BIRZEIT UNIVERSITY

Faculty of Graduate Studies

M.Sc. Program in Water and Environmental Engineering

Evaluation of Windrow Composting Pilots for Domestic Organic Waste Amended by Horse Manure and Biosolids

تقييم عملية مشاهدات دبال لنفايات منزليه عضويه معززه بروث خيل وحمأه

A Master Thesis Prepared By:

Ali T.M. Odeh

Student number (1135397)

Supervised By:

Dr. Rashed Al-Sa`ed

June, 2016

BIRZEIT UNIVERSITY

Faculty of Graduate Studies

M.Sc. Program in Water and Environmental Engineering

Evaluation of Windrow Composting Pilots for Domestic Organic Waste Amended by Horse Manure and Biosolids

تقييم عملية مشاهدات دبال لنفايات منزليه عضويه معززه بروث خيل وحمأه

A Master Thesis Prepared By:

Ali T.M. Odeh

Student number (1135397)

This thesis was submitted in partial fulfillment of the requirements for the Master's Degree in Water and Environmental Engineering from the Faculty of Graduate Studies, at Birzeit University, Palestine.

June, 2016

Evaluation of Windrow Composting Pilots for Domestic Organic Waste Amended by Horse Manure and Biosolids

تقييم عملية مشاهدات دبال لنفايات منزليه عضويه معززه بروث خيل وحمأه

By:

Ali T.M. Odeh

(Reg. #: 1135397)

This thesis was prepared under the supervision of Dr. Rashed Al-Sa'ed and has been approved by all members of examination committee:

Dr. Rashed Al-Sa'ed

(Chairman of the Committee) ....

Dr. Nidal Mahmoud

(Member) ....

Prof. Dr. Khalid Swaileh

(Member) ....

The findings, interpretations and conclusions expressed in this study do not necessarily express the views of Birzeit University, the views of the individual members of the M.Sc. Committee or views of their respective employers.

Date of Defense: 13-06-2016

Dedication

To my beloved parents, for all the love, guidance, giving, support, prayers, and continuous encouragement.

To Dr. Rashed Al-Sa`ed, my main supervisor for his guidance and continuous support.

To all my teachers, who taught me, especially Dr. Nidal Mahmoud and Dr. Maher Abu-Madi.

I dedicate this research study.

Acknowledgments

First, thanks God and peace be upon His messenger Mohamad, for blessing and giving me the all the strength necessary throughout my studies.

Many thanks are due to my main supervisor Dr. Rashed Al-Sa'ed for his continuous support and guidance throughout my M.Sc. study. The constructive comments from Dr. Nidal Mahmoud and Prof. Khaled Swaileh, members of the examination committee, helped me improve the thesis work quality.

To carry out this study, funding was provided through a joint research project carried at Birzeit University within the framework of “University of California-Davis-Diamond Dubai Sustainability Research and Training Program (SRTP)”, project No. 201500387-02, which is highly acknowledged.

Special thanks go to CDM smith; my current employer, for the support provided and kind understanding that enabled me achieve my studies successfully.

There are no words to describe the support provided by my family, great thanks to my parents, sisters and brothers for continuous inspiring and support during my whole study.

Abstract

The current solid waste management in Palestine is unsustainable due to inefficient resources recovery, weak institutional capacity, limited financial resources and severe environmental impacts. To achieve sustainability in Palestinian communities and enhance the protection of environment, recycling of organic waste using windrow composting warrants further exploration. Windrow composting of domestic organic waste forms an environmentally sound technology to alleviate the challenges facing waste management in Palestine. The specific aim of this research is to operate and evaluate two composting experiments including assessment of finished products.

The conduction of composting pilots was performed in two stages. The first stage was during the winter season. Five composting piles with different mixtures (ratio 2:1 wet weight) were prepared as follows:

- Pile No. 1 (2 Domestic organic waste + 1 Horse manure and saw dust spared through laying the mixture), pile No. 2 (2 Domestic organic waste + 1 Horse manure), pile No. 3 (2 Domestic organic waste + 1 Sludge and saw dust spared through laying the mixture), pile No. 4 (2 Domestic organic waste + 1 Sludge) and pile No. 5 (Domestic organic waste only and saw dust speeded through laying the mixture). All piles were prepare inside soil trenches.

The second experimental run was made during the summer period. Carbon to nitrogen ratios (C: N) were tested for four mixed samples as follows:

- First (1 Organic+ 1 Horse manure+ 1 Sludge), Second (1 Organic+ 2 Horse manure+ 1 Sludge), Third (1 Organic+ 1 Horse manure+ 2 Sludge), Fourth (2 Organic+ 1 Horse manure+ 1 Sludge).

Two mixture samples with the highest C:N ratios were selected to conduct the second experimental trials. The mixtures formed two compost piles: Pile No.1 (2 organic + 1 horse manure + 1 sludge) and pile No.2 (1 organic + 2 horse manure + 1 sludge). The various mixtures were processed using plastic containers in the greenhouse at university campus.

The composting process was controlled regularly (moisture content, temperature and pH). In both experimental stages, no major deviations in moisture content and pH values, but larger deviations were recorded in temperature measurements. Over the 100 experimental days

during winter first composting stage, the temperature ranged from 7 °C to 41 °C. Through summer second composting stage, the temperature ranged from 23 ^{0}C to 66 ^{0}C and at the end of composting process temperature values dropped down to be close from ambient temperature which considered indication of finishing composting process.

Lab analysis for compost quality parameters were made at Birzeit University Central Labs, tested parameters included heavy metals, nutrients and pathogens for the raw and finished compost. Compost maturity was performed for finished compost obtained from the first and second composting experiments. Results for heavy metals contents revealed that the compost quality for the both experimental stages complied with US EPA regulations. All samples of raw and finished compost were free from the *Salmonella*. For the first experiment there were no major differences in the content of microorganisms (fecal coliforms and *E. coli*) in the finished compost obtained from all compost piles which were less than 100 CFU/g except pile No. 3 (Organic + Sludge with Sawdust), this might be attributed to a low degree in sludge stabilization reflected in a higher microbial indicators content. For the second experiment, pathogens content in the finished compost were match US EPA standards were the fecal coliform less than 1000 CFU/g and *Salmonella* absent in the produced compost from the two piles. *E.coli* was within the international limits in the second pile but not in the first pile which could be affected by moisture content and nutrients content. Reduction in mass weight of raw compost materials reached to 58% for pile No.2 during summer experimental stage, for winter experiment pile No.5 presented 56 % weight reduction.

Pile No. 4 (2 Domestic organic waste + 1 Sludge) that processed during first experiment and pile No. 2 (1 organics, 2 horse manure, 1sludge) which processed during second experiment, presented results more comply with USEPA 40 CFR Part 503 standards than other piles in two the experiments.

This research study demonstrates operational methods that will aid in the design, operation and control of diverse windrow composting piles, especially those treating organic mixtures of different origins. To promote an integrated solid waste management in Palestine, the results obtained showed that windrow composting is an environmentally sound technology for resource recovery and waste reduction considering using compost for land reclamation and limited capacity of current landfills.

ملخص

تبحث هذه الدراسة في فاعلية تحويل النفايات الصلبه العضويه إلى سماد حيوي بواسطة عملية الدبال، حيث تعتبر هذه التكنلوجيا أمنه بيئياً وتمثل طريقه لمواجهة تحديات إدارة النفايات الصلبه خاصه في البلدان النامية. التصميم والتشغيل الامثل لعملية انتاج الدبال يعتبر الأهم وذلك لتعزيز الاستدامة في المراكز الحضرية وحماية البيئة الحضرية بطرق فاعله. يهدف هذا البحث الى تشغيل وتقييم تجربتين لانتاج سماد عضوي (دبال)، وتهدف ايضا الى تقييم جوده المنتج النهائي.

تم انجاز البحث من خلال تجربتين، وكان أولها خلال فصل الشتاء الذي حيث تم انجاز خمس محاولات لأنتاج السماد العضوي باستخدام خمس خلطات مختلفه، وتم استخدام نسبة (2: 1) لمزج المكونات الخام كما يلي: الكومه رقم (1) (خليط من نفايات عضوية منزليه + روث خيل وتم وضع نشارة الخشب بين طبقات الخليط)، خليط رقم (2) (نفايات عضوية منزليه + روث خيل) ، خليط رقم (3) (نفايات عضوية منزليه + حمأة وتم وضع نشارة الخشب بين طبقات الخليط)، خليط رقم (4) (نفايات عضوية منزليه + حمأة) و خليط رقم (5) (نفايات عضوية منزليه وتم وضع نشارة الخشب بين طبقات الخليط). حيث تم نشر كل خلطه من هذه الخلطات في حفره مخصصه وتمت اداره العمليه كما هو مبين في الفقره الثالثه.

التجربه الثانيه من البحث تمت خلال فصل الصيف ، في هذه التجربة تم فحص نسبة الكربون للنيتروجين لأربع خلطات كما يلي:

خليط رقم (1) (1 نفايات عضويه منزليه : 1 روث خيل: 1 حمأه) , خليط رقم (2) (1 نفايات عضويه منزليه : 2 روث خيل: 1 حمأه), رقم (3) (1 نفايات عضويه منزليه: 1 روث خيل: 2 حمأه), رقم (4) (2 نفايات عضويه منزليه : 1 روث خيل:1 حمأه) ومن ثم تم اختيار اثنتين من العينات والتي تحتوي على اعلى نسبة كربون للنيتروجين, حيث كان الخليط رقم 2 والخليط رقم 4. ثم تم نشر كل خلطه داخل برميل بلاستيكي وتمت اداره العمليه كما هو مبين اسفل.

تمت التحكم بالعملية من خلال إجراء قياسات دورية هي الرطوبة ودرجة الحرارة ودرجة الحموضة. في كلا المرحلتين الرطوبة ودرجة الحموضة وافقت المعايير والمواصفات ولكن فرق كبير لوحظ في قياسات درجات الحرارة خلال التجربتين . خلال التجربه الاولى واللتي كانت خلال فصل الشتاء تراوحت قياسات درجات الحرارة خلال 100 يوما من 7 درجه مئويه إلى 40 درجه مئويه في حين ان التجربه الثانيه واللتي كانت خلال فصل الصيف تراوحت القياسات خلال 76 يوما من 66 درجه مئويه إلى 23 درجه مئويه وفي نهاية هذه المرحله أصبح درجات الحراره على مقربة من درجة الحرارة المحيطة 25 درجه مئويه حيث انا ذلك يعتبر مؤشرا على انتهاء عملية انتاج الدبال.

تم تحليل معايير الجودة لجميع خلطات الدبال في مختبرات جامعة بيرزيت. اشتمل التحليل على قياسات المعادن الثقيلة والعناصر الغذائيه ومسببات الأمراض في المواد الخام والكمبوست الناتج، بعد انتهاء عملية انتاج الدبال في التجربه الأولى والثانية. بينت نتائج تحاليل المعادن الثقيله ان الدبال المنتج من كلتا التجربتين يقع ضمن مواصفات الوكالة الأمريكيه لحماية البيئه. هذا وقد أظهرت نتائج التحاليل ان الكمبوست الناتج من كلتا التجربتين خال من السالمونيلا.بالنسبة للمجهريات الاخرى مسببه للامراض "ايكولاي، والكولفورم"، تم القضاء عليها خلال في التجربه الاولى واللتي فصل الشتاء حيث لم يكن هنالك فرق كبير في الاحتواء على هذه الكائنات حيث ان المنتج النهائي من التجربه احتوى على اقل من 100 CFU/g باستثناء كومة رقم 3 (نفايات عضوية + الحمأة + نشارة الخشب) واللتي من الممكن انها تاثرت بانخفاض تثبيت الحماه واالذي ادى الى وجود هذه الكائنات بكميه اكبر. التجربة الثانية أظهرت احتواء اقل من مسببات الأمراض حيث توافقت النتائج مع مواصفات وكالة حماية البيئه الامريكيه وكان احتواء المنتج النهائي من الكولفورم اقل من 1000 CFU/g ، اما بالنسبه للايكولاي فكان وجودها في الكومه رقم (2) ضمن مواصفات الوكالة الأمريكيه لحماية البيئه بينما الكومه رقم (1) تجاوزت المواصفه واللتي من الممكن انها تاثرت بنسبة الرطوبه ووجود العناصر الغذائيه. اما نسبه تقليل كمية النفايات في المرحله الأولى وصلت إلى 56٪ من وزن الكميه في الكومه رقم (5)، في حين وصلت في المرحله الثانية التي أجريت خلال فصل الصيف إلى 58٪ من وزن الكميه في الكومه رقم (2).

جوده الدبال المنتج في التجربه الاولى من كومة رقم (4) (نفايات عضوية منزليه + حمأة) والمنتج في التجربه الثانيه من كومة رقم 2 (1 مواد عضوية، 2 روث خيل و 1 حمأة) كان الاكثر تطابقا مع متطلبات الجوده للوكالة الأمريكيه لحماية البيئية.

