece of bona fide research work carried out by **Md. Mahmudul Hasan Likhon**, Registration number: **11-04502** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.

I further certify that any help or source of information, received during the course of this investigation has duly been acknowledged.

Dated: June, 2018

Place: Dhaka, Bangladesh

Dr. Md. Kausar Hossain
Professor
Supervisor

Dedicated to

Those parents who always look for a groom
for their daughter with an MS degree

ACKNOWLEDGEMENTS

First of all, I express my best gratitude to Almighty Allah for His never-ending blessing to complete this work successfully. It is a great pleasure to express profound thankfulness to my respected parents, who entitled much hardship inspiring for prosecuting my studies, thereby receiving proper education.

I would like to express my earnest respect, sincere appreciation and enormous indebtedness to my reverend Supervisor ***Prof. Dr. Md. Kausar Hossain****, Department of Agroforestry and Environmental Science, Sher-e-Bangla Agricultural University, Dhaka-1207, for his scholastic supervision, helpful commentary and unvarying inspiration throughout the research work, and preparation of the thesis.*

I wish to express my gratitude and best regards to my respected Co-Supervisor, ***Dr. Jubayer-Al-Mahmud****, Associate Professor, Department of Agroforestry and Environmental Science, Sher-e-Bangla Agricultural University, Dhaka-1207, for his continuous direction, constructive criticism, encouragement and valuable suggestions in carrying out the research work and preparation of this thesis.*

I feel to express my heartfelt thanks to the **Chairman, Dr. Nazmun Naher** *and all the of the Department of Agroforestry and Environmental Science, Sher-e-Bangla Agricultural University, Dhaka, for their valuable suggestions and encouragement during the period of the study.*

I also wish to extend sincere gratitude to the Ministry of Science and Technology, Government of the People's Republic of Bangladesh for providing me financial support to conduct the research.

I found no words to thank my mother Murshida Parvin for her unquantifiable love and continuous support, their sacrifice never ending affection, immense strength and untiring efforts for bringing my dream to proper shape.

June, 2018 ***The Author***
SAU, Dhaka

USE OF GRASS CLIPPINGS ENHANCES THE MATURITY AND STAILITY OF MUNICIPAL SOLID WASTE INTO COMPOST

ABSTRACT

More than thirteen thousand metric ton of Municipal Solid Waste (MSW) is generated each day in Bangladesh currently where only 37% are collected by the authority. Experts predict that more than 47 Metric ton of MSW will be generated by 78 million of urban people by in 2020. So the management of MSW is and will be one of the major challenges of Municipal Authority of Bangladesh. Improper management of municipal solid waste (MSW) causes hazards to inhabitants. Various studies reveal that about 90% of MSW is disposed of unscientifically in open dumps and landfills, creating problems to public health and the environment. Bioconversion of MSW can be a better alternative to avoid environmental pollution. But the decomposition of MSW is not the best way for compost preparation. Grass Clippings (GC) at optimum level can help promote the compost process in more effective way. Optimum amount of GC along with optimum level of cow dung (CD) for the compost preparation from MSW are critically studied. In this study, MSW amended with bulking materials GC and nitrogen source cow dung (CD) were evaluated for improved stability and maturity during composting of MSW where 15 kg GC and 5 kg of CD showed the most promising efficiency in terms of physical, and chemical parameters. The study is concluded with a few fruitful suggestions that is use of other lignocellulosic materials like water hyacinth and herbaceous weeds can also be used instead of grass clippings which may be beneficial to encourage the competent authorities/researchers to work towards further improvement of the present system.

LIST OF CONTENTS

LIST OF CONTENTS (Contd.)

LIST OF CONTENTS (Contd.)

LIST OF CONTENTS (Contd.)

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

The restless race of human society towards modern urban life around the world generates tremendous amount of municipal solid waste (MSW), because the generation rate is mounting even faster than the rate of urbanization (Gabhane *et al*., 2016). Global MSW generation showed a twofold increase just only within 10 years from 0.68 billion tons per year in 2000 to 1.3 billion tons per year in 2010. Moreover, it is projected to reach 2.2 billion tons per year by 2025 and 4.2 billion tons per year by 2050 (Pimentel, 1995). This humongous waste load of urbanized world if not managed properly will certainly have a negative impact on sustainable living style, local environment, and human health (Lazarovits, 2001; Noble and Coventry, 2005). Severe MSW management problems are reported in a number of cities of different countries like China (Mathur *et al.*, 1993), India (Singh *et al*., 2011), Malaysia (Johari *et al*., 2012), Thailand (Requena *et al.*, 1996), and Bangladesh, because of rapid population growth, fast industrialization, and urbanization.

Tremendous generation of MSW because of fast population growth and ongoing economic development is already blamed for significant environmental glitches in Bangladesh (Ahsan *et al*., 2014). Bangladesh has enjoyed tremendous growth in its economy over the last few years, and this persuades a great influx of village workforce to cities. In this circumstance, for sustainable MSW management population and economy growth should be constructively transformed, because they are the major drivers of wastes generation (Perez *et al.*, 2002; Johari *et al*., 20120). Around the world to ensure sustainable MSW management, four options are now considered, such as thermal treatment, biological treatment, landfilling with energy recovery, and recycling (He *et al.*, 1995; Requena *et al.*, 1996). Among them, Biological treatment is one of the best options for management of such huge MSW, as it yields nutritionally rich manure which improves soil health and fertility. Bioconversion is process of biotransformation of complex organic material to simple and stable material which supplies essential soil mineral for plant with implementing soil conditioning properties with reducing toxicity and pathogenic organisms (Garcia-Gomez *et al*., 2005).

Annually approximately 2.5 million tons of pesticides are applied to agricultural fields worldwide. The proportion of pesticides applied reaching the target pest has been found to be less than 0.3%, whereas the remaining 99.7% went elsewhere in the environment (Pimentel, 1995). This leads to exposure of non-target organisms, and undesirable side-effects on some species, communities or ecosystems as a whole (Van der Werf, 1996). More recently, the price of mineral fertilizers (mainly NPK) has increased substantially. Some mineral fertilizers are produced from fossil fuels through a process that is associated with the buildup of greenhouse gases. As a result, increasing public concerns regarding environmental safety forced restrictions of synthetic pesticides and fertilizer usage and encourages research on alternative methods for agricultural production (Lazarovits, 2001; Noble and Coventry, 2005).

Composts improve soil quality by altering physiochemical and properties, increase organic matter content, water holding capacity, overall diversity of microbes, provide macro-and micronutrients essential for plant growth and suppress diseases which contribute to plant growth enhancement (Siddiqui Y. and Sariah M. 2009). Application of rice straw composts which is high in silicon and nutrients has been documented in enhancing plant growth, soil health and disease resistance (Watanabe *et al*., 2009). Microorganisms present in composts such as Trichoderma, Rhizobacteria and fluorescent Pseudomonas are known to enhance plant growth and systemic resistance to phytopathogen (Park *et al*., 2013).

These microbes benefit plants through different modes of action including production of secondary metabolites such as antibiotics, hormones, siderophores, phosphate solublization and nitrogen fixation. Trichoderma spp. alone or in combinations with other beneficial microorganisms has been documented as an effective biocontrol agent for disease control in various host–pathogen systems in vitro as well as in field trials (Jinantana and Sariah, 1998). PGPM has been developed to enhance the efficacy of composts in promoting plant growth and control of diseases. Recently, the use of PGPM-fortified rice straw composts significantly enhanced disease resistance, growth and yield as well as soil health of aerobic rice (Ng *et al*., 2012). Therefore, it is important to evaluate the suitability of microbial infused rice straw composts on induction of disease suppression, growth and yield of crop for sustainable cultivation.

Maturity and stability is another important consideration in compost application. Non-stable composts produce phytotoxic effects (He *et al.,* 1995; Requena *et al.,* 1996) by creating anaerobic conditions (Mathur *et al.*, 1993). The decomposition of phytotoxic compounds produced in the earlier phases of the composting process is referred as compost maturity (Wu *et al.*, 2000), and the proportion of stable humus formed as a consequence of the modification of organic matter. Compost maturity is achieved when compost is stable, but still active enough to support increased microbial activity, especially when considering application as a biological control or suppressive agent of plant pathogens. Compost maturity and stability are influenced by the nature of the organic materials, its structure and composition, and the capacity of microorganisms to degrade the macromolecules that make up the composting substrates. Phytotoxic metabolites are produced during bioconversion process of MSW as it is slowly decomposed (Requena *et al.*, 1996). On the other hand, the humification process is fed by intermediate compounds generating from the bioconversion process (Perez *et al.*, 2002). Thus, the success of composting process and the usefulness of compost as an organic amendment are dependent on the potential of microbial population.

The composting of MSW through amendment of optimum bulking agent, nitrogen as well as microbes source might be a promising technique for creating mature compost in a short period of time.

Information on the composting process of MSW amended with lignocellulolsic grass clippings (GC) has not been widely investigated and very few reports have been published.

Hence, the need to determine feasibility of lignocellulolsic GC amendment in rapid composting of MSW. The present study was undertaken with the following objectives:

Therefore, the objectives of this study were

i) to find out more effective recycling method of composting from Municipal Solid Wastes

ii) to evaluate the effect of lignocellulosic Grass Clippings on the stability, maturity and quality of the compost from Municipal Solid Waste

CHAPTER II

LITERATURE REVIEW

Municipal solid waste

Municipal solid waste (MSW), commonly known as trash or garbage is a waste type consisting of everyday items that are discarded by the public. The composition of municipal solid waste varies greatly from municipality to municipality (Kumar *et al*., 2016) and it changes significantly with time. In municipalities which have a well-developed waste recycling system, the waste stream mainly consists of intractable wastes such as plastic film and non-recyclable packaging materials. In developed areas without significant recycling activity it predominantly includes food wastes, market wastes, yard wastes, plastic containers and product packaging materials, and other miscellaneous solid wastes from residential, commercial, institutional, and industrial sources (A. Ahsan, 2014). Most definitions of municipal solid waste do not include industrial wastes, agricultural wastes, medical waste, radioactive waste or sewage sludge. Waste collection is performed by the municipality within a given area. The term residual waste relates to waste left from household sources containing materials that have not been separated out or sent for processing (Vergara and Tchobanoglous, 2012).

Classification of Municipal solid waste

Biodegradable waste: Food and kitchen waste, green waste, paper (most can be recycled although some difficult to compost plant material may be excluded.

