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Sustainable rural community: waste to business (W2B) model

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Sustainable Rural Community:
Waste to Business (W_2B) Model

By
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Abstract

Many environmental issues are facing rural villages in Egypt. The main problems rural villages are suffering from are lack of adequate sewage system, absence of wastewater treatment plants, poor agricultural and municipal solid waste management. These problems are causing environmental, economic and social issues in rural villages. Rural communities' residents suffer from many disease, unemployment as well as poor living conditions. It becomes imperative to find solutions to this tragic situation facing rural villages associated with dumping and burning waste. Unfortunately, not enough research is published to propose solutions to approach full utilization of all types of wastes generated in rural villages and reach sustainability.

The main goal of this research work is to develop and propose a concept to help rural communities in Egypt approach full utilization of all types of wastes generated. This research work is divided into three parts as follows: (1) developing a model to help rural villages in Egypt reach full utilization of waste, (2) recycling of organic waste, (3) recycling of rejects.

In the first part of this research work desk research method is used. From the data analysis it is proposed to use the concepts developed in industrial sector to reach sustainable development such as the concept of cradle-to-cradle, industrial ecology, eco-industrial park, environmental balanced industrial complex and green economy in the development of rural villages. The concept of Waste to Business Model (W_2B) is developed. It consists of developing a facility in each rural village that groups simple and obtainable technologies in one area to fully utilize all types of wastes generated from the rural village and transform it into useful products.

The two following parts of this research work focus on two types of wastes that cause huge problems in rural villages in Egypt which are: (1) organic waste and (2) rejects.

There are several types of organic waste and this research focuses on rice straw and animal manure. It is estimated that around 2.5million tons/year of rice straw and 63milliom

ton/year of animal manure are generated in Egypt. Composting process is and easy and cheap solution to recycle organic waste. However, this method is not widely practiced in developing countries because it is time consuming and the quality of product can be unstable. There have been increasing attention on improving composting process. The aim of this part is to transform rice straw into high quality soil amendments and organic fertilizer. This part is divided into two sets of experiments. The objective of the first set of experiment is to transform rice straw into soil amendment and evaluate the effect of different additives on the produced compost. In the first set of experiment rice straw is inoculated with animal manure, Chinese starter, cellulose decomposer and starter from the Egyptian Ministry of agriculture. The results of the first set of experiments revealed that the application of different additives in composting of rice straw exhibited an improvement of compost quality and results indicated that a higher decomposition rate of treatment having animal manure, compared to other treatments. Therefore, a second set of experiment has been conducted with substrate rice straw and animal manure inoculated with different types of additives (Effective – micro-organisms, biochar, Chinese starter) and mixture of natural rocks (rock phosphate, feldspar, sulfur, dolomite, bentonite) to produce organic fertilizer. The results revealed that the application of different additives in composting of rice straw exhibit an improvement in maturation time and final product quality. The highest decomposition rate and highest organic fertilizer quality was obtained in pile containing rice straw and 40% of animal manure mixed with natural rocks (2.5% of rock phosphate, 2.5% feldspar, 2.5% sulfur, 2.5% dolomite and 10% bentonite) and inoculated with 1L of activated EM and 10% biochar compared to other treatments. The pile reached maturation after around 42 days. All analysis of the properties of the final product indicated that it was in the range of the matured level and can be used without any limitation as an organic fertilizer as it has met all the requirements by the Egyptian Specifications of Organic fertilizers. The price of the produced high-quality organic fertilizer is 330LE/ton compared to chemical fertilizer market price ranging from 1,700LE/ton to 12,000LE/ton (non-subsidized price). In addition to the direct cost, the use of chemical fertilizer damages the atmosphere and the water. This damage has an unforeseen relatively high cost. Therefore, organic fertilizer produced from organic waste can substitute expensive chemical fertilizer

The second major issue tackled in this research work is recycling of rejects. Rural villages in Egypt suffer from poor recycling of the huge amount of MSW. Some types of MSW can be easily recycled such as metals, glass, thermoplastics, etc., while others are perceived as difficult or impossible to recycle. These un-recyclables are usually referred to as rejects. This research focus on three types of rejects including (1) thermosets including melamine-formaldehyde (a hard thermoset) and ethylene-propylene-diene- monomer rubber (EPDM rubber an elastic thermoset), (2) multi-layer flexible packaging material, and (3) contaminated plastic bags.

This part of the research work proposes two techniques to recycle rejects: (1) hot technology and (2) a cold technology.

In the hot technology compression molding technique is used to produce the composite material from waste multi-layer packaging material as the matrix and melamine-formaldehyde as the filling material. In compression molding, the sample is subject to 50bar pressure and heat for 30min. A full design of experiment is conducted to study the effect of the following three factors on the property of the produced materials: (1) temperature, (2) %wt. of filling material, and (3) particle size of filling material. For higher accuracy samples are produced at random order using Design Expert software. The experimental results indicate that the highest mechanical properties are obtained in samples produced using molding temperature of 145°C, melamine-formaldehyde having a particle size of sieve 20 and 30%wt. fraction of melamine-formaldehyde. The resulting product is found to be competitive to commercial MX and NX types of Light Traffic Paving units in terms of cost and mechanical performance. In fact, the cost of produced material is 1.2LE/m^2 compared to 150LE/m^2 for interlock market price. Also, substituting melamine-formaldehyde with other filling material like EPDM rubber waste or sand and substituting the packaging material with contaminated plastic bags waste showed to produce material slightly lower mechanical properties but can still be a competitive substitute to produce interlocks.

In the second part, an innovative cold technology is proposed to produce cement bricks. This technique consists of mixing contaminated plastic bags as coarse aggregates with sand, marble powder and melamine-formaldehyde as fine aggregates with cement. The mix is then pressed using a manual pressing machine without applying heat for few minutes to take the shape of the mold. Then the brick is left to cure at ambient conditions and water is added every day. The experimental results indicated that the highest properties are obtained after 28days of curing in the mix made of 25%cement, 30% contaminated plastic bags, 15% sand, 15% marble powder, 15% melamine-formaldehyde. The resulting product is found to be competitive to the commercial non-load bearing masonry brick in terms of mechanical performance and cost. In fact, the cost of produced material is 0.6LE/brick compared to 0.9 LE/brick for cement bricks.

The results of the research work indicate that applying the concept of W_2B model in rural villages will help these communities produce useful good that can substitute the use of imported expensive products. Also, it will lead to creation of new job opportunities, conservation of natural resources, and reduction of environmental and health problems related to poor waste management.

List of Publications

- Omar, Hala, and Salah El-Haggar. "Zero Waste Rural Community Complex ($ZWRC^2$)." *Environmental Management and Sustainable Development* 6, no. 1 (2017): 105-118
- Omar, Hala, and Salah El-Haggar. "Sustainable Industrial Community. "*Journal of Environmental Protection* 8, no. 03 (2017): 301-318.
- El-Haggar, Salah, and Hala Omar. "Sustainable and Cost-Effective use of Organic Waste". *Current Trends in Biomedical Engineering & Biosciences* 7, no. 4 (2017)
- Omar, Hala and Salah El-Haggar. "Proposed Sustainable Rural Community Framework". 4th International Conference on Sustainable Solid Waste Management, Cyprus (2016)
- Omar, Hala contributor in chapters 7 and 9. Road Map for Global Sustainability: Rise of The Green Communities", by S.M. El-Haggar *et. al.*, Advances in Science, Technology & Innovation, IEREK Interdisciplinary series for Sustainable Development, Springer Publisher House, 2019.
- Omar, Hala, Ibrahim, Yahia and El Haggar, Salah "Sustainable Bioconversion of Rice Straw into High Quality Organic Fertilizer" submitted to *Journal of Environmental Protection*
- Omar, Hala and Salah El Haggar, "Development of Innovative Cold Technology to Produce Bricks from Rejects" *in progress*

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Dedication

I would like to dedicate this work to my children Youssef and Mariam for being my everlasting source of love and inspiration.

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List of Abbreviations

ANOVA	Analysis of variance
ASTM	American Society for Testing Material
CAPMAS	Central Agency for Public Mobilization and Statistics
C2C	Cradle to Cradle
C2G	Cradle to Grave
Cd	Cadmium
C/N ratio	Carbon to Nitrogen ratio
COD	Chemical Oxygen Demand
Cr	Chromium
EBIC	Environmentally Balanced Industrial Complex
EC	Electric conductivity
EIP	Eco-Industrial Park
EM	Effective Micro-organisms
EPA	United States Environmental Protection Agency
EPDM	Ethylene-Propylene-Diene Monomer
GI	Germination Index
HI	Humification Index
IE	Industrial Ecology
MF	Melamine-formaldehyde
MP	Multilayer packaging material
MSW	Municipal Solid Waste
NH_3^-	Nitrate Nitrogen
NH_4+	Ammonia nitrogen
OC	Organic Carbon
OM	Organic Matter
PB	Plastic bags
Pb	Lead
SDG	Sustainable Development Goals
TDS	Total Dissolved Solids
TK	Total Phosphorous
TN	Total Nitrogen
TP	Total Potassium
TSS	Total Suspended Solids
W_2B Model	Waste to Business Model

CHAPTER 1 – INTRODUCTION

1.1. Background

Egypt is making many progress in many fields; yet, millions of individuals are still living in extreme poverty in rural areas. According to Central Agency for Public Mobilization and Statistics (CAPMAS) [1], 57.4% of the Egyptian population lives in rural areas in 2018. Also, CAPMAS income and expenditures survey for the year 2015 [2] revealed that 27.5% of the Egyptian population is under the national poverty line (poverty line is LE 485 per month). The poverty rate in Cairo is 17.5%, while the poverty rate in rural areas varies from 13.1% to 66% [2]. Of course, not all villages are equally poor, smaller and more remote villages called satellites or affiliated villages tend to be poorer than larger and less remote ones, known as mother villages.

In these rural areas, people live in miserable conditions. They do not have adequate dwelling, they suffer from illiteracy, unemployment, they are at high risk for disease and suffer from high mortality rate and low life expectancy [3, 4, 5, 6]. To solve their problems people living in rural areas look for cheap and easy solutions to their problems. They informally build their own houses and drainage system as well as use electricity connections from adjacent houses. However, these solutions most often result into environmental problems including spreading of substandard housing, poor sewage system, poor environmental sanitation, etc. They also suffer from unemployment or work in irregular and low paid-jobs. Many people do not tolerate theses harsh living conditions and are forced to leave their home villages and move to the capital.

The rampant urban growth has widened urban-rural disparities. These challenges are ignored by governments, entrepreneurs, environmentalists and society and pretend that these areas do not have any impact on urban prosperity. Yet, the growth of slums and informal settlements in urban areas is strongly related to the urban-rural disparities. It became urgent to propose innovative solutions to help ameliorate the quality of life of millions of residents of rural villages.

1.2. Justification

Rural communities in Egypt are confronted with many environmental issues due to the huge amount of waste generated every year including municipal solid waste (such as metals, glass, plastics, rejects, ...), wastewater, organic waste (such as agricultural waste and animal manure, ...) etc. These wastes are poorly disposed of and managed causing serious problems and burden to the country, while they could be hidden treasures if used optimally. These problems are causing environmental, economic and social issues in rural villages Rural communities' residents suffer from many disease, unemployment as well as poor living conditions [4, 7, 8]. It becomes imperative to find solutions to the environmental, economic and social tragic situation facing rural villages associated with dumping and burning waste. Many efforts have been made since the emergence of the concept of sustainable development to reach zero-pollution. To address the problems of depletion of natural resources and environmental problems caused by human activities the concepts of cradle-to-cradle have been developed to fully utilize industrial waste. Not enough research is published to propose solutions to approach full utilization of all types of wastes generated in rural villages and reach sustainability.

The Egyptian Government as well as the United Nations have defined Sustainable Development Goals (SDGs) for 2030 to help the country develop a clean, safe and healthy environment leading to improved economic situation, providing new job opportunities and reducing poverty [9, 10]. Therefore, the main goal of this research work is to aid rural communities reach zero-pollution via sustainable and affordable methods to contribute to the SDGs. In order to reach these goals, the Waste to Business Model (W_2B) for rural communities is developed and proposed in this research work as a solution to help rural villages reach 100% full utilization of all types of wastes.

While studying the different waste streams generated in rural areas in Egypt, it became obvious that one of the utmost important problems facing rural villages in Egypt is the huge amount of organic waste that represents around 133million tons/year [11]. There are several types of organic waste and this research focuses on agricultural waste as a type of organic waste. Egypt generates up to 30 million ton/year of agricultural waste [12], from which 52% are directly burnt in the fields [13]. The lack of environmental awareness of farmers coupled with poor farmers skills and knowledge in managing agriculture waste [14] and high cost of traditional disposal methods causes farmers to burn their waste in the field [5]. This causes depletion of natural resources as well as pollution of the environment. One of the main types of agricultural waste generated in Egypt is rice straw [15]. It is estimated that about 3.1million tons per year of rice straw are disposed of by directly burning in open fields causing serious environmental problems, including air pollution and soil degradation due to lack of cost-effective treatment approaches [16, 17]. Composting process is considered one of the most suitable alternatives to manage and treat organic waste to produce soil amendments and organic fertilizers [18, 19, 20]. However, this method is not widely practiced in developing countries because it is time consuming and quality of product received can be unstable [11, 21]. Hence, many studies reported methods to improve composting process including co-composting with animal manure as well as inoculation of compost piles with microbial additives or biochar to accelerate the composting process and increase the nutritional values of produced soil amendment or organic fertilizer. Yet, there are still knowledge gaps to fully understand the composting process due to the variety of feedstock. Therefore, the second aim of this research is to study and compare the effect of co-composting with animal manure, inoculation of compost piles with different commercially available microbial additives and biochar on the composting process of rice straw.

Another serious problem rural villages suffer from is poor municipal solid waste (MSW) management. According to the country report on the solid waste management in Egypt prepared by the Regional Solid Waste Exchange of Information and Expertise Network in Mashreq and Maghreb Countries (SWEEP-Net) in 2014 [11], Egypt generates 21million tons of MSW per year. Only 65% of the generated waste is collected and properly disposed of or recycled [11]. The rest either accumulates in streets, waterways, drains and/or illegal dumping sites causing many environmental and health problems [5, 6, 22]. In order to adequately manage municipal solid waste, it is also crucial to raise awareness of people and develop simple and cheap technologies to recycle waste.

A large amount of waste generated in Egypt is made out of unrecyclable waste known as rejects [5]. There are many types of rejects and this research focuses on three types of rejects: (1) thermosets, (2) packaging materials, and (3) contaminated plastic bags.

Thermoset is a type of plastic that have many attractive properties (high hardness, thermal resistance, insulation, etc.), which make it significantly used in many applications. All of these properties are attributed to the complex three-dimensional structure of the material. Yet, this cross-linked nature makes thermosets very challenging to recycle as they decompose and degrade when subject to heat. Therefore, most of the thermoset products end up in landfills or are incinerated at the end of their life, which causes serious environmental concerns due to the fact that plastic waste contains various toxic elements, which can pollute soil and water [23, 24]. Due to the increasing environmental concern, recycling of non-biodegradable thermoset wastes has been the major issue for researchers [25].

Another type of reject is packaging materials. Packaging material could be made of paper and cardboard, glass, aluminum, plastics or laminated packaging material. The laminated packaging material are usually the ones referred to as rejects as they are hard to recycle because they are made of multilayer films of different materials bonded together. The Central Department of Solid Waste estimate that around 29% of MSW in Egypt could be made of packaging materials, which represents 6 million tons [11]. Very limited number of publications reported the mechanical recycling of multi-layer flexible packaging material to produce useful goods. Most of literature focus on expensive and energy consuming recycling techniques, such as thermal-chemical methods, microwave induces pyrolysis or plasma technology to separate the layers and recover each material separately, which makes them not implemented and introduced in poor developing countries.

The third type of rejects is single-use garbage plastic bags usually made of low-density polyethylene (LDPE). They cause a huge threat to the environment as they are non-biodegradable. It is estimated that 5 trillion bags are produced worldwide every year [26].There is no published data about the exact amount of garbage plastic bags consumed; however, the head of the Environmental Affairs Agency, Shehab Abdel Wahab stated in an interview with Egypt today online journal that around 12 billion waste plastic bags are generated each year [27]. Plastic bags are also often burned, releasing toxic fumes into the air causing environmental problems. Hence, the Egyptian Ministry of Environment launched the EU-funded initiative called “Enough Plastic Bags” in 2017, aiming to reduce their use due to the negative effects on the environment and the economy. Yet, the current huge amounts of plastic bags produced needs to be recycled. Very few number of publications reported the mechanical properties of products recycled from garbage plastic bags [28].

Therefore, the third aim of this research is to develop easy and cheap technology to recycle rejects to produce useful goods for rural community. This part of the research will focus on recycling of melamine- formaldehyde (a hard thermoset), ethylene-propylene-diene-monomer rubber (an elastic thermoset), multi-layer flexible packaging material and garbage plastic bags.

1.3. Research goal

The main goal of this research work is to find innovative means to ameliorate the quality of life in rural villages and develop Sustainable Rural Communities and reach zero-pollution via sustainable and affordable methods.

n order to achieve this main goal, this research work is divided into three parts having the following aims:

1. To develop a concept/model to help rural villages reach 100% full utilization of all types of wastes.
2. To produce high quality organic fertilizer from organic waste generated in rural areas to substitute expensive chemical fertilizers currently used
3. To produce new composite materials from rejects generated in rural areas and make useful goods

1.4. Structure of the dissertation

Chapter 1 is the introduction to this research work; it contains background information and presents problems facing rural areas in Egypt and finally introduced the main goals of the research. This chapter is followed by the literature review (Chapter 2) that presents data collected and found in books, journal papers, conference papers, governmental reports, international organizations' statistics and websites concerning the main environmental problems facing rural areas in Egypt, the traditional waste disposal methods, the sustainability concepts, composting of organic waste and recycling of rejects. Afterwards, the three parts of this research work are presented, consecutively as follows:

- Chapter 3 is entitled “Waste to Business Model (W_2B) for Sustainable Rural Communities”. In this chapter the developed concept of W_2B is fully described.
- Chapter 4 is entitled “Sustainable Bio-conversion of Agricultural Waste into High Quality Organic Fertilizer: Case Study of Rice Straw”. In this chapter the effect of different additives, including biochar, effective micro-organisms (EM), animal manure and commercial microbial inoculants, on the bioconversion of rice straw is investigated. Two sets of experiments are described. The aim of the first set of experiment is to produce high quality soil amendment and the aim of the second set of experiment is to produce high quality organic fertilizer. The used materials and bioconversion method are fully explained, and the results and discussions are thoroughly presented. The cost of the produced organic fertilizer is compared with the price of commercially available chemical fertilizer.
- Chapter 5 is entitled “Approaching Full Utilization of Municipal Solid Waste: Case Study of Rejects”. In this chapter two innovative technologies and products are proposed to recycle rejects (packaging material, melamine formaldehyde, EPDM rubber and garbage plastic bags) to produce interlock paving units and bricks. The mechanical properties of the produced composite material are fully presented. The costs of the produced materials are compared with price of commercially available products having comparable properties.