توضح دراسة البحث طرق تشغيلية من شأنها أن تساعد في تصميم وتشغيل وضبط مختلف عمليات مشاهده للدبال، وخصوصا تلك التي تعالج خليط من المواد العضوية ذات أصول مختلفة. ولتعزيز الإدارة المتكاملة للنفايات الصلبة في فلسطين، أظهرت نتائج هذه الدراسه بان تكنلوجيا الدبال تمثل طريقه أمنه بيئيا يتحقق معها تدوير المواد العضويه وعناصر التغذيه وكذلك خفض كميات النفايات الصلبه واستخدام الدبال لاستصلاح الأراضي باعتبار محدودية قدرة الأستيعاب لدى اللمكبات البلديه الحاليه.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

ARIJ: Applied Research Institute, Jerusalem.

C:N : Carbon, Nitrogen Ratio.

EPA: Environmental Protection Agency.

ICP: Inductively coupled plasma

ISO: International Organization for Standardization

ISWM: Integrated Solid Waste Management.

MC: Moisture content

MSW: Municipal Solid Waste.

MSWM: Municipal Solid Waste Management.

NGOs: Non-Governmental Organizations.

NPK: Nitrogen, Phosphorous, Potassium

OM: Organic Matter.

PCBs: Palestinian Central Bureau of statistics.

pH: Acidity or Basicity

SWM: Solid Waste Management.

TKN: Total Kjeldahl Nitrogen

UCD: University of California, Davis

WB: West Bank.

WM: Waste Management.

USEPA: United States Environmental Protection Agency.

WEF: Water Environment Federation

WWTP: Wastewater Treatment Plant

CFU: Colony forming unit

MSW: Municipal Solid Waste

MPN: Most Probable Number

Dw: Dry Weight

1. Chapter One – Introduction

1.1. Background and Problem Definition

During the decade, last community and business clients believed that the waste materials, as of remaining organic foods, grass, animal manure and biosolids is a problem that needs to be solved. After deep research and experiments many of environmental agencies and businesspersons are converting this former problem into an environmental friendly income resource.

Accumulating large amounts of urban solid waste which is causing environmental pollutions have promoted researches into waste recycling (Körner et al., 2003). The organic waste fraction can be used as fertilizers for agricultural land and bioremediation of degraded soil (Garcia et al., 1991). However, direct use of urban waste streams may cause short and long term environmental problems pertinent to heavy metals and pathogenic microorganisms, mischievous odors or phytotoxic organic compounds (Diez et al., 2001; Garcia et al., 1991). These risks can become less by stabilizing the organic matter founded in these wastes by composting (Pascual et al., 1997; Tognetti et al., 2005).

The current solid waste management in Palestine is unsustainable due to technical, financial, socio-cultural, management and political issues. This current situation, urges for pollution sources control to reduce annual pollution loads caused by wild dumpsites and illegal waste disposal on land, seasonal wadis, and uncontrolled dumpsites. Achieving an integrated solid waste management forms one of the main challenges facing sustainability for Palestinian communities, where only 65% of population are served by centralized joint service councils (Mafarjeh, 2011). Due to the high organic content of municipal solid waste that reach up to 70 %, composting remains an interesting treatment option (ARIJ, 2006).

Improper waste management in Palestinian communities pose adverse impacts considering the heterogeneous composition with hazardous materials. Diaz et al., (2003) reported that uncontrolled waste disposal with poorly controlled intermediate decomposition products contaminated natural resources (air, water and soil). Composting is an environmentally sound treatment technology for municipal solid waste, where finished compost can increase the quantity of the soil organic fertilizers, hence protecting the environment. However, to get high compost quality, composting techniques have to be improved efficiently. Therefore, the manipulative measures of the nutrient element used in the composting are an important approach to improve the agronomical compost value (Hua et al., 2006).

Worldwide, urban centers and suburb areas, like The Sustainable City in Dubai, are envisaging zero waste emission considering solid waste recycling. Establishing recycling facilities through waste reuse, repair, retrieve, and recycling promote environmental protection, and waste reduction and health risk reduction also integrated waste management strategy for any given community. A research team (Pandey et al., 2014) are developing a supply chain model aiming at the determination of available organic waste fraction, conversion efficacy (from feedstock C, N, P to C, N, P of digestate), soil amendment yield and demand of The Sustainable City, Dubai, engaged in urban agriculture.

Composting is the aerobic biological degradation of organic materials to produce a stable humus-like product (USEPA, 1993). Naturally biodegradation is a biological process. Food scraps rotting in a trash can be an example of natural and slow uncontrolled decomposition. Controlling environmental conditions during the composting process can enhance the rate of degradation and derive the most benefit from this natural process to obtain high quality of finished compost (Illmer and Schinner, 1997).

The finished product of the windrow compositing process is called compost, in addition to water and carbon dioxide as by-products. Weed seeds and pathogens should be absent in the finished compost. Temperature needed to reduce pathogens is 55 ^{o}C or over for 15 d at least, according to USEPA's recommendations (Yaghmaeian et al., 2005).

In Palestine most of Wastewater treatment plants throw periodically dewatered sludge into an uncontrolled dump sites. Also households produce daily 2,551 ton of solid wastes which represents 79% of all generated wastes (PCBS, 2015), most of generated household wastes are organics accumulation of these wastes causes a lot of environmental problems, such as odors, pathogen insects and sometimes affect shallow ground water aquifers.

Recycling and composting have not been applied to any significant levels in Palestinian cities that under occupation (ARIJ, 2005) also Palestine territories are suffering from shortage of land spaces and insufficient funds to create health landfill sites .Therefore, strategies that reduce waste volume, protect natural resources and less energy consumable are needed, as of composting researches may be significant solutions to deal with these pollutants and to produce organic , safe and cheap fertilizers.

Particular emphasis should be given on type and mixture of waste feed, proper height and volume of the composting pile, C:N ratio, moisture content, aeration, and turning frequency when designing windrow composting facilities in Palestine. Footprint is a crucial design parameter for windrow composting technology due to land scarcity required the establishment of composting facilities in most urban areas in the country. Innovative design of the composting plant should consider a rapid decomposition of waste materials to ensure less land demand for the compost plant. The above design parameters are very useful in space requirements determination and for preparing effective layout plans of the composting facility envisaged. Therefore, innovative and optimized design procedures for windrow composting technology are needed to promote sustainable waste management in Palestinian communities. To the best of our knowledge, there are neither single comprehensive design procedures nor a unified quality criteria for finished compost. Large scale projects are still lacking in Palestine, where few industrial attempts failed due to week public awareness (Hmaidi, personal communications). This research study aims at exploring the main design parameters, process operation and quality of finished compost using windrow pilots of different organic mixtures at Birzeit University campus.

1.2. Aim and Objectives

The major aim of this study is to identify proper design and operational parameters for windrow composting pilots using domestic waste mixed with horse manure and biosolids.

This study aims at achieving the following specific objectives:

- Identify optimal process design and operation of windrow composting pilots
- Understand, observe and elucidate the factors that affect composting process
- Evaluate amount of reduction of waste due to this type of composting.
- Assess the quality of finished compost for land use considering USEPA compost quality guidelines.

The finding of this research study will provide guidance for waste policy makers and farmers, especially for projects which are planned to use organic waste stream, animal manure and biosolids as soil amendment for agricultural land.

1.3. Research Approach and Methodology

Mix of material consisting of dewatered sludge obtained from AL Tireh – Ramallah WWTP and horse manure obtained from Horses farm in Abu Qash village – Ramallah in addition to organic wastes obtained from the university cafeteria and vegetables peels. Several windrow composting piles were constructed inside the Birzeit university greenhouse (Figure 1-1), which's located 10 Km north of Ramallah city. Five windrow composting piles were operated through winter season and two through summer with different percentages from raw materials mentioned above.

Birzeit has Mediterranean climate. In winter temperature ranges from 0 to 10 °C and reaches to 30 °C through summer. Location of the study selected to protect the piles from rain. Figure 1-1 shows the green house from inside and outside.

Figure: 1-1 Study Location

1.4. Research Questions

- Which operational parameter will influence compost duration and finished product quality?
- Using different organic fractions of different origins (Domestic waste, horse manure, biosolids), which optimal mixture produces the highest quality of finished product?
- Will stabilized biosolids have impacts on compost process and finished product?
- What impacts will diverse C/N ratios have on composting process and finished product?

1.5. Thesis Outline

Chapter One – Introduction

This chapter Identifies problem definition, objectives of the study, research approach and research questions.

Chapter Two – Literature review

This chapter identifies composting Municipal solid waste management options (MSW) definition and classification of composting, impact of composting process on microbial activity, and the impact on chemicals also this chapter included composting methods ,phases and operation process and discussed quality factors of finished compost also uses of the finished compost.

Chapter Three - Research Methodology

This chapter clarifies the procedures and period used for preparing and controlling also assessing the quality of the compost process and this chapter clarifies parameters tested and lab analysis procedure for the study.

Chapter Four - Results and Discussion

This chapter includes analysis of the lab tests results and periodic filed measures.

Chapter Five – Conclusion and Recommendations

This chapter summarizes main conclusions with recommendations.

Chapter Six – References

This Chapter depicts all the references cited.

2. Chapter Two - Literature review

2.1 Municipal Solid Waste Management Options

To dispose from municipal solid wastes through efficient and health manner, protection agencies proposed some options as of EPA proposed integrated solid waste management options, some of them land filling, waste combustion and composting. Also (ISWM) principles recycling, reusing, reducing and recovery which are attractive and costless options to deal with municipal solid wastes (Yaghmaeian et al., 2005).

2.1.1 Land Disposal

It's a place to dispose from produced wastes by burial which consider the ancient form of waste disposal. Historically, landfills have been the most common method of organized waste disposal and remain in many places all around the world. Landfilling is easy method for waste disposal .Modern landfills developed to control the emissions and waste leachate to minimize negative impacts on the public health and environment whereas these techniques require additional costs (Sida, 2006, USEPA, 1995).

2.1.2 Combustion (Incineration)

Incinerating is a waste disposal process that includes burning organic materials contained in waste stream Knox et al., (2005). Method of using high-temperature for waste treatment is called "thermal treatment". Waste Incineration converts the waste into ash, flue gas, and heat, Incineration reduces the wastes volume by 90% and 20-30% of the original waste weight is left as ash Sakai et al., (1996). In some cases, the heat produced by incinerators can be used in producing electric power.

2.1.3 Reduce, Reuse, Recycle

Waste reduction is avoidance of generating wastes at source; EPA describes waste reduction as the design, manufacture, purchase or use of materials to decrease their amount or toxicity prior reach the waste stream (USEPA, 1995).

Reuse is using the products another time after it has been used the creative reuse is to use the product for a different purpose, Recycling is the process of converting waste materials into reusable objects to prevent waste of potentially useful materials, Recycling comes from converting wastes as of glass, paper and metal into a material that can be used again may be as a raw material for a new products. (The League of Women Voters, 1993). Composting also can be considered as a reuse and recycling since it works to biodegrade organic wastes to produce organic fertilizers.

2.2 Composting Definition and Process Characteristics

Composting is a managed technique for the biological decomposition and stabilization process for organics and Biosolids, composting has grown due increases in other solid waste management options like incineration, landfill, ocean disposal. Most solids composted in U.S are used as organic soil amendment and fertilizer (WEF, 1995). Some principal objectives of composting are, biological conversion of organics to a stabilized form, pathogen reduction through heat generated during composting, mass minimization through moisture and volatile solids removal and finished compost can help in reduction costs of using chemical fertilizers. According previous study carried by Sherman (1997) preferred characteristics to start composting process are listed in Table 2-1.

Table 2-1. Preferred values to start Composting Process (Sherman, 1997)

Characteristic	Practical range	Favored range
Carbon to nitrogen	20:1 - 40:1	25:1 - 30:1
Moisture content	40% - 65%	50% - 60%
Oxygen content	>6%	16% - 18.5%
pH	5.5 - 9.0	6.5 - 8.5
Particle size	1/8 - 2 inches diameter	Varies*
Temperature	110 - 140° F	130 - 140° F

2.3 Objectives of Composting Process

Irrespective of the composting process, the finished product should comply with local and regional public and environmental requirements. Biosolids and animal manure with organic waste impair the finished product. Therefore the composting process should achieve pathogens reduction, maturation and drying (WEF, 2010).

2.3.1 Pathogen Reduction

According to a study prepared by Gong et al., (2005) through analysis of some composting samples, pathogenic bacteria were detected which were coliform bacteria, *Salmonella* and *E. coli*. The number of coliform bacteria reached to 2.5 x 10^6 CFU/g dw and for *Salmonella* reached to 6.0 x 10^3 CFU/g (dw). The analysis presented that the moisture content was a main reason to the heat sensitivity of pathogenic bacteria in compost. As of *E.coli* will be more sensitive in moisture conditions than dry ones.

Temperature is key parameter to evaluate the level of elimination of pathogenic microorganisms and weed seeds which cause diseases for human and plant. Temperatures higher than 55 ^{o}C have been attributed to the removal of pathogenic microorganisms (Joshua, 1998). Composting operator has to take in consideration excess raise of temperature because the increment above 60-65 ^{0}C, may kill the beneficial microorganisms (Trautman et al., 1997).

Composting in the thermophilic range remove practically all viral, bacterial, and parasitic pathogens (WEF, 2007), some fungi (e.g., *Aspergillus fumigatus*) are the most tolerant and, therefore, stay alive.