Recyclable materials: paper, cardboard, glass, bottles, jars, tin cans, aluminum cans, aluminum foil, metals, certain plastics, fabrics, clothes, tires, batteries, etc.

Inert waste: construction and demolition waste, dirt, rocks, debris.

Electrical and electronic waste (WEEE)- electrical appliances, light bulbs, washing machines, TVs, computers, screens, mobile phones, alarm clocks, watches, etc.

Composite wastes: waste clothing, Tetra Packs, waste plastics such as toys.

Hazardous waste : including most paints, chemicals, tires, batteries, light bulbs, electrical appliances, fluorescent lamps, aerosol spray cans, and fertilizers.

Toxic waste: including pesticides, herbicides, and fungicides.

Biomedical waste: expired pharmaceutical drugs, etc.

Municipal Solid Waste Management System in Bangladesh

In Bangladesh, like in most developing countries, the solid waste management has so far been ignored and least studied environmental issues. Recently the concerned stakeholders have begun to consider this area to be an essential component to protect human health and nature. The urban population in Bangladesh has increased at a very steep rate of about 6% per year and concentrated mostly in six major cities, namely, Dhaka, Chittagong, Khulna, Rajshahi, Barisal, and Sylhet. Current estimations showed that about 13% of total population and 55 to 60% of total urban population are living in these cities (Alamgir *et al*., 2005). In these cities, the city authority, nongovernmental organizations (NGOs), community based organizations (CBOs), and private organizations are working together to manage the MSW system properly. However, the overall situation remains unchanged. It becomes evident that an integrated solid wastes management system (ISWM) is required considering the relevant socioeconomic settings and technological aspects of the country (Ayuso *et al*, 1996). To explore the possibility of adopting an ISWM, the limitations, constraints, and relevant experiences of existing management system are required to examine explicitly (Beguin *et al*, 1994) . For this purpose, a feasibility study has been conducted to identify the present status including problems and limitations of MSW management in the least developed Asian countries (LDACs) through a research project, shortly named as Waste Safe (Alamgir and Ahsan, 2007).

Source Storage and Collection of Municipal Solid Wastes

Residential wastes are the main sources of MSW in Bangladesh. The other important sources are commercial wastes including markets, hotels, and restaurants, hospital/clinical wastes, institutional wastes including schools, colleges, universities, and government offices, construction and demolition wastes, and municipal services wastes such as street sweeping, drain cleaning but excluding treatment facilities. In Bangladesh, a significant portion of population does not have access to waste collection services and only a fraction of the generated wastes are actually collected by door-to-door collection systems introduced by NGOs and CBOs in late 90s in Bangladesh for tiny payment. Moreover, due to a lack of motivation, awareness, and commitment, a considerable portion of wastes, 40–60%, are not properly stored, collected, or disposed in the designated places for ultimate disposal. As a result, the unmanageable increasing quantity of MSW creates alarming environmental problems.

Residents participating in the existing solid waste management system store their solid wastes in plastic or metal containers of different sizes and shapes and keep them inside their house or premises, mostly in the kitchen and/or corridor (Bertoldi, 1983). Waste collection workers collect the container, then dispose it into the collection van, and return the empty container. Study reveals that source storage and separation of organic, inorganic, and hazardous wastes are highly neglected by the city dwellers. Generally, commingled solid wastes are collected in single-compartment vehicles (Brunow *et al*, 1997). Where door-to door collection systems are not available, house dwellers or servants carry wastes to nearby community bins/secondary sites on their own (Binz *et al*, 1997). The waste collection trucks collect the wastes at regular intervals for ultimate disposal. Households store the wastes at their own responsibility; however, some NGOs and CBOs even supply the bins to motivate people to cooperate with waste management system. Experiences reveal that proper storage and disposal are first steps to achieve the desired goal of solid waste management. Motivation of house owners and the door-to-door collection are proven to be very useful. However, the city authority has the lack of resources (e.g., manpower and budget) to provide the door-to-door collection system for each house. Chittagong and Rajshahi city authorities are involved in the door-to-door collection system. In Khulna, total management in a ward (out of 31 wards) including door-to door collections has been running by a private sector for the last 10 years. Figure 4 shows the wastes collection system from generation sources and disposal. The role of NGOs and CBOs in waste management is reported by Ahsan *et al*. (2012).

On-Site Storage of Municipal Solid Wastes

On-site storage spaces are the secondary disposal sites (SDSs), transfer stations, and handover points, which receive wastes from primary sources and then the wastes are transferred from this point to the designated location for processing/recycling/treatment and mostly for ultimate disposal (Camarero *et al*, 1999). There is no transfer station or handover point in Bangladesh in a true sense. The SDSs are considered as the facilities where large amounts of wastes are accumulated and finally transferred to the desired sites by large vehicles such as open or closed trucks and demountable haul container truck. A SDS may be an open space or roadside accumulation of solid wastes. They are large concrete bins, demountable large steel haul container, roadside spaces, and unused open low-lying areas. In Bangladesh, city authority is solely responsible for providing SDS, collecting wastes from SDS, and transferring for final disposal as per existing city corporation act. These sites are located in the selected places based on population, space availability, accessibility, and other unseen factors. Wastes are deposited in SDS directly by the generators, NGOs, CBOs and city authorities. In some cases, especially for the residential areas along narrow streets where SDS is not suitable to provide, community bins are provided, from where wastes are transferred to SDS. A wide variety of types and shapes of community bins are built by the civic bodies and/or city authorities, which are located on the roadsides at frequent intervals. Community bins are mostly made of concrete but masonry and steel containers are also available. The concrete and masonry bins are in variable sizes but normally rectangular in shape which is one-meter wide, one-meter high, and one-/two-meter long. Generally, there is a door at one side and no cover on the top of the community bins. Wastes from community bins are transferred to SDS mostly by city authorities through nonmotorized rickshaw van and hand trolley (Ahsan *et al*., 2014).

In Dhaka City Corporation (DCC) areas, there are more than 846 SDS, 640 community bins, and 206 waste containers. For the last 2 years, two private organizations (in 6 wards) disposed the wastes from SDSs to ultimate disposal sites (UDSs). They built their own SDS (with a large area) and practiced better management. In Chittagong City Corporation (CCC) areas, the total number of SDS and community bins is 1506: 849 masonry bin, 66 concrete bins, 32 steel container, and 558 open spaces. Besides, there are huge numbers of unauthorized small dumping sites spreading throughout CCC. In Khulna City Corporation (KCC), there are more than 60 SDSs, around 1200 community bins, and 28 haul containers located on roadsides throughout the city. In Rajshahi City Corporation (RCC) areas, there are 44 open types SDSs and about 190 community bins spreading over the whole city. There are no dustbins in RCC areas; recently all the dustbins have been removed from SDS. Rickshaw van pullers collect wastes from different sources and dump them into the open spaces randomly at SDS. There are 150 SDSs in Barisal

City Corporation (BCC) areas spearing unevenly over the whole city; as a result, some wards of BCC do not have SDS. In Sylhet City Corporation (SCC) areas, there are about 74 SDSs out of which only 30 to 35 sites are in use. In general, the SDSs have bin(s) made of concrete or masonry. Recently, three large sized SDSs with better facilities have been constructed with the assistance of an NGO (Ahsan *et al*., 2014).

In the MSW management tier, SDS plays a very pivotal role. However, the situations of SDSs in all city corporations are very much unpleasant and alarming. Since SDS, situated mostly at busy roadsides, receives and delivers wastes, proper management with very strict timing for collection and transfer is required which cannot be addressed by the city authority with existing management system, so alternative options of SDS should be considered. In the meantime, BCC already demolished all the permanent structures in SDS, while SCC is not using some points of SDS and already removed roadsides littering boxes. DCC is preparing a master plan and KCC is considering building a transfer station as an experimental station. In such situation, options should be kept open to solve these problems either by transfer station or handover points (Ahsan *et al*., 2014).

Transportation of Municipal Solid Wastes

The functional element of collection includes not only the gathering of solid wastes and recyclable materials but also the transportation of these materials after collection, to the location where the collection vehicle is emptied. Only respective city authority is responsible for collecting wastes from secondary points and transporting them by motorized vehicles/trucks and finally disposing them in the designated UDS(s) of the city. Although NGOs and CBOs collect wastes from households/generation points and dump them in the SDSs, they do not take responsibility for the collection and transportation of wastes from SDSs. However, in DCC it is found that two private companies have been collecting and transferring wastes from SDS to the city authority's UDSs for the last 2 years. These two private companies served only 6 wards out of 90 wards on a contract basis. In KCC, a private company has been collecting and transporting wastes for dumping them in the UDS for the last 10 years only in one ward out of the existing 31 wards (Ahsan *et al*., 2014).

Conservancy department set up the time schedule and fix vehicles for collection and transportation. Generally, collection vehicles such as dump truck, normal truck, open truck, tractor with trolley, tipping truck (container carrier), desledging vacuum tanker with tractor, and power tiller with trolley stand on the road nearby the SDS for operation. Staff are assigned with each vehicle for collection and disposal (Ahsan *et al*., 2014).

Demountable containers are only hauled by tipping truck and no workers are required for collection and disposal but its numbers are also limited. Wastes are mostly collected in daytime obstructing the movement of pedestrians and traffics and also transported through busy city areas creating nuisance and pollution due to being over heaped and uncovered and due to leakage of liquid from the wastes. City authority does not have the required number of vehicles and staffs to perform the operation successfully. Besides, the present management system is not capable of utilizing the existing resources properly. As a result, the collection of wastes from SDSs is very disappointing and creating a lot of hazards as wastes remain there for longtime (Ahsan *et al*., 2014).

Ultimate Disposal Sites of Municipal Solid Wastes

The safe and reliable long-term disposal of solid wastes is an important component of integrated waste management. Although source reduction, reuse, recycling, and composting can divert significant portions of MSW, a large amount of wastes still needs to be placed in landfills. There is no controlled/ engineered/sanitary landfill in Bangladesh. The sites are situated in and around the city areas of low-lying open spaces, unclaimed lands, riverbanks, and roadsides. DCC and CCC, each operates at two sites, namely, Matuail and Gabtali and Raufabad and Halishahar, respectively, while other city corporations operate at one site each, namely, Rajbandha, Shishu Park, North Kawnia, and Lalmati. All types of MSW are disposed including some portions of medical/ hospital wastes. Crude open dumping sites are always incompatible with the surroundings. Wind blows wastes to the surroundings. No proper land filling system is followed. Wind blows litters and spreading wastes outside the site and on the surrounding pond and adjacent surface water.