These three chapters presents the objectives methodology, and results and discussion for each topic.

The conclusion and recommendations are finally presented in chapter 6.

CHAPTER 2 – LITERATURE REVIEW[1]

This literature review discusses thoroughly the major environmental problems related to poor waste management facing rural communities in Egypt as well as their impact on different aspects of life. The major reason behind poor waste management is that the cost of traditional methods of waste disposal is exponentially escalating and this cause a huge financial burden for poor rural communities' residents. On the other hand, finding new sources of raw material is becoming costly and difficult. Therefore, the advantages and disadvantages of traditional disposal methods used in rural Egypt are fully presented as well. This research focuses on implementing concept of sustainability in rural context and then two major problems facing rural communities are tackled in depth:

- Recycling of Organic waste as one of the utmost important problems facing rural villages in Egypt is the huge amount of organic waste generated every year, and
- Recycling of Rejects as large amount of rejects; such as packaging material, thermosets, contaminated plastic bags, are generated every year and accumulates in streets, water canals and/or illegal dumpsites as they are very challenging to recycle.

Hence, state-of-the art methods found in the literature for composting of organic waste as well as recycling of rejects are fully presented.

2.1. Main Problems facing rural communities in Egypt

Egypt is a major actor in the Middle East and North Africa. It has the largest and most densely settled population among the Arab countries. It is divided into twenty-seven governorates that can be divided as follows [3, 29, 30]:

[1] Part of the work in this chapter was published in a review papers by Omar, Hala and El-Haggar, Salah entitled "Sustainable Industrial Community" [43] as well as in chapter 9 of a book entitled "Road Map for Global Sustainability: Rise of The Green Communities", by S.M. El-Haggar et. al., Advances in Science, Technology & Innovation, IEREK Interdisciplinary series for Sustainable Development, Springer Publisher House, 2019 [28].

- Urban governorates: Cairo, Alexandria, Port Said and Suez, that have no rural population
- Lower Egypt: having nine governorates subdivided into urban and rural areas
    - Behera
    - Dakahlia
    - Gharbia
    - Menoufia
    - Kalyoubia
    - Ismailia
    - Sharkia
    - Damietta
    - Kafr El-Sheikh
- Upper Egypt: having eight governorates subdivided into urban and rural areas
    - Fayoum
    - Giza
    - Menia
    - Luxor
    - Aswan
    - Asyiut
    - Beni-Suef
    - Qena
    - Suhaj
- Frontier Governorates located on eastern and western boundaries of Egypt
    - Red Sea
    - New Valley

- South Sinai
- Matruh
- North Sinai

Egypt population is increasing dramatically. According to the Central Agency for Public Mobilization and Statistics (CAPMAS), the Egyptian population has increased from 72million people in 2006 to 97 million people in 2018 [31, 1]. According to Central Agency for Public Mobilization and Statistics (CAPMAS) [1], 57.4% of the Egyptian population lives in rural areas in 2018. Based on Nassar and Biltagy [4], most of the country's poor people live in rural Upper Egypt. In fact, out of the 1000 poorest villages in Egypt 941 are located in Upper Egypt [4]. Upper Egypt is home to about 40% of the Egyptian population and contains 60% of the poor [29]. Of course, not all villages are equally poor, smaller and more remote villages called satellite or affiliated villages tend to be poorer than larger and less remote ones, known as mother villages. According to Nassar and Biltagy [4], Qena governorate suffers from poverty most severely from among all Upper Egypt.

The absence of adequate sewage system, lack of agricultural and municipal solid waste management makes residents of rural areas in Egypt live in squalid areas. They burn their waste in the field or throw them in the streets and/or in the nearest water way. These practices cause air, soil and water pollution. These people also suffer from social and economic problems including diseases, high mortality rate, low life expectancy, illiteracy and unemployment [28].

2.1.1. Huge amounts of organic waste

One of the utmost important problems facing rural villages in Egypt is the huge amount of organic waste. There are several types of organic waste including organic waste from municipal solid waste (MSW), agricultural waste, animal manure, sewage, and waterway cleansing waste (dredging, floating weeds, etc.) as shown in **Figure 2.1** and fully described below.

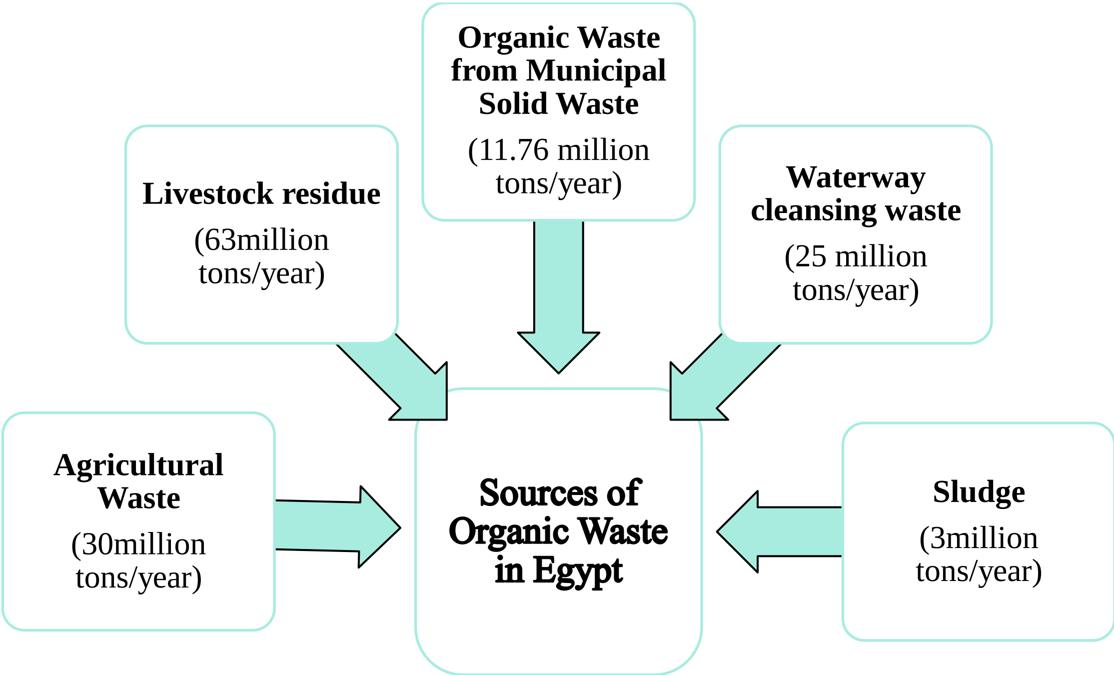


Figure 2.1: Sources of Organic Waste in Egypt

Agricultural waste is the result of agricultural production following the different harvesting activities. Egypt is a large agricultural producer; in fact, the agricultural sector contributed to 14.5% of Gross Domestic Product (GDP) in 2013 [12]. Large quantities of wastes are produced from this sector in many forms including straw, stalks, husk, shells etc. Egypt produces up to 30 million ton/year [12]. **Table 2.1** presents average quantities of some agricultural residues in rural Egypt.

Table 2.1: Average quantity of some agricultural residues in rural Egypt from 2011 to 2013 [12]:

Crop Residues	Tons
Maize stalk	1,776,010
Rice straw	1,075,458
Sugar cane bagasse	774,201
Cotton stalk	516,893

It is worth mentioning that Delta region generates the highest amount of residues is, followed by Upper and Middle Egypt regions. According to Kamel *et al*. [12], the governorates of El-Behera, Sharkeia, Dakahlia and Kafr el Sheikh in the delta region generates between 0.59 to 0.87 million tons of agriculture residues every year. Middle Delta region generates a high amount of maize stalk, rice straw and cotton stalk, while Upper Egypt region like Qena and Asswan generate large amounts of sugar cane bagasse [12].

It is estimated that 52% of the agricultural waste are directly burnt in the fields (refer to **Figure 2.2**) [13]. The poor agricultural waste management is attributed to absence of environmental awareness and low level of knowledge and skills of peasants in handling agricultural waste. There are many environmental laws available in Egypt to force farmers properly dispose of their waste. The traditional environmental protection procedures are very expensive and cause a financial burden on farmers. After the harvest of crops the farmers wants to rapidly get rid of their waste to re-cultivate their land so as a quick solution, they burn waste in field. This tradition made Egypt one of the countries that have highest rates of greenhouse gas emission all over the world [12, 28]. Also, burning of waste in field kills microorganisms in soil leading reduction in quality and quantity of yield produced. Also, leaving waste in the field attacks harmful pathogens and pests again reducing the quality and quantity of new crops [14].

Figure 2.2: Burning Agricultural Waste in field in rural Egypt [32]

In addition to the agricultural waste, there is also livestock residues, which consists of chicken and cattle manure. According to the FAO (Food and Agriculture organization of the United Nations) 2017 report [33], it is estimated that around 57million tons of cattle manure and 6 million tons of chicken manure are produced each year. The highest cattle manure production is found in the Middle Delta region, at 31 million tons per year (55% of total manure production in Egypt). Upper Egypt region generates 13 million tons of cattle manure per year (23%) followed by the Middle Egypt region, which produces 10 million tons (19 %) [33].

Another source of organic waste is municipal solid waste (MSW). According to the country report on the solid waste management in Egypt in 2014 [11], Egypt generates 21million tons of MSW per year from which 56% are organic waste (equal to 11.76 million tons per year). Also, 25million tons per year of waterway cleansing waste and 3million tons of sludge are generated in Egypt [11].

2.1.2. Huge amounts of Municipal Solid Waste

Another serious problem rural villages suffer from is poor MSW management. A large portion of the MSW are dumped in open dump sites, waterways and/or streets causing extensive health, ecological and environmental problems. As previously stated, Egypt generates 21million tons of MSW per year and its composition is illustrated in **Figure 2.4**. **Table 2.2** also shows the daily amount of MSW generated in some of the Upper and Middle Egypt regions.

Figure 2.3: Municipal Solid Waste dumped in waterways, in Egypt

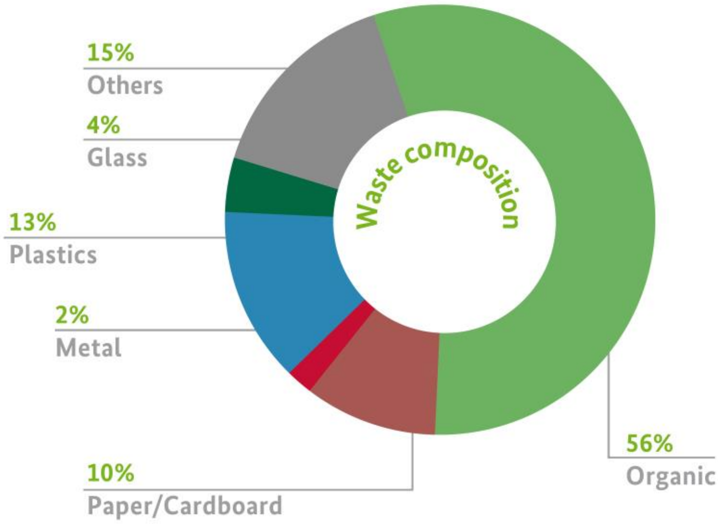


Figure 2.4: MSW Composition in Egypt [11]

Table 2.2: Daily generated MSW in some governorates in Egypt in 2012 [11]:

Governorate	Daily generated MSW (ton)
Menia	1,300
Aswan	800
Asiut	700
Beni Suef	800
Fayoum	720
Luxor	470
Sohag	1,100
Qena	1,080

More than 35% of waste generated in Egypt are thrown in illegal dump sites, street and water canals, which result into serious environmental and public health problems [11].

No serious measures were taken before 1992 for waste management. The first National Environmental Action Plan was introduced in 1992 followed by the Environmental Conservation Law No.4 in January 1994 for the protection of the environment and the strengthening of the Egyptian Environmental Affairs Agency (EEAA) [34]. Lack of collection system, poor maintenance and lack of modern treatment equipment are ones of the major problems facing WM in Egypt [11]. In order to adequately manage municipal solid waste, it is also crucial to raise awareness of people and develop simple and cheap technologies to recycle waste.

As shown in **Figure 2.4** most of the MSW is made of organic waste followed by plastics (13%). Plastic products have opened up a new era in the industrial history as they allow to make products that are highly resistant to corrosion, very flexibility in manufacturing and relatively not expensive. The amount of plastics used has increased from 1.5million tons in 1950 to 299 million tons in 2013 and it is estimated that the plastic production could triple by

2030 [35]. Yet, the production of plastic waste has been an important issue due to the pollution and environmental impact of poor disposal of plastics. Dumping of plastic waste in open areas is still the most commonly used disposal method in developing countries. Plastics are divided into thermoplastics and thermosets, there is no data about the amount of each one separately generated in Egypt. Thermoplastics can be easily recycled as they melt once subjected to heat; however, thermosets are harder to recycle as they do not melt when heated. That's why thermosets are referred to as rejects.

Another type of reject is packaging materials. Packaging material could be made of paper and cardboard, glass, aluminum, plastics or laminated packaging material. The laminated packaging material are usually the ones referred to as rejects as they are hard to recycle because they are made of multilayer films of different materials bonded together. The Central Department of Solid Waste estimate that around 29% of MSW in Egypt could be made of packaging materials, which represents 6 million tons [11]. This percentage is not clearly stated in **Figure 2.4** as laminated packaging materials are made of different types of materials including aluminum, plastic and binding material. Therefore, some of these waste could be found under plastics, metals and others in **Figure 2.4**. Research effort is still needed to find ways to easily recycle rejects.

2.1.3. Other important problems

In addition to poor management of organic waste and MSW, rural areas in Egypt suffer from other issues including lack of infrastructure. Large part of Egypt is connected to supply water network; however, many rural villages do not have access to drainage system. The Egyptian government has invested a lot in supplying water to households all over the country increasing dramatically water usage. Yet, only 4% of the Egyptian villages have proper drainage systems [36, 37, 38]. This large discrepancy between water supply and sanitary drainage force residents of rural village dispose of their wastewater in an informal way. Most of wastewater are dumped in streets, waterways, or irrigation drainage network. People usually use septic tanks to collect their wastewater, which are usually not properly sealed. Thus, wastewater leaks and pollutes surrounding ground water. Unfortunately, this contaminated water is usually used for irrigation and/or drinking. Abdel Wahed *et al*. [39] studied the water quality in Fayoum and concluded that both drinking and irrigation water are contaminated and have high values of BOD, COD, metals and TSS. This is because people directly throw their wastes in waterways.

This practice caused not only poor water quality but also caused many dieses including typhoid, diarrhea, bilharizia, hepatitis C. In fact, water contamination along with poor hygiene causes around 88% percent of reported cases of diarrhea worldwide [40]. WHO stated that 25.1% of diseases can be reduced by improving the quality of water and having better hygiene [41].

In addition to all of the above-mentioned problems, rural villages in Egypt suffer from poverty, low standard of living, health problems, illiteracy and unemployment [29]. Also, housing conditions are far from satisfactory. Houses in rural Egypt usually consists of mud or red bricks houses, which are very close to each other and roofing is usually made of reeds, which led rain through and often catch fire [42].

2.2. Traditional Methods of Waste Disposal

The rapid increase in population and economic growth has led to an increase in the generation of waste. Consequently, several methods have been developed to safely dispose of waste including waste reduction and waste recovery for reuse, recycling, incineration and landfilling. The most common ways of waste disposal internationally are incineration and/or landfilling. Incineration is a process in which solid waste is burnt and converted to ash. This process allows to reduce the waste volume. The produced ash is usually landfilled. The landfilling process uses polyethylene, high-density polyethylene and polyvinyl chloride as liner, it also required a leachate collection system, biogas collection system as well as a storm water drainage system. Several environmental protection laws and regulations are drafted and adopted in Egypt to force the proper and safe waste disposal. However, these disposal techniques and environmental protection procedures are seen as a burden and not properly implemented. According to the country report on the solid waste management in Egypt in 2014, only 30% of MSW is collected in rural areas and 50-65% in urban areas. Only 7% of the MSW is composted and 10-15% recycled, 7% landfilled and the rest end up in open dump sites [11]. In Egypt there are 22 planned sanitary landfills from which 2 are under construction and 7 operational [11]. The main disadvantage of incineration and landfilling processes is that they require high capital, high running costs, and most importantly they deplete natural resources causing them to be unsustainable [43]. In developing countries like Egypt, landfills have not been very successful because they are poorly controlled causing negative effects on the environment from the formed leachate [44]. Some of these impacts include fires, explosions, soil degradation, unpleasant odor, groundwater pollution, air pollution due to GHG emissions as well as scarcity of land [45, 44, 46]. Instead of properly disposing of waste, most of the wastes generated are either burnt or end up in open, public and random dumpsite or water canals, which contribute to the health, ecological and environmental problems especially in rural areas. Unfortunately, very few literatures are giving attention to optimize and study possible innovative solutions for sustainable waste management in rural villages in developing countries like Egypt [46]. Therefore, it is an essential aspect to consider approaching 100 % full utilization of wastes and develop sustainable solutions in rural villages in Egypt in order to help in the development of these areas.

2.3. Sustainability

The concept of sustainability was developed in 1972 during the United Nations Conference on Human Environment. The first definition of the term ‘sustainable development’ appeared in publication of Brundtland Report entitled ‘Our Common Future’ as the “development that meets the needs of the people today without compromising the ability of future generations to meet their own needs” [47]. After that, considerable efforts were made to implement the concept of sustainability in many fields. Indeed, Sustainable Seattle, a non-profit organization promoting sustainability, has defined Sustainable Development as “economic and social changes that promote human prosperity and quality of life without causing ecological or social changes” [5]. From the definition of sustainable development, it is clear that all plans should allow a collaboration between environmentalist, research institutes, policy makers, businessmen and society.

Based on the tragic situation – refer to Chapter 1 – in rural Egypt and the definitions of sustainability, rural communities in Egypt can be called “unsustainable”. Rural communities in Egypt can be described as an open system as they consume natural resources and produce waste and this generated waste is poorly managed. To reach sustainability, it is imperative to introduce the concepts of cradle-to-cradle, industrial ecology, environmentally balanced Industrial Complex to reach sustainable development in rural communities in Egypt.

2.3.1. From Cradle-to-Grave to Cradle-to-Cradle

The industrial sector has been following a linear model known as “Cradle-to- Grave” illustrated in **Figure 2.5**. In this model, new products are made from raw material resources and at the end of their life they are thrown away.