Salmonella can regrow in finished compost. However, parasite ova and virus cannot. Regrowth can be reduced by not using the same equipment to handle both raw feed and finished compost or by cleaning the equipment before handling finished compost. Many microorganisms can function as secondary pathogens, although composting conditions favor the growth of some more than others, where a fungus *A. fumigatus* has been isolated at relatively high concentrations from finished compost and from compost-pile zones at less than 60°C (WEF, 2010).

During composting operations of windrow and reactor studies at the Los Angeles County Sanitation District in California (WEF, 2010), it was found that compost feedstock contained 1000 to 10 000 CFU/g; after composting, biosolids contained 10 CFU/g. Exposure to airborne spores can be minimized by controlling dust. So, compost should not be allowed to become too dry, and workers should be provided with dust masks when working in dusty areas.

2.3.2 Maturation

Maturation is conversion of the mixture's rapidly biodegradable components into materials as of soil texture, which decomposes slowly. Insufficiently mature compost will reheat and generate odors when stored and rewetted. It also may inhibit seed germination (by generating organic acids) and plant growth (by removing nitrogen as it decomposes in soil). Stability refers to the reduction in microbial-degradation rate of the mixture's biodegradable components. Cellulose materials (e.g., wood and yard wastes) take longer to decompose than wastewater residuals, so screening out the bulking agent may improve stability. Mature compost should have a carbon-to-nitrogen ratio less than 20:1 (WEF, 2010). Compost curing usually takes three to four months to produce biologically stable humus (USEPA, 1995).

2.3.3 Drying

To dry compost, operators have to provide enough aeration or agitation to facilitate the removal of water vapor. This increases the solids content from 40% to 55% or more. Drying is critical activity that includes screening, since the screens do not perform well if the compost contains less than 50% to 55% solids (WEF, 2010).

2.4 Composting Methods

Degree of control imposed on a system can range from periodically turning a pile or windrow to the more involved enclosed or in-vessel system with mechanical recirculation and forced aeration.

To satisfy global requirements, a number of composting methods have been developed. These methods offer the following benefits: accelerating a naturally occurring biological process, providing process control variables such as moisture, carbon, nitrogen, and oxygen, containing odors and particulate, reducing land area requirements; reliably producing consistent product quality, and integrating aesthetically pleasing facilities into local and regional sites (WEF,2010).

2.4.1 Windrow Composting

In windrow composting, the raw mixture is formed into long parallel windrows whose cross-sections are either trapezoidal or triangular (Figure 2-1). The material then is turned on detected time by a front-end loader or a dedicated windrow-turning machine to control the moisture, and for aeration (WEF, 2010).

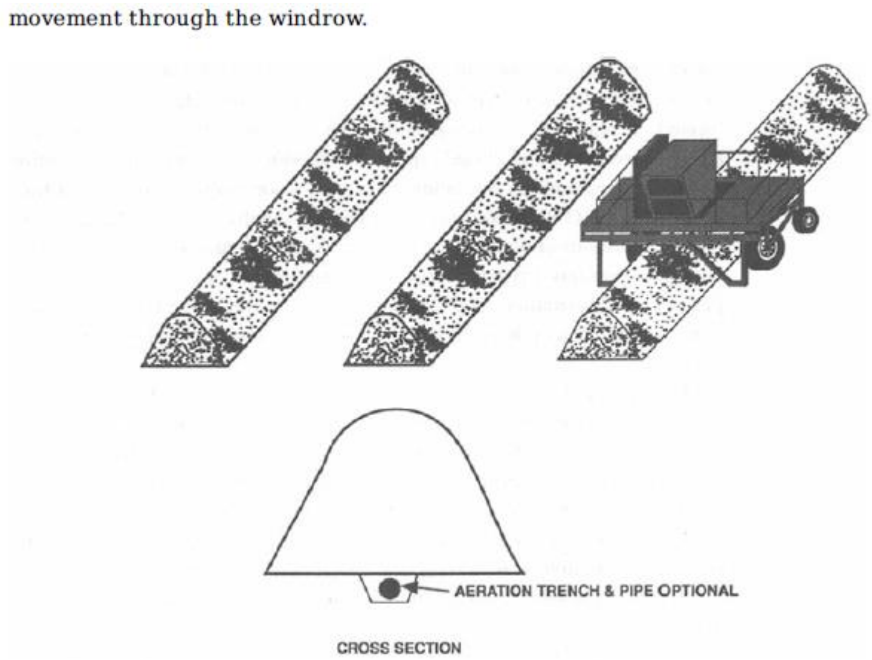

Figure 2-1- Schematic of a windrow composting system (WEF, 2010).

In the aerated windrow method, windrows are constructed over air channels to protect aeration piping from the turning equipment. Air can either be forced up through the Windrow or pulled down through the Windrow into the channel. The windrows are turned frequently to expose more particles to air. Aeration and turning optimize the composting rate and release of moisture.

Windrow composting occurs at open outdoor sites or covered sites. This system needs more space than other composting technologies because of pile geometry and the room needed to maneuver a windrow-turning machine (WEF, 2010).

2.4.2 Aerated Static-Pile Composting

Aerated static-pile composter is also called the Beltsville Method this composter involves aerating piled feedstock (Figure 2-2). This flexible method is popular in the United States. In this method, the mixture is constructed into a (2 to 4 m) deep pile over an aeration floor and then covered with a (150 to 300 mm) deep insulating blanket of wood chips or unscreened finished compost to ensure that all of the mixture will meet the temperature standards for pathogen reduction.

Small operations may construct individual piles, while large ones may divide a continuous pile into sections representing each day's contribution. The mixture typically remains in the pile for 21 to 28 days while the plenum forces air through the material to provide an aerobic composting environment. Then the piles are broken down, and the material is either moved directly to a curing area, or screened and then moved to the curing area. Compost must contain at least 50 to 55% solids before screening. In some facilities, an intensive drying step precedes screening. Some facilities screen the compost after curing (rather than before curing) (WEF, 2010).

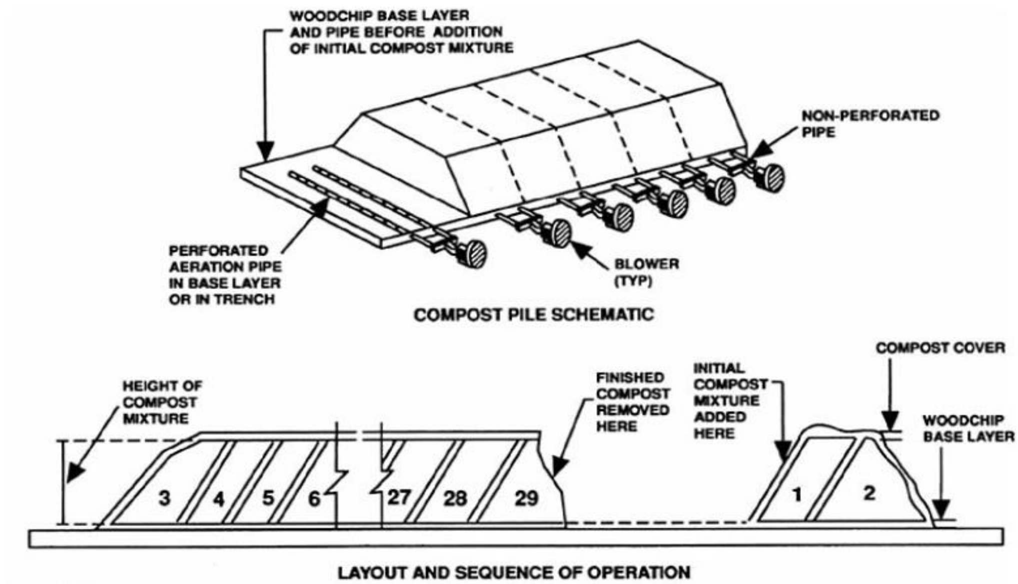

Figure 2-2: Aerated static-pile composter (WEF, 2010).

Aerated static-pile composter originally was developed for outdoor sites, but many systems are either partially or fully enclosed to control odors or facilitate operations during unfavorable environmental conditions as of temperature and / or rainfall extremes.

2.4.3 In-Vessel Composting

According to WEF (2010), in-vessel systems typically combine aeration with some type of automated material movement in a reactor.

The solids retention time inside the composter ranges from 10 to 21 days, depending on system-supplier recommendations, regulatory requirements, and costs. It also should be based on desired product characteristics and take into account the overall solids residence time in the entire composting operation (al process phases). Once discharged from the reactor, the composted biosolids typically must be further stabilized for 30 to 60 days to achieve the desired product stability.

According to Iyengar et al., (2005), there are basically three types of in-vessel composting systems: vertical plug-flow reactors, horizontal plug-flow reactors, and agitated bay systems. Vertical plug-flow reactors are made of steel, concrete, and/or reinforced fiber-glass panels (Figure 2-3). A mix of dewatered cake, amendment, and recycled solids is loaded in the top of the reactor, where it is aerated but not mixed. It moves as a plug to the bottom of the reactor, where it is removed via a traveling auger. Horizontal plug-flow reactors are similar to vertical ones, except that the solids– amendment mixture is moved laterally through the reactor by a hydraulic ram.

Agitated-bay reactors are open-topped bays with, with blowers and piping systems that supply air from the bottom (Figure 2-3). Unlike plug-flow reactors, they also have mechanical devices that periodically agitate the mixture during its stay in the reactor. These systems are designed to function much like aerated windrows. A variety of methods are used to transfer compost from the reactors (Iyengar et al., 2005).

The most commonly used in-vessel system is the horizontal agitated-bed reactor. These reactors are rectangular, aerated from the bottom with independently programmable aeration zones, and enclosed in a building. A loader places the solids–amendment mixture into the front end. The agitation device operates only in agitation mode, and typically makes one pass through the reactor each day. The composting material is dug out and redeposited about 4 m (11 ft) behind the machine until it has moved through the entire length of the reactor (WEF, 2010).

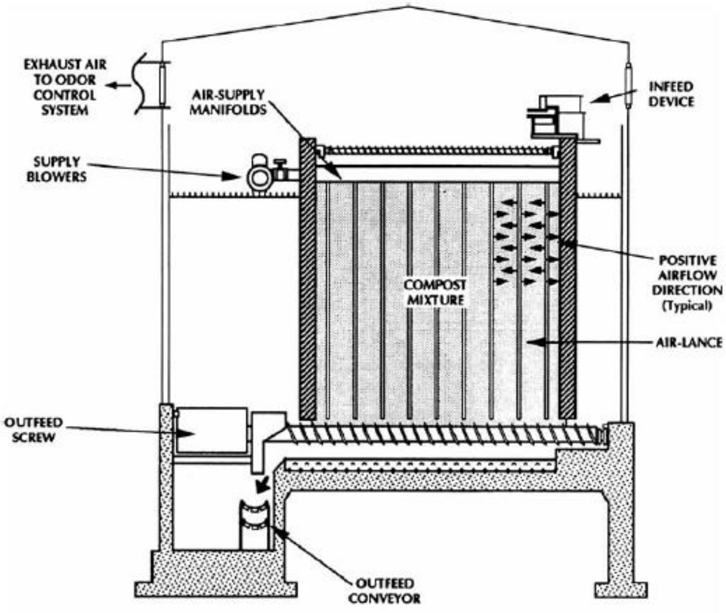

Figure 2-3: Cross-section of a vertical plug-flow reactor (WEF, 2010).

2.5 Composting Quality Control Factors

In a study by Naylor et al., (2004) biodegradable (compostable materials) are affect by environmental conditions some of them important for the growth others for sterilize as clarified

2.5.1 Particles Size and Composability

Naylor et al., (2004), reported that particle size, surface to volume ratio and shredding are main physical items need consideration to increase piles porosity, when using large particles the porosity will be less so its preferred to use small particle size to increase the voids, to get good biodegradability, the preferred particle size is 1/8 to 2 inches diameter.

2.5.2 Temperature

Preferred temperature during operation has to include thermophilic temperatures due to some organisms in the process have their optimal level in thermophilic temperatures, to reduce weed seeds and pathogen as high part of them cannot resist exposure to thermophilic temperatures. Temperature isn’t preferred to 60 °C in order to prevent inhibition of some microbes.