Environmental pollution at open dumping site may include air pollution, water and soil contamination due to generation of leachate, gas, odor, dust, and potential fire hazard. The uncontrolled burning of solid waste creates smoke and other types of air pollution. Garbage nuisance conditions also pose higher risks for human beings. As major parts of disposed wastes are biodegradable organic wastes, anaerobic decomposition gases are generated continuously. However, there is no provision for the management of these gases in existing sites, causing risk of explosions and fire hazard. In UDS, leachate may percolate and contaminate surface and ground water because these sites are not designed for leachate containment. The sources (tube-well) of groundwater are very close to the UDS. People use this water for different purposes like bathing, washing, drinking, and farming. Surface water is also contaminated because solid wastes are dumped near/at the marshy land, ponds, rivers, and canals. Contaminated water is harmful for fish and aquatic lives by reducing the amount of dissolved oxygen in the water. Chemical and oil constituents, which are usually mixed with MSW, can also cause severe water contamination that may kill water birds, shellfish, and other wildlife. Details can be found in Alamgir *et al*. (2005a; 2005b) and Mohiuddin *et al*. (2005).

City authorities are facing problems to get new sites for ultimate disposal. Due to nonengineered situation, the existing sites are also going for early closure. People also protested to close the existing sites because of nuisance. The existing method, that is, crude open dumping for ultimate disposal, is not supported by concerned environmental experts/stakeholders. Therefore, the city authority is thinking of upgrading the existing sites to control the negative impacts of the existing situation and may propose an environmentally safe sanitary landfill in accordance with local conditions and technological and financial capabilities.

Waste Minimization and Treatment of Municipal Solid Wastes

The MSW management includes and is not limited to the following components: source control, reuse, recycling, composting, land filling, and energy recovery. In the studied cities, there is no controlled or planned waste minimization program.

Recycling: Recycling is the reprocessing of wastes, into either the same product (closed loop recycling) or a different product (open loop recycling). It is the key mechanism to recover useful products and reduction in waste quantity. Source separation is the best process where different categories of recyclables and organics are separated at source, that is, at the point of generation, to facilitate reuse, recycling, and composting. Informal sectors by various groups of community are playing an important role in recycling of solid waste in Bangladesh. All the buyers of the recyclable items belong to the informal sector and only a few formal manufacturers are involved in using recyclable substance as raw material. However, in the studied areas, recycling is not practiced widely and effectively except for certain urban areas.

In Bangladesh, generally recycling is carried out in three phases. Phase one is the source separation, where the generators separate refuse of higher market value such as papers and paper products, bottles, fresh containers, plastic materials, tin, glass, metal, old clothes, and shoes and sell these things to street hawkers. Hawkers collect reusable and recyclable materials from house to house and sell them to nearer "Vangari Dokans" (recycling shops). In the second phase, the poor children of slum dwellers known as "Tokai" are collecting different items of low market value from onsite storage bins/containers and open storage spaces. The items include broken glass, cans, cardboard, waste papers, rags, pet bottles, coconut shells, metals, and miscellaneous commercial waste discarded by householders. The final phase is the recovering of reusable and recyclable materials from UDSs. Scavengers (Tokai) collect recyclable items mainly when collection vehicles are being unloaded at dumping site. The reclaimed materials are sold to Vangari Dokans by scavengers where intermediate processing like washing, drying, and sorting is carried out in proper form and sell these things to whole sellers. Ultimately, all reclaimed materials are supplied to the appropriate processing factories for reuse as raw materials. Plastic materials, in small scale, are also exported to the capital city after shredding and cleaning.

Composting: Another form of recycling is composting. Controlled biological decomposition of organic wastes produces a soil-like material known as compost. Composting is nature's way of recycling organic wastes into new soil used in vegetable and flower gardens, landscaping, and many other applications. The MSW of Bangladesh is suitable for composting due to its high moisture and organic contents.

In Bangladesh, mainly NGOs are involved in composting. They are involved in composting of organic wastes in 4 city corporations, namely, Dhaka, Chittagong, Khulna, and Sylhet.There is no compost plant in Barisal and Rajshahi city. Besides the city corporation areas, compost plants are also set up in some municipalities with technical supports from experienced NGOs, financial support from donor agencies with the collaboration of local city authorities. Recently, private companies have also come forward to invest in this sector. However, this sector is also facing several problems such as finance, appropriate technology, land, proper location, supply of wastes, quality of wastes, quality of compost, and marketing facilities. Recently, a compost plant in Sylhet was forced to stop its operation due to the objection from adjacent inhabitants. The situation of the surveyed compost plants is also not encouraging (Alamgir *et al*., 2005a); some of them are in a stage of closing the operation for the inherent reasons. In general, health and hygienic aspects are absent in all the compost plants. The staff are not properly trained and even do not care of using personal protective equipments. Most of them have been suffering from persistent diseases such as cough, allergy, and skin problem (Englehardt *et al*., 1999; Ray *et al*., 2005).

Integrated Municipal Solid Waste Management Approach

As there is no “solution” for MSW problems; an approach is required for evaluation, analysis, and synthesis of all aspects necessary for the selection of an ISWM suitable for Bangladesh. The approach is to seek the improvement of waste management through (i) a structural dialogue between stakeholders and (ii) the planning and implementation of change. The dialogue aims to promote desirable checks and balances between the focus and motivation of specific interests through a modern spreadsheet: (i) to promote a device to think the problems systematically and holistically, and (ii) to help for setout more selectively a balanced "business and sustainability" for some proposed intervention action. The common spreadsheet format consists of (i) waste system components forming the row headings of the spreadsheet, that is, contain and collect; sort and recover; transfer and treat; and dispose and make safe, and (ii) aspects of evaluating components forming the column headings of the spreadsheet, that is, sources and streams; costs and returns; health and environment; and community and structure. The municipal authority may decide to set up four working groups, corresponding to the four elements: contain and collect, sort and recover, transfer and treat, and dispose and make safe (Visvanathan *et al*., 2004).

The municipal authority may appoint independent chairpersons, involved representatives from key stakeholders, and organized technical support and wider consultative processes for each group. Overall programming and coordination are provided by the municipality itself. When the functional elements of the waste management services have been evaluated and selected and all the interfaces and connections between elements have been matched for effectiveness and economy, the concerned stakeholders/authorities/communities are said to have developed an integrated waste management system (Campbell, C.L. and Madden, L.V., 1990). The IMSW management is defined by researchers and academics as the selection and application of appropriate techniques, technologies, and management programs to achieve specific waste management objectives and goals. Understanding the interrelationships among various waste activities makes it possible to create a plan in which individual components complement one another Visvanathan *et al*. (2004).

In general, the situation of MSW management in Bangladesh is very alarming, poses serious health threats to humans and nature, and demands immediate and sustainable solutions. The study concludes that the problems will only be solved by introducing IMSW management systems, based on local needs and socioeconomic conditions to ensure environmental sustainability.

Biodegradation of lignocellulosic materials

Biodegradation of cellulose

A large number of microorganisms produce cellulolytic enzymes on lignocellulosic materials. Both cellulolytic and non-cellulolytic microorganisms establish synergistic relationship to break down the cellulose during the biodegradation of lignocellulosic materials. Their complementary interactions result in a complete biodegradation of lignocellulosic materials that release CO_2 and H_2O in aerobic condition and CO_2, CH_4 and H_2O in anaerobic conditions (Maheshwari *et al.,* 2000). The cellulases are multicomponent enzymes. Three major cellulase enzymes take part during the biodegradation of cellulose. These include endoglucanase (endo-1,4-β-d-glucanase, EC 3.2.1.4), cellobihydrolase (exo-1,4-β-d-glucanase, EC

3.2.1.91) and β-glucosidase (1,4-β-d-glucosidase, EC 3.2.1.21). Endoglucanase randomly cleaves the glycosidic bonds in cellulose. Cellobihydrolase acts on the non-reducing end of cleaved cellulose chain and removes cellobiose units from cellulose chains. Finally β-glucosidase acts on cellobiose and converts it into glucose units (Saha, 2004).

Cellulases are inducible enzymes (Aro *et al.,* 2005). Cellulase biosynthesis is stimulated remarkably in the presence of inducers. Cellobiose and sophorose (β-1, 2-glucobiose) are good inducers of cellulase enzymes. However, glucose is a strong repressor of cellulase enzymes (Ilmen *et al.,* 1997; Kubicek and Penttila, 1998). When wheat and RST were used as carbon sources *Melanocarpus* sp. *Neurospora crassa, Scytalidium thermophilum* and *Myceliophthora* sp. produced higher amounts of cellulases during the biodegradation process (Kaur *et al.*, 2006; Badhan *et al.*, 2007). However, when ammonium salts were used as nitrogen source cellulase production in *Thermoascus aurantiacus* and *Aspergillus fumigatus* were inhibited (Kalogeris *et al.*, 2003).

Biodegradation of hemicellulose

Hemicellulose is a heterogeneous polymer of pentoses, hexoses and sugar acids. Hemicellulose is degraded by the synergistic actions of hemicellulases. Xylanases are the best studied hemicellulase enzymes. Endoxylanases and xylosidases found in *Trichoderma* spp. and *Aspergillus* spp can completely breakdown xylan polymers. Endoxylanases cleave the backbone of xylan into smaller oligosaccharide xylobiose, which is further broken down to xylose by xylosidases (Malherbe and Cloete, 2002).

Biodegradation of lignin

Lignin-degrading mechanisms are extracellular and unspecific as lignin is a large and highly branched biopolymer. Oxidative enzymes cleave stable ether and carbon-carbon bonds in lignin (Hammel, 1997). The most important lignin-modifying enzymes are lignin peroxidases (LiPs), manganese peroxidases (MnPs), functional hybrids of both enzymes (versatile peroxidases VP) and laccases (phenol oxidases). All extracellular peroxidases and laccases catalyze oxidation reactions resulting in the formation of radicals which undergo several spontaneous reactions. These enzymes use low molecular mass mediators during lignin biodegradation which lead to various bond cleavages including aromatic ring fission (Kirk and Farrell 1987; Hatakka, 2001).

Microbial Composting

In Agriculture, composts have been used for thousands of years but its recent development is remarkable. The term 'composting' was first reported in English literature in 1587 and the verb 'to compost' in 1757 (Fitzpatrick *et al.*, 1998). Composting and compost refer to the biodegradation process and the end product, respectively (Stentiford and Dodds, 1992).