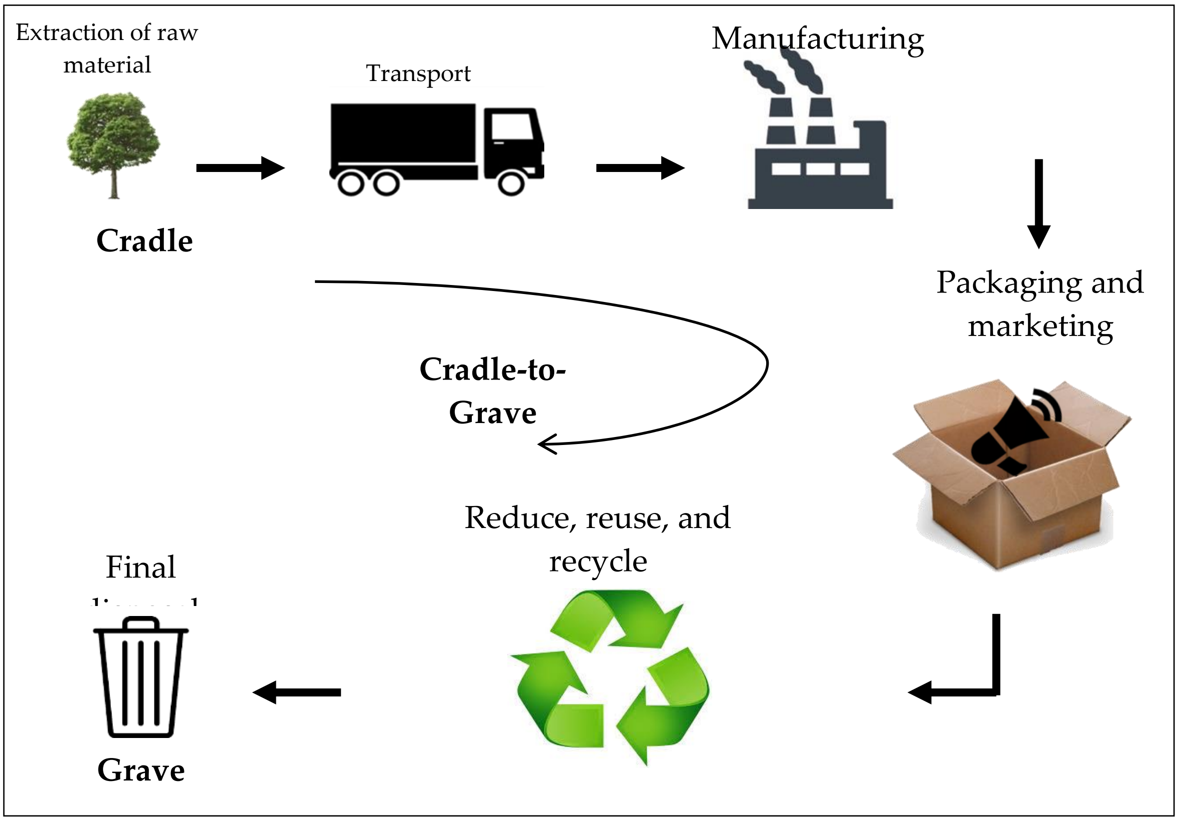


Figure 2.5 - Cradle- to- Grave Approach [43]

In order to make profits, many companies followed the concept of "built-in-obsolescence", in which products are designed for a limited period of time. After certain period of time buying a new product becomes cheaper than repair old product using old technology. Also, large amount of material is wasted in packaging that do not have any function except attracting the attention of the buyer and the material waste almost immediately. By following this strategy to sell more products, sellers are overlooking ecological and long-term impact of the huge amount of waste generated and depletion of natural resources.

The concept of cradle-to-cradle is proposed by McDonough and Braungart [48], it consists of infinitely using waste for the production of new goods. McDonough and Braungart made the papers of their book entitled "Cradle-To-Cradle: Remaking the way we make things" out of recycled plastic set a practical example for the concept of cradle-to-cradle. This concept of C2C is illustrated in **Figure 2.6**. Following this concept, will allows to reduce waste generated every year as well as ensure a sustainable source of high-quality material.

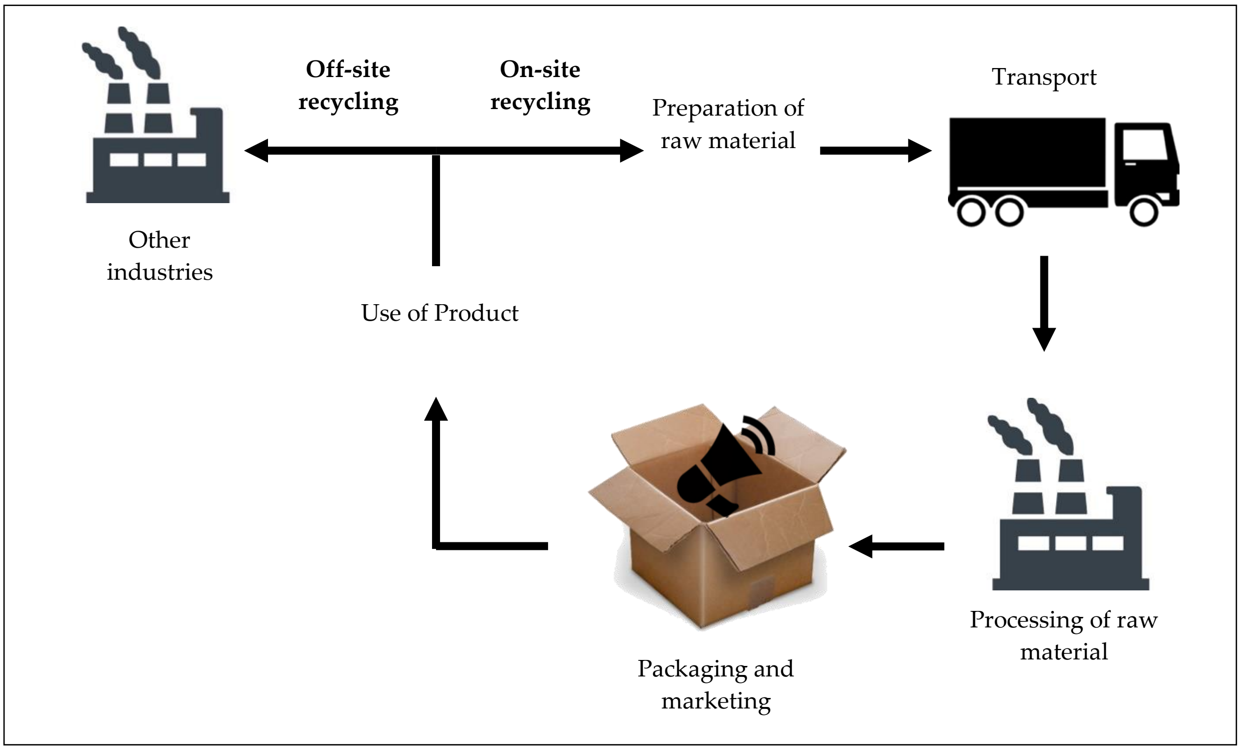


Figure 2.6 – Cradle-to-Cradle Approach [43]

2.3.2. Industrial Ecology (IE) and Eco-Industrial Park (EIP)

The concept of Industrial Ecology (IE) was defined by Frosch and Gallopoulos in 1989 to reach sustainable development. It is defined as a system in which "energy and materials is optimized, waste generation is minimized, and the effluents of one process […] serve as the raw material for another" [49]. This concept was inspired by the natural ecosystem cycle [37]. As industrial waste is non-biodegradable, it is imperative to produce goods were waste of one industry can be the raw material of another [51], and have a cyclical flow of material [52]. Industrial ecology will make the not only solve the waste problem, but also will reduce the cost of raw material used in industry. Applying this concept will open the road to "niche industries", serving the main industry, to grow [51]. These new industries will buy and sell waste, which will reduce the amount of waste generated and maximize their reuse. Industrial Ecology; therefore, promotes sustainable industries in a sustainable society.

The concept of Industrial Ecology has been applied in the industrial sector by developing Eco-Industrial Parks (EIP). In this park any waste generated from an industry is reused or recycled to ensure sustainable development. EIPs are a direct application of the industrial ecology approach. The main aim of EIP is to group different industries in one location in order to minimize energy and material waste. Many research indicate that sustainable development of the economy can be promoted via implementation of a successful eco-industrial park [53].

2.3.3. Environmentally Balanced Industrial Complex (EBIC)

The concept of Environmentally Balanced Industrial Complex (EBIC) was developed by Nemerow and Dasgupta in 1986. Nemerow defined EBIC to be "a selective collection of compatible industrial plants located together in one area (complex) to minimize both environmental impact and industrial production costs" [54]. Unlike EIPs, the EBIC proposes to group compatible industries large and or small industries in one area close to each other. By doing that different industries will use the waste of each other to produce new goods. This complex will not only minimize waste generated by industries but also will reduce the cost of raw material, transportation, storage, and waste disposal and treatment.

2.3.4. Green Economy (GE)

Green economy is a new model for the economic development based on sustainable development and knowledge of ecological economics. The UN Environment Program (UNEP) defines the green economy as "one that results in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities" [55]. The aim of green economy is to reach a win-win solution and provide economic, social and environmental well-being.

2.3.5. Sustainable Development Goals

Reference to "Sustainable Development Strategy: Egypt Vision 2030" report prepared by the Minister of Planning, Monitoring and Administrative Reform in 2015, one of the main goals of Egypt is "to preserve natural resources and support their efficient use and investment, while ensuring next generations' rights. A clean, safe and healthy environment leading to diversified production resources and economic activities, supporting competitiveness, providing new jobs, eliminating poverty and achieving social justice" [9].

Also, the United Nations has developed seventeen sustainable development goals for 2030 including the following [10]:

- Goal 3 – Good health and well being
- Goal 6 – Clean water and sanitation
- Goal 8 – Decent work and economic growth
- Goal 11 – Sustainable cities and communities
- Goal 12 – Responsible consumption and production

As mentioned in chapter 1, around 56.9% of the Egyptian population lives in rural areas; therefore, to contribute to these goals it is imperative to help rural villages reach sustainable development and not only focus on urban development.

2.4. Composting of organic waste

Biodegradable material or organic waste usually accounts for over 50% of the MSW stream in developing countries. In fact, as previously mentioned, in Egypt 56% of the MSW is organic. Other types of organic waste include agricultural waste, livestock residue, waterway cleansing, sludge, etc., which represent around 133million tons of waste/year (**Figure 2.1**). Hence, there has been an increasing attention on improving the management of organic waste. The composting process is considered one of the most suitable alternatives to manage and treat organic solid waste [18, 19, 20]. This process occurs in nature, called rotting, but slowly. The composting process allows to create the best environment (by adding water and oxygen to compost pile) for organic material to decompose as quickly as possible. Aerobic bacteria in the presence oxygen and water decompose organic waste and transform it int soil amendments and by adding additive having high nutritional value the compost can be transformed into organic fertilizer as illustrated in **Figure 2.7**.

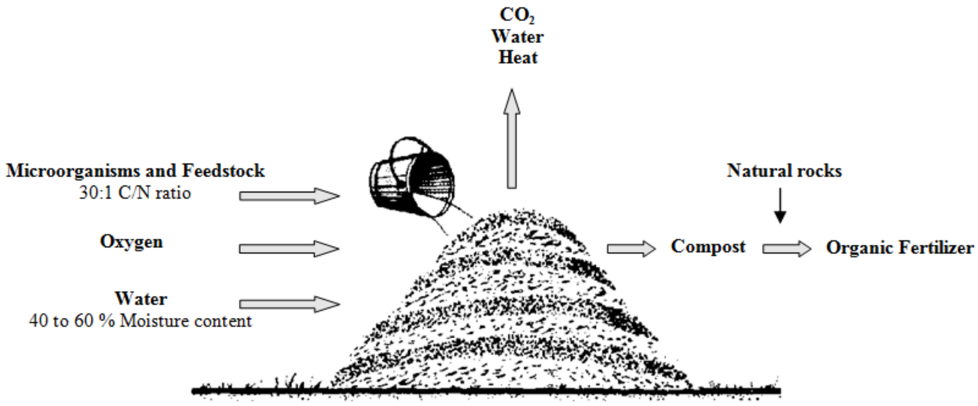


Figure 2.7 – Summary of composting process [28]

Many research is done to understand the composting process. This is particularly clear as the number of publications related to compost increased to 11,353 from 1971 to 1993 [56]. Sir Albert Howard has conducted the first large scale composting process and called it Indore process [56].

Composting has many environmental benefits including the following:

- Reduce GHG emissions caused by burning of food waste [18]
- Decrease leachate quantities once discarded in landfills [19]
- Increase calorific value of feedstock to generate more energy in case of incineration [20]
- Compost can be used as soil amendment or organic fertilizer, adding compost to soil was found to provide nutrients for plant growth, improves soil structure, increase water retention capacity, reduce the reliance on fossil-fuel based fertilizers [57, 58, 59, 60].

Although composting has many advantages, it is not widely practiced, especially in developing countries. In fact, in Egypt only 7% of MSW is composted [11].

2.4.1. Basic Concepts of Composting

Composting is a biological process in which complex organic matters are degraded by aerobic thermophilic and mesophilic microorganisms and converted into mineralized products (CO_2, H_2O,) and stabilized organic matter that can then be used as plant nutrients [61, 62, 63]. A number of factors influence the composting process including temperature, moisture content, carbon-to-nitrogen (C/N) ratio, and oxygen or aeration.

As shown in **Figure 2.8**, there are three stages during the composting process. First mesophilic bacteria grow at low temperatures not exceeding 45°C and consume easy degradable organic material. Then when temperatures start to range between 45 to 70°C the mesophilic bacteria stop growing rather thermophilic bacteria grow and start consuming organic material[6]. Then temperature gradually decreases to reach ambient temperature this is the curing stage [64].

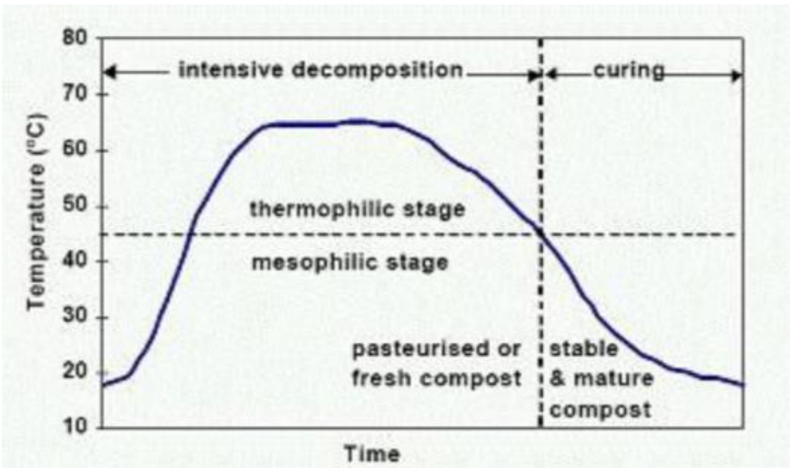


Figure 2.8: Phases of the composting process [56]

During the composting process oxygen should be introduce and pile should be turned to make sure that all the organic material is decomposed. Also, water should be added to allow optimum microbial activity. Many studies showed that the most recommended moisture content is 40 to 60% [5, 6, 64, 21].

The presence of carbon (C) and nitrogen (N) is very important to ensure optimum microbial activity. Studies showed that the recommended C/N ratio is between 20:1 to 30:1 [6, 64]. In other words, for each nitrogen part microbes consume between 20 to 30 parts of carbons. A low C/N ratio does not allow efficient micro-organism activity and incomplete nitrification process, which cause pile to have bad odor [6, 5]. In fact, Hansen *et al.* [67] reported that ammonia emission from the poultry manure was four times greater than piles with C/N ratio of 20. If the C/N ratio is too high, the decomposition process will slow down [64].

Composting involve aerobic bacteria so continuous supply of oxygen is crucial for the process to occur. Many research has been conducted to find the best aeration rate. But results of these studies are quite different, some studies suggested rates as low as 0.04-0.08L air/min-kg [68], while other studies recommended ranges as high as 0.87-1.87 air/min-kg [69]. There are different techniques used to aerate the compost pile including [5]:

- Natural composting in which compost piles are manually turned.
- Passive composting consists of having perforated PVC pipes at the bottom of the compost piles to introduce air to pile without having to turn it.
- Forced composting is similar to the passive composting process, in this process PVC pipes are connected to a blower to ensure that continuous air supply at constant velocity are introduced at the center of the pile.

Yet, composting has some disadvantages including the following:

- Composting is a time-consuming process that can take up to six months [21, 6, 70]
- Composting can create unstable product quality [21] and composts should be in high degree of maturity and stability to be safely applied on agricultural lands without any adverse effect [71]
- Composting is a complex process and there are still knowledge gaps in understanding the process due to the high variety and heterogeneity of feedstock

In rural areas large portions of land are used to dump wastes also these villages suffer from extensive pollution. Therefore, it became of high importance to develop a method to accelerate the composting process, while having a stable and high-quality product at the end [71]. Therefore, many research efforts have been made in field of composting [72, 73, 74, 75, 76, 77, 78].

2.4.2. Composting of Rice Straw

Rice is the third most important grain crop in the world behind wheat and corn. Based on FAO statistics, the global production of rice was estimated to be 650 million tons in 2007 [79]. Every kilogram of harvested rice generates around 1-1.5 kg of straw, which makes rice straw one of the most abundant lignocellulosic waste materials in the world [80]. Egypt is an agricultural country and the largest producer of rice in Africa. It is estimated that around 5.9million tons of rice straw were generated in 2013 [17]. A portion of the rice straw is mainly used as fuel for cooking and house heating, animal feed, fiber for pulping and plowing into farmland. A large amount of rice straw is dumped and burned. In Egypt, it is estimated that about 3.1million tons per year of rice straw are disposed of by directly burning in open fields causing serious environmental problems, including air pollution and soil degradation due to lack of cost-effective treatment approaches [16, 17]. Rice straw contains cellulose and hemicellulose and lining. Several studies showed that rice straw could be used to produce high value-added products via composting process [81, 82]. Yet, stable and mature organic fertilizer is hard to obtain with rice straw as it is difficult to degrade and a variety of micro-organisms type is involved in the composting process [83, 84, 85, 86]. Therefore, there had been many research effort to improve the quality of composting of rice straw and increase rate of composting process [87, 76, 17, 78].

2.4.3. Methods to improve composting process

Many studies have been done to develop methods to accelerate and improve composting process. One method is to develop closed-type bioreactors in which all factors affecting composting process are optimized (temperature, humidity, aeration, pH values, C/N ratio, etc.) [21]. However, this method is expensive.

Another-way is co-composting of agriculture waste or food waste with animal manure. Some studies have reported the effect of animal manure on composting process [88]. Dehshan *et al.* [89] reported that co-compost of cattle manure with rice straw at ratio of 4:1 produced an organic matter, total nitrogen and C/N ratio contents suitable for soil amendment. Abdelhamid *et al.* [90] reported that 20 to 30% of poultry manure on rice straw can form high quality soil amendment. Zhang and He [91] investigated the properties of co-composting pine staw and swine manure and reported that addition of 30% of swine manure while maintaining the C/N ratio at 40 produces high quality composts. Li *et al.* [64] added animal manure to rice straw and investigated the effect of different composting parameters including oxygen introduction method and rate, moisture content and manure age on the properties of final product. Ogunwande *et al.* [92] studied co-composting of raw chicken manure and saw-dust and found that incrasing C/N ratio and aeration rate increases the moisture loss of the pile. Also, significant organic waste degradation and caused loss of total nitrogen via ammonia volatilization and decrease in total carbon losses. Tiquia *et al.* [93] reported that co-composting of poultry manure and yard trimmings showed increase in micro-organisms activity level, and removal of phytotoxicity. Quian *et al.* [71] reported that co-composting of swine and rice straw (60% swine manure 40% rice straw) and dairy manure and rice straw (67% dairy manure and 33% of rice straw) results into higher maturation rates.