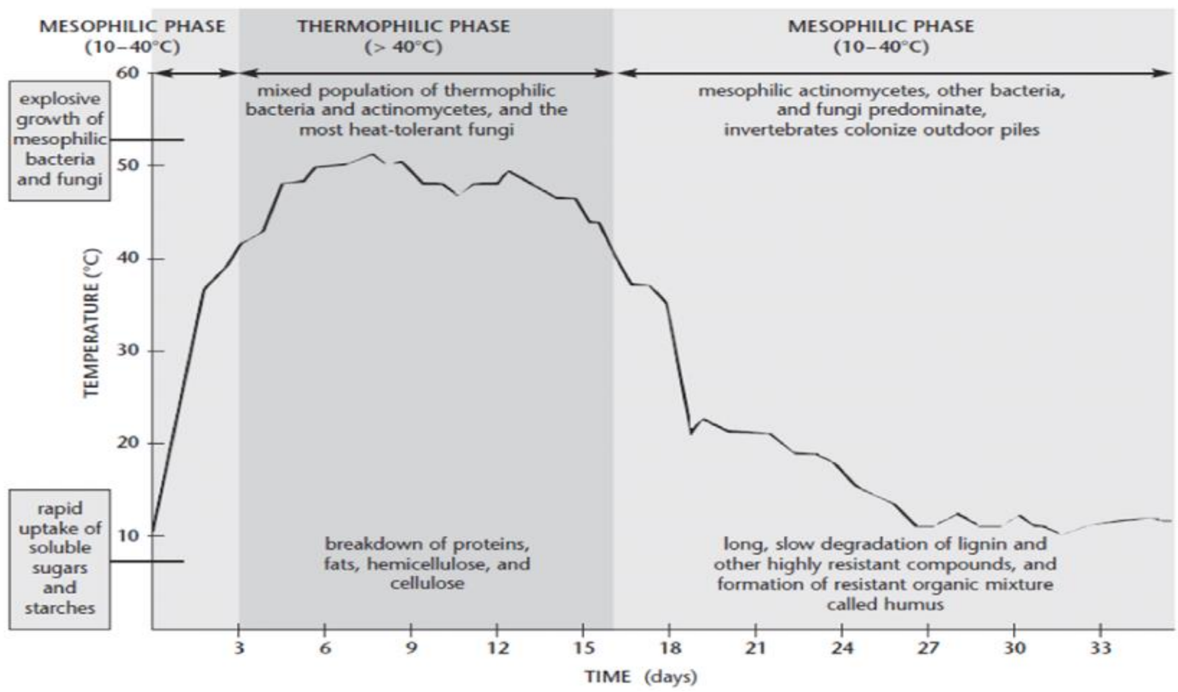

Figure 2-4: Temperature changes during composting (Trautman et al., 1997).

According USEPA, (1993) Part 503 regulations, the optimum temperature range for volatile solids destruction and pathogen removal is about 55 to 60°C. At the same time, pile temperatures excess of 70°C inhibit the biological decomposition process. Also, if high temperatures keep for periods longer than several weeks, the potential of spontaneous combustion can occur in very dry material (>75% solids).

In turned windrow operations the temperature and oxygen content are controlled by the porosity of the windrows and the frequency of turning. Initial porosity is controlled by thorough blending of the feedstock and having the proper bulking agent to biosolids mix ratio. Once the windrows are in place both temperature and oxygen content are controlled by turning of the windrow. Turning incorporates oxygen, and releases heat and moisture. Although turning releases heat, the pile temperature will raise upwards shortly after turning (WEF, 2010).

2.5.3 Moisture Content

Water, reflecting the moister content (MC), is essential for microorganisms metabolic processes also help them move about. 40% to 60% moisture is preferred for most material mixtures. Below 40 %, microbial activity become slow and sometimes stops when MC less than 15 %. When moisture content exceed 65 %, air may be displaced by water in the pore spaces of the raw materials, that cause anaerobic conditions produce odors and weak decomposition. Since the amount of water produced from the decomposition process is less than that evaporated, water must be added to keep moisture at ideal levels EPA, (1995) or turning over the piles when moisture content exceed the specified limits Edriss et al., (2006). Minimizing evaporation should be managed by controlling the piles size, larger volume has less evaporating surface per unit volume than smaller volume (EPA, 1995).

2.5.4 Mixing

Good mixing accelerates degradation which helps in producing high quality homogenous compost which's better for use and marketing (Schneider et al., 2001; Illmer et al., 1997). Dewatered solids must be well mixed with a bulking agent to ensure uniformity and good airflow characteristics during composting. Therefore, mixing system should be taken in consideration in the design. A good mixture consists of bulking agent particles uniformly coated with solids containing no balls of dewatered solids that are more than 126 mm (5 in.) in diameter. Mixing dewatered solids with a bulking agent minimizes storage-facility size and possibility of odor generation. A solids and bulking agent mixture can be loaded and conveyed more easily than dewatered cake alone (WEF, 2010)

2.5.5 Carbon to Nitrogen Ratio

Sine carbon consider as of energy source and nitrogen as of nutrient source so concentrations of those two items affect the value of the compost Willson, (1989) whereas desirable ratio to start composting range is 20 to 30 Sadaka et al., (2003), . If the ratio is less than 25:1, excess nitrogen will be released as ammonia, reducing the compost's nutrient value and emitting odor. If the ratio exceeds 35:1, organic material will break down more slowly, remaining active well into the curing stage (Poincelot, 1975). Calculating the C:N ratio is complicated, because some of the carbon becomes available more slowly than the nitrogen (Kayhanian and Tchobanoglous, 1992). If sawdust is the bulking agent, for example, only a thin surface layer of the wood provides available carbon. The carbon in sawdust, on the other hand, is more readily available to degradation.

According to a previous study carried by Sadaka et al., (2003), C: N reduction in summer is higher than in winter. So the decomposition and stabilization through summer is higher than in winter.

2.5.6 pH

According to USEPA (1995), the preferred pH range is 6 to 8 to keep availability of nutrients the enzymes which work for controlling the metabolic activity. Results of past studies (Trautmann et al., 1997; Schneider et al., 2001) showed that the organic acids accumulated caused a pH decrease and stimulated fungi growth, oxygen was adequate to facilitate microbial degradation of organic acids. If the oxygen isn't be in sufficient quantity pH value may become less than 6 which will affect the decomposition process. To adjust pH value in the composters lime and sulfur can be used , lime works to increase the pH and sulfur to decrease it (USEPA, 1995), finished compost have to not exceed 8 because it may kill some plants if it used in large amounts.

2.5.7 Oxygen

If the composting process oxygenation isn't sufficient, the process become slow, and nuisance odors produce. Sufficient oxygen needed for composting process range (16% to 18.5%) is ideal, when the percentage becomes less than 6 % odors will produce. To aerate composting process, the piles can be turned or aerated by blowers (McFarland, 2001).

2.5.8 Curing

Curing is the process in which compost becomes biologically stable, this stage needs longer time, in which rapid decomposition takes place resulting in significant lost in compostable materials weight, the microbial activity continued in the curing phase slowly to complete maturation. Curing stage usually takes several weeks to six months; typical period for curing is three to four months to obtain a fine texture and stable product (USEPA, 1995).

2.5.9 Screening

Screening is to separate compost from non-composted materials, and to reduce compost's particle size. Compost is screened before or after curing. The moisture content of the compost being screened should be less than 40 %. Except for leaves and sawdust, bulking agents can be separated out of the finished compost and reused. This reduces bulking agent costs by 50% to 80%. Screening also produces more uniform. Vibrating screens and rotating screens typically are used. All screens should have a self-cleaning feature (e.g., rotating brushes in rotating trammel screens or a layer of balls between the decks of a vibrating deck screen). Vibrating screens and rotary trammel screens can separate material into multiple sizes, which can be useful if some markets demand a product with fine particles.

2.6 Finished Compost Quality

Several parameters determine the quality of compost, including particle size, pH, soluble salts, stability, pathogens content, heavy metals, weed seeds, glass, and plastic. Materials age and storage conditions also affected compost quality. In curing phase most of available nitrogen converts from ammonium-nitrogen to NO_3-N. End compost must be stored as small piles in an aerated dry location, to allow aerobic respiration and prevent anaerobic respiration which produces odors, alcohol, and organic acids that are damaging plants. Figure 2-5 shows an overview of the major compost quality criteria.

Figure 2-5: Major Compost quality criteria (Rothenberger et al., 2006).

Curing or maturing finished compost is an important factor for planting, finished compost has to not release any acidic substances as of ammonia that affects plants growth, immature compost cause adverse effects on plants roots that transport nutrients for the yield growth, there’s no detected test to analyze the maturity but some indicators were used as of color to be dark, no bugs or insects and smell close to earthy one, temperature should not exceed ambient temperature if measured into the compost heap and the pH reading should be around 7 ± 0.5 (Rothenberger et al., 2006). According USEPA (1994), chemical pollutants in MSW produced from batteries, motors oil, cleaning products, paints, solvents which all these contains heavy metals have to be taken in consideration in composting quality analysis , limits of heavy metals content of compost (dry matter; DM) in some countries are listed in Table 2-2.

Table 2-2: Heavy metals limits for compost standards (mg/kg DM) (Hogg et al., 2002).

Country	Cd	Cu	Ni	Pb	Zn
Austria	0.7	70	25	45	200
France	3	-	200	800	-
Germany	1.5	100	50	150	400
Greece	10	500	200	500	2000
Italy	10	600	200	500	2500
Spain	40	1750	400	1200	4000
UK	0.7	70	25	45	200
Canada	3	100	62	150	500
New Zealand	15	1000	200	600	2000
USA	39	1500	420	300	2800

According to a previous study (Rothenberger et al., 2006), the conventional (traditional) compost contains about 1 to 2 % of natural nitrogen content, which is low when compared to chemical fertilizers to get compost with high NPK ratios as compete chemical fertilizers. Compost can be supplemented with additives such as potash or chicken manure. Table 2-3 shows a comparison of nutrient contents for conventional and enriched compost.

Table 2-3: Nutrients contents in conventional and enriched compost of waste concern (Rothenberger et al., 2006).

Nutrient	Traditional Compost	Supplemented compost
Organic matter	(35-40) %	30 %
Nitrogen	(1.0 – 2) %	7 %
Phosphorus	(.4 – 4) %	7 %
Potassium	(.5 – 2.6) %	14 %
pH	7.8	7.5

2.7 Composting Impact on Microbial Activity

Pathogens that are found in organic materials, animal manure and biosolids will cause diseases if it’s not treated properly (Pell, 1997). Pathogens as of *Salmonella* and *E.coli*

O157:H7 may be found in crops that are exposed to animal manures which consider as of source for fecal contamination (Wang et al., 1996). According to a previous study on a municipal solid waste composting carried by Watanabe et al., 1997; Deportes et al., (1998), temperatures more than 50 ^{o}C for 10 days and >60 ^{o}C for 5 days were adequate to eliminate *Salmonella* and minimize fecal coliforms from 8.96 log cfu/g dry to <2 log cfu/g. and according research on sludge composting with wood by-products. Shuval et al., (1991) reported that temperatures more than 55 ^{o}C reduced fecal coliforms (from 105 to 101 CFU/g), and Salmonella (from 103 to <0.1 CFU/g).

Microbial activity during composting occurs in three basic stages: mesophilic, when temperatures in the pile range from ambient to 40°C ; thermophilic, when temperatures range from 40 to 70°C ; and a cooling period associated with a reduction in microbial activity and the completion of composting. The optimum temperature in the thermophilic range seems to be between 55°C and 60°C where the maximum rate of volatile solids destruction occurs. Biological solids, newly harvested wood wastes, and yard wastes provide a diverse population of microflora that can respond to changes in temperature and substrate. Under most circumstances, an inoculum of pure cultures does not significantly enhance composting. Sawdust decomposition, however, can be accelerated by inoculating a cellulose-decomposing fungus and adding nutrients.

In a composting study by Cekmecelioglu (2005), the fecal coliforms were in the range of ≥377- in winter and ≥365-460 MPN/g in summer, analysis showed that summer windrows sustained thermophilic temperatures for longer duration than winter, existence range 19-53 MPN/g compost on the 28 and 66 days, which verify the requirement of precise monitoring composting process.

Russ and Yanko (1981) reported that *Salmonella* growth in sludge composting happened in the mesophilic (temperature range 20-40 ^{o}C) when the moisture content was more than 20 percent and Carbon to Nitrogen ratio more than 15/1.

2.8 Finished Compost Uses

Based on previous studies (Farrell et al., 2010; Hargreaves et al., 2008; Mylavarapu et al., 2009; Semple et al., 2001; Weber et al., 2007), compost can be used for soil improvements as organic fertilizer, nutrient source, and for land remediation also control erosion, reduce the bulk density, destroy pathogens, compost can be used to adjust soil temperature and may improve the water draining. According to Mafarjeh (2011) using composts as a fertilizer have several benefits as nutrient release take long time and compost contains micronutrients that not found in fertilizers.

3. Chapter Three - Research Methodology

3.1 Introduction

This Chapter presents design and setup for two composting experiments for pilot scale trials using different mixtures of organic materials. The first stage was in winter through a joint research project between Birzeit University (BZU) and University of California Davis (UCD), and American University of Beirut (AUB) and the second one was through summer season. All compost piles were conducted inside the greenhouse at BZU campus.

3.2 Trial Mixtures and Compost Piles Designs

This research was executed during two different seasons; the first stage was conducted through winter season. Sampling, monitoring, controlling and analysis activities started was on 26th November 2014 and finished on 9th March 2015 and second composting stage conducted through summer starting from 13th August 2015 and finished on 1st November, 2015.

3.2.1 First Stage

Based on previous studies, five mixed materials were prepared with a ratio (2:1) (Nikaeen et al., 2015). Weight of each pile using different mixtures of organic materials was (10 kg vegetables, 5 kg of horse manure or sludge) as following in Table 3-1:

Table 3-1: Summary of 1st stage piles content

Pile No.	Pile 1	Pile 2	Pile 3	Pile 4	Pile 5
Mixture content / Ratio	2 Organic+ 1 Horse manure	2 Organic + 1 horse manure	2 Organic + 1 Sludge	2 Organic + 1 sludge	Organic
Notes	Saw dust speeded through laying mixtures		Saw dust speeded through laying mixtures		Saw dust speeded through laying mixtures

Prior and after composting process, heavy metals, pathogens, organic matter and total nitrogen were tested as following for each piles mixtures as in Table 3-2.