Composting is the biodegradation of organic materials under moist, self heating and aerobic conditions. It is characterized by a series of different microbial populations. Temperature, pH and nutrients change constantly during the composting process (Ryckeboer *et al.*, 2003). It is an environmental friendly and sustainable alternative for recycling of organic wastes. It reduces the bulk volume of organic materials, destroys weed seeds and pathogenic microorganisms in the ultimate end product (Bernal *et al.*, 2009). Typically composting results in a 25-35% weight reduction of the starting materials. This weight loss is due to the liberation of CO_2 and H_2O for microbial activity.

Composting process

Composting is different from natural rotting. Natural rotting occurs in an unmanaged waste pile, sanitary landfill and/or open dump (Roger *et al.*, 1991). However, composting is a controlled biochemical process. Different microbial populations mainly bacteria, actinobacteria and fungi convert organic materials to humus-like substances during the composting process. The composting end product is used as soil conditioner and/or organic fertilizer (Ahmad *et al.*, 2007).

Composting is a form of microbial farming. Microorganisms need food and energy during the composting process. They need carbon as energy source and nitrogen to build up cell structure, proteins, enzymes, and hormones. They take their necessary foods and nutrients from complex organic substances. The composting process continues as long as the nutrients are available to microorganisms. Nutrients released during the composting process remain in compost as humus and the dead bodies of microorganisms (Hamdy, 2005).

Biochemical changes in microbial composting

Microorganisms carry out the biodegradation of organic materials through various biochemical reactions. Different enzymes play important roles in catalyzing the biotransformation during the composting process (Garcia *et al.*, 1992). The enzymes involved in the composting process can be classified as (i). Intracellular enzymes which remain inside viable cells, and (ii) Extracellular enzymes, released by the microorganisms and remain outside of the cell. Intracellular enzymes act on reactions that occur inside the microbial cell. On the other hand, extracellular enzymes catalyze the reactions occurring outside the cell from which it originates. In both cases, the enzymes catalyze the biodegradation of complex organic materials into its building blocks. During the biotransformation of organic nitrogen, extracellular enzymes hydrolyze the proteins into nucleic acids and urea. The microorganisms assimilate the nucleic acids and ammonium is produced in microbial cells by the action of intracellular enzymes (Tiquia *et al.*, 2001).

Organic materials are composted through different biochemical pathways resulting in mineralization, transformation or stabilization (Said-Pullicino *et al.*, 2007). Microorganisms release various hydrolytic enzymes namely cellulases, hemicellulases, proteases, lipases, phosphatases and arylsulphatases (Cunha Queda *et al.*, 2002; Mondini *et al.*, 2004; Goyal *et al.*, 2005). Cellulases catalyze the hydrolysis of cellulose and provide energy to microorganisms. Lipases hydrolyze fats, waxes and microbial cell membranes; proteases and ureases catalyze the biodegradation of proteins to organic acids and ammonia. Phosphatases mineralize organic phosphorus and make it available to plants and microorganisms.

At the beginning of the composting process, nitrogen remains as simple peptides and proteins. Microorganisms mineralize the organic nitrogen to ammonia by ammonification reaction. Depending on the composting condition, the ammonia undergoes different biochemical processes, or may be dissolved as ammonium. Microorganisms use ammonium as a nitrogen source and convert it to organic nitrogen. On the other hand, when high temperatures prevail along with high pH (above 7.5), ammonia is volatilized and given off from the composting mixture (Witter and Lopez-Real, 1987). The nitrifying bacteria transform ammonium to nitrate when the temperature of the composting process remains below 40 ^{0}C with favorable aeration. When the oxygen supply is not sufficient, the microorganisms use nitrate as oxygen source which leads to denitrification and stops nitrification (Tisdale *et al.*, 1985). The nitrifying bacteria lower the pH of the medium due to the liberation of hydrogen ions during the nitrification process, and these changes can be summarized by the following equations

$$2NH_4^+ + 3O_2 = 2NO_2^- + 4H^+ + 2H_2O \quad (1)$$

$$2NO_2^- + O_2 = 2NO_3^- \quad (2)$$

Factors affecting microbial composting

Temperature

Temperature is the most important factor in the composting process. Microbial activity and decomposition rate during the composting process depends on temperature. It is an indicator of how long the decomposition has progressed and how the system is working (Horisawa *et al.*, 2008). Warm temperatures speed up while lower temperature slows down the biodegradation rate. The optimum temperature of the composting process ranges from 40 to 65 ^{0}C. Temperatures of 55 ^{0}C and above kill pathogenic microorganisms and destroy unwanted materials in the composting pile. When the temperature exceeds 65 ^{0}C the microbial activity declines rapidly. Microbial activity approaches to the lowest level at temperature 72 ^{0}C. The regulation of temperature is essential to control the composting process. In the composting process, temperature can be controlled through control of size and shape of the composting mass, improved cooling, turning and ventilation operations of the composting system (Bernal *et al.,* 2009).

Generally, the composting process is grouped into the biooxidative phase and the maturation or curing phase (Chen and Inber, 1993; Bernal *et al.*, 1996). The biooxidative phase can be further divided into three phases as follows (Keener *et al.*, 2000).

i) The mesophilic phase during which mesophilic microorganisms degrade simple compounds such as amino acids and proteins which increases the temperature quickly.

ii) The thermophilic phase where thermophilic and/or thermotolerant microorganisms biodegrade cellulose, hemicellulose, lignin and fats.

iii) The cooling phase when the mesophilic microorganisms again colonize the composting mixture and utilize the remaining sugars, cellulose, hemicellulose and lignin.

During the biooxidative phase complex organic substrates are converted to CO_2 and NH_3 with the consumption of O_2. On the other hand, during the maturation phase humification and stabilization of the organic matter occur and produce mature compost with humic characteristics. Thus the mature compost is achieved through the composting process as sanitized and stabilized end product (Gajalakshmi and Abbasi, 2008).

pH

The pH is an important factor in the composting process. It affects growth, development and activity of microorganisms during the composting process. Bacteria and actinobacteria are efficient in neutral pH conditions, while fungi and yeasts prefer acidic pH conditions (Olsson and Hahn-Hagerdal, 1996). Aerobic composting proceeds at neutral pH, and rarely encounters extreme drop or rise in pH. The optimum pH range for composting of organic materials is from 5.5 to 8.0. The optimum pH range for the biodegradation of glucose and protein is 7-8 and 6-9, respectively (Nakasaki *et al.*, 1993). At the beginning of the composting process, soluble and easily degradable carbon sources, such as monosaccharides, starch and lipids are utilized by microorganisms. As a result of this, the composting substrates become slightly acidic due to the production of short chain organic acids mainly lactic and acetic acid (Beck-Friis *et al.*, 2001). At low pH the acids remain in un-dissociated forms. The un-dissociated form of organic acids is toxic to microorganisms. They inhibit microbial activity during the composting process. As the temperature rises, microbial sensitivity to un-dissociated organic acids also increases. The low pH causes corrosion, odor and slow decomposition which reduces efficacy of the composting process. The low pH is also a serious problem in attaining high temperatures for proper sanitation. When microorganisms begin to degrade proteins, ammonium is produced as by-product. As a result, pH of the composting substrates increases. In addition, frequent turning and increased porosity of the composting substrates give faster reduction in short-chain organic acids. The mature compost has a pH range from 6 to 8 (Yang, 1997; Mc Lauren and Wade, 1999). Most garden plants grow well in a slightly acidic to neutral soil pH (pH 6.5-7). When compost with the pH range 6 to 8 is added to soil, it acts as a chemical buffer and increases plant tolerance to a broader pH range.

C/N ratio

The C/N ratio is an index of compost maturity. It affects growth and development of microorganisms during the composting process. The optimum C/N ratio varies with the nature of the substrates. Generally, the optimum C/N ratio is 25-30. Microorganisms use 30 carbon atoms for each nitrogen atom. They use carbon as their energy source. The major portion of carbon (approximately 2/3) is released as CO_2 during the oxidation reactions. The remaining portion serves to form cell protoplasm along with nitrogen, phosphorus, potassium and other micro-elements. Excess carbon slows down the microbial activity. On the other hand, excess nitrogen increases biodegradation rate. It also increases nitrogen loss through volatilization. Microorganisms use nitrogen in the synthesis of cell structure, hormones, enzymes, and proteins. They take nitrogen in the form of ammonium ion produced from the de-amination of proteins. It is also produced by the hydrolysis of urea, purines and pyrimidines. The lignocellulosic materials mixed with nitrogen sources resulting in optimum C/N ration enables smooth biological transformation. The C/N ratio in general changes throughout the composting process. A C/N ratio of less than or equal to 20 will be considered satisfactory during the maturation phase of the compost, when the initial values were between 25-30 (Sharma *et al.*, 1997; Goyal *et al.*, 2005).

Particle size

Smaller particle size increases the surface area of the composting materials. Porosity of the composting substrates also depends on particle size. In aerobic composting, the air-filled pore space should be in the range of 35 to 50 %. Large particles do not decompose quickly. Microorganisms cannot access easily into the interior of large particles as the surface area of larger particles become coated with an impassable humified layer. For rapid composting particle size must be less than 2 inches. Smaller and uniform particle size also enables the composting process to generate heat evenly throughout the composting pile. It prevents excessive drying at the surface of the pile. The composting piles having smaller particle size conserves heat and prevents moisture penetration from rain. On the other hand, too small a particle size can compact the pile and reduce the porosity of the composting substrates. This creates anaerobic conditions and bad odor generation (Bernal *et al.*, 2009).

Moisture

Moisture initiates the composting reaction. It provides the medium for transportation of dissolved nutrients required for the metabolic and physiological activities of microorganisms. In the composting process, decomposition occurs on the surfaces of composting particles in a thin liquid film. Generally, 60-70% moisture is optimum to begin the composting reactions. At final phase, the optimum moisture content is 50-55%. During the composting process, moisture adjustment is essential to balance between microbial activity and oxygen supply. Either high or low moisture content inhibit the composting process. Very low (<30%) moisture content creates early dehydration of the composting materials and very high moisture content causes anaerobic condition in the pile (Tiquia *et al.*, 1996, 2002). Excess moisture limits oxygen transportation by occupying pore spaces of the composting substrates. It creates putrefaction of the composting substrates resulting in bad odor and undesirable products. On the other hand, insufficient moisture limits the growth and development of microorganisms. As a result biodegradation rate is slowed down or even stopped. Therefore, it is important to maintain optimum moisture content during the composting process (Gajalakshmi and Abbasi, 2008).