In addition to co-composting, some studies showed that inoculation of compost piles with microbial additives can accelerate the composting process and increase nutritional value of final compost. Some countries, like China and Egypt, have produced commercial microbial inoculants mainly containing lactic acid bacteria, yeasts and photosynthetic bacteria and are available in the local market. Yet, the scientific data for the type of strains and their composition are often not revealed and generally remained as trade secrets. No published studies have reported their exact composition nor their effects on composting process.

Another widely known microbial additive is Effective micro-organisms (known as EM.1). Professor Dr. Teruo Higa developed EM in 1970s at Ryukyus University, Okinawa, Japan [94]. It consists of various strains of naturally occurring anaerobic nontoxic and non-pathogenic microorganisms in a carbohydrate-rich liquid carrier substrate (molasses nutrient solution). It is mainly composed of three main groups of micro-organisms: (1) photosynthetic bacteria - synthesis useful substances like amino-acid, nucleic acid, bioactive substance and sugars from organic matter and harmful gases (H_2S), which promote plant growth and development, (2) lactic acid bacteria - these bacteria produce lactic acid from sugars and carbohydrates, which suppresses harmful microorganism and enhance decomposition of resistant materials (cellulose) and removes undesirable effects of decomposition, (3) Yeast - synthesize anti-microbial and other substances required for plant growth from amino-acids and sugars produced by photosynthetic bacteria [95]. However, its exact composition is very complex and remains a secret.

Jusoh *et al.* [94] evaluated the effect of adding 5% of commercial EM on the composting pile having rice straw and goat manure and green waste. The study indicated that compost with EM has higher nutritional value compared to compost without EM.

Lim *et al.* [96] reported the effect of inoculating oil palm fruit bunches with commercial EM. The study indicated that adding EM improves decomposition. In fact, lower total organic carbon content and C/N ratios were recorded at the end of the composting process in compost pile with EM compared to compost pile without EM.

On the contrary, Fan *et al.* [97] reported that EM do not have significant effect on composting of food waste at home scale.

Few studies have also reported the effect of specific types of bacteria on the composting process. Abdel-Rahman *et al.* [17] evaluated the effect of applying two types of bacteria (*Bacillus licheniformis* and *Bacillus sonorensis*) maturation time and quality of compost produced by composting rice straw and cattle manure. This study indicated that these additives improved the composting maturation time and increase the nutrient content of final compost. Also, Abdel-Rahman [15] developed a solution mainly containing two types of bacteria, *Bacillus amyloliquefaciens* and *Bacillus licheniformis*. This solution showed improvement in rice straw composting and gave results that are comparable to the ones obtained using EM. Also, this study showed that addition of natural rocks including dolomite, feldspar, rock phosphate and zinc enhance the decomposition process.

Gou *et al.* [98] investigated the effect of a consortium of psychrotrophic bacteria and thermophilic fungus as inoculant for dairy manure-rice straw composting in cold climate. The study revealed that this microbial additive accelerated the start of composting under cold climate conditions. Also, more prolonged thermophilic phase was observed, and compost reached maturity with greater decrease in total organic carbon and C/N ratio, as well as a higher increase in total nitrogen and germination index.

In addition to microbial additives, several recent studies showed that biochar could have positive effects on the composting process. Biochar is produced via pyrolysis of biomass residues under limited oxygen conditions [99]. Currently biochar is used in many applications including soil improvement, carbon sequestration, energy production, and pollution remediation [100, 101]. Very few studies have evaluated the effect of biochar on organic waste composting. Several advantages have been reported including: (1) improving aeration conditions as biochar is porous material and allow oxygen to enter the pile[102] , (2) reducing odors and greenhouse gases emissions [103, 102], (3) reducing ammonia nitrogen losses [104], (4) accelerating the decomposition and humification of organic matter [103, 102, 105], (5) improving the quality of end compost [106], (6) reducing heavy metals in soil [107], (7) enhancing micro-organisms activity level [108]. Some studies have shown that biochar has great potential for remediate the soil contaminated with organic pollutants and heavy metals [109, 110, 111, 112, 113]. However, multi-contaminated soil may require addition of other soil amendments to help reduce heavy metal availability and improve soil fertility [114]. Some studies have shown that the application of biochar is inexpensive and sustainable and can have positive impact on soil remediation and plant growth [115]. Several studies reported application of biochar with doses from 2% to 50% [116]. According to Sanchez Monedero *et al.*, the recommended application dose of biochar to compost is around 10% [78]. Some studies have also reported use of higher doses up to 50%; however, some authors have reported that doses higher than 20% can slow down the composting process [117].

As presented above, composting is one of the ideal ways to recycle the huge amount of organic waste generated in rural villages in Egypt. However, composting is time consuming process Unfortunately, very few research studies reported the effect of these different additives on composting of organic waste like rice straw. Therefore, it is essential to study the effect of these different additives on composting of organic waste like rice straw.

2.5. Recycling of thermosets and packaging materials

As previously discussed, another serious problem rural villages suffer from is poor MSW management, which contribute to many problems facing rural communities. Most of the MSW is composed of organic waste followed by 13% of plastic waste,10% of paper/cardboard, 4%glass, 2%metal, and 15%other types of material including composite materials (refer to **Figure 1.4**). This research focus on recycling of two types of materials that are difficult to recycle and referred to as rejects or unrecyclable: thermosets and packaging materials.

2.5.1. Recycling of thermosets

Plastics also known as polymers are material that can be shaped or molded by heat. Although the use of plastic has many technological advantages, the extensive use of plastics causes serious environmental problems as they are non-biodegradable. Their impact on environment is very harmful if it is burnt it causes air pollution. There are two types of polymers: (1) thermoplastics that consist of individual long-chain molecules that are easily recycled as they melt once subject to heat, and (2) thermosets that contain highly cross-linked three-dimensional network, which makes it tedious to recycle as they do not melt once heated.

Nowadays, thermosets are used in a wide range of applications including adhesives, coatings, polymer composites, electrical insulation, printed circuit boards, etc. Yet, the recycling at the end of their life cycle is a very difficult challenge because of their cross-linked nature. Once heated thermosets decompose and degrade unlike thermoplastics. As thermosets are perceived as difficult or impossible to recycle, there have been suggestions to avoid their use. Yet, their attractive properties (high hardness, thermal resistance, insulation, etc.) make them significantly used in many applications. Therefore, most of the thermoset products end up in landfills or are incinerated at the end of their life, which causes serious environmental concerns due to the fact that plastic waste contains various toxic elements, which can pollute soil and water [23, 24].

Due to the increasing environmental concern, recycling of non-biodegradable thermoset wastes has been the major issue for researchers for the last two decades [25]. In 2011, Thomas *et al.* [118] proposed a comprehensive review about methods of recycling of thermosets and their composites. There are two types of thermosets: (1) hard thermosets and (2) elastic or rubber thermosets.

Hard thermosets

Hard thermosets have Van der Waals bonds (weak bonds) and have a stronger covalent bonds linking chains together. This "cross-linking" between the chains prevent the material to soften once heated. In the case of thermoplastic polymers chains are linked together via weak bonds, which make these materials softened when subject to heat. So they can be heated and remolded and once they cool down they take the shape of the mold and recover their initial properties.

Thermosets are generally stronger than thermoplastics due to the three-dimensional network bond. They are used in high-temperature applications. However, they are more brittle than thermoplastics. Since their shape is permanent, they are very hard to recycle as a source of newly made plastics.

There are several types of hard thermosets such epoxy, Phenol- formaldehyde and melamine formaldehyde etc. Many published papers have reported different techniques to recycle epoxy and epoxy composites. However, few papers have investigated recycling of melamine formaldehyde. Melamine formaldehyde is made from the polymerization of formaldehyde (chemical formula CH_2O) with melamine (chemical formula $C_3H_6N_6$). Excess melamine forms three-dimensional network structure with further quantities of melamine monomer.

Melamine formaldehyde is characterized by superior properties. The melamine is water repellant, has good electrical properties and has high heat resistance. It has a wide color range, track resistance and scratch resistance. It is used in many applications including tableware, electrical applications and knobs and handles for kitchen utensils.

Recycling of hard thermosets

Several recycling methods of thermosets have been investigated including mechanical, thermal, and chemical approaches [101].

Mechanical recycling is a basic technology which can be incorporated into new sheet moulding compounds (SMC) parts [103], in a thermoplastic matrix [104], or in concrete [102, 100]. Petterson and Nilsson [119] studied the addition of recycled car bumpers into the SMC to produce new car bumpers. The bumpers have been grounded to form particle size ranging from 200μm to 1mm. Ground material have been added to SMC (10% ground material – 90% raw material), it was found that this method increased flexural strength of bumpers. Kouparitsas *et al.* [120] produced new composite material having high tensile strength by adding grounded polyester and epoxy composites to thermoplastic matrix. Chaitongrat and Siwadamrongpong [23] found that adding 25% of melamine formaldehyde waste powder (as fine aggregate to partially replace river sand) could produce high compressive strength light weight concrete. The study showed that adding 25% of melamine formaldehyde waste powder could produce high compressive strength concrete that comply with ASTM standard for non-load-bearing lightweight concrete.

Chemical processes have been investigated as well; however, these methods involve the use of strong chemicals at high pressure and relatively high temperature [121, 122], which limits its spread and large-scale uses. Recently, Kuang *et al.* [123] developed a chemical solvent that can quickly dissolve epoxy. Also, La Rosa et al. [124] developed a chemical technique using acetic acid recycling bath of 70 °C for 1 h to transform epoxy thermoset into thermoplastic.

Other methods that have been reported to recycle thermosets are composites thermosets are recycled using: (1) incineration, (2) co-incineration in cement kilns, (3) pyrolysis consisting of heating material in an oxygen free atmosphere in order to recover polymer as oil [125].

Mechanical recycling has many advantages compared to the previously presented recycling methods. In fact, mechanical size reduction is a simple, inexpensive technique that does not have any environmental impacts [125].

Synthetic Rubbers

Rubber provided tremendous benefits because of its unique properties related to its cross-linked structure as well as very high elasticity, which resulted from vulcanization process [126]. Due to these outstanding properties, rubber is used in many fields an applications including automotive and electronics manufacturing [127, 128]. There are many types of rubber available in the market including natural rubber (NR), styrene-butadiene rubber (SBR), nitrile, ethylene-propylene-diene monomer (EPDM) rubber, etc. Therefore, rubber waste is found in many forms such as scrap tires, inner tubes, discarded and rejected rubber glove, balloons, rubber bands, shoe soles, mattresses, hoses, seals, gaskets, diaphragms etc. However, the complex structure and high properties of rubber makes it very difficult to recycle or degrade it.

According to the International Rubber Study Group, the world total rubber consumption in 2017 is 28.05million tons and this number is expected to increase by a rate of 2.8% annually from 2017 to 2025 [129]. Due to these significant increase of rubber products, rubber waste is becoming a serious problem. Most of rubber waste is landfilled or dumped in open dump sites as an easy and cheap solution leading to many environmental problems [130]. Therefore, many research efforts have been made in waste management of waste rubber.

Recycling of waste rubber

Large volume of waste tyres are generated every year [130]. Sustainable utilization of waste tyres has been studied extensively in recent years. Nuzaimah *et al.* [130] and Ramarad *et al.* [131] published a comprehensive review regarding the utilization of waste rubber as filling material that indicated that waste tyres can be used in many applications.

Abu Jyadil *et al.* [132] developed a composite material made of polyester as the matrix and rubber tyres particles as the filler. Rubber concentration up to 40% was added to polyester and material thermal conductivity, water retention, density, thermal stability and micro-structure have been investigated. The study revealed that this composite material has the potential to be used as thermal insulator in constructive applications as the composite material produced has high mechanical properties comparable with the currently used material as well as has relatively low thermal conductivity and low water absorption.

Shu and Huang [133] published a comprehensive review of the use of waste tyres into asphalt paving. The literature review conducted indicated that the use of rubber tyres waste in asphalt have been extensively studied and have been reported to be successful due to the compatibility and interaction between rubber particles and asphalt binder.

Yang [135] reported the use of waste tyres as fillers in drainage structures such as for underground and horizontal drain.

Svoboda *et al.* [136] highlighted the use of that waste tyres as filler in concrete. The study revealed that waste tyres can improve the properties of concrete such as ductility, damping, acoustic and impact resistance.

In addition to waste rubber tyres, some research studies revealed the possibility of using other types of rubber waste in different applications. Guendouz and Boukhelkhal [137] investigated the use of rubber obtained from old shoes sole to partially replace sand concrete. The results indicated that rubber waste particles increased the workability and reduce the bulk density of sand concrete and improved the thermal insulation performances of sand concrete. Also, Riyajan *et al.* [128] showed that use of rubber gloves as filling material increase impact strength, tensile strength and decrease stiffness of materials.

As presented above, many studies reported the use of waste tyre to produce new goods. s. Yet, recycling of other types of rubbers is very limited. After tyres, ethylene-propylene-diene- monomer (EPDM) represents the second largest type of elastomeric material thrown away. However, very few studies reported the use of EPDM rubber in the production of new goods. EPDM has many good properties such as excellent resistance to heat, oxidation, ozone and weather aging, excellent electrical insulation. All of these properties make it used in many applications including weather stripping and seals, hoses and gaskets of automobiles, wire and cable harnesses, roof membranes electrical insulations and stinger covers. Yet, very few reports are available in the literature investigating the utilization and recycling of waste EPDM [25]. Jacob *et al.* [138] mixed waste EPDM with raw EPDM and results indicated a reduction in die swell, improved surface smoothness and reduced extrudate distortion. Jeong *et al.* [25] mixed waste ethylene-propylene-diene-monomer with polyethylene foam to produce a new foam composite material. The study showed that this composite material can be used as a foaming mat for artificial turf. De-vulcanization is another method that have been reported to recycle rubber [139]. There are several types of de-vulcanization including chemical, ultrasonic, microwave, thermo-mechanical. This process allows to break down sulfur-sulfur and carbon-sulfur chemical bond without degrading the material. Yun *et al.* [140] reported the possibility of recycling EPDM rubber using ultrasonic de-vulcanization of EPDM. However, these methods are very expensive and sophisticated to be implemented in rural areas of developing countries. Therefore, there is a need to develop easy and cheap solutions to recycle different rubber wastes.

2.5.2. Recycling of food packaging materials

Another type of waste that is difficult to recycle is packaging material. As previously stated, the Central Department of Solid Waste estimate that around 29% of MSW in Egypt could be made of packaging materials, which represents 6 million tons [11]. Packaging is defined as "any material, which is used to contain, protect, handle, deliver or present goods. Packaging waste can arise from a wide range of sources including supermarkets, retail outlets, manufacturing industries, households, hotels, hospitals, restaurants and transport companies. Items like glass bottles, plastic containers, aluminum cans, food wrappers, timber pallets and drums are all classified as packaging" [11].

The majority of the packaging material is used in the food industry. The major functions of food packaging are: (1) to protect food products from ambient conditions during distribution, (2) to give an attractive image of the products and (2) to write the ingredient and nutrition information of the product. Package design and construction play significant roles in determining the shelf life of a food product. Materials that have traditionally been used in food packaging include the following:

- Paper and cardboard packages are one of the most widely used packaging materials. Cardboard are made in a way similar to regular papers but with higher thickness. It's mostly used to protect the fragile food like cereals to improve the package appearance and strength and help not to lose its shape. Some papers are treated with a layer of wax to produce "waxed papers". These papers are used to provide moisture barrier and allow a little heat insulation.
- Glass packaging, which is the most common form of food packaging that can prevent moisture, odors and micro-organisms from traveling into the food. It doesn't react or migrate into the food and can be reused or recycled. The main disadvantage of glass is that it is heavy and brittle
- Aluminum sheets used in packaging are made of different thicknesses that vary from aluminum foil wrap to aluminum beverage cans. They provide a total protection of the contents but also have a high manufacturing cost which make cans expensive. It can be easily recycled and re-used in packaging materials.
- Plastic films including polyethylene, polypropylene, poly-vinyl chloride (PVC), Polyethylene terephthalate (PET), polystyrene films, etc. are widely used because of the following properties: excellent barrier properties, good chemical resistance and strength, transparency, stretching capabilities, ease of extrusion into sheets, and cheapness

Today's packaging material often combine several materials to exploit each material's functional or aesthetic properties. Laminating aluminum foil with plastic films is known as "multi-layer flexible packaging" is widely used in many applications including food, beverages, pharmaceuticals, and other consumable products. Packaging material act as a barrier between ambient conditions to protect food and increases its shelf life of food. Currently around 17% of world film production is multilayer films [141]. In Europe it is estimated that 40% of the total production of plastic is used to make multi-layer packaging material, which requires more than 19 million tons of oil and gas to produce, with an estimated annual increase of 5–7% [141]. Unfortunately, most of the multi-layer flexible packaging material are not recycled because of their multilayer structure. Rather, they end-up in landfills, incinerated, or in open dump sites causing a lot of environmental problems [142, 143].

Recycling of multi-layer flexible packaging material

Several reasons that have been reported behind poor recycling of multi-layer packaging material including the following [144]:

- large variety of materials used for each layer
- difficulty to identify different materials used in each layer
- lack of system solutions for the collection of these materials

Few studies have investigated the recycling of different multi-layer packaging materials. Some industries in developed countries use plasma process (around 15000°C) to recover aluminum from packaging material [145]. Other industries use microwave induces pyrolysis, which separates aluminum from plastic laminates by heating it to a temperature of 500°C [146]. This process of heating is carried out in a low oxygen atmosphere for better results. However, because of the high cost and energy consumption of these techniques, they are not implemented in developing countries. Thus, many research efforts focused on developing chemical or wet technologies to first separate the aluminum from polymer layer and then recycle each layer of material separately.

Cervantes-Reyes *et al.* [143] studied separation and recovery of polyethylene from polyethylene-aluminum multi-layer packaging material. This is done by dissolving the composite material into a series of organic solvents at high temperature (up to 560°C) for few hours (around 6hours).

Fávaro *et al.* [147] separated multi-layer packaging material containing polyethylene (PE), aluminum and poly-ethylene terephthalate (PET). First the composite material was delaminated using ethanol at 50°C under stirring for 4h. Then PET was depolymerized under supercritical conditions in a vessel at temperature of 225°C and a pressure of 11.65MPa and for up to 120min. This process resulted into formation of pure diethyl terephthalate. The recovered PE and aluminum can also be easily recycled.

Rodríguez-Gómez *et al.* [148] reported the possibility of separating aluminum and polyethylene (PE) layers using waste vegetable oil. The composite material was dissolved in waste vegetable oil at 140 °C for 1 h with stirring for 50 min. This study concluded that 80% of PE and 85% of aluminum has been recovered.

Yan *et al.* [149] showed that by dissolving polyethylene -aluminum packaging material in Methanoic acid solution at 60 to 80°C for 30min could result into the separation of the two materials. The study indicated that the recovery rate of polyethylene and aluminum is 98% and 72%, respectively.