Table 3-2: Tested parameters for each 1st stage piles content

Heavy metals	pb, Zn, Cd, Cu, Ni
Nutrients	Nitrogen , Phosphorus, Potassium
Periodic tests	Temperature : Daily, pH: weekly, Moisture: weekly
Pathogens	Total Coliform , Fecal Coliform , *E.coli* , *Salmonella*
C/N	Tested for raw mixtures and for finished compost
Total Nitrogen	Tested for finished compost

Each mixture was spread in a trench, the dimensions of each, were length 25cm x width 20cm and depth 50cm. Each pile was covered by plastic sheet as in Figure 3-1.

Figure 3-1: One of Piles used in 1st stage

Initially each pile has been turned twice a week for 2 weeks using a fork, then once a week for the remaining duration to aerate the mixture EDRISS et al., (2006). The temperature was recorded daily inside each pile. Also ambient temperature was recorded until the pile temperature stopped decreasing. Moisture content kept under control through periodically measurements which calculated through the following equation:

$MC = \frac{Wet\ Weight - Dry\ Weight}{Wet\ Weight} x100\%$, where dry weight measured after drying the mixtures in oven at 40 ^{0}C for 24 hours. Moisture content maintained within the specified range through adding water and turning when the moisture content became less than recommended limit.

The pH was monitored once a week using electronic pH meter as shown in Figure 3-2.

Figure 3-2: Monitoring pH values

Compost was produced approximately after 15 weeks from beginning of the experiment which was through winter season. The finished compost was screened using a manual sieve of (0.4 cm pore size), also representative sample from each pile was taken from the finished compost to make the tests mentioned in Table 3-2. The results were compared with USEPA standards in order to verify the quality of finished compost.

3.2.2 Second Stage

Through this composting stage, carbon to nitrogen ratios were tested for four mixtures that were selected randomly, the two samples that have higher C: N ratios were selected to be composted this experiment as following in Table 3-3:

Table 3-3: Selection of 2nd stage piles content

Mixture No.	Mix 1	Mix 2	Mix 3	Mix 4
Mixture content / Ratio	1Organic: 1Horse manure: 1Sludge	1Organic: 2Horse manure: 1Sludge	1Organic: 1Horse manure: 2Sludge	2Organic: 1Horse manure: 1Sludge
Selected Mixtures for Composting		✓		✓
Notes		Saw dust spread through laying mixtures		Saw dust spread through laying mixtures

After analyzing C/N for the above mixes, mixtures [2] and [4] were selected due to having higher Carbon to Nitrogen ratios, a total of 100 Kg of each mixture was used, divided as the percentages mentioned before, each mixture spread loosely in layers of 15 cm inside each composter between each layer saw dust used for ventilation and as carbon source.

Two composters were prepared, which were two plastic barrels with distributed penetrations all around each barrel shown in Figure 3-3, the height of each one was 1.2 m and the diameter was .75 m.

Figure 3-3: Piles used in 2nd stage

According USEPA, (1993) Part 503 Heavy metals, pathogens, organic matter and total nitrogen were tested prior and after the process to be compared with Quality limitations. Piles and ambient temperatures were recorded daily; moisture content and pH were measured weekly, Figure 3-4 presents monitoring periodic parameters.

Figure 3-4: Monitoring moisture content, pH and temperature

Composting process was considered finished when decomposing the raw materials was no longer active and is biologically and chemically stable. This was after 12 weeks from beginning of the experiment. According Mafarjeh (2011) Produced compost was spread under sun and air, and screened using 0.4 cm pores manual sieve to separate finished compost from impurities, and to reduce compost's particle size. Representative samples were taken to retest mentioned quality parameters as clarified in Table 3-2. Results were compared to US. EPA standards in order to verify the quality of finished compost.

3.3 Laboratory Analysis

For the raw materials ten samples from each raw mixture and finished compost were collected from different locations and depths of each composting pile and mixed well together to be more homogenized then the samples were placed in a labeled plastic container and transported to laboratory at the same day of sampling. (Ryan et al, 2001). All collected samples were analyzed at Birzeit University testing labs according to official methods and the parameters analyzed included pH, moisture, total nitrogen, total Kjeldahl nitrogen which is the summation of ammonia and organic nitrogen. Heavy metals: (Pb, Zn, Cd, Cu, Ni), organic matter (N: P: K: C) and pathogens (total coliforms, *Salmonella, E. coli*, and fecal coliforms). Quality of finished compost was verified using USEPA (1993) standards.

Heavy metal and minerals values for composting mixtures were analyzed using Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) according to the Standard Method (ICP multi element stander solution 4 certiPUR lot- No. HC957274). Total nitrogen was determined by analyzing the organic and ammonia nitrogen using Kjeldahl method and the inorganic nitrogen was analyzed capillary ion analyzer (CIA).

Total coliform was analyzed according to horizontal method for the enumeration of coliforms-colony technique, ISO 4832:2006 with 2009 corrigendum. Fecal coliform was analyzed according standard method of U.S. Food and Drug Administration (FDA). *Escherichia coli* was analyzed according to Horizontal method for the enumeration of beta-glucuronidase-positive *E. coli*, ISO 16649. *Salmonella sp.* detected according to ISO 6579:2002 microbiology of food and animal feed stuffs—Horizontal method for detection of *Salmonella spp.*

4. Chapter Four - Results and Discussion

4.1 Periodic Tests Results

Along the study some parameters were measured daily as the temperature and others measured weekly as of moisture content and acidity (pH) and others tested one time before and after the study as of pathogens content, heavy metals and nutrients. Following sections shows those results

4.1.1 Temperature measurements during the first experimental stage

According Stentiford (1996) proposed that temperatures higher than 55^{o}C maximized sanitation, those between 45 and 55^{o}C maximized the biodegradation rates, and between 35 and 40 ^{o}C maximized microbial diversity in the composting process. According to Strauch and Ballarini (1994) only the thermophilic range of 55 ^{o}C is sufficient to destroy pathogens (Strauch and Ballarini, 1994). The EPA recommended exposure standard of 15 days at 55^{o}C in the windrow or piles (U.S EPA, 1984). Through the first composting stage which conducted during a period experienced along day of cold fronts ended with a snow fronts where the ambient temperature reached -1^{0}C which's a reason of the low temperature of the compost piles and explains the instability in the temperature increase trends also low decomposition rate, where the experiment took 100 days until curing indications appeared.

Daily measurements of temperature inside the compost piles and the ambient temperature inside the greenhouse were recorded as shown in Annex 1 Table 1. Figure 4-1 below clarifies variation in temperature with time for all composting piles. Pile No.4 reached thermophilic phase after 70 days since the process start which can be considered a cause for pathogen removal achieved where Fecal coliform, *Salmonella* and *E.coli* content less than USEPA standards limitations. For other piles the temperature kept within the mesophilic range but recorded pathogen removal which could be done due to consuming the nutrients required for pathogens growth.

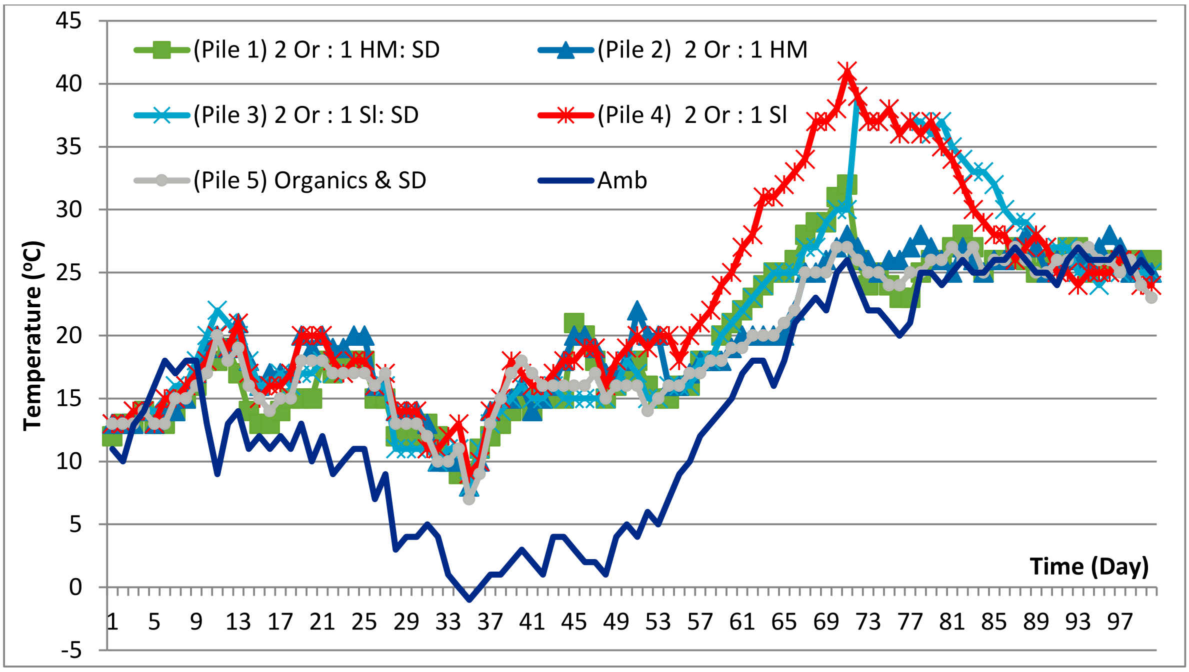

Figure 4-1: Temperature (°C) change during 1st composting experiment

4.1.2 Temperature measurements during the Second experimental stage

Through the second composting phase which was conducted during summer season a rapid increase in temperature was recorded during the initial days of composting. Temperature reached the thermophilic phase in the third day and kept more than 55^{0}C for 28 days in the two composting piles which comply EPA recommendation for pathogens and weed seeds removal through exposure windrow pile 15 days at 55°C (USEPA, 1984). Initially, the temperature of the composting pile gradually increased to reach 65^{0}C at the end of the first week, then ranged from 65 to 40 ^{0}C beginning from the second and ending by fifth week where the maximum biodegradation rates occur according Stentiford (1996) which clarifies less duration for finishing composting process through summer season, then it began to decrease gradually in the beginning of the sixth week to become close to the ambient temperature 20 ^{0}C to 26 ^{0}C at the end of the 11th week, which consider indication for finish composting process as of Rothenberger et al., (2006). Figure 4-2 shows temperature variations in 40 cm depth of the two composting piles and the ambient temperatures.

Water vapor volatilization was observed during turning of the compost pile. This can be explained as the ambient temperature was 40 ^{0}C and microbial community in the pile produced heat as a by- product because of intensive metabolic activity.

Daily measurements of temperature 40-50 cm inside the two composting piles and turning frequency for aeration purposes according EDRISS et al., (2006) were recorded in annex 1 in Table 2.

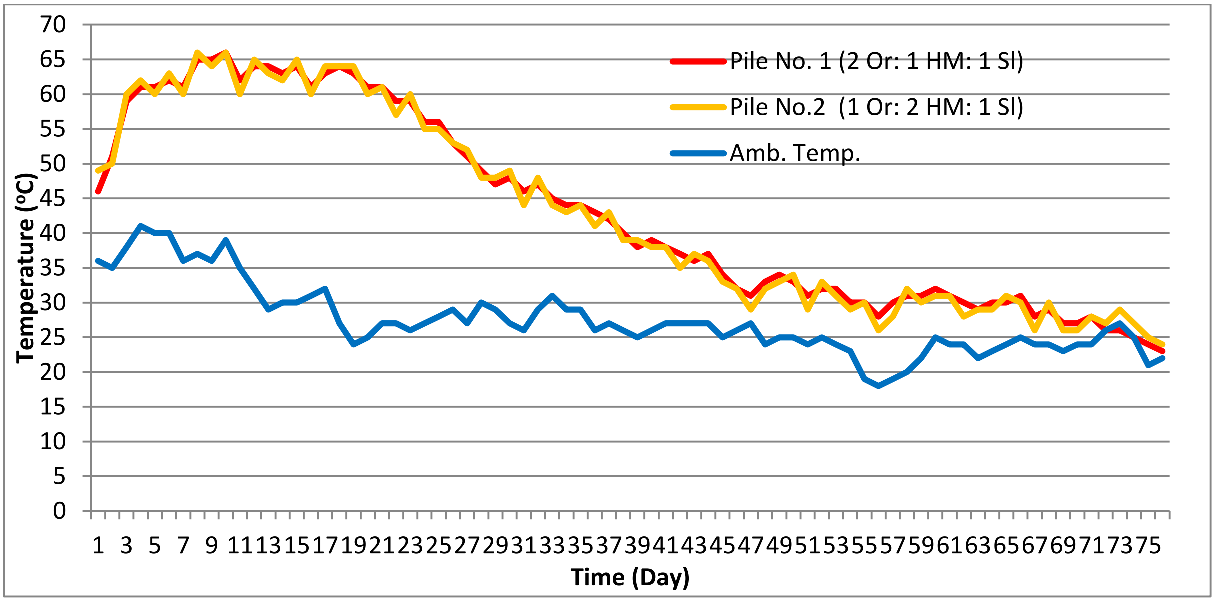

Figure 4-2: Temperature (ºC) change during 2nd composting experiment

4.1.3 pH measurements

The pH of the compost usually has to be within a range of 6 to 8. The pH affects the growth and productivity of plants and vegetation, therefore the recommended range pH for potting soil is 6 to 8 for soil amendments (Nilsson, 1994). The pH values decreased in the beginning as a result of organic acids build-up that was produced by bacterial digestion to organic matter (Trautmann et al., 1997; Schneider et al., 2001). Thereafter, the pH began to increase by the second week end as of organic acids decomposition or volatilization. According to Mafarjeh (2011), pH decreased at the end of the first week down to 6.3 then has increased up to 8.2 on the day 15th. This drop in pH may assist the growth of fungi, hence aid in the degradation of cellulose and lignin; slow degradable organic materrials. All The pH values measured weekly by electronic meter for first and second stage composting piles, where the results within the US EPA limitations.