Aeration

Aeration is essential for rapid decomposition. Aeration supplies O_2 to microorganisms. It also controls the heap temperature, removes excess moisture and CO_2. Proper aeration increases pH and microbial activity. It is essential to produce stable and quality end product. Low aeration creates anaerobic conditions which produce organic acids and as a result pH remains low (Brinton, 1998). Absence of air leads to different types of anaerobic microorganisms to develop causing acidic condition, putrefaction and bad odor. Ideally, the average carbon dioxide and oxygen content inside the mass should be about 20%, with O_2 concentration of 15-19.5% and CO_2 concentration of between 0.5- 5%. During the composting process, the O_2 concentration falls and CO_2 concentration increases. If the oxygen content falls below 15% the anaerobic microorganisms begin to exceed over the aerobic ones. Aeration is supplied by forced air flow through aeration pipes and mechanical turning or mixing. Mechanical turning or mixing increases porosity by loosening of the composting substrates, which increase aeration and removes CO_2 from the composting pile (Mc Lauren and Wade, 1999).

Composting of Grass Clippings

Yard waste/trimmings are defined as waste materials consisting of leaves, grass clippings, yard and garden debris, and brush, including clean woody vegetation material no greater than 6" in diameter, excluding any stumps, roots, or shrubs with intact root balls (State of Wisconsin 1994). Traditionally yard trimmings have been placed in landfills. In the last decade, stringent environmental requirements imposed on the design and construction of landfills have resulted in a substantial increase in the cost of landfilling. This has led to a movement to conserve existing landfill space by banning the placement of yard trimmings in landfills.

With this ban, municipalities, industries, and especially homeowners have been given the responsibility of recycling or properly disposing of yard trimmings without landfilling. Many municipalities and private companies have taken advantage of the landfill ban by providing compost related services. Compost facilities have tried to increase decomposition rates and improve the efficiency of the composting process which differs for various raw materials such as leaves, brush, grass clippings, wood chips, sawdust and pine needles (Brodie 1994). Intensively managed composting operations maintaining optimum conditions have converted grass clippings into compost within six weeks (Razvi, 1992). Improper management has resulted in poor quality product, longer time needed for decomposition (1-2 years), increased space needed for materials accumulated, and undesirable odors which annoy neighbors (Finstein 1986; Walker 1991; and Horst 1991).

The amount of time it takes to produce a mature compost must be balanced with the availability of space (Chandler 1990). With current technology, the composting process may be accelerated by controlling certain environmental conditions critical in the process, e.g., physical particle size, porosity, moisture content, pH, temperature, oxygen concentration, essential nutrients including nitrogen, available form of carbon, C:N ratio of feedstock, type of microorganisms, and lack of toxic substances (Inbar 1990; Golueke 1992; and Repenning 1994). When these conditions are carefully adjusted, microbial decomposition of the compost feedstock can be optimized. Compost activators/ additives/ starters are being marketed to help begin and/ or maintain high decomposition rates, despite an early study that showed there were no benefits from this practice.

Compost activators/ additives/ starters consist of varying amounts of different forms of microorganisms, mineral nutrients, vitamins, enzymes, and readily available forms of carbon. These activators claim to enhance critical microbial activity when in contact with waste material. The initial spurt of microbial activity may be able to, in some cases, sustain continued rapid decomposition with the conversion to compost. Compost activators are available to the consumer at most lawn and garden/ hardware stores across the USA. A common myth among many backyard composters is that some kind of compost activator/additive/starter is necessary for composting (Kourik 1993). In some cases, the starter is assumed to be a substitute for turning or watering the compost pile.

The effects of seven manufactured commercially available activators were evaluated for their efficiency in the composting of yard trimmings (grass clippings / wood chip mixture). Two naturally available additives, and a control (absence of activator) were also evaluated. Four measures of com posting efficiency were used to compare the overall decomposition response for each activator: weight loss, volume reduction, volatile solids decrease, and oxygen uptake rate. Four experimental blocks were set up in the field, and two experimental blocks were set up in the laboratory. The physical/ chemical characteristics of the compost material were monitored as a function of time for each additive. Interrelationships between measures of composting efficiency were also evaluated. Results showed that grass clippings can be composted as efficiently with naturally available materials such as topsoil or mature compost, as with commercially available compost activators, or an unactivated control. The cost of commercially available activators was $1.37 to $9.36 per cubic yard of compostable grass clippings. Naturally available materials such as topsoil and mature compost are available in needed quantities at no cost to backyard composters (Aga *et al*., 2015).

Decomposition Rates and Nitrogen Release of Turf Grass Clippings

Returning grass clippings provides a biodegradable source of organic N to the turfgrass ecosystem. The amount of mineralizable N available in such a system has a direct impact on the quality and vigor of the turf. By returning clippings, nutrients are recycled into the turfgrass system and N fertilization requirements may be reduced (Busey and Parker, 1992). However, literature reviewed on this topic indicated that there are few published, peer reviewed studies that have examined the effects of returning grass clippings upon the turfgrass/soil system. In particular, there are no field studies that have examined decomposition of turfgrass clippings and the rate of release of clipping N in a turfgrass/soil system. Therefore, it was the objective of this research to determine decomposition rates and N release patterns of cool-season turfgrass clippings returned to turf managed as a residential lawn. It was a further objective to determine whether the practice of returning clippings affected a cumulative decomposition response in turfgrass with time.

Decomposition rates and N release patterns of turfgrass clippings from lawns are not well understood. Litter bags containing clippings were inserted into the thatch layer of a cool season turf. The experiment was arranged as a 2 × 4 factorial in a randomized complete block design with three replicates. Treatments included four rates of N fertilizer (0, 98, 196, and 392 kg N ha-1 yr-1) and two clipping treatments (returned vs. removed). Litter bags were removed periodically over the growing season and samples were analyzed for biomass, N and C concentrations, and C:N ratio on an ash-free basis. Percentage N loss from the clippings after 16 weeks ranged from 88% to 93% at the 0 and 392 kg N ha-1 rates, respectively, and from 86% to 94% when clippings were removed (CRM) or returned (CRT), respectively. Percentage C loss from the clippings ranged from 94% to 95% at the 0 and 392 kg N ha-1 rates, respectively, and from 92% to 96% with CRM and CRT, respectively. Cumulative N release was similar across N fertilization rates, (ranging from 131 g N kg-1 to 135 g N kg-1 tissue) but was higher for CRT (151 g N kg-1 tissue) than for CRM (128 g N kg-1 tissue). Grass clippings decomposed rapidly and released N quickly when returned to the turf thatch layer. This indicates the potential for reduced N fertilization when clippings are returned. Such rapid decomposition also suggests that the contribution of grass clippings to thatch development is negligible (Kelly and Guillard, 2004).

CHAPTER III

MATERIALS AND METHODS

Experimental site

The experiment was conducted during October 2017 to February 2018 at Agroforestry Field Laboratory, SAU, Dhaka-1207.

Materials

The municipal solid waste (MSW) and cow dung (CD) was collected from SAU Campus, Dhaka-1207. MSW was consisted mainly of mixed foods, papers, plastics, vegetables parts, glasses, others residential wastes, etc. At first plastics, glasses, metals, and others inert materials were sorted out carefully from the MSW. Then MSW was left for drying and then ground with a mechanical grinder. Grass clippings (GC) collected from Agroforestry field laboratory was used as bulking materials. The GC was cut into uniform size by a chopper to facilitate the bioconversion process.

Characteristics of municipal solid waste (MSW), cowdung (CD) and grass clippings (GC)

The moisture contents of air dried MSW, GC and CD were 14.53, 11.22 and 13.93% (dry weight basis), respectively. The physiochemical properties of the MSW, GC and CD are given in Table 1.

Table 1. Chemical characteristics of substrates used in composting of municipal solid waste

Parameters	Municipal Solid Waste (MSW)	Cow dung (CD)	Grass Clippings (GC)
Carbon (%)	40.22 ± 0.59	31.42 ± 0.22	43.58 ± 0.66
Nitrogen (%)	1.12 ± 0.02	4.07 ± 0.29	0.96 ± 0.07
C/N ratio	35.91 ± 0.30	7.71 ± 0.03	45.39 ± 0.07
Phosphorus (%)	0.75 ± 0.02	2.15 ± 0.03	0.39 ± 0.03
Potassium (%)	1.80 ± 0.03	2.09 ± 0.03	1.12 ± 0.03
Calcium (%)	1.30 ± 0.02	1.68 ± 0.03	0.96 ± 0.02
Magnesium (%)	0.68 ± 0.02	1.33 ± 0.03	0.33 ± 0.02

Values are means of three replicated samples (± standard error)

Composting procedure

The composting process was conducted at the Agroforestry Field Laboratory, SAU, Dhaka-1207. Twenty kg of MSW along with 20 kg of CD and GC were mixed together according to treatments (Table 2) and amended with water to obtain a moisture content of about 60% (w/w). The moisture content was adjusted with a moisture meter. The prepared substrate was transferred into individual pit containing 40 kg of substrates and incubated for 12 weeks. Water was sprayed as required to maintain the moisture at the optimum level. The heaps were turned manually every other day for the first three weeks, and thereafter once a week to allow aeration and homogenization of the mixture.

Samples were collected at 4, 8 and 12 weeks during the bioconversion process.

Table 2. Treatments used in the bioconversion of Municipal Solid Waste

Code	Treatments
T_1	20 kg MSW + 20 kg CD
T_2	20 kg MSW + 5 kg CD + 15 kg GC
T_3	20 kg MSW + 10 kg CD + 10 kg GC
T_4	20 kg MSW + 15 kg CD + 5 kg GC
T_5	20 kg MSW + 20 kg GC

Analysis of end product

The bioconversion process was considered complete when the temperature at the center of the compost heap had cooled down to ambient air temperature. Compost samples from each treatment were taken accordingly during turning and analyzed for physical, and chemical properties. Each composite sample comprised of five random samples from each heap and mixed together. Composite samples were dried to constant weight (60 ^{0}C for 2 days) and used for chemical analysis. The dried samples were ground to pass through 2 mm sieve and stored in screw capped jars.

Temperature

The temperature of the compost heap was observed regularly between 9.00-10.00 am by hand feelings (Wong *et al*., 2001).