As presented above, most of research conducted to separate aluminum from polymeric layer focus only on the selection of the separation reagents, an approach which is insufficient for extensive production [145].

Very limited number of publications reported the mechanical recycling of packaging material to produce useful goods. Ayrilmis *et al.* [150] mixed lignocellulosic wastes (rice husk and saw dust) as filler in the polyethylene aluminum composite using injection molding technique. High tensile and flexural strength composite material was obtained. The authors proposed that this material could be used in automotive interiors and outdoor decking applications. Stanhope *et al.* [151] published a patent on 2018 describing process to recycle multi-layer packaging material to produce composite material. The inventors mixed organic filler with waste multilayer composite material containing polyethylene, polyethylene terephthalate and aluminum film in order to produce composite material that can be a substitute for wood in products such as deck boards, railing, fencing, pergolas, residential cladding/siding, sheet products and other applications. However, very few publications in the literature report mechanical recycling methods to recycle multi-layer packaging material to produce useful goods. Thus, research is still needed in this area.

2.6. Summary of literature

Rural villages in developing countries like Egypt are confronted with many environmental problems due to poor waste management. In fact, wastes end up in water canals, streets or in open dump sites. This is mainly due to the high capital and running cost of traditional disposing methods. This situation causes many problems to the rural villages in Egypt. The Egyptian government has developed sustainable development goals for 2030, which main goal is to preserve natural resources and support their efficient use. Similarly, the United Nations drafted seventeen Sustainable Development Goals for 2030. In order to contribute to these goals and most importantly alleviate the burden on rural villages, it is imperative to develop a new framework for waste management in rural villages to approach 100% full utilization of waste.

Since the emergence of the concept of sustainable development many efforts have been made to reach zero pollution, especially in the industrial sector. The concepts of cradle-to-cradle, industrial ecology/eco-industrial park, environmentally balanced industrial complex, and green economy have been developed to move from linear flow of material to cyclical system reduce depletion of natural resources and environmental problems cause by huge amount of waste generated. Unfortunately, not enough studies are made to propose solution to reach full utilization of all types of wastes generated in rural villages to reach Sustainable rural community.

There are many environmental problems facing rural communities in Egypt. In this research two major problems will be tackled.

The first major problem rural villages in Egypt suffer from is poor management of the huge amount of organic waste generated every year. Composting process is considered one of the most suitable alternatives to manage and treat organic waste. However, this method is not widely practiced in developing countries because it is time consuming and quality of product can be unstable. Hence, there have been increasing attention on improving composting process. Few studies have reported that co-composting as well as inoculation of compost with microbial additives or biochar can accelerate the composting process and increase the nutritional values of produced soil amendment or organic fertilizer. Yet, there are still knowledge gaps to fully understand the composting process due to the variety of feedstock.

The second major issue facing rural villages in Egypt is poor recycling of the huge amount of MSW. Some types of MSW can be easily recycled such as metals, glass, thermoplastics, etc., while others are perceived as difficult or perceived as impossible to recycle. These un-recyclables are usually referred to as rejects. This research focus on two types of rejects including (1) thermosets and (2) laminated or multi-layer packaging material as they are found in large amounts in Egypt.

Thermosets are used in many applications as they have excellent properties due to the three-dimensional network bond. However, this structure makes them difficult to recycle. There are two types of thermosets: (1) hard thermoset, and (2) rubber or elastic thermosets.

Several studies have reported mechanical, thermal and chemical methods to recycle hard thermosets. However, these methods are still not implemented in large scale. Mechanical recycling methods shows significant environmental and economic advantages when compared to the other recycling routes.

Also, many studies have extensively investigated recycling of waste tyres in recent years. Yet, recycling of other types of rubbers is very limited. Large amounts of Ethylene-propylene-diene- monomer (EPDM) waste are generated it is estimated to be the second largest after tyre waste; yet, very few published paper discuss the recycling techniques of EPDM rubber. There are no published data on the amount of EPDM rubber generated in Egypt and most specifically in rural areas. However, it is the second largest elastomeric waste worldwide and it is used in many applications including weather stripping and seals, wire and cable harnesses and electrical insulations and stinger covers. Thus, EPDM rubber waste was selected to be recycled.

The other type of reject is multi-layer packaging material. Most of the literature focus on studying different chemical solution or microwave induces pyrolysis or plasma technology to separate the layers and recover each material separately. Very limited number of publications reported the mechanical recycling of packaging material to produce useful goods. Yet, mechanical recycling seems to show significant environmental and economic advantages when compared to other techniques.

Recycling of rejects is still not widely practiced especially in developing countries as the developed techniques require high cost and large energy consumption. Therefore, most cost-effective and easy technologies need to be investigated to meet the needs of rural villages in developing countries like Egypt.

2.7. *Main Goal*

The main goal of this research work is to develop and propose a concept to help rural communities in Egypt approach full utilization of all types of wastes generated. This research work will focus on two types of wastes streams: (1) Organic Waste – rice straw and animal manure, (2) Municipal Solid Waste – rejects.

CHAPTER 3 – WASTE TO BUSINESS MODEL (W_2B) FOR SUSTAINABLE RURAL COMMUNITIES[2]

3.1. Introduction

As mentioned in the previous chapters, rural villages in Egypt suffer from poor waste management, which causes many environmental, health and economic problems. People tend to directly throw their waste in streets and nearest waterways as an easy and cheap solution to the huge piles of waste generated every year. These traditional behaviors need to be changed as they not only cause environmental problems but also present an economic loss. Integrated waste management system in the Egyptian rural areas is not yet among the priorities of the Egyptian government. Hence, the main goal of this research work is to aid rural communities' approach zero-pollution via sustainable and affordable methods. The aim of this chapter is to propose a solution for the waste problem in rural areas via the Waste to Business Model (W_2B).

3.2. Objectives

The objectives of this section are to:

- Evaluate the current waste management system and waste streams in rural villages in Egypt
- Identify the problems associated with waste management practices in rural villages in Egypt

[2] The work in this chapter was first presented in a conference paper by Omar, Hala and El-Haggar, Salah entitled "Proposed Sustainable Rural Community Framework" at the 4th International Conference on Sustainable Solid Waste Management in Limassol, Cyprus [207]. Then the idea was further developed and published in two journal paper by Omar, Hala and El-Haggar, Salah entitled "Zero Waste Rural Community Complex ($ZWRC^2$)" [22] and "Cost-Effective use of Organic Waste" [5]
The work in this chapter was also published in Chapter 7 of a book entitled "Road Map for Global Sustainability: Rise of The Green Communities", by S.M. El-Haggar et. al., Advances in Science, Technology & Innovation, IEREK Interdisciplinary series for Sustainable Development, Springer Publisher House, 2019 [28].

- Implement the concepts of sustainability, cradle-to-cradle, industrial ecology/eco-industrial park, environmentally balanced industrial complex and green economy in rural context
- Propose a concept to help rural communities in Egypt reach sustainability and full utilization of all types of waste

3.3. Methodology

The aim of the first part of this research work is to develop and propose a new concept to help rural communities in Egypt approach full utilization of all types of wastes generated. To do that, desk research method is used in which secondary data are collected from different sources including books, journal papers, conference papers, governmental reports, international organizations' statistics and websites.

In order to gather relevant information to the problem, some research questions are developed as follows:

- What are the major waste streams generated in rural villages in Egypt?
- What are the proposed recycling techniques for each type of waste in the literature?
- Are there any policies and/or government goals to solve these problems?
- What are the currently available and implemented solutions to these problems in other sectors (such as the industrial sector)?

From these research questions a list of keywords is generated including: waste, rural communities in Egypt, recycling, sustainable development, zero pollution, cradle-to-cradle, sustainable rural community, organic waste, composting, biogas, animal fodder, industrial waste, sustainable industrial community, cleaner production, eco-industrial park, environmentally balanced industrial complex, green economy.

These key words are then used to search for relevant sources using the AUC library, google scholar website, Egypt knowledge bank, government and international organizations websites. Note all papers, books and reports found using these key words were precisely matching the problem. Therefore, the data collected is screened for a second time after reading the abstracts and conclusions in details. Only sources that are both relevant, reliable and recent are used.

The first type of sources used are reports and documents describing the current waste management system and types of waste streams in Egypt and rural villages in particular. These reports are governmental reports and/ or reports from international organizations like the United Nations or World Bank.

The second type of sources used are journal and conference articles published, and books. These are mainly used to explain some of the key concepts used in this research work, which are discussed in detail in the literature review. Concepts such as sustainable development, cradle-to-cradle, eco-industrial park, industrial ecology, environmentally balanced industrial complex, green economy, etc. More articles with a specific focus on the techniques and methods used to recycle different types of waste in Egypt and in other developing countries are used. These articles are used to back up the argument for integration of waste management in rural Egypt as well as identify relevant techniques for context of rural Egypt.

The main limitation encountered during the research is the lack data to quantify the amount of waste by type generated in rural areas. The numbers available are based on estimations made at the national and governorate levels and are cited in several reports. Most of the published studies focus on waste management in Great Cairo and very few studies are conducted in rural areas. This lack of data makes it report exact numbers describing the amount of uncollected waste by geographical location and the exact amount of waste generated by types.

After thorough study of the gathered literature, the collected data are discussed to reply to the above questions. Then the limitations of the disposal methods and recycling techniques for rural villages are identified and a concept is developed and proposed to help rural areas in Egypt reach Sustainable Rural Communities.

3.4. *Evaluation of the current waste management system in rural villages in Egypt*

As the population grows, the quantity of waste also increases. The Egyptian population size is constantly escalating and in rural areas this increase was not accompanied with adequate development plans. Hence, the number of job opportunities in the agricultural sector became limited. People tend to either leave their hometown and move to large cities to find jobs or stay resident in their villages and find job in adjacent towns and cities and others went abroad to work. This situation led to significant changes in rural communities' lifestyle and consumption patterns [34], which resulted in significant changes in quantity and type of waste generated.

3.4.1. Major Waste composition in Egypt

There are no available data found in the literature or in governmental or non-governmental reports that clearly states the exact amount of each type of waste generated in rural villages in Egypt. Only few studies give estimates of some of the types of waste in few rural villages as fully discussed in the literature review (Chapter 2). **Figure 3.1** summarizes the major constituents of waste generated in Egypt.

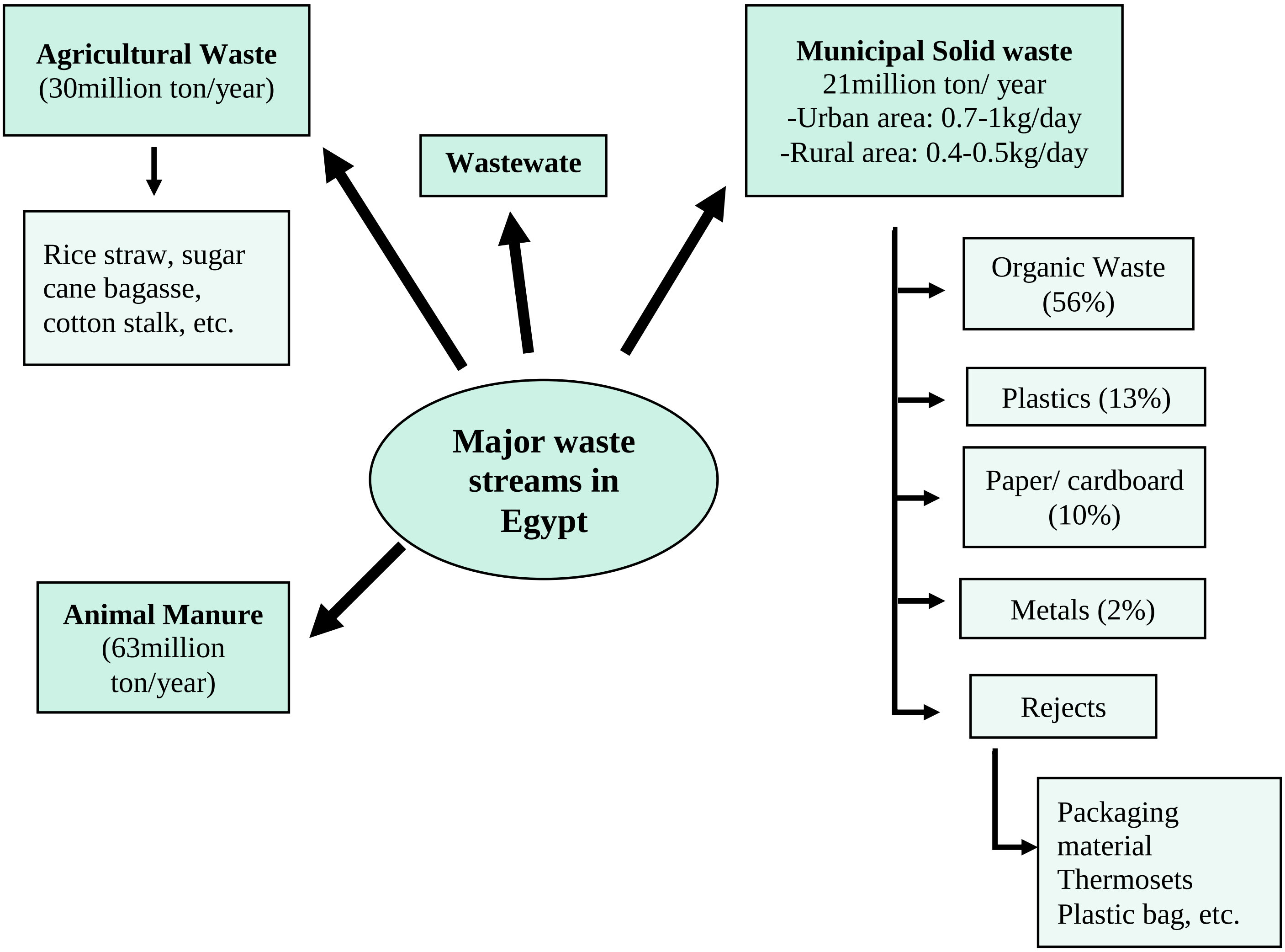


Figure 3.1: Major waste constituents in Egypt

3.4.2. Current practices of waste management in rural villages in Egypt

As thoroughly discussed in the literature review (Chapter 2), rural villages suffer from poor waste management system. Waste management system include collection, transport, sorting, treatment and/or final disposal. Few studies have been conducted in poor rural villages in Egypt like in Sohag, Dakaheleya, Fayoum and Menia, they reported that rural areas do not receive door-to-door services by municipalities like in big cities (Cairo, Giza, Alexandria, etc.) [152]. Instead people throw their waste in the nearest water way or street. In large town few trucks sent from municipalities run around open dump sites. Also, some residents of rural villages pay monthly for private collectors to pick their waste Even the private sector showed poor waste management. In fact, open trucks are usually used to collect garbage in large plastic bags causing spreading of bad odor in the village and leakage of leachate from plastic bags and truck. Therefore, people tend to throw their waste in the nearest water way or open dump site or burn them in the street causing many environmental problems. Very few percentage of waste is landfilled, according to the country report of waste only 7% of MSW generated in Egypt is landfilled. There is no accurate data on the percentage of landfilled solid waste in rural areas. Yet, El Messery *et. al* [34] evaluated the waste management system in 143 rural villages and concluded that only 27% of waste generated in these villages are collected and transferred to landfills. The study also revealed that these landfills are not well designed and constructed nor well operated, they resemble more to open dump sites. Similar results were reported in the annual report of the Ministry of State for Environmental Affairs [153]. This can lead to pollution of surface and ground water as well as many other environmental problems related to burning of solid waste. Also, only 7% of the MSW is composted and 10-15% recycled and the rest end up in open dump sites [11].

In rural villages waste is usually re-used or recycled on a household level. In fact, in Fayoum for example it was reported that plastics and glass bottles are re-used for storage purposes in households and also families recycle the organic matter and use it as animal fodder [153]. Also, in some areas there are waste dealers that buy recyclable waste such as plastics, glass, metals and papers. The rest of the waste is perceived as being unrecyclable or have no value.

3.4.3. Problems associated with waste management in rural villages in Egypt

The literature presented in the previous sections as well as in Chapter 2 reveals that the major problems associated with waste management in rural villages in Egypt are as follows:

- Population growth leading to generation of huge amounts of wastes
- Three major problems facing rural villages:
    - Generation of huge amounts of organic waste

    - Generation of huge amounts of MSW
    - Presence of waste that is perceived as impossible or hard to recycle are left in open dump site and streets
- High cost of traditional waste disposal methods (incineration and landfilling) causing huge burden on municipalities and farmers in rural areas causing the following:
    - Lack of collection services in small rural villages
    - Available landfills are not well designed and constructed and resemble more to open dump sites
- As an easy and cheap solution, residents of rural villages tend to throw their waste in the nearest water way and open dump site or burn them in the streets
- Most of the missing wastes in dumpsites, streets and water ways are perceived as being unrecyclable and of no value

3.5. Pathway to Sustainable Rural Communities in Egypt

3.5.1. Sustainable Strategies in industrial sector

The development of the concept of sustainability raised the awareness of people on the importance of conservation of natural resources. This concept has been widely implemented in industrial sector as thoroughly presented in chapter 2. The following concepts have been developed and implemented in many countries reach sustainable industrial community. The first concept is cradle-to-cradle (C2C) that aims to move towards a cyclical flow of material in which goods are made of material that can be recycled an infinite number of time. The second concept is Industrial Ecology (IE) from which many Eco-Industrial Parks (EIP) has been implemented. The third concept is Environmentally Balanced Industrial Complex (EBIC), in which compatible industries are grouped in one area to facilitate the use and transportation of waste among different industries. The main advantage of adopting these concepts is to minimize and/or eliminate the cost of raw material, transportation, storage, and waste disposal and treatment. Unfortunately, limited number of studies focused on developing concept that can allow full utilization of waste generated in rural villages and reach sustainable rural communities.

3.5.2. Plans and strategies for waste management in Egypt

The government of Egypt is aiming to achieve sustainable development to improve people's living conditions. In 2016, the government of Egypt launched its Sustainable Development Strategy: Egypt Vision 2030, which frames the government's actions for the next 15 years and acts as its long-term development strategy covering the three development dimensions; economic, social, and environmental. The main goal of the Egyptian government is to "end all forms of poverty, fight inequalities, and tackle climate change, while ensuring that no one is left behind" [5].

Egypt has launched its SDGs: Egypt: Vision 2030 as it is committed towards achieving the United Nations Sustainable Development Goals (SDGs), which includes a set of 17 Sustainable Development Goals (SDGs) to end poverty, fight inequality and injustice, and tackle climate change by 2030.

Rural villages in Egypt have been marginalized for a long time pretending that these areas are isolated and far away from urban cities and does not have any impact on urban prosperity. However, millions of people are living in these areas and suffer from serious environmental problems that caused many economic and social challenges. As illustrated in **Figure 3.2**, one way to develop Sustainable Rural Communities and contribute to UN and Egyptian Sustainable Development Goals is to introduce and implement concepts used in industrial sector.