The experiment experienced a consistent value of pH by performing proper monitoring and control, Figure 4-3 and Figure 4-4 show variation in pH values along the first and second stage

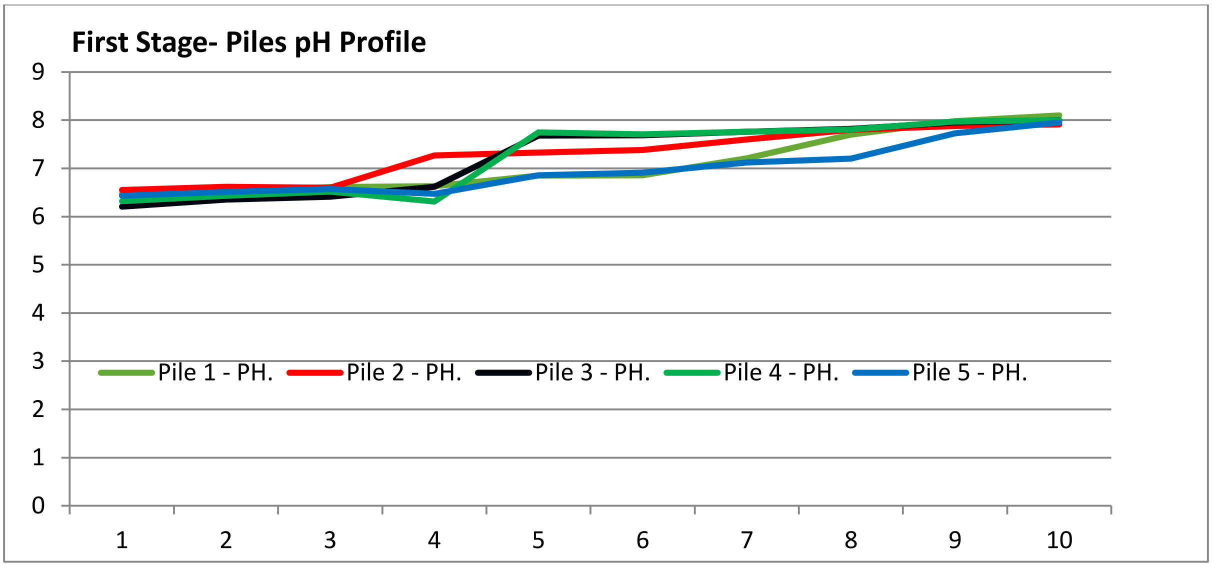

Figure 4-3: pH variation during composting piles of 1st experiment.

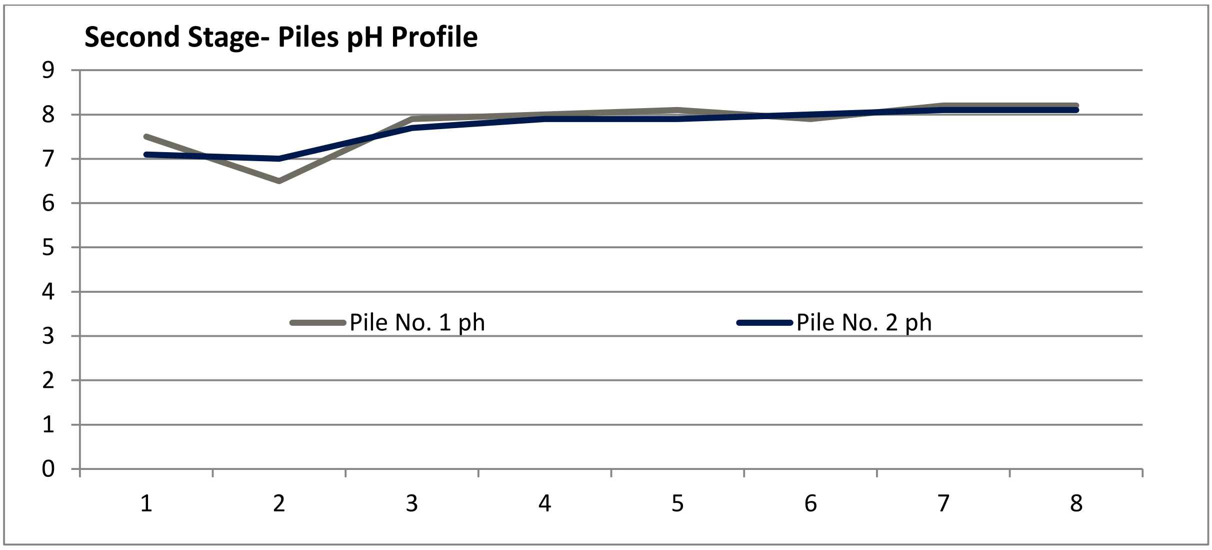

Figure 4-4: pH variation during composting piles of 2nd experiment.

4.1.4 Moisture Content

During the two composting experiments, moisture content were monitored and controlled according to the lab results, as mentioned in chapter three. Turning the piles was done as required to keep MC within the optimal limits 55% - 65% (Cronjé et al., 2004; Gajalakshmi and Abbasi, 2008; Kumar et al., 2010). Due to the temperature increase during the active phase moisture content started to release from the piles so water has been added along with turning. Figure 4-5 presents measured moisture content values for 1st composting experiment where they was high at beginning of composting process due to higher MC in raw mixtures and cold weather conditions that assist to conserve moisture from evaporation. By monitoring and prober controlling through turning, MC values came back to the specified limits as in EPA, (1995). Figure 4-6 presents moisture content values along the second experiment, most of the values for the two piles kept within the specified limits whereas pile No.2 presents better moisture content values match with the optimal standards 55% to 65%.

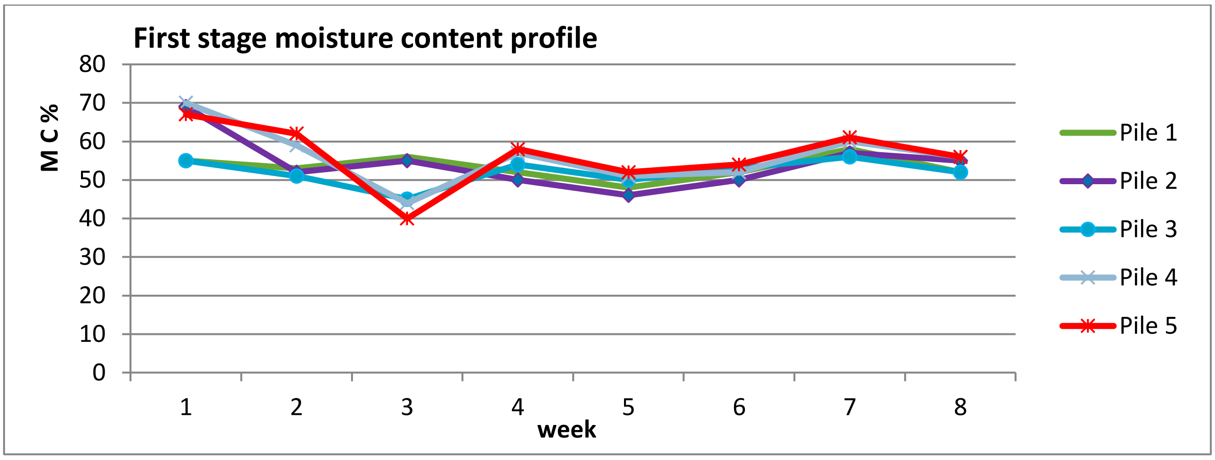

Figure 4-5: Moisture content variations during 1st experiment composting

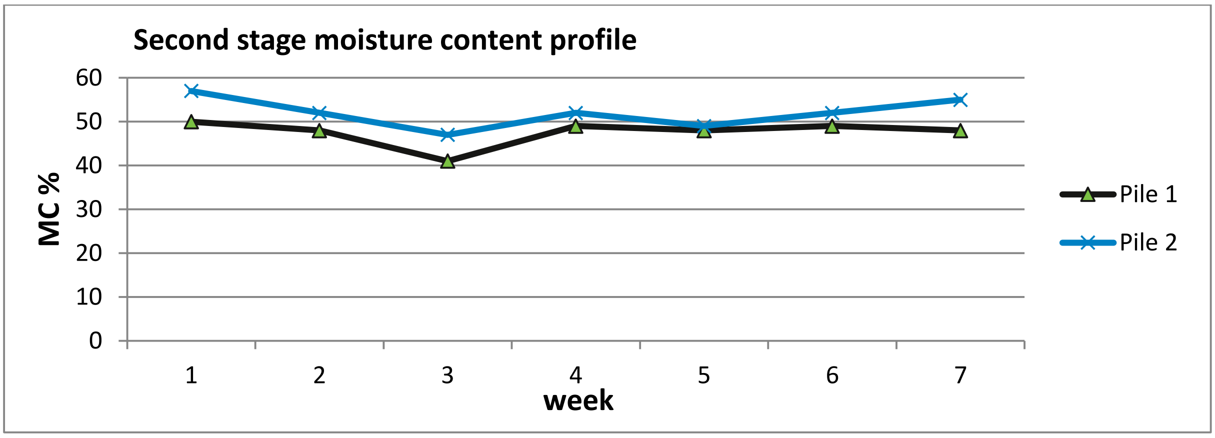

Figure 4-6: Moisture content variations during 2nd experiment composting

4.2 Chemical and Biological Laboratory Results

The following parameters were measured for the final product of the two composting experiments, after 3.3 months for the first stage and after 2.5 months for the second stage since start of each experiment. These parameters were compared against the US EPA 40 CFR 503 standards to make sure that the final product is an environment friendly product for land application.

In addition to the regular measurements (Temperature, pH, Moisture Content) which controlled to keep the finished product quality comply with the international standards. Biological and chemical quality parameters monitored and recorded prior and after the two composting experiments to evaluate the final produced compost quality.

For the first compost stage, all of heavy metals analyzed (Cd, Cu, Mg) as listed in table 4-1 and table 4-2, analysis results were within the limits of (EPA 40 CFR 503), same results noticed for the second stage. These were expected due to lack of industrial sources. Accordingly, heavy metals content in finished compost qualify it to be used to the land with no any toxic impacts.

Fecal coliform, total coliform, *Salmonella* and *E.coli*, are considered as indicators for compost pathogenicity (Sahlström et al., 2004; Gerba and Smith, 2005; Sidhu and Toze, 2009). According to a study by Haug, (1993) fecal coliforms can stay present under aerobic and anaerobic conditions and are usually found in all starting compost piles. Since the fecal coliform is responsible for some human diseases were analyzed to evaluate if the used method for pathogenic reduction (Heat from compost) is efficient in fecal reduction that qualify the compost match with the international standards. The pathogens will be considered eliminated when the fecal coliform becomes less than 1000 CFU/ gram dry wt. (Thompson et al., 2003).

Pathogenic analysis for the first composting experiments presented in Table 4-1 shows that fecal coliform, *E. coli* and *Salmonella* content in finished compost of piles No. (1,2,4,5) <100 CFU/g these results comply with the EPA, (1993) where the temperature which consider the main factor for pathogens removal kept within the mesophilic range although the pathogens content comply with the international standard, which could be resulted due consuming required nutrients for pathogens growth. For pile No.4 its exposed to thermophilic range which could be a reason for pathogens removal. For pile No.3 (Organic + Sludge + Sawdust) pathogens content exceeded EPA, (1993) which could be resulted by insufficient temperature values (Trautman et al., 1997) or because pH value (6.4) difficult to control the reduction of fecal coliform, Adela Fernández et al, (1992).

For the second composting experiment pathogenic analysis presented in Table 4-2 shows that fecal coliform and *Salmonella* content in finished content of the two piles <1000 CFU/g these results confirmed that the temperatures range during the composting process were enough to decrease those pathogens. For *E.coli* analysis pile No.2 showed results match with EPA, 1993 40 CFR section 503 whereas pile No.1 not which could be resulted from low moisture content in comparison to the pile No.2 and physiological aspects of bacteria (stationary phase) could explain part of the prolonged survival of E. coil in compost according Environ et al., (2005).