Bulk Density

Two copper rings were overlaid over each other with a tape and lined at the bottom with mesh filter. Individual substrate was filled into the rings and saturated with water and left overnight. The twin copper rings were separated and the sample was sliced to the same level or volume as a single ring. The weight of water saturated substrate (W_1) was determined and then oven dried at 105 ºC for 24 hours. After oven drying, the dry weight was recorded (W_2). Then the sample was removed from the copper ring and the weight of the empty copper ring (W_3) was determined to obtain the ring volume. Bulk density was calculated using the following formula (Blake and Hartge, 1986).

$$\text{Bulk Density} = \frac{weight\ after\ oven\ dry\ (g)}{volume\ of\ copper\ ring\ (cm^3)}$$

Where, Weight after oven dry

$$= \frac{net\ weight - (net\ weight \times moisture\ content)}{100}$$

$$\text{Net weight} = W_2 - W_3$$

$$\text{Moisture content} = \frac{W_1 - W_2 \times 100}{W_1 - W_3}$$

Phytotoxicity

The phytotoxicity of the compost extracts were evaluated based on germination index (GI) using chilli (*Capsicum annum* L.) seeds. Two g (dry weight) compost was mixed with 20 ml of distilled water in a jar with lid and shake vigorously. The compost extract was then filtered through Whatman No. 1 filter paper. Two ml of the supernatant was diluted with 1 ml of distilled water and sprayed into a Petri dish lined with double layer of Tissue paper. Twenty chilli seeds were placed in each dish and allowed to germinate. Dishes lined with Tissue paper moistened with distilled water served as controls. All plates were incubated in the dark at 28 ±2 ºC for five days and the number of germinated seeds and radicle lengths were recorded. The GI was determined by multiplying germination and radicle length expressed as percentage of control according to the following equation (Zucconi *et al*., 1981).

$$\text{GI} = \frac{\textit{Seed germination } (\%) \times \textit{Radicle length of treatment}}{\textit{Seed germination } (\%) \times \textit{Radicle length in distilled water}} \times 100$$

Total carbon

Organic matter was determined as loss of weight on ignition of samples maintained at 500 ^{0}C for 4 hours (Storer, 1984), and total carbon was calculated as 58% of organic matter (Chefetz *et al.,* 1996). One g samples of dried compost were weighed in a crucible and placed in a muffle furnace and ashed at 300 ^{0}C for one hour initially, and subsequently the temperature was raised to 500 ^{0}C for four hours. The carbon content was calculated based on the following equation:

$$\text{Carbon (\%)} = (100 - \%\ \text{ash}) \times 58\%$$

Determination of N, P, K, Ca and Mg

The N, P, K, Ca and Mg contents of compost samples were determined using the digestion method (Hach Company, 1999). A 0.25 g sample was placed in a digestion flask with 5 ml concentrated sulfuric acid (H_2SO_4) and digested on a block in a fume chamber. Initially, the mixture was heated at 200 ^{0}C for 30 min and then the temperature was raised to 360 ^{0}C for one hour. Then ten ml hydrogen peroxide (H_2O_2) was added and the digestion was allowed to continue until the solution become colorless. After cooling, the digested solution was made up to 100 ml with distilled water, and filtered through Whatman No. 2 filter paper into a plastic vial. Nitrogen and phosphorus were determined using the Autoanalyzer (System 4, Chem lab), while potassium, calcium and magnesium were determined using Absorption Spectrophotometer (Perkin Elemer Model 310).

Experimental design and data analysis

To investigate the individual treatment effect on the composting process of MSW, the five possible treatment combinations were arranged in a completely randomized design with three replications. The data were subjected to analysis of variance (ANOVA) and differences between means were tested for significance using Least Significant Difference (LSD) using the PC-SAS software.

CHAPTER IV

RESULTS AND DISCUSSION

Results

Bulk density

The mutual effects of grass clippings (GC) and cowdung (CD) on the changes in bulk density of substrate during the composting of municipal solid waste (MSW) are presented in Table 3. At the very beginning, the bulk density of the MSW substrate was 0.23-28 g cm^{-3}. The table 3 reveals that the bulk density continued to increase and reached values of between 0.32-0.48 g cm^{-3} at day 60. The treatment B showed significantly higher efficiencies compared to other treatments after day 30. At day 60, the significantly highest bulk density was found in treatment B (0.48 g cm^{-3}) followed by C with the value of 0.43 g cm^{-3}.

Table 3. Changes in bulk density (g cm^{-3}) during the microbial composting of RST at various pH levels

Treatments	Days of composting				
	0	15	30	45	60
T_1	0.23 c	0.23 b	0.26 ab	0.29 cd	0.34 cd
T_2	0.24 b	0.24 b	0.28 a	0.38 a	0.48 a
T_3	0.23 c	0.23 b	0.26 ab	0.34 b	0.43 b
T_4	0.23 c	0.24 b	0.26 ab	0.31 c	0.36 c
T_5	0.28 a	0.27 a	0.26 ab	0.28 d	0.32 d
$LSD_{0.05}$	*	*	*	*	*

Means within columns with the same letters are not significantly different at 5% level of probability

Temperature

When the pits are made and the water is added with the materials for compost, the temperature starts rising with time and it gets more than 72 ^{0}C after 15 days. The increased temperature results in killing the harmful microbial activities and makes the decomposition faster for optimum use as compost. With the time temperature gets cooler and gets down below 36 ^{0}C and helps generate beneficial microbial activities.

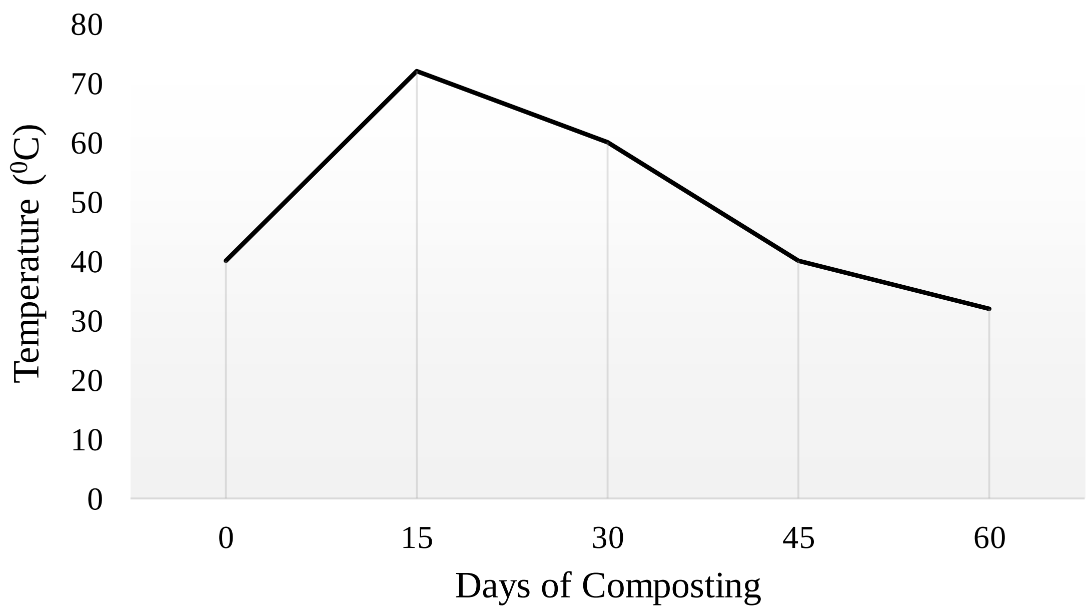

Figure 1. Changes in Temperature in Different Period of Time for MSW Compost

Germination Index

The combined effects of CD and GC on the germination response of chilli seeds during the composting of MSW are presented in Table 4. The decreasing trend at the very beginning and thereafter increased at the progress of the composting process was observed in the germination index (GI) of chilli seed. The GI was significantly lower in CD amended treatments compared to un-inoculated treatments at day 15, after that the trend reversed obviously. The GI of MSW reached to higher than 75 due to the combined effects of 5 kg CD and 15 kg GC at day 30 in treatment B. It was noted that at day 45 the highest GI was also found in treatment B (83.86%) whereas it was the lowest in non-amended treatment E (58.3%).

Table 4. Changes in germination index during the composting of MSW

Treatments	**Days of composting**				
	0	**15**	**30**	**45**	**60**
T_1	24.81 a	9.93 b	55.98 d	61.22 e	84.34 c
T_2	21.59 d	6.85 d	76.55 a	83.86 a	98.13 a
T_3	23.35 b	7.82 c	68.95 c	72.36 c	85.17 c
T_4	22.95 c	8.82 b	71.67 b	77.82 b	95.22 b
T_5	19.28 e	14.36 a	47.89 e	58.27 d	73.52 d
$LSD_{0.05}$	*	*	*	*	*

Means within columns with the same letters are not significantly different at 5% level of probability

C/N ratio

The effects of CD and GC on the changes in C/N ratio of chilli seeds during the bioconversion of MSW are presented in Table 5. At the onset of bioconversion process**, t**he initial C/N ratio in the substrates was in between 30.31 to 29.28 which continued to drop during composting. As expectation, significantly lower C/N ratio was found in inoculated treatments compared to un-inoculated treatments at day 14 and onwards. After day 30, C/N ratio reduced to the range of 17.17 to 23.87 in inoculated treatments whereas it was 25.68 in non-inoculated treatments. On day 45, the highest reduction in C/N ratio was found in treatment B (16.99) and it was the lowest in treatment E (19.46). Similar trend was also found in all treatments at day 60 where 34% faster decomposition was found in treatment B compared to treatment E.

Table 5. Changes in C/N ratio during the composting of MSW

Treatments	Days of composting				
	0	**15**	**30**	**45**	**60**
T_1	29.28	29.13 a	23.87 b	20.31 a	18.06 b
T_2	30.31	26.18 b	17.17 d	16.99 d	15.22 e
T_3	29.30	29.07 a	18.96 c	18.56 b	16.89 c
T_4	29.30	28.69 a	19.37 c	17.65 c	16.04 d
T_5	29.30	28.97 a	25.68 a	20.83 a	20.38 a
$LSD_{0.05}$	NS	*	*	*	*

Means within columns with the same letters are not significantly different at 5% level of probability

4.3.14 Accumulation of macronutrients

The combined effects of CD and GC on the accumulation of calcium (Ca), phosphorus (P), potassium (K) and magnesium (Mg) contents in the end products during the bioconversion of MSW are presented in Table 6. All the macronutrients increased during composting process of MSW, CD and GC. The higher efficiency was observed on the accumulation of Ca, P, K and Mg in the substrates which were amended with GC compared to non-amended condition. Comparing to other treatments, the substrates receiving treatment B showed higher trend of mineralization for all macronutrients.