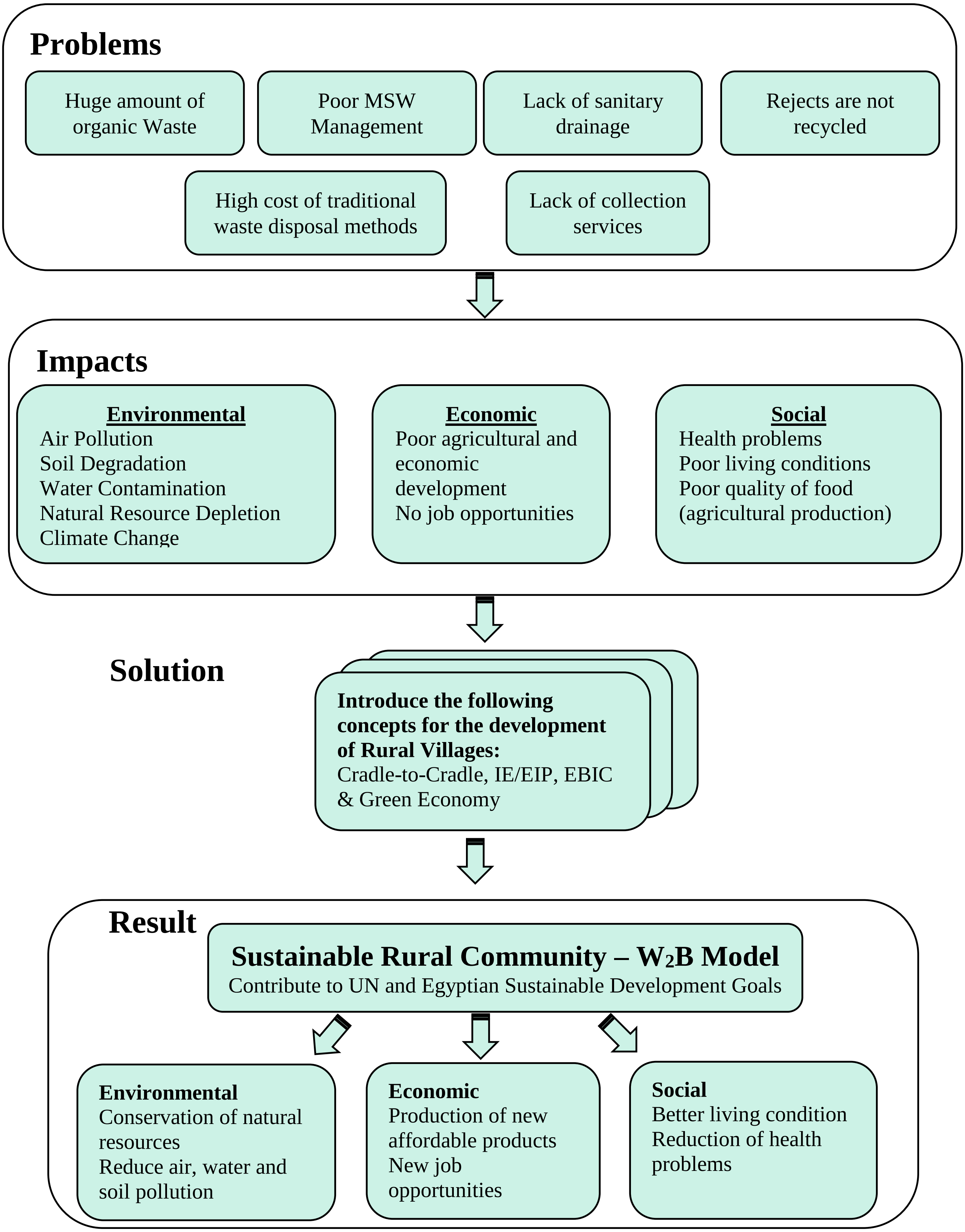


Figure 3.2: Pathway to Sustainable Rural Community in Egypt

3.6. Proposed Waste to Business Model (W_2B) for Rural Communities

Rural villages in Egypt have always been neglected and marginalized and always perceived as isolated areas. Yet, these areas are home to a large portion of the Egyptian population, which are confronted with many environmental, economic and social problems that cannot be ignored anymore. Resident of rural communities suffer from pverty and poor waste management systems, which make them live at high risk for diseases in informal houses, drinking and eating polluted water and food. The best solution to solve these problems is to develop a concept similar to the ones developed in the industrial sector that will allow to alleviate the environmental, economic and social problems facing these areas.

The Waste to Business Model (W_2B) consists of developing in each rural village a facility that groups small and affordable technologies to recycle all types of wastes generated from rural this village. This facility will receive all types of waste generated from the rural village, naming, agricultural waste – municipal solid waste, wastewater, as a source of raw material – and distribute them among the following four main units including (1) animal fodder unit, (2) biogas unit, and (3) composting/ organic fertilizer unit, (4) recycling of municipal solid waste unit. The idea of this facility is illustrated in **Figure 3.3.** This waste will; thus, be used to produce organic fertilizer, bio-energy, animal fodder and other products according to the market need.

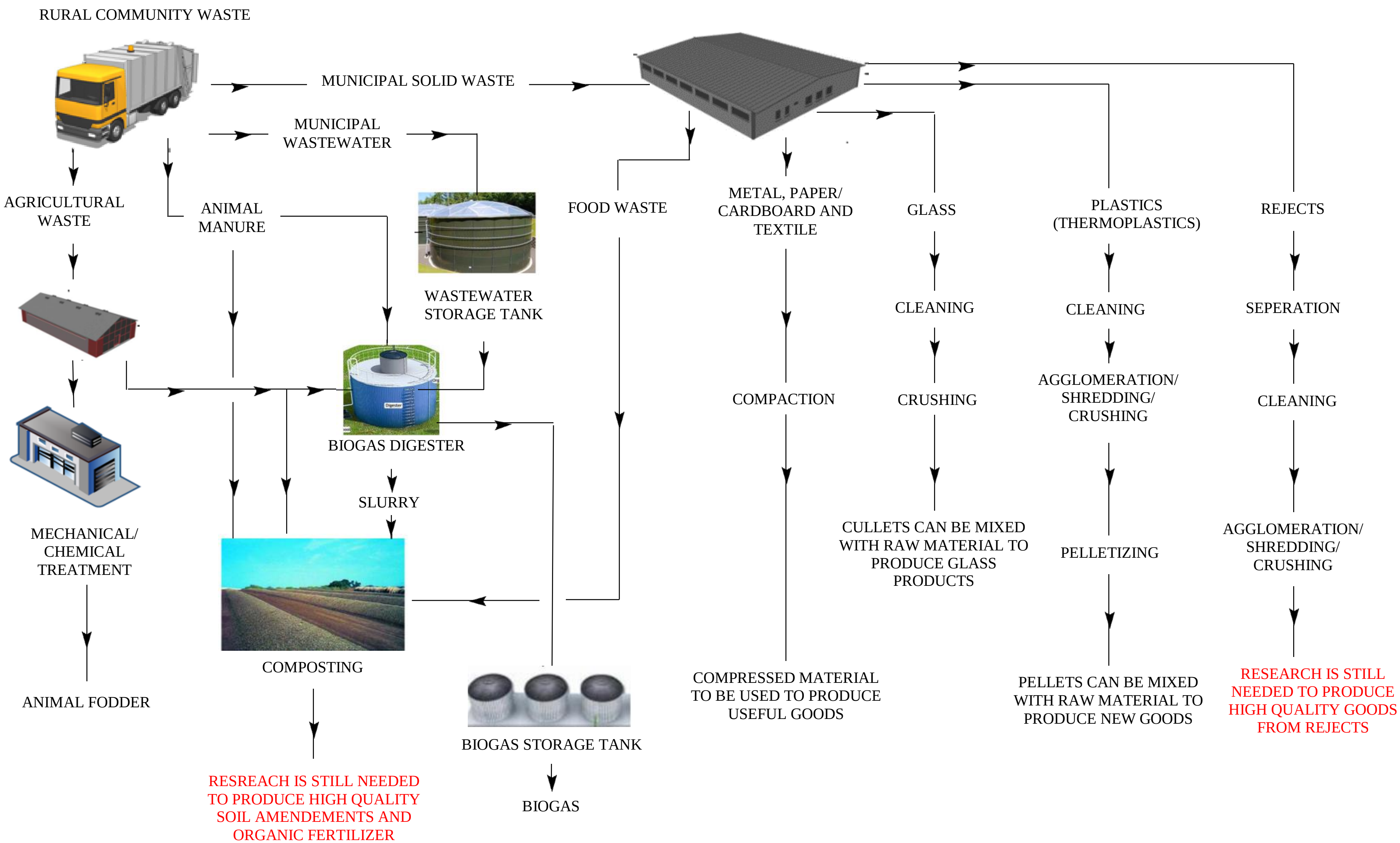


Figure 3.3: Waste to Business Model for Sustainable Rural Communities

Composting/Organic fertilizer

As thoroughly discussed in chapter 2, composting is a process in which optimum environment are settled (moisture content and oxygen) for aerobic bacteria to decompose organic matter and produce soil amendment and/ or organic fertilizer. There are several methods for composting process. In rural areas, it is recommended to use natural composting method that require manual turning of piles as it is a cheap technique that does not require high capital cost. This method requires lot of workers, which is an advantage in rural areas as they people suffer from unemployment. Using organic fertilizer and/or soil amendment made from composting of organic waste is advantageous as it will improve the soil structure and eliminate the pollution caused by burning of waste. Other additives can be inoculated to the compost pile such as natural rocks (phosphate - source of phosphorus, feldspar - source of potassium, dolomite - source of magnesium, etc.) to produce organic fertilizer for organic farming, which can replace expensive imported chemical fertilizers [6]. However, composting is not widely practiced in developing countries because it is time consuming and quality of product received can be unstable. More research is required to understand the process more and increase the quality of compost and/or organic fertilizer produced.

Animal Fodder

Animal foodstuff is not available in large quantities in the local market in many rural villages in Egypt. Rather, animal foodstuff is imported to fill the gap in the market at relatively high cost. Hence, several research is done to produce animal foodstuff from agricultural waste to overcome this deficiency.

The size and toughness of many agricultural wastes makes it hard for animals to consume them directly. They need to be mechanically or chemically treated first. [154]. The mechanical treatment consists of reducing the size of agricultural waste via chopping, shredding and grinding. Then the waste is soaked in water to soften it, and finally is streamed under pressure. However, this mechanical method requires several equipment that consume energy which make it relatively expensive and thus prevent its spread.

Another method consists of mixing agricultural waste with urea or ammonia. The mix is covered with covered with a 2mm thick polyethylene wrapping material for 2 weeks in summer and 3 weeks in winter. Then the cover is removed, and the mix is left for 2 to 3 days to release remaining ammonia before being used [154]. . This method was reported to be feasible and produce high quality animal fodder [14, 154, 155].

Biogas

Many rural villages suffer from incessant power outage; therefore, they meet their energy needs via traditional energy sources including firewood, dung and crop residues. These traditional methods are often expensive and/or time-consuming [6]. On the other hand, huge amount of organic waste is generated every year such as agricultural waste, food waste from MSW, wastewater, animal manure and animal residues. These wastes are left in the streets, open dump sites and water canals causing extensive pollution. Many research indicated that these wastes are organic carbon-based material that are subject to natural anaerobic degradation when left and release from 590 to 800 million tons of methane in the atmosphere [156]. In other words, if these wastes are placed in optimum conditions for anaerobic decomposition to take place, large amount of biogas can be produced and used to meet the energy needs of the rural population instead of using natural resources.

To produce biogas, organic material is placed in a container in the absence of oxygen for anaerobic bacteria to grow and consume organic matter to produce a mixture of methane and carbon dioxide. Biogas is a clean, efficient and renewable source of energy that can be used as a substitute for natural gas in rural communities. Research has found that 1.0 m^3 of purified biogas is equivalent to 1.1 L of gasoline, 1.7 L of bioethanol, or 0.97 m^3 of natural gas [157].

The slurry from the digester has high nutritional value and can therefore be utilized in the composting process produce organic fertilizer.

Many countries started using biogas. For example, in China 30 million household digesters are operating and aiming to reach 80 million by 2020. There are 162 farms scale plant in America serving 41,000 homes. Germany has more than 4,000 farm scale digesters, Austria has 350, United Kingdom 65 [157]. However, biogas technology is not very popular in Africa and needs to be more researched via universities and research centers to suit different country's needs.

There are several types of biogas digesters including [156]:

- Chinese fixed dome digester: It consists of a digester topped with a fixed (non-movable) dome (or well) made out of concrete and usually constructed underground. Raw material is introduced to the fermentation reservoir via a feed tank. Once gas is formed it expands and gas is pushed out of the reservoir also the produce gas pushes the slurry to overflow into the overflow tank to be stored. This design is easy to use and construct as it does not have any moving parts. Yet, gas produce is not constant, so it is difficult to use in applications where energy cannot be fluctuating.
- Floating dome digester: It consists of a movable cylindrical dome shaped digester made of stainless steel and a guiding frame to prevent the dome from tilting while moving up and down. The dome floats up and down depending on the amount of biogas produced in the digester. Also, the gas produced in not constant as in the case of Chinese fixed dome digester. This design is more expensive and require more maintenance compared to the fixed done design.
- Bag digester: The Union Industrial Research Laboratories in Hsinchu, Tawian developed the bag digester, which consists of a plastic bag digester. The reactor is made of a mixture of PVC and red mud generated from the production of aluminum known

as Red Mud Plastic (RMP). There are several types of bag digester among them is the balloon digester. In this design the digester skin is made of thin and flexible plastic allowing for the agitation of slurry, which optimize the digestion process. Bag digesters is recommended type of digester to be use in rural areas as it is relatively inexpensive. However, research is still needed to fully understand how it works and increase it efficiency.

Municipal Solid Waste (MSW)

As thoroughly discussed previously MSW is a major concern in rural communities. Most of the MSW generated in rural villages ends up in open, public and random dumpsites resulting into environmental, economic and social problems. Bad odors are emitted from MSW left without proper disposal techniques. These piles of wastes dumped everywhere attract flied and mosquitos, which put the residents of rural villages at high risk for diseases. Also, waste leachate and waste dumped in waterways contaminate both water pass ways as well as ground water and burning the waste releases greenhouse gases to the atmosphere, which pollute the air.

The traditional disposal techniques including landfilling or incineration are very expensive and contribute to depletion of natural resources. Also, the accumulation of piles of garbage in the streets can cause social and economic impact in addition to environmental problems. The absence of awareness of people of the size of the problem make recycling of MSW in rural villages in Egypt challenging. Also, to solve the problem people tend to import expensive technologies that are not suitable for the rural context of Egpt, which limit their use and spread.

The W_2B facility will receive all types of MSW generated in rural village. The waste will be placed on a conveyor belt and manually sorted and distributed among different units.

Thermoplastics will first be cleaned, cut and shredded and/or agglomerated depending on type of plastic. It will be subject to heat via extrusion machine and pelletized. The formed pellets can then be reprocessed to form products suitable for the market need.

Glass are cleaned and crushed into small pieces called cullets, which can then be mixed with raw material to produce new glass products, which will reduce raw material and energy used in the production of glass.

A hydraulic press is used to compact metal, paper and cardboard and textile wastes to be easy stored, handled and transported to recycling facilities. Ingots are formed by melting metals that can then be used to produce new products. Also, compacted paper, cardboard and textile can then be reprocessed to produce useful products.

Food waste can be recycled via composting as described above.

MSW also contained rejects, which are material that are perceived as hard or impossible to recycle such as packaging material, contaminated plastic bags, thermosets, etc. Very few research is done to recycle rejects using simple and affordable methods suitable for rural communities. As fully discussed in Chapter 2 several expensive methods have been proposed in the literature that cannot be implemented in rural villages, hence, it is imperative to develop easy and cheap technologies to recycle rejects.

3.7. Conclusion

It is proposed that the government, the rural community, business community and academic institutions and research centers collaborate to implement W_2B model in rural communities. W_2B model consists of having a facility in each rural community that groups simple and obtainable technologies to fully utilize all types of wastes generated in rural village and produce useful products. The waste is manually sorted among different units. Wastewater is stored in a tank and then used to produce biogas. The slurry from the biogas digester along with agricultural waste, food waste and animal manure are used in composting process to produce high quality fertilizer. Yet research is still needed to understand the effect of different additives on the composting process and to accelerate the process. MSW is then sorted manually and distributed among different units to produce useful goods depending on the market need of the village. One type of MSW is reject, material that are hard to recycle, still research is needed to fully utilize rejects to produce useful good at an affordable manner. In other words, this facility will collect all type of wastes generated in the rural village and will recycle them to produce useful products. By applying this approach, the village will be able to conserve natural resources, reduce the environmental, health, economic and social problems facing these remote areas due to burning and dumping waste. It will also help in creating new job opportunities and reduce the cost of goods.

While reviewing different waste streams it became obvious that there are two main important problems in rural villages in Egypt that need to be studied in depth:

- Recycling of organic waste
- Recycling or rejects

Therefore, the two following chapters will focus on recycling of these two types of waste as illustrated in **Figure 3.4**.