Results of C/N analysis for the first stage raw mixtures ranged from 23% to 36% as listed in Table 4-1, that's match practical range to start composting according (Sherman, 1997) and results of C/N for finished compost of piles No. (1, 3, 4) less than 15% which consider indication for compost has good curing van Heerden et al.,(2002); Kim et al., (2008).

For the second composting stage C/N ratio for the raw mixtures were around 11% for the two piles as in Table 4-2, which's possible to start composting according (Kumar et al., 2010). Where C/N for finished compost from pile No.1 was 7% and 5% for pile No.2 which's consider indication for good curried compost where the preferd range of finished compost is less than 15% van Heerden et al.,(2002); Kim et al., (2008). Less ratio for finished compost explained by, the microorganisms multiply rapidly and consume carbon as a food source and nutrients to metabolize and build proteins.

The analysis presented that the compost had high organic-matter content which's considered as indicator for high quality compost. The ratios of nitrogen, phosphorus, and potassium (NPK ratio), was analyzed and recorded in table 4-1 and table 4-2. Analysis results were complying with (NPK ratios) of fertilizers content, according (Thompson et al., 2003) a sum more than 5 consider as indication for nutrient rich compost, so can be used safely to amend soil by nutrients. Compost has (NPK) summation less than 2 indicate poor nutrient content, so the addition of organic matter can be used to improve the soil structure, usually compost range between 2 to 5.

Table 4-1: First composting phase lab results of quality parameters (chemical, biological and nutrients)

Parameter*	USEPA max limit	2 Organic+ 1 Horse manure with saw dust		2 Organic + 1 horse manure		2 Organic + 1 Sludge with saw dust		2 Organic + 1 sludge		Organic with saw dust	
		Pile 1 Raw Mat.	Pile 1 Finished Compost	Pile 2 Raw Mat.	Pile2 Finished Compost	Pile 3 Raw Mat.	Pile3 Finished Compost	Pile 4 Raw Mat.	Pile4 Finished Compost	Pile 5 Raw Mat.	Pile5 Finished Compost
Total nitrogen			0.351 %		0.72 %		0.345 %		0.46 %		0.208 %
Nitrates			400		1429.3 %		840.8		788.8		448.3
Kjeldahl-N			0.3418 %		0.6867 %		.3255 %		.4221 %		0.1975 %
C/N		30.1%	11%	23.2%	22.4%	36%	12%	31.5%	7.2%	34%	33%
Pb	<300		7.6		3.8		5.3		5		6.4
Zn	<2800		49.8		71.8		68.5		68.8		55.7
Cd	<39		-		-		0.35		0.3		0.24
Cu	<1500		12.5		23.3		100.6		83.5		19.3
Ni	<420		31.2		22.5		24.3		27.3		31.2
P			1425		5256		2294		2475		1555
K			6535		9970		5760		5309		4885
*Salmonella***	<3 MPN/g	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent
Total coliform**		$35x10^5$	$2x10^5$	$5.7x10^5$	2600	$73x10^5$	$34x10^4$	$55 x10^5$	32000	$186 x10^5$	140000
F. Coliform**	<1000 MPN/g	$1168 x10^3$	100	$47 x10^4$	Absent	$15 x10^3$	3200	$15 x10^3$	50	$24 x10^4$	70
E. coli**	<100	$22 x10^4$	60	$16 x10^3$	Absent	$5 x10^3$	1700	$1x10^5$	10	$1x10^5$	30
pH	6-8		7.26		7.02		6.46		7.16		6.96

*Units are in mg/L; otherwise stated, ** CFU: colony forming unit per gram (CFU/g)

Table 4-2: Second composting phase lab results of quality parameters (chemical, biological and nutrients)

Parameter	US EPA max limit	Pile 1 (Raw Mat.)	Pile 2	Pile 2 (Raw Mat.)	Pile2
Total nitrogen			23138		25082
Nitrates			641.62		334.3
C /N		10.5 %	7 %	10.81 %	5 %
Pb	<300		1.48		.94
Zn	<2800		106.1		57.9
Cd	<39		0.23		0.13
Cu	<1500		189		89.8
Ni	<420		3.24		3.4
Selenium	<36		Not Detected		Not Detected
Molybdenum	<75		1.33		0.55
Arsenic	<41		Not Detected		Not Detected
P			78.4		49.8
K			7.71		6.32
*Salmonella***	<3 MPN	260	Absent	120	Absent
Total coliform**		$33.6x10^6$	3200	2.7×10^6	4100
Fecal Coliform**	<1000 MPN	$14x10^6$	330	$4.6x10^5$	200
*E. coli***	<100	3.82×10^5	310	2.52×10^5	100
pH			7.78		7.91

*Units are in mg/L; otherwise stated, ** CFU: colony forming unit per gram (CFU/g)

Composting was demonstrated to be a sustainable technology for stabilizing the different mixtures and reducing the volume and the need for the landfilling of solidwaste. The two composting phases showed efficient organic solid waste reduction, percentage of compost yield from for the first phase ranged between 43% to 50 % Table 4-3, and the second stage presented higher weight reduction especially pile No.2 which could be resulted from higher temperature values recorded where the percent of yielding was from pile 48 No.1 and 42 % from pile No.2 as in Table 4-4 below. Results of waste reduction could be considered feasible when comparing to other waste reduction methods as of combustion, although it's sometimes reduce the wastes up to 90% Sakai et al., (1996) but don't benefit from the wastes as a source, in contrast with composting that produce organic fertilizers, also when comparing to landfilling, this method consumes lands and other costs without benefiting from the wastes (Sida, 2006, USEPA, 1995).

Table 4-3: Weight of compost produced from 1st Composting experiment

Pile No.	Raw Mixture Weight (kg)	Finished Compost Weight (kg)
1	15	7.4
2	15	7
3	15	7.5
4	15	6.9
5	15	6.5

Table 4-4: Weight of compost produced from 1st Composting experiment

Pile No.	Raw Mixture Weight (kg)	Finished Compost Weight (kg)
1	100	48
2	100	42

5. Chapter Five - Conclusions and Recommendations

This section summarizes the major conclusions and main recommendation elucidated from this research study.

5.1 Conclusions

This research study demonstrates operational methods that will aid in the design, operation and control of diverse windrow composting piles, especially those treating organic mixtures of different origins. The finished compost from pile No. 4 (Domestic organics and Sludge) in first phase and pile No.2 (2 organics, 1 horse manure and 1sludge) in second phase were the best mixtures matching international compost standards where pathogens content and heavy metals content within the accepted limits also the two piles exposure to temperatures within the thermophilic phase which warrants pathogens, weed seeds removal.

Moisture content control is very important since it affects the microbial growth responsible for aerobic degradation of compost materials, also it affects the process temperature and the quality of finished compost during the final screening process.

The duration to produce finished compost depends on several factors, the main of which is the process temperature; composting process was more effective at high temperatures during the summer periods, where the moisture content was controlled effectively. Operational difficulties were faced due to conducting first experiment in winter days, where the required process temperature of compost pile was delayed several days.

Heavy metals values in initial and final compost were within the limits of published guidelines. This is due to the fact that domestic waste contains low heavy metals and no industrial waste fractions were used. The only heavy metals sources might originate from the horse manure and biosolids used in the mixtures.

The pilot trials using different C:N ratios revealed a finished compost of a high quality that complied with international compost standards. Therefore, windrow composting can ensure a compost of high quality and reduce environmental and health hazards. A sustainable waste management shall consider composting as a resource recovery and waste reduction.

5.2 Recommendations

Considering waste minimization, recycling, resource recovery, recycling and reuse as strategic option for a sustainable waste management sector, composting programs (decentralized or centralized) to recycle different organic fractions including domestic, urban, agricultural waste, and biosolids are necessary to enhance the economic and environmental development in Palestinian communities.

The feasibility of mono-composting or co-composting of sludge and biosolids, generated from Palestinian WWTPs, warrants further studies at large scale pilots, since a successful co-composting was achieved in this study. In doing so, composting removes large quantities from municipal landfills. Sustainable biosolids disposal is, a high priority consideration, calls for an immediate, sufficient attention by the responsible governmental officials.

International funding agencies, municipalities and local institutions should consider public awareness and community outreach as integral parts of any solid waste management program to ensure acceptance and cooperation.

Composting at household should be encouraged, where centralized large scale composting facilities have a priority. Lessons gained locally should be utilized to promote and wide spread composting projects for environmental and economic benefits. However, composting programs should entail source separation of waste components, which should be promoted, reuse and recycling of resource materials by the industry should be encouraged, as well.

Government and local authorities should support and promote building capacity and public awareness programs. Municipalities and Sloid Waste Joint Service Councils should consider the involvement of the private sector in solid waste management, especially composting the organic waste. Environmental health institutions, academic institutions and NGOs should be encouraged to promote and support pilot projects to increase community participation to develop compost facilities. Finally, the Ministry of Agriculture should encourage farmers to use compost in order to improve soil properties, and explain the impacts of using fresh manure or excessive amounts of chemical fertilizers.

6. Chapter Six - References

Applied Research Institute - Jerusalem (ARIJ) (2006). Status of the Environment in the occupied Palestinian Territory, Final Report, ARIJ, Bethlehem, Palestine.

Cronjé, A.L., Turner, C., Williams, A.G., Barker, A.J., Guy, S. (2004). The respiration rate of composting pig manure. Compost Science & Utilization 12, 119–129.

Diaz, L., Savage, G., Eggerth, L., Golueke, C. (2003). Solid Waste Management for Economically Developing Countries, Calrecovery, Inc, 2454 Stanwell Drive, Concord, California, USA.

Cekmecelioglu, D., Demirci, A., Graves, R., Davitt, N. (2005). Optimization of Windrow Food Waste Composting to Inactivate Pathogenic Microorganisms. Transactions of the ASAE, 2023 - 2032.

Deportes, I., Benoit-Gyuod, J.L., Zmirou, D. (1998). Microbial disinfection capacity of municipal solid waste (MSW) composting [J]. Applied Microbiology, 85: 238–246

Diaz, L.F., Savage, G.M. (2007). Factors that Affect the Process. In: Diaz, L.F., de Bertoldi, M., Bidlingmaier, W. (Eds.), Compost Science Technology. Elsevier, Amsterdam, pp. 49–64.

Diez, De la Torre, A.I., Cartagena, M.C., Carballo, M., Vallejo, A., Munoz, M.J., (2001). Evaluation of the application of pig slurry to an experimental crop using agronomic and eco toxicological approaches. Journal of Environmental Quality 30, 2165–2172.

Edriss, B., Mohammad, Z., Javad, Z., Anoushirvan, B., (2006). Evaluation of microbiological and chemical parameters during wastewater sludge and sawdust co-composting. Journal of Applied Sciences and Environmental Management 10 (2) 115 -119.

Gong, C., Koichi, I., Shunji, I., Takashi, S. (2005), Survival of pathogenic bacteria in compost with special reference to Escherichia coli. Journal of Science (China). 17(5):770-4.

Farrell, M., Jones, D.L. (2010). Use of composts in the remediation of heavy metal contaminated soil. Journal of Hazardous Materials 175, 575-582.

Gajalakshmi, S., Abbasi, S.A., (2008). Solid waste management by composting: state of the art. Environmental Science and Technology. 38, 311–400.

Garcia, C., Hernandez, T., Costa, F. (1991). The influence of composting in the fertilizing value of anaerobic sewage sludge. Plant Soil 136, 269-272.

Tchobanoglous, G., Kreith, F. (2002). Composting of municipal solid waste. In: Handbook of Solid Waste Management, 2nd Edition, McGraw-Hill Professional, USA.

Hargreaves, J.C., Adl, M.S., Warman, P.R. (2008). A review of the use of composted municipal solid waste in agriculture. Agriculture, Ecosystems and Environment 123, 1–14.

Haug, R.T., (1993). The Practical Handbook of Compost Engineering. Lewis, Boca Raton, FL, USA.

Hogg D., Barth, J., Favoino E., Centemero M., Caimi V., Amlinger F., Devliegher W., Brinton W., Antler S. (2002). Comparison of compost standards within the EU, North America, and Australasia, Main report. The waste and Resources Action Program (wrap).

Hua, T.J., Zenga, G.M., Huanga, D.L., Yu, H.Y., Jiang, X.Y., Fang, D. (2006). Use of potassium dihydrogen phosphate and sawdust as adsorbents of ammoniacal nitrogen in aerobic composting process, Department of Environmental Science and Engineering, Hunan University, Changsha 410082, China

Illmer, P., Schinner, F. (1997.) Compost turning a central factor for a rapid and high quality degradation in household composting. Bioresources Technology 59, 157-162.

Iyengar, S.R., Bhave, P.P. (2005). In-vessel composting of household wastes. Waste Management 26, 1070-1080.

Knox, A. (2005). An Overview of Incineration and EFW Technology as Applied to the Management of Municipal Solid Waste (MSW). University of Western Ontario, Canada.

Körner, I., Braukmeier, J., Herrenklage, J., Leikam, K., Ritzkowski, M., Schlegelmilch, M., Stegmann R. (2003). Investigation and optimization of composting processes-test systems and practical examples. Waste Management 23, 17–26.