Table 6. Accumulation of macronutrients (%) during the composting of MSW

Treatment	**MSW Compost**							
	Ca		**P**		**K**		**Mg**	
	Day 0	**Day 60**	**Day 0**	**Day 60**	**Day 0**	**Day 60**	**Day 0**	**Day 60**
T_1	1.21	2.01 c	0.71	1.27 b	1.91	2.21 c	0.73	0.97 d
T_2	1.19	2.61 a	0.69	1.43 a	1.89	2.69 a	0.72	1.51 a
T_3	1.23	2.19 c	0.73	1.37 b	1.89	2.61 b	0.73	1.19 c
T_4	1.18	2.50 b	0.74	1.47 a	1.90	2.72 a	0.71	1.42 b
T_5	1.20	1.92 d	0.71	1.04 c	1.91	2.18 cd	0.72	0.85 e
$LSD_{0.05}$	NS	*	NS	*	NS	*	NS	*

Means within columns with the same letters are not significantly different at 5% level of probability

4.3.16 Characteristics of matured MSW compost

Table 7 shows the properties of 60 day-old MSW compost amended with 5 kg CD and 15 kg GC. Different physical, and biochemical parameters showed that the MSW amended with 5 kg CD and 15 kg GC had reached a satisfactory level of maturity and stability known as MSW compost on the 60 day of composting.

Table 7. Properties of 60 day-old MSW compost amended with 5 kg CD and 15 kg GC

Parameters	MSW Compost
Bulk Density (gcm^{-3})	0.48
Total Carbon (%)	29.37
Total Nitrogen (%)	1.93
C/N ratio	15.22
Germination Index (%)	98.13
P(%)	1.47
K(%)	2.72
Ca(%)	2.61
Mg(%)	1.51

Discussion

Composts prepared from different organic materials differ in their quality and stability which depend on composition of raw materials and microorganisms (Ranalli *et al.,* 2001). Compost quality is related to its stability and maturity which cannot be evaluated by a single parameter (Bernal *et al.,* 2009). In this study, MSW amended with bulking materials GC and nitrogen source CD were evaluated for improved stability and maturity during composting of MSW where 15 kg GC and 5 kg of CD showed the most promising efficiency in terms of physical, and chemical parameters.

Bulk density (BD), germination index (GI) and C/N ratio are regarded as the typical physical and chemical parameters for compost stability and maturity (Zucconi *et al.,* 1981; Tiquia *et al.,* 1996; Hua-Shan, 2007). Bulk density (BD) is an important criterion in assessment of compost maturity. BD in the amended treatments of MSW was found higher than that of non-amended treatments during composting. This was due to the increased microbial activity which broke down the raw materials in the MSW into smaller pieces resulting in an increase in BD (Hua-Shan, 2007). Moreover, BD increased with composting time as the ash content increased and particle size was reduced due to increased biodegradation and frequent turning (Raviv *et al.,* 1987). Germination index (GI) is also a reliable tool to detect the damaging effects and phytotoxicity in composting process (Wong, 1985). It is reported that composts with GI values of above 50 are suitable for agricultural utilization (Jimenez and Garcia, 1989), and a value above 80 indicates that the compost is mature enough for field application (Tiquia *et al.,* 1996). The results of GI obtained in this study showed that CD and GC amendments exhibited phytotoxic effects during the early stage (first 15 days), but these gradually disappeared as composting proceeded. The GI of chilli seeds tested increased to over 75 at day 30 indicating the maturity of MSW compost. The initial phytotoxicity might be due to the release of high concentration of ammonia and low molecular weight organic acids (Fang and Wong, 1999). The increase in GI level after day 15 indicates volatilization of phytotoxins, especially ammonia and reduction of unstable organic acids. Previous research findings also showed that the presence of phytotoxins in decomposing organic matter represents a transient stage, and as the organic matter has become completely stabilized, the phytotoxins disappear (Inbar *et al*., 1990). The C/N ratio is used in compost maturity and stability assessment. The C/N ratio generally decreases except for an occasional increase due to loss of ammonia in initial phase, which finally reaches a more or less stable level. A C/N ratio of less than 20 is considered satisfactory maturation level for compost (Heerden *et al*., 2002. After day 30, the C/N ratio in treatment, B was 17.17 which indicate that MSW compost prepared with 20 kg of MSW, 5 kg CD and 15 kg GC was mature and suitable for field application. This result was in consistent with the findings of previous researches (Raut *et al*., 2009; Hossain *et al*., 2014) where they found C/N ratio was reduced to less than 15 from an initial value of 30.0 after 3 weeks of composting amended with lignocellulosic bulking agent.

The increase in total P, K, Ca and Mg in MSW compost was attributed due to the optimum extent of amendments with CD and GC which created favorable micro-environment for increased microbial activity during composting. The concentration of mineral elements increased with a consequent loss in dry weight of composting substrates (Bernal *et al.*, 2009). Moreover, the addition of the organic nitrogen source (CD) to lignocellulosic substrates increased the total nutrient contents in compost.

CHAPTER V

SUMMARY, CONCLUSION AND RECOMMENDATION

SUMMARY

Global MSW generation showed a twofold increase just only within 10 years from 0.68 billion tons per year in 2000 to 1.3 billion tons per year in 2010. Moreover, it is projected to reach 2.2 billion tons per year by 2025 and 4.2 billion tons per year by 2050. This humongous waste load of urbanized world if not managed properly will certainly have a negative impact on sustainable living style, local environment, and human health. Therefore, the objectives of this study were to find out more effective recycling method of composting from Municipal Solid Wastes and to evaluate the effect of lignocellulosic Grass Clippings on the stability, maturity and quality of the compost from Municipal Solid Waste. The agroforestry research field of SAU was occupied by a lot of weeds mostly consisted of grasses. It was like nuisance in the research field. It was necessary to either utilize the weeds or remove it. Besides the research plots needed compost and manure for the growth of the plants. So, one of the ways of utilizing the weeds for a research to find out best composting method with Municipal Solid Wastes and the right proportion was yet to be found out. The research was conducted on finding the better ratio of mixture with MSW as a composting agent, Cow dung as a Nitrogen Source and Grass Clippings as bulking agent. It was proven that the presence of grass clipping enhanced the temperature of the compost pit and the use of cow dung helped reach optimum Carbon and Nitrogen ratio at 15:1 after day 60. The addition of 15 kg of GC and 5 kg of CD enhanced the rate of MSW composting. Optimum physical (bulk density, GI and C/N ratio) were found with 15 kg of GC and 5 kg of CD compared to other combinations of GC and CD amendments. Higher nutrients (Ca and Mg) accumulation were also found under 15 kg of GC and 5 kg of CD indicating that amendments of bulking materials and nitrogen source was essential for the composting of MSW. Dumping the MSW at landfill creates environmental hazards and instead of decomposing of organic matters due to consisting of more than 70% water in the organic matters inside the MSW more of the time it gets rotten. Using the grass clipping and cow dung in optimum proportion enhances the stability, maturity and quality of compost from MSW.

CONCLUSION

The lignocellulosic materials grass clippings (GC) and nitrogen source cow dung (CD) amended with MSW produced good quality end product in a short period of time based on the physical, and chemical properties of MSW compost produced. The addition of 15 kg of GC and 5 kg of CD enhanced the rate of MSW composting. Optimum physical (bulk density, GI and C/N ratio) were found with 15 kg of GC and 5 kg of CD compared to other combinations of GC and CD amendments. Higher nutrients (Ca and Mg) accumulation were also found under 15 kg of GC and 5 kg of CD indicating that amendments of bulking materials and nitrogen source was essential for the composting of MSW.

RECOMMENDATION

i. As only grass clipping was used as bulking agent during the research it is recommended that other lignocellulosic materials like water hyacinth and field weeds can also be used as bulking agent.

ii. More research is highly appreciated before commercialization of the method.

CHAPTER VI

REFERENCE

Ahmad, R., Ghulam, J., Muhammad, A., Zahir A.Z. and Azeem, K. (2007). Bio-conversion of organic wastes for their recycling in *Agri.*: an overview of perspectives and prospects. *Annals of Micro.* **57**(4):471-479.

A. Ahsan, M. Alamgir, M. Imteaz, N. N. N. Daud, and R. Islam, (2012). "Role of NGOs and CBOs in waste management," *Iranian J. of Public Health*, **41**(6):27–38,

A. Ahsan, M. Alamgir, M. M. El-Sergany, S. Shams, M. K. Rowshon, and N. N. Nik Daud. (2014). Assessment of Municipal Solid Waste Management System in a Developing Country. *Chinese J. of Eng.* **2014**(561935):11, http://dx.doi.org/10.1155/2014/561935

Ayuso, M., Hernandez, T., Garcia, C. and Pascual, J.A. (1996). *Biochem.*ical and chemical-structural characterization of different organic materials used as manures. *Bio. Tech.* **57**:201–207.

Bernal, M.P., Alburquerque, J.A. and Moral, R. (2009). Composting of animal manures and chemical criteria for compost maturity assessment. A review. *Bio. Tech.* **100**(22):5444-5453.

Bernal, M.P., Navarro, A.F., Roig, A., Cegarra, J. and Garcia, D. (1996). Carbon and nitrogen transformation during composting of sweet sorghum bagasse. *Bio. and Fertility of Soils* **22**:141–148.

Bernal, M.P., Paredes, C., Sanchez-Monedero, M.A. and Cegarra, J. (1998). Maturity and stability parameters of composts prepared with a wide range of organic wastes. *Bio. Tech.* **63**:91–99.

Beguin, P. and Aubert, J.P. (1994). The biological degradation of cellulose. *FEMS Micro. Reviews* **13**:25–58.

Bertoldi, M. de, Vallini, G. and Pera, A. (1983). The Biology of Composting: A Review. *Waste Manage. and Res.* **1**:157-176.

Binz, T. and Canevascini, G. (1997). Purification and partial characterization of the *Ext.*racellular laccase from Ophiostoma novo-ulmi. *Current Micro.* **35**: 278–281.