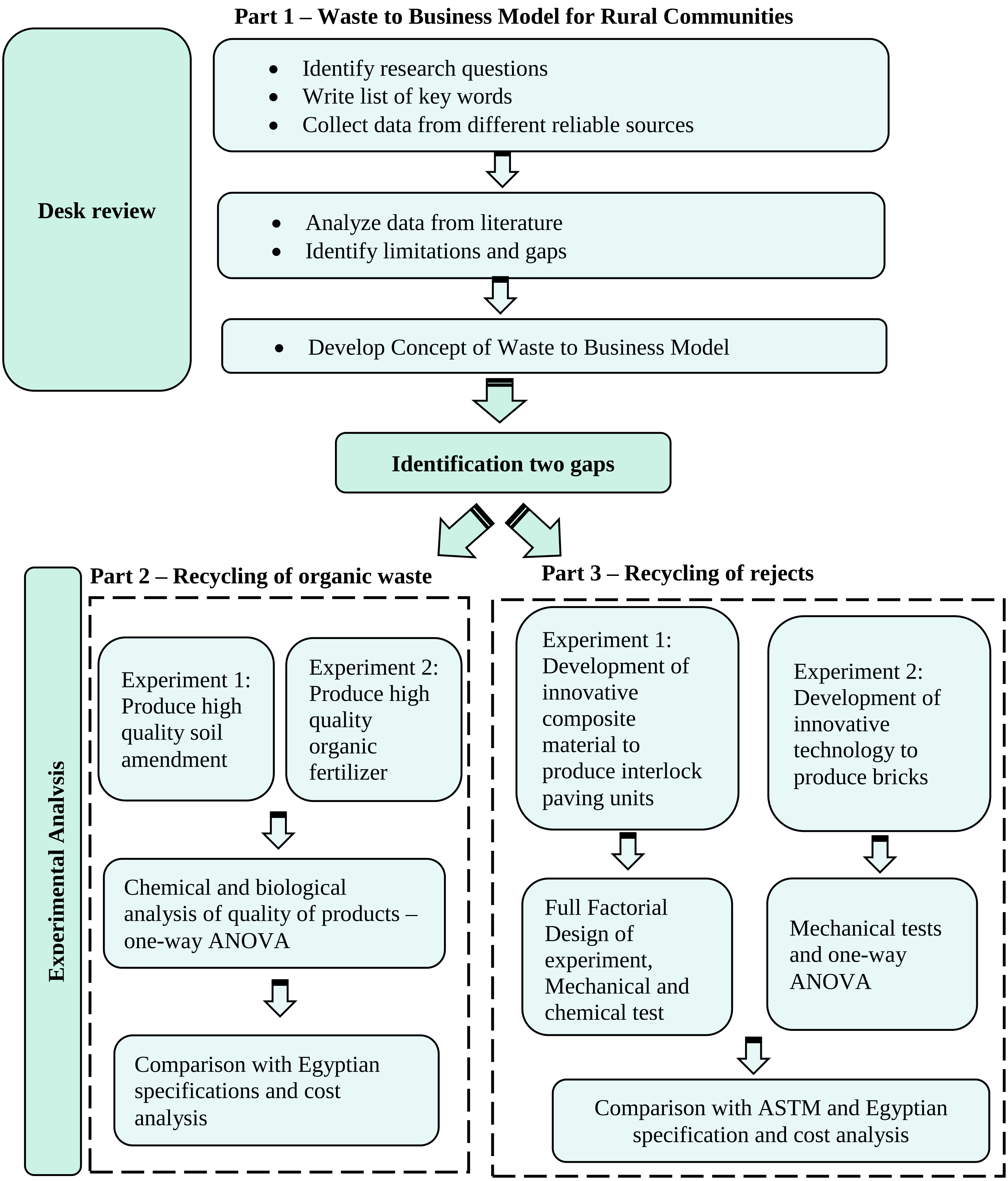


Figure 3.4: Summary of the Research Sequence

CHAPTER 4 – SUSTAINABLE BIO-CONVERSION OF AGRICULTURAL WASTE INTO HIGH QUALITY ORGANIC FERTILIZER – CASE STUDY OF RICE STRAW

As thoroughly discussed in the previous chapters huge amounts of organic wastes are generated every year in rural areas in Egypt. There are several types of organic waste and this research focuses on agricultural waste as a type of organic waste. Egypt generates up to 30 million ton/year of agricultural waste [12], from which 52% are directly burnt in the fields [13]. One of the main types of agricultural waste generated in Egypt is rice straw. Even after the decision of the Ministry of Irrigation and Water Resources to reduce the amount of rice cultivated in Egypt from 1,700,000 feddans to 724,200 feddans still this generates huge amounts of rice straw every year in Egypt. It is estimated that around 5.9million tons of rice straw were generated in 2013 [17]. Therefore, it could be estimated that today around 2.5million tons of rice straw are generated per year. A portion of the rice straw is mainly used as fuel for cooking and house heating, animal feed, fiber for pulping and plowing into farmland. A large amount of rice straw is dumped and burned in open fields causing serious environmental problems, including air pollution and soil degradation [16, 17]. Rice straw contains cellulose and hemicellulose and lining. Several studies showed that rice straw could be used to produce high value-added products via microbial fermentation process [81, 82]. There is an urgent need to find efficient and cost-effective methods to reduce environmental pollution and recycle agricultural resources.

Composting is an efficient method to transform agricultural waste into high quality soil amendment and/or organic fertilizer and instead of degrading the soil via burring of waste in the field, the use of organic fertilizer made of waste can rebuild the soil structure. [5, 17, 22, 71]. Thus, replace the overuse of expensive chemical fertilizer that largely contributed to environmental deterioration. Composting is a biological process in which complex organic matters are degraded by aerobic thermophilic and mesophilic microorganisms and converted into mineralized products (CO_2, H_2O,) and stabilized organic matter that can then be used as plant nutrients [61, 63, 158]. Although composting has been widely practiced, the process is still not fully understood due to high variety and heterogeneity of feedstocks [71]. The objectives of composting are to accelerate and create optimum conditions for the naturally occurring decomposition process to take place.

Composting goes through four phases: (1) mesophilic phase is a preparatory stage, which initiates organic matter decomposition; (2) thermophilic phase in which microorganisms decompose organic matter at high temperatures ranging from 40–70°C; (3) second mesophilic phase allowing re-establishment of the heat resistant microbes; and (4) maturity phase of constant nutrient contents [159].

There are several factors that affect the quality and decomposition rate of the compost, including moisture content, temperature, oxygen, and C/N ratio [22]. Also, the inoculation of microbial additives can tolerate composting condition, accelerate the composting process and increase nutrients is important to study.

Some studies showed that the use of additives is a beneficial option to improve nutritional value of compost and accelerate the degradation process [103]. Some of these amendments include biochar, effective micro-organisms (EM), cellulose decomposing bacteria, starters containing bacillus, fungi, yeast, lactic acid bacteria, and animal manure. Several producers of these additives claim that they can generate higher quality compost during short period of time. Yet, the effect of these additives on the composting process is not fully studied and understood. The aim of these experiments is to evaluate the effect of different additives on the quality of rice straw compost.

4.1. Objectives

In this part rice straw has been chosen as one type of organic waste that is present in huge amounts in rural Egypt. The aim of this part is to produce high quality soil amendments and organic fertilizers by composting of rice straw. This part is divided into two sets of experiments as follows:

- The objectives of the first set of experiment are to:
  - Transform rice straw into soil amendment or soil conditioner
  - Evaluate and compare the effect of different additives on the quality of produced soil amendment
- The objectives of the second set of experiment are to
  - Transform rice straw and animal manure into high quality organic fertilizer
  - Evaluate and compare the effect of different additives on quality of produced organic fertilizer
  - Compare the cost of produced organic fertilizer with commercially available chemical fertilizer

4.2. Materials and Methods

Based on the first part of this research work, it became obvious that recycling of organic waste is still not fully understood and need to be investigated. In order to address this aim, experimental analysis is conducted.

The aim of this part of the research work is to evaluate and compare the effect of inoculating different types of additives on composting process. To achieve this aim two pilot scale experiments are conducted at the American University in Cairo, Egypt to study the bioconversion of agricultural waste into a valuable product (compost) with application of different additives.

4.1.1. *Raw Material*

The main raw material used for composting in the two set of experiments is rice straw, which was sun dried and chopped. **Table 4.1** shows the properties of rice straw used in this study.

Table 4.1: Properties of rice straw

Parameters	Units	Value
Density	Kg/m^3	72
Moisture Content	%	8.35
pH		6.37
Electrical conductivity (Ec)	dS/m	2.64
Total Nitrogen	%	0.612
Organic matter	%	82.19
Organic carbon	%	47.67
Ash	%	17.81
C/N ratio		77.89:1
Total phosphorus (P_2O_5)	%	0.34
Total Potassium (K_2O)	%	0.517
Dry matter	%	91.65
Crude protein	%	3.76
Humicellulose	%	24.88
Cellulose	%	40.26
Lignin	%	14.2
Mn	mg/kg	67
Zn	mg/kg	103
Cu	mg/kg	41

4.1.2. *Organic additives*

Six different additives were inoculated to rice straw and the quality of final compost was evaluated. The additives include the following:

- Animal manure
- Imported Starter from China
- Cellulose decomposer
- Starter obtained from the Egyptian Ministry of Agriculture
- Effective micro-organisms (EM)
- Biochar

As presented in the literature review (Chapter 2), many studies showed that co-composting with animal manure provide high nutrient content of the compost. Anwar *et al.,* reported that adding around 30% of the animal manure provide an initial C/N ratio of about 40, which is desirable for composting organic substrate [16]. Some studies showed that the addition of 30% of animal manure to rice straw produces high quality compost [17]. Other studies showed that high quality compost is obtained by adding up to 60% of animal manure to organic substrate [18]. Based on that, 40% of animal manure was added to rice straw in all treatments.

Other commercial microbial inoculants are available in local markets. They mainly contain lactic acid bacteria, yeasts, photosynthetic bacterial, etc. Yet, their exact composition is not revealed and are seen as trade secret. No published studies have reported their exact composition nor their effect on composting process. Therefore, three types of commercial microbial inoculants are used in this study: (1) starter imported from China, (2) cellulose decomposer, and (3) starter obtained from the Egyptian Ministry of Agriculture.

The composting starter imported from China is mainly made of bacillus, fungi, yeast, lactic acid bacteria. The manufacturer recommends adding 1kg of the starter to 1 ton (0.1%) of organic substrate.

Cellulose decomposer is bought from the Egyptian Agriculture Research Center. It was recommended to add 10% of cellulose decomposer solution to organic substrate.

Another composting starter is obtained from the Egyptian Ministry of Agriculture. It was recommended to add 10% of this starter to organic substrate.

Effective micro-organisms (EM) consists of various strains of naturally occurring anaerobic nontoxic and non-pathogenic microorganisms in a carbohydrate-rich liquid carrier substrate (molasses nutrient solution). One part of commercial EM (EM-1) solution was added to one part of molasses and mixed with 20 parts of water to active EM solution and 100mL of active solution was added to 50kg of rice straw as recommend in other studies [19].

Biochar is another type of additive and many studies showed that it can have a lot of positive impacts on quality of compost. Several studies reported application of biochar with doses from 3 to 50%. According to the literature, the recommended application dose of biochar to compost is between 10% [39]. Some studies have also reported use of higher doses up to 50%; however, some authors have reported that doses higher than 20% can slow down the composting process [40]. Therefore, doses of 10% and 20% are used in this study.

4.1.3. Composting procedure

Two sets of experiments are conducted. The objective of the first set of experiment is to transform rice straw to soil conditioner. In the first set of experiments five compost piles are constructed, each pile contains 50kg of rice straw and different activator as shown in **Table 4.2**. It is worth to mention that this set of experiment is conducted in winter season.

Table 4.2: Piles content used for composting process in set of experiment # 1

Treatment No.	Pile Content
E1.T1	50kg of rice straw+50g of Chinese starter+1kg urea
E1.T2	50kg of rice straw+1kg of cellulose decomposer
E1.T3	50kg of rice straw+ 5kg of starter obtained from Egyptian Ministry of Agriculture
E1.T4	50kg of rice straw+ 20kg of animal manure
E1.T5	50kg of rice straw+ 20kg of animal manure + 50g of Chinese starter+ 1kg of urea

The objective of the second set of experiments is to transform rice straw to high quality organic fertilizer. In the second set of experiments, nine compost piles are constructed, each pile contained 50kg of rice straw and different activator as summarized in **Table 4.3**. Different types of rocks are added at the beginning of the composting process to all treatments to enrich the compost nutritional value. Previous study conducted at the American University in Cairo revealed that the addition of different types of rocks to the compost with the percentages presented in **Table 4.4** enriches the nutrition value of final compost product [5]. It is important to mention that this set of experiment was conducted in summer season.

Table 4.3: Piles content used for composting process in set of experiment # 2

Treatment No.	Pile Content
E2.T1	50kg of rice straw+20kg of animal manure+ Mixture of Rocks
E2.T2	50kg of rice straw+20kg of animal manure + 50g of Chinese starter+ Mixture of Rocks
E2.T3	50kg of rice straw+ 20kg of animal manure +1L of activated EM + Mixture of Rocks
E2.T4	50kg of rice straw+ 20kg of animal manure + 5kg biochar (10%) + Mixture of Rocks
E2.T5	50kg of rice straw+ 20kg of animal manure + 50g of Chinese starter + 5kg of biochar (10%) + Mixture of Rocks
E2.T6	50kg of rice straw+ 20kg of animal manure + 1L of activated EM+ 5kg of biochar (10%) + Mixture of Rocks
E2.T7	50kg of rice straw+ 20kg of cow manure + 10kg of biochar (20%) + Mixture of Rocks
E2.T8	50kg of rice straw+ 20kg of animal manure + 50g of Chinese starter + 10kg of biochar (20%) + Mixture of Rocks
E2.T9	50kg of rice straw+ 20kg of animal manure + 1L of activated EM + 10kg of biochar (20%) + Mixture of Rocks

Table 4.4: Types of rocks used and their corresponding quantities

Type of rock	Percentage (%)	Quantity (kg)	Value Added
Rock phosphate	2.5%	1.25	Source of Phosphorous
Feldspar	2.5%	1.25	Source of Potassium
Sulfur	2.5%	1.25	Natural Pesticide
Dolomite	2.5%	1.25	Source of magnesium and calcium
Bentonite	10%	5kg	Source of Magnesium, calcium, potassium, and iron

In both sets of experiments, the treatments are composted aerobically in large fabric bags with aeration through turning. The moisture content is kept at around 60% in all piles by adding water. The materials in each pile were manually turned every week. **Figure 4.1** summarizes the composting process. Ambient temperature and treatments temperature were measured three times a week through the center of the compost piles at different locations using a digital thermometer. The treatments are left three months for composting. Three homogenized and randomized samples are taken manually after 10 days, 30 days. 60 days and 90 days from top, middle and bottom of compost piles.

Figure 4.1: Summary of composting process

4.1.4. Measured Parameters

All the samples are tested as per the Egyptian Specification for Compost for the year 2017 [160] to be analyzed for the following physical, chemical and biological parameters at the Soil, Water and Environment Research Institute, Agriculture Research Center:

- **Organic Matter (%OM)** is the difference between ash and dry weight. The weight of dry sample is measured. Then the sample is burnt in a furnace at 750°C for 4 hours and the weight of formed ash is measured.
- **Organic carbon (%OC):** Van Bermmelem factor of 1.7241 is used to calculated %OC from %OM [161],

- **Total nitrogen, ammonium nitrogen and nitrate nitrogen:** Kjeldahl method is used to analyze the total nitrogen [154]. The sulfuric acid is added to the sample and heated which decomposes the organic substance by oxidation to liberate the reduced nitrogen. Ammonium nitrogen is extracted 2N KCl, then estimated by the steam distillation Kjeltic method in alkaline media [155].
- **C/N ratio** is calculated by dividing %organic carbon with %total nitrogen.
- **Moisture content and bulk density**: to measure the moisture content the sample is dried at a temperature of 105°C until the weight becomes constant. The bulk density of compost is calculated by dividing the weight of the sample by its unit volume
- **pH and electrical conductivity (EC):** Stirred 5 g of the sample in 50 ml distilled water. The pH value is measured using a pH digital meter with a glass electrode. The EC is measured using EC meter.
- **Germination index (GI):** The sample is shacked with distilled water for 1 h, and then filtered to be used for germination of Eruca sativa seeds using Petri dishes. Seed germination in distilled water was used as control. The percentage of seed germination (GI) is then calculated using the following equation [162]:

$$\mathrm{GI}(\%) = \frac{\text{No. of seeds germinated in compost extract}}{\text{No. of seeds germinated in control}} \mathrm{x}100$$

- **Humification index (HI):**

First, compost sample is mixed with a solution $NaOH/Na_4P_2O_7$ 0.1 N for 48 h at 65 °C. Samples were centrifuged at 2500 rpm and supernatant solution filtered through a 0.45 µm Millipore filter. Extracts were stored at 4 °C under nitrogen atmosphere.

Then, the extract is acidified with H_2SO_4 to separate humic-like acids (HA) (precipitated) from fulvic-like acids (FA) (in solution). HA and FA are then purified on a polyvynilpyrrolidone (PVP) column, resolubilised with NaOH and then joined to the humic portion. Combined fractions (HA+FA) were quantitatively transferred into a calibrated 50-ml flask, brought to volume with NaOH and stored at 4°C under nitrogen atmosphere. Total organic carbon in compost samples, total extractable carbon and humic and fulvic acids carbon (HA+FA) as proposed by Ciavatta *et al.* [156]. Then the Humification Index is calculated using the following equation:

$$\mathrm{HI}(\%) = \frac{nonhumified\ fraction\ (NH)}{\mathrm{HA} + \mathrm{FA}} \mathrm{x}100$$

- **Pathogenic bacteria (Total Coliform, Fecal Coliform, Salmonella and Shigella):** Pathogenic bacterial count was determined using agar plates containing specific media for coliform group, Escherichia coli, Salmonella and Shigella.
- **Total Phosphorous (TP) and Total Potassium (TK):** Total phosphorous is measured calorimetrically according to the methods described by Snell and Snell [157]. Total potassium was determined in the digested solution by flame photometer.

The objective of each measured parameter is summarized in **Table 4.5**

Table 4.5: Summary of measured parameters

Parameter	Objective
Organic Matter (%OM)	Measure of amount of OM and OC present in compost pile at different stages of composting process. OM and OC are consumed by micro-organisms during composting process. Thus, the analysis of %OM and %OC give an indication of the activity level of micro-organisms.
Organic Carbon (%OC)	
Total Nitrogen, ammonium nitrogen and nitrate nitrogen	Total nitrogen, ammonium nitrogen and nitrate nitrogen are used as maturity index for composting.
C/N ratio	C/N ratio is used as a measure of maturity level, compost stability and indicates nitrogen availability in compost pile.
Moisture content	Gives an indication that composting process has been conducted using proper conditions.
Bulk density	Gives an indication about the weight of solid material in the volume of compost.
pH	pH is measured to indicate that the compost is suitable to be used for plants. pH is a measure of acidity in the feedstock or compost. Ideal pH depends on compost use. A neutral pH is suitable for most applications.
Electric conductivity (EC)	EC is measured to indicate that the compost is tolerable by plants. Soluble salts are determined by measuring EC. High salinity may be toxic to plants. Ideal soluble salt levels will depend on the end use of the compost.

Germination Index	Measure the toxicity level of compost.
Humification Index	Measure the maturity level of compost.
Pathogenic bacteria	Measure the presence of harmful bacterial in compost piles.
Total phosphorus and total potassium	Phosphorus (P) and potassium (K) are plant macronutrients. These results provide an indication of the nutrient value of the compost sample.