Kumar, M., Ou, Y-L., Lin, J-G. (2010). Co-composting of green waste and food waste at low C/N ratio. Waste Management 30, 602–609.

McFarland, L. (2001). Biosolids Engineering. Biosolids Management Practices and Regulatory Requirements, Chapter (McGraw-Hill Professional, 2001), Access Engineering.

Mafarjeh, M.A. (2011). Feasibility of a Windrow Composting Pilot for Domestic Organic Waste Recycling in Beit Liqia Village-Palestine. M.Sc. Thesis, Faculty of Graduate Studies, Birzeit University.

Mylavarapu, R.S., Zinati, G.M. (2009). Improvement of soil properties using compost for optimum parsley production in sandy soils. Scientia Horticulture 120, 426-430.

Naylor, L. (2004). Biosolids Composting. Advances in Water and Wastewater Treatment: pp. 284-302.doi: 10.1061/9780784407417.ch16.

Nikaeen, M., Nafez, A.H., Bina, B,, Nabavi, F., Hassanzadeh, A. (2015). Respiration and enzymatic activities as indicators of stabilization of sewage sludge composting. Waste Management 39, 104-110.

Nilsson, J. (1994). Testing for compost quality. In The Marketing and Use of Compost in Montgomery County, PA.

Pandey, K., Talhouk, S., Chalak, A., Al-Sa`ed, R., Suidan, M., Hamadeh, S. (2014). Developing an integrated approach for assessment and utilization of biomass for improving the sustainability of a city. Project proposal, UC Davis, USA.

Pascual, A., Ayuso, M., Garcia, C., Hernandez, T. (1997). Characterization of urban wastes according to fertility and phytotoxicity parameters. Waste Management and Research 15, 103–112.

Pell, A. (1997). Manure and Microbes. Public and Animal Health Problem. Dairy Science 80 (10), pp. 2673–2681. DOI: 10.3168/jds.S0022-0302(97)76227-1.

Rothenberger, S., Zurbrügg, C., Enayetullah, I., Maqsood, S., Abu Hasnar, M. (2006), Decentralized composting for cities of low- and middle-income countries. A users' manual.

Ryan, J., Estedan, G., Rashid, A. (2001). Soil and plant analysis laboratory manual. 2nd Ed. ICARDA and NARC. Aleppo, Syria.

Sadaka, S., and A. El- Taweel. (2003). Effects of aeration and C:N ratio on household waste composting in Egypt. Compost Science & Utilization 11(1), 36-40.

Sahlström, L., Aspan, A., Bagge, E., Danielsson-Tham, M.L., Albihn, A., (2004). Bacterial pathogen incidences in sludge from Swedish sewage treatment plants. Water Research 38, 1989–1994.

Sakai, S., Sawell, E., Chandler, J., Eighmy, T., Kosson, S., Vehlow J., van der Sllot H.A., Hartlen J., Hjelmar O. (1996). World trends in municipal solid waste management. Waste Management, 16, 341–350.

Semple, T., Reid, J., Fermor, R. (2001). Impact of composting strategies on the treatment of soils contaminated with organic pollutants. Environmental Pollution 112, 269-283.

Sherman, R. (1997). Large-scale organic composting material, Extension Waste Management Specialist Biological & Agricultural Engineering Department North Carolina Solid Waste Management Rules and Law. Solid Waste Section, Division of Waste Management, North Carolina Department of Environment and Natural Resources.

Shuval, H., Jodice, R., Consiglio, M., Spaggiarri, G. & Spigoni, C. (1991). Control of enteric microorganisms by aerobic-thermophilic cocomposting of waste-water sludge and agro-industry wastes. Water Science and Technology 24(2), 401-405.

SIDA, Swedish International Development Cooperation Agency (2006). Urban solid waste management. Urban issue paper.

Stentiford, T., (1996). Composting control: Principles and practice. In: DeBertoldi, M., Sequi, P., Lemmes, B., Papi, T. (Eds.), The Science of Composting. Chapman & Hall, pp. 49–59.

Strauch, D., Ballarini, G., (1994). Hygienic aspects of production and agricultural use of animal wastes. Journal of Veterinary Medicine 41, 176–228.

The League of Women Voters (1993). The Garbage Primer. New York: Lyons & Burford. pp. 35–72. ISBN 1-55821-250-7.

Thompson, W., Leege, P., Millner, P., Watson, M.E., (2003). Test Methods for the Examination of Composts and Composting. The US Composting Council, US Government Printing Office.

Tognetti, C., Laos, F., Mazzarino, M.J., Hernandez, M.T., (2005). Composting vs. vermicomposting: a comparison of end product quality. Compost Science and Utilization 13, 6–13.

Trautman, N.M., Krasny, M.E. (1997). Compositing in the classroom: scientific inquiry for high school students. Center for environment, Department of natural Resources, Cornell University.

USEPA, Environmental Protection Agency. (1993). 40 CFR Part 503 - Standards for the Use or Disposal of Sewage Sludge. U.S. Environmental Protection Agency, USA.

USEPA, Environmental Protection Agency. (1995). Decision maker's guide to solid waste management, volume II. U.S. Environmental Protection Agency, USA.

USEPA, Environmental Protection Agency. (1984). Use and Disposal of Wastewater Sludge. EPA 625/1-84-003, U.S. Environmental Protection Agency, USA.

Van Heerden, I., Cronje, C., Swart, S.H., Kotze, J.M. (2002). Microbial, chemical and physical aspects of citrus waste composting. Bioresource Technol. 81, 71–76.

Wang, G., Zhao, T., Doyle, M.P. (1996). Fate of enterohemorrhagic Escherichia coli O157:H7 in bovine feces. Appl. Environ. Microbiol. 62(7): 2567-2570.

Watanabe, H., Kitamura, T., Ochi, S., Ozaki, M. (1997). Inactivation of pathogenic bacteria under mesophilic and thermophilic conditions. Water Sci. Tech. 36(6-7):25-32.

WEF, Water Environment Federation. (1995). Wastewater Residuals Stabilization. Manual of Practice No. FD-9, Alexandria, Va. USA.

WEF, Water Environment Federation. (2010). Composting. In: Design of Municipal Wastewater Treatment Plants: Manual of Practice No. 8, Fifth Edition. McGraw-Hill Professional.

Weber, J., Karczewska, A., Drozd, J., Licznar, M., Licznar, S., Jamroz, E., Kocowicz, A. (2007). Agricultural and ecological aspects of a sandy soil as affected by the application of municipal solid waste composts. Soil Biology & Biochemistry 39, 1294–1302.

Willson, G. B. (1989). Combining raw materials for composting. Biocycle (August), 82-85.

Yaghmaeian, K., Malakootain, M., Noorisepehr, M. (2005). Comparison between Windrow and Pit Compositing of Poultry Wastes, Leaves and Garbage of Municipal Solid Waste in Damghan, Iran. Iranian Journal Environmental Health & Science Engineering 2, 22-27.

Annex 1

Table 1: Temperature measurements inside the first stage five composting piles.

Day	Pile 1 Temp. (^0C)	Pile 2 Temp. (^0C)	Pile 3 Temp. (^0C)	Pile 4 Temp. (^0C)	Pile 5 Temp. (^0C)	Amb. Temp. (^0C)	Turning
1	12	13	13	13	13	11.0	
2	13	13	13	13	13	10	
3	13	13	14	14	13	12.9	
4	14	14	14	14	14	14	
5	13	13	14	13	13	16	
6	13	14	15	15	13	18	
7	14	14	16	15	15	17	Done
8	15	15	16	16	15	18	
9	16	17	18	17	16	18	
10	18	19	20	18	17	13	
11	18	20	22	20	20	9	
12	19	19	21	19	18	13	
13	17	21	20	21	19	14	
14	14	18	18	17	16	11	
15	13	16	16	15	15	12	Done
16	13	17	16	16	14	11	
17	14	17	17	16	15	12	
18	15	17	16	17	15	11	
19	15	20	17	20	18	13	
20	15	19	17	20	18	10	
21	18	20	18	20	18	12	
22	17	19	17	18	17	9	
23	18	19	17	17	17	10	
24	18	20	18	18	17	11	
25	18	20	18	18	17	11	Done
26	15	16	16	16	16	7	
27	15	16	16	17	17	9	
28	12	14	11	14	13	3	

Table 1: (Cont`d)							
30	12	14	11	14	13	4	
31	13	13	11	11	12	5	
32	12	10	10	11	10	4	
33	10	10	11	12	10	1	
34	9	10	11	13	11	0	
35	9	8	8	9	7	-1	
36	11	10	11	10	9	0	
37	12	14	13	14	13	1	
38	13	15	14	15	15	1	
39	14	15	15	18	17	2	
40	15	16	16	17	18	3	
41	14	14	15	16	17	2	
42	15	15	15	16	16	1	
43	15	16	16	17	16	4	
44	15	18	15	18	16	4	
45	21	20	15	18	16	3	
46	20	20	15	19	16	2	Done
47	18	19	15	19	17	2	
48	15	17	15	16	15	1	
49	16	17	16	18	16	4	
50	17	18	18	19	16	5	
51	18	22	17	20	16	4	
52	16	20	15	19	14	6	
53	15	20	15	20	15	5	
54	15	16	16	20	16	7	
55	16	16	16	18	16	9	
56	16	17	16	20	17	10	
57	18	18	18	21	17	12	
58	18	18	18	22	18	13	
59	20	18	20	24	18	14	
60	21	19	21	25	19	15	
61	22	20	22	27	19	17	

Table 1: (Cont`d)							
62	23	20	23	28	20	18	
63	24	20	24	31	20	18	
64	25	20	25	31	20	16	
65	25	20	25	32	21	18	
66	26	22	25	33	22	21	
67	28	25	27	34	25	22	
68	29	25	27	37	25	23	
69	29	26	29	37	25	22	
70	31	27	30	38	27	25	Done
71	32	28	30	41	27	26	
72	26	27	39	39	26	24	
73	24	26	37	37	25	22	
74	25	25	37	37	25	22	
75	24	26	38	38	24	21	
76	23	26	36	36	24	20	
77	23	27	37	37	25	21	
78	25	28	37	36	25	25	
79	26	27	36	37	26	25	
80	26	26	37	35	26	24	
81	27	25	35	34	27	25	
82	28	27	34	32	26	26	
83	27	26	33	30	27	25	
84	25	25	33	29	25	25	
85	26	26	32	28	26	26	
86	26	26	30	28	26	26	Done
87	27	27	29	26	27	27	
88	26	28	29	27	26	26	
89	25	27	28	28	25	25	
90	26	25	27	27	25	25	
91	26	26	27	25	26	24	
92	27	26	27	25	26	26	
93	27	26	25	24	27	27	

Table 1: (Cont`d)							
94	25	26	25	25	27	26	
95	26	27	24	25	26	26	
96	26	28	25	25	26	26	
97	26	27	25	26	25	27	
98	26	25	26	26	26	25	
99	26	26	25	24	24	26	
100	26	25	25	24	23	25	

Table 2: Temperature measurements inside the 2nd stage two composting piles.

Time (Day)	Pile No. 1		Pile No.2		Ambient Temperature (^0C)	Turning
	Temperature (^0C)	pH	Temperature (^0C)	pH		
1	46		49		36	
2	51		50		35	
3	59		60		38	
4	61		62		41	
5	61	7.5	60	7.1	40	
6	62		63		40	Turning Done
7	61		60		36	
8	65		66		37	
9	65		64		36	
10	66		66		39	
11	62		60		35	
12	64		65		32	
13	64	6.5	63	7	29	
14	63		62		30	
15	64		65		30	
16	61		60		31	
17	63		64		32	
18	64		64		27	
19	63		64		24	
20	61	7.9	60	7.7	25	
21	61		61		27	
22	59		57		27	
23	59		60		26	
24	56		55		27	
25	56		55		28	
26	53		53		29	
27	51		52		27	
28	49	8	48	7.9	30	
29	47		48		29	

Table 2: (Cont`d)						
30	48		49		27	
31	46		44		26	
32	47		48		29	
33	45		44		31	Turning Done + water
34	44		43		29	
35	44		44		29	
36	43		41		26	
37	42		43		27	
38	40		39		26	
39	38	8.1	39	7.9	25	
40	39		38		26	
41	38		38		27	
42	37		35		27	
43	36		37		27	
44	37		36		27	
45	34		33		25	
46	32		32		26	
47	31		29		27	Turning Done
48	33		32		24	
49	34	7.9	33	8	25	
50	33		34		25	
51	31		29		24	
52	32		33		25	
53	32		31		24	
54	30		29		23	
55	30		30		19	
56	28		26		18	
57	30		28		19	
58	31		32		20	
59	31		30		22	
60	32		31		25	
61	31		31		24	

Table 2: (Cont`d)						
62	30	8.2	28	8.1	24	Turning Done + water
63	29		29		22	
64	30		29		23	
65	30		31		24	
66	31		30		25	
67	28		26		24	
68	29		30		24	
69	27	8.2	26	8.1	23	
70	27		26		24	
71	28		28		24	
72	26		27		26	
73	26		29		27	
74	25		27		25	
75	24		25		21	
76	23		24		22	