Brunow, G. (2001). Methods to reveal the structure of lignin. In: Steinbüchel A. (ed.) Biopolymers. **1**: Hofrichter M., Steinbüchel A (eds.) *Lignin, Humic Substances and Coal*. Wiley-VCH, Germany, pp: 89–116.

Camarero, S., Sarkar, S., Ruiz-Duenas, F.J., Martínez, M.J. and Martínez, A.T. (1999). Description of a versatile peroxidase involved in the natural degradation of lignin that has both manganese peroxidase and lignin peroxidase substrate interaction sites. *The J. of Bio. Chem.* **274**:10324–10330.

Campbell, C.L. and Madden, L.V. (1990). Introduction to plant disease epidemiology. Wiely-inter*Sci.*. New York.
Chefetz, B., Chen, Y. and Hadar, Y. (1998). Purification and characterization of the laccase from *Chaetomium thermophilum* and its role in humification. *App. and Envi. Micro.* **64**:3175–3179.
Chefetz, B., Hatcher, P.G., Hader, Y. and Chen, Y. (1996). Chemical and biological characterization of organic matter during composting of municipal solid waste. *J. of Envi.l Quality* **25**:776-785.
Edens, W.A., Goins, T.Q., Dooley, D. and Henson, J.M. (1999). Purification and characterization of a secreted laccase of *Gaeumannomyces graminis* var. *tritici*. *Applied and Envi. Micro.* **65**:3071–3074.
Fang, M. and Wong, J.W.C. (1999). Effects of lime amendment on availability of heavy metals and maturation in sewage sludge composting. *Envi. Pol.* **106**:83-89.
Gabhane J, Tripathi A, Athar S, William P, Vaidya AN, Wate SR. 2016. Assessment of bioenergy potential of agricultural waste: A case study cum template. *J. Biofuel & Bioenergy* **2**:122-131.
Garcia-Gomez A, Bernal MP, Roig A. 2005. Organic matter fraction involved in degradation and humification processes during composting. *Compost. Sci. Utiliz.* **13**: 127–135.
Hamdy, H.S. (2005). Purification and characterization of the pectin lyase produced by *Rhizopus oryzae* grown on orange peels. *Annals of Micro.* **55**(3): 205-211.
Hammel, K.E**.** (1997). Fungal degradation of lignin. In: Driven by Nature: Plant Litter Quality and Decomposition. G. Cadisch and K.E. Giller (Eds.) *CAP International Wallingford* pp: 33–45.
Heerden, I.V., Cronje, C. Swart, S.H. and Kotze, J.M. (2002). Microbial, chemical and physical aspects of citrus waste composting. *Biore. Tech.* **81**:71-76.
Hua-Shan Tai and Wei-Hsiung He. (2007). A novel composting process for plant wastes in Taiwan military barracks. *Resources, Conservation and Recycling* **51**(2):408-417.
Inbar, Y., Chen, Y. and Hadar,Y. (1990). Characterization of humic substances formed during the composting of organic matter. *Soil Sci. Society of American J.* **54**: 1316-1323.
Inbar, Y., Hadar, Y. and Chen, Y. (1993). Recycling of cattle manure: the composting process and characterization of maturity. *J. of Ext. Quality* **22**:857-863.
Ilmen, M., Saloheimo, A., Onnela, M.L. and Penttila, M.E. (1997). Regulation of cellulase gene expression in the filamentous fungus *Trichoderma reesei*. *Applied and Ext. Micro.* **63**(4): 1298–1306.
Jimenez, E.I. and Garcia, V.P. (1989). Evaluation of city refuse compost maturity: a review. *Bio. Wastes* **27**:115-142.

Jinantana, J. and Sariah, M. (1998). Potential for biological control of sclerotium foot rot of chilli by *Trichoderma* spp. *PertanikaJ. of Tropical Agri. Sci.* **21**:1-10.

Kaur, J., Chadha, B.S. and Saini, H.S. (2006). Regulation of cellulase production in two thermophilic fungi *Melanocarpus* sp. MTCC 3922 and *Scytalidium thermophilum* MTCC 4520. *Enzyme and Microb. Tech.* **38**: 931–936.

Kirk, K. and Farrell, R.L. (1987). Enzymatic "combustion": the microbial degradation of lignin. *Annual Review of Micro.* **41**:465–505.

Kubicek, C.P. and Penttila, M.E. (1998). Regulation of production of plant polysaccharide degrading enzymes by *Trichoderma.* In G. E. Harman and C. P. Kubicek (eds.), *Trichoderma* and *Gliocladium*, vol. 2 Taylor & Francis Ltd., London, United Kingdom, pp:49–72.

Kumar, S., Dhar, H., Nair, V.V., Bhattacharyya, J.K., Vaidya, A. N., Akolkar, A. B. 2016. Charac. of municipal solid waste in high-altitude sub-tropical regions. Ext. Tech.. ***37*** *(20): 2627–2637.* doi:10.1080/09593330.2016.1158322. PMID 26915419.

Malherbe, S. and Cloete, T.E. (2002). Lignocellulose biodegradation: fundamentals and applications. Reviews in *Ext. Sci.* and *Bio. Tech.* **1**:105–114.

Mathur, S.P., Owen, G., Dinel, H. and Schnitzer, M. (1993). Determination of compost biomaturity. *Bio. Agri and Hort.* **10**: 65–85.

Perez, J., Munoz-Dorado, J., de la Rubia, T. and Martinez, J. (2002). Biodegradation and biological treatments of cellulose, hemicellulose and lignin: an overview. *International Micro.* **5**:53–63.

Pimentel, D. (1995). Amounts of pesticides reaching target pests: *Ext.* impacts and ethics. *J. of Agri.l and Ext. Ethics* **8**:17-29.

Raut, M.P., Prince William, S.P.M., Bhattacharyya, J.K., Chakrabarti, T. and Devotta, S. (2009). Microbial dynamics and enzyme activities during rapid composting of municipal solid waste – A compost maturity analysis perspective. *Biore. Tech.* **99**:6512–6519.

Raviv, M., Medina, S. and Shamir, Y. (1999). Cocomposting- a method to improve results of poultry manure composting. *Compost Sci. and Utilization* **7**:70-73.

Raviv, M., Tarre, S., Geler, Z. and Shelef, G. (1987). Changes in some physical and chemical-properties of fibrous solids from cow manure and digested cow manure during composting. *Biological Wastes* **19**:309–318.

Requena, N., Azcon, R. and Baca, M.T. (1996). Chemical changes in humic substances from compost due to incubation with ligno-cellulolytic microorganisms and effects on lettuce growth. *Applied Micro. and Biotech.* 45:857–863.

Rodriguez, J., Ferraz, A., Nogueira, R.F.P., Ferrer, I., Esposito, E. and Duran, N. (1997). Lignin degradation by the ascomycete *Chrysonilia sitophila*. *Applied Biochem. and BioTech.* **62**:233–242.

Roger, S.W., Jokela, E.J. and Smith, W.H. (1991). Recycling composted organic wastes on Florida forest lands. Dept. of Forest Resources and Conservation, Florida Cooperative Extention Services, University of Florida, USA.

Ryckeboer, J., Mergaert, J., Coosemans, J., Deprins, K. and Swings, J. (2003). Microbiological aspects of biowaste during composting in a monitored compost bin. *J. of Applied Micro.* **94**:127–137.

Saha, B.C. (2004). Production, purification and properties of endoglucanase from a newly isolated strain of *Mucor circinelloides*. *Process Biochem.* **39**:1871–1876.

Siddiqui, Y., Sariah, M., Ismail, M.R., Rahmani, M. and Ali, A. (2008). Bio-efficiency of compost Extracts on the wet rot incidence, morphological and physiological growth of okra (*Abelmoschus esculentus* [(L.) Moench]). *Scientia Hort.* **117**:9–14.

Stentiford, E.I. and Dodds, C.M. (1992). Composting. In Doelle, H.W. *et al*., (eds.) Solid Substrate Cultivation. Elsevier *Sci.* Publishers Ltd, London, 211-230.

Storer, D.A. (1984). A simple high sample volume ashing procedure for determination of soil organic matter. *Soil Sci. and Plant Analysis* **15**:759-772.

Tiquia, S.M., Tam, N.F.Y. and Hodgkiss, U. (1996). Microbial activities during composting of spent pig-and sawdust litter at different moisture contents. *Biore. Tech.* **55**:201–206.

Tiquia, S.M., Wan, J.H.C. and Tam, N.F.Y. (2001). Extracellular enzyme profiles during co-composting of poultry manure and yard trimmings. *Process Biochem..* **36**: 813–820.

Van der Werf, P. and Ormseth, J. (1997). Measuring process parameters at an enclosed composting facility. *Biocycle* **38**(5):58-61.

Wong, J.W.C, Mak, K.F., Chan, N.W., Lam, A., Fang, M., Zhou, L.X., Wu, Q.T. and Liao, X.D. (2001). Co-composting of soybean residues and leaves in Hong Kong. *Biore. Tech.* **76**(2): 99-106.

Wong, J.W.C., Li, S.W.Y. and Wong, M.H. (1995). Coal fly ash as a composting material for sewage sludge: effects on microbial activities. *Ext. Tech.* **16** (11):527–537.

Wong, M.H. (1985). Phytotoxicity of refuse compost during the process of maturation. *Ext. Pol (Series A) Eco and Bio.* **37**(2):159-174.

Yang, S.Q., Yan, Q.J., Jiang, Z.Q., Li, L.T., Tian, H.M. and Wang, Y.Z. (2006). High-level of xylanase production by the thermophilic *Paecilomyces thermophila* J18 on wheat straw in solid-state fermentation. *Biore. Tech.* **97**:1794–1800.

Yang, S.S. (1997). Preperation of compost, and evaluating its maturity. *Food and Fertilizer Tech. Center, Ext. Bulletin* (ISSN 0379-7587; 445) p23.
Yang, X., Chen, H., Gao, H. and Zuohu, L. (2002). Bioconversion of corn straw by coupling ensiling and solid-state fermentation. *Biore. Tech.* 78:277-280.
Zucconi, F., Monaco, A., Forte, M. and de Bertoldi, M. (1985). Phytotoxins during the stabilization of organic matter. In: Gasser, J.K.R. (Ed.), Composting of Agricultural and Other Wastes. Elsevier Applied *Sci.* Publishers, Barking, pp. 73–85.
Zucconi, F., Pera, A., Forte, M. and de Bertoldi, M. (1981). Evaluating toxicity of immature compost. *Biocycle* **22**:54–57.