4.1.5. Statistical Analysis

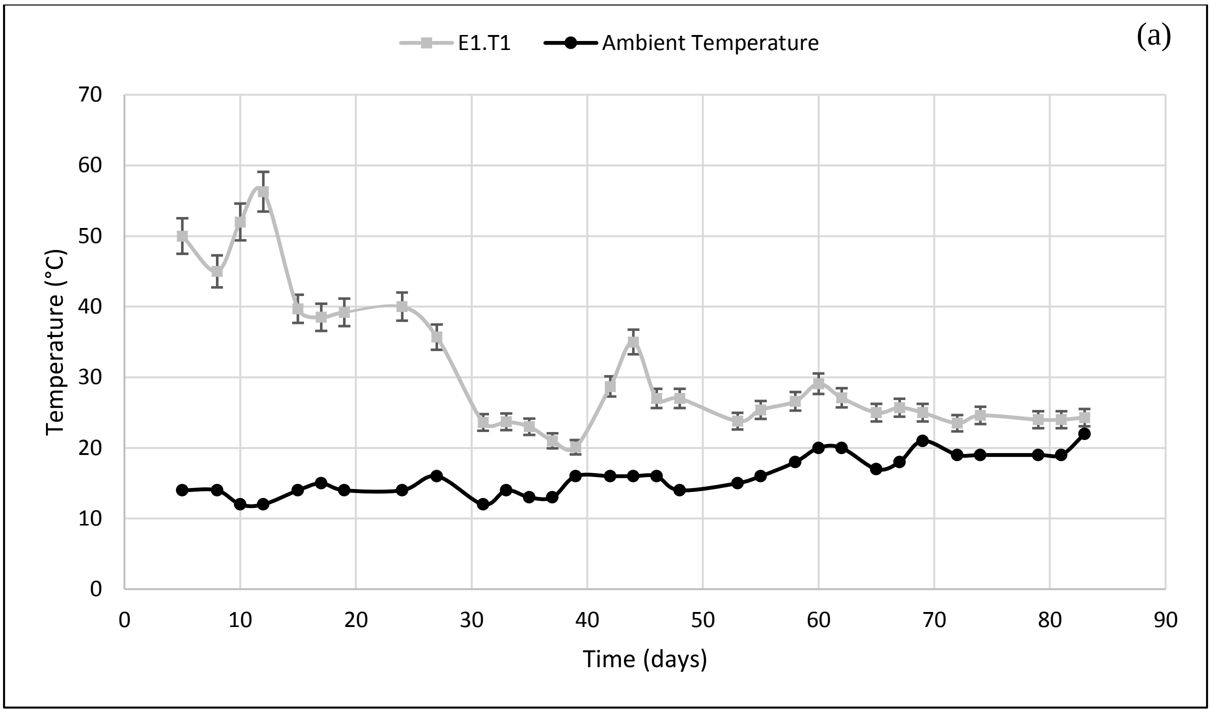
All results are presented as the average of three replicates, and the means among different treatments are compared using one-way ANOVA using SPPS version 23. The null hypothesis states that the population means are all equal. A significance level α =0.05 is used. The statistical results are presented in the **Appendix**.

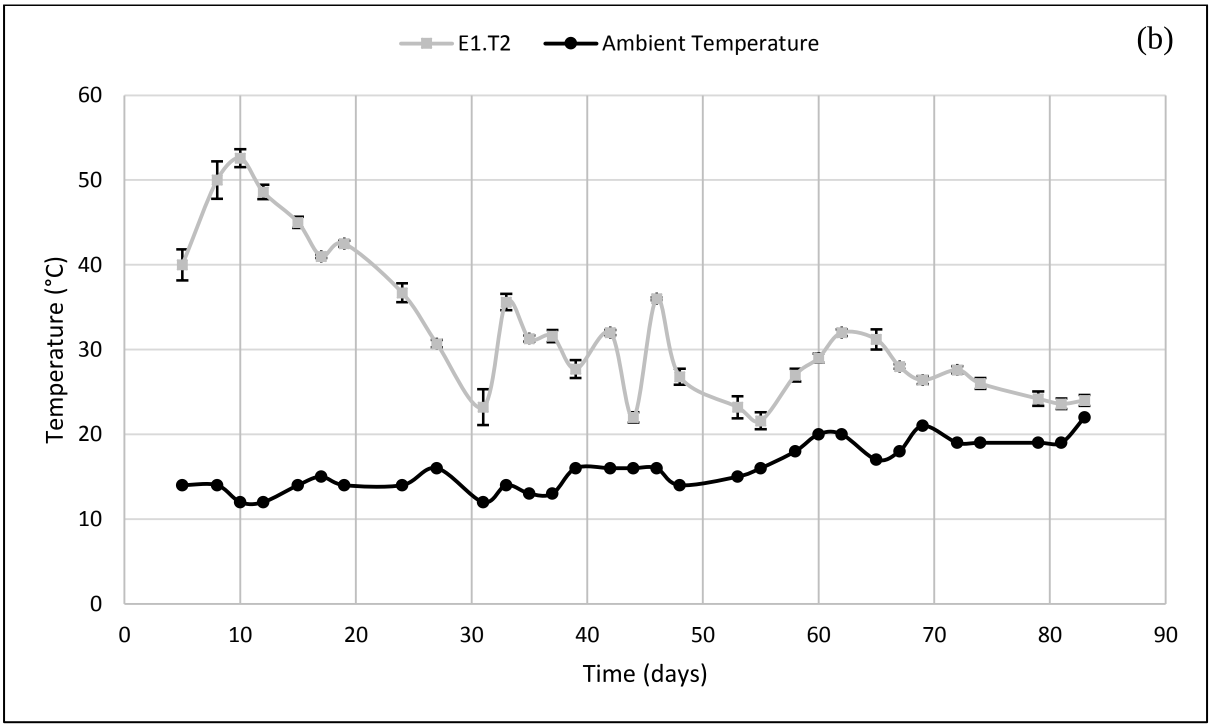
4.3. Results and discussion

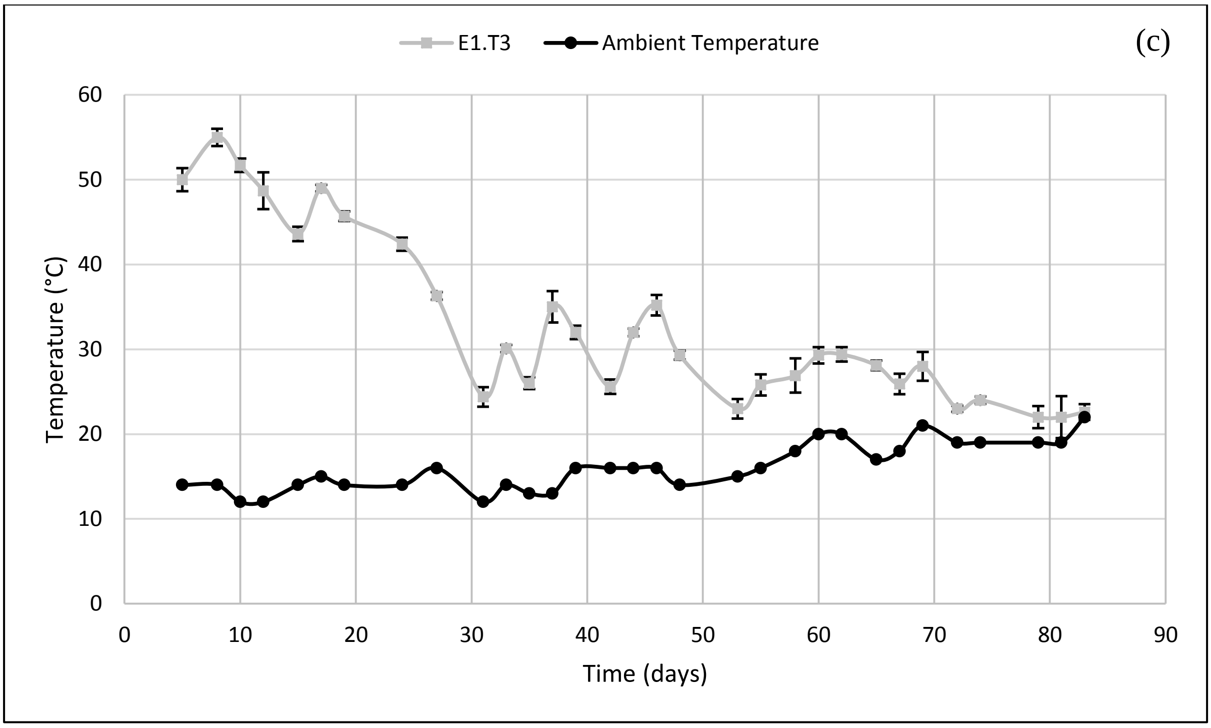
4.3.1. Bioconversion of organic waste into soil amendment

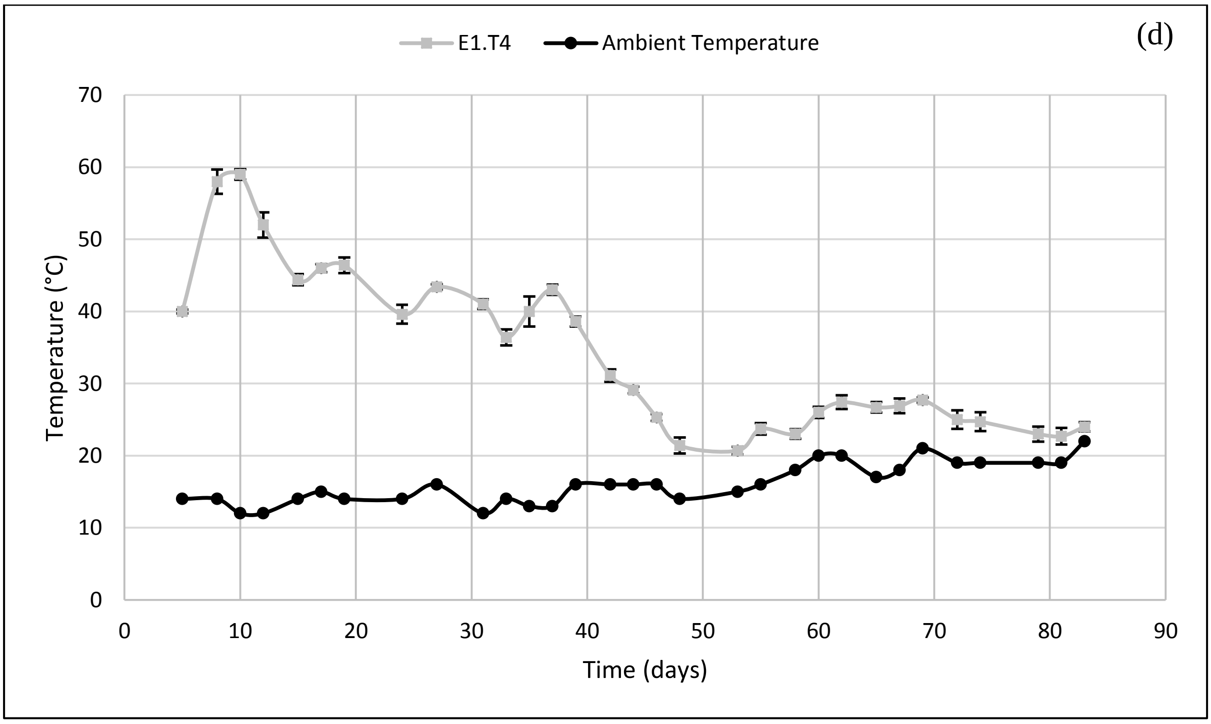
Temperature changes of Experiment # 1

The temperature changes for the first set of compost piles and the corresponding ambient temperatures were recorded and summarized in **Figure 4.2**. The temperatures were measured three times a week through the center of the compost piles at different locations using a digital thermometer. The full data are presented in the **Appendix**. It is important to note that the composting process was conducted during winter season. The ambient temperature variations throughout the composting period varied between 14°C and 22°C. An increase in piles temperatures was observed right after composting started.


E1.T1
Ambient Temperature
(a)
Temperature (°C)
Time (days)


E1.T2
Ambient Temperature
(b)
Temperature (°C)
Time (days)


E1.T3
Ambient Temperature
(c)
Temperature (°C)
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
90
Time (days)


E1.T4
Ambient Temperature
(d)
Temperature (°C)
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
90
Time (days)

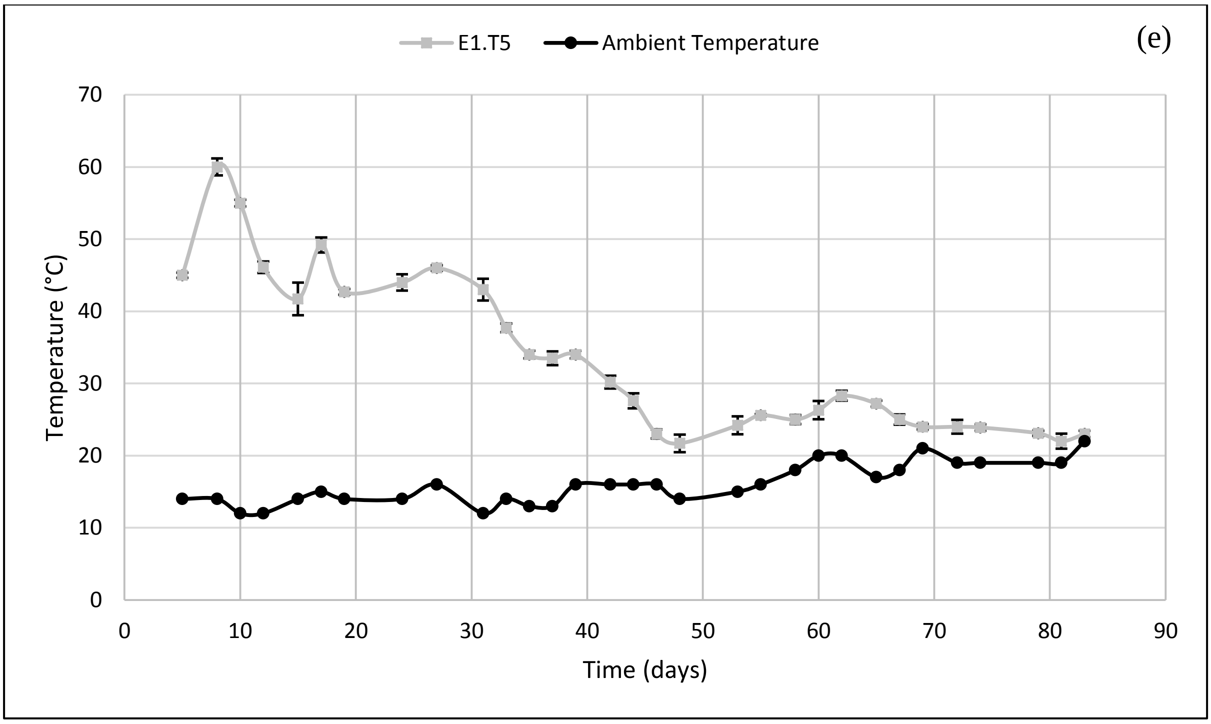


Figure 4.2: Changes in temperatures in compost piles with relation to ambient temperatures for (a) E1.T1, (b) E1.T2, (c) E1.T3, (d) E1.T4 and (e) E1.T5

In the first set of experiment the temperatures increased rapidly to reach more than 45°C after 5days for E1.T1, E1.T3 and E1.T5 and after 8days for the rest of the treatments, which marks the end of the initial mesophilic phase and beginning of thermophilic phase. The temperatures continued to increase and reached their maximum values of 56.3°C after 12 days, 52.6°C after 12 days, 55°C after 8 days, 59°C after 10 days and 60°C after 8 days respectively for treatment E1.T1 to E1.T5. After that, the temperatures started to decrease gradually, some increases in temperatures were recorded after turning the piles till the third week. Then the temperature gradually decreased to reach mesophilic phase. After that, it stabilized near the ambient temperature after 60 days.

According to Hassen *et al.* [163], the temperature profile indicates the success of an aerobic composting. The increase in temperature during composting is due to the activity of microorganisms to degrade agricultural wastes [164]. In other words, higher temperatures indicate greater microbial activity. Based on the results obtained in first set of experiment, treatments E1.T4 containing animal manure and E1.T5 inoculated with animal manure and Chinese starter, reached the highest temperatures and the most rapidly compared to other piles. The decrease in temperatures marks the reduction in microbial activity. The turning of piles was important to provide oxygen needed to support aerobic micro-organisms activities and maintain compost temperature high and obtain efficient thermophilic decomposition of organic waste. The results indicated a fluctuation of piles temperatures, which is contributed to the incorporation of external materials into the piles.

Organic Carbon (OC, %) and Organic Matter (OM, %) in Experiment #1

The %OM were measured for all piles; three measurements were taken for each pile and %OC were calculated from %OM. All data and ANOVA results are presented in the **Appendix**. The %OM was 62.6, 79.92, 71.38, 61.72 and 67.97% at the beginning of the composting process for treatments E1.T1 to E1.T5 respectively. The average %OM results of the first set of experiment are presented in **Figure 4.3**. One-way ANOVA was performed on the data after 90 days and results indicate that p-value of 0.00 less than 0.05 confidence interval, which means that there is a significant difference between the means of different treatments. The %OM decreased to be 42.8%, 58.34%, 55.93%, 38.54% and 39.78% for treatments E1.T1 to E1.T5 respectively. These values are much higher than the minimum required value of 16% for organic fertilizers made of agriculture waste from the Egyptian Specifications for Organic fertilizers [160].

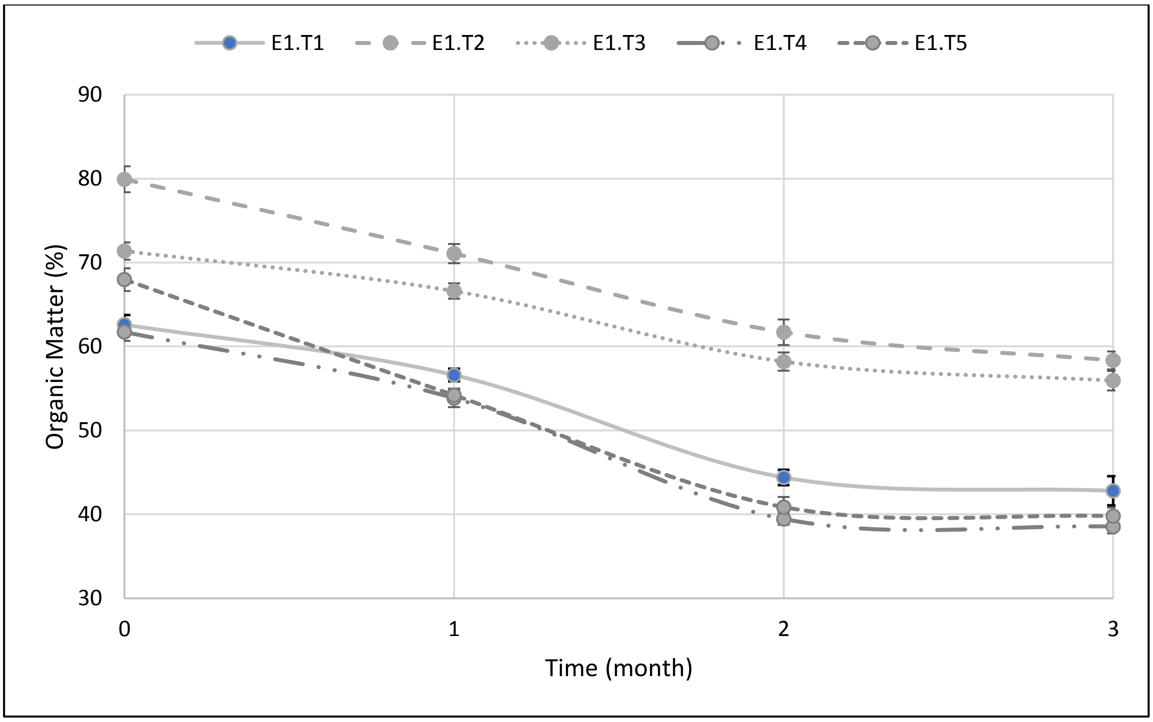


Figure 4.3: Changes in %organic matter in different compost treatments in set of experiment # 1

The %OC was 36.3, 46.4, 41.4, 35.8, 39.4 for treatments E1.T1 to E1.T5 respectively. The average %OC results of the first set of experiment are presented in **Figure 4.4**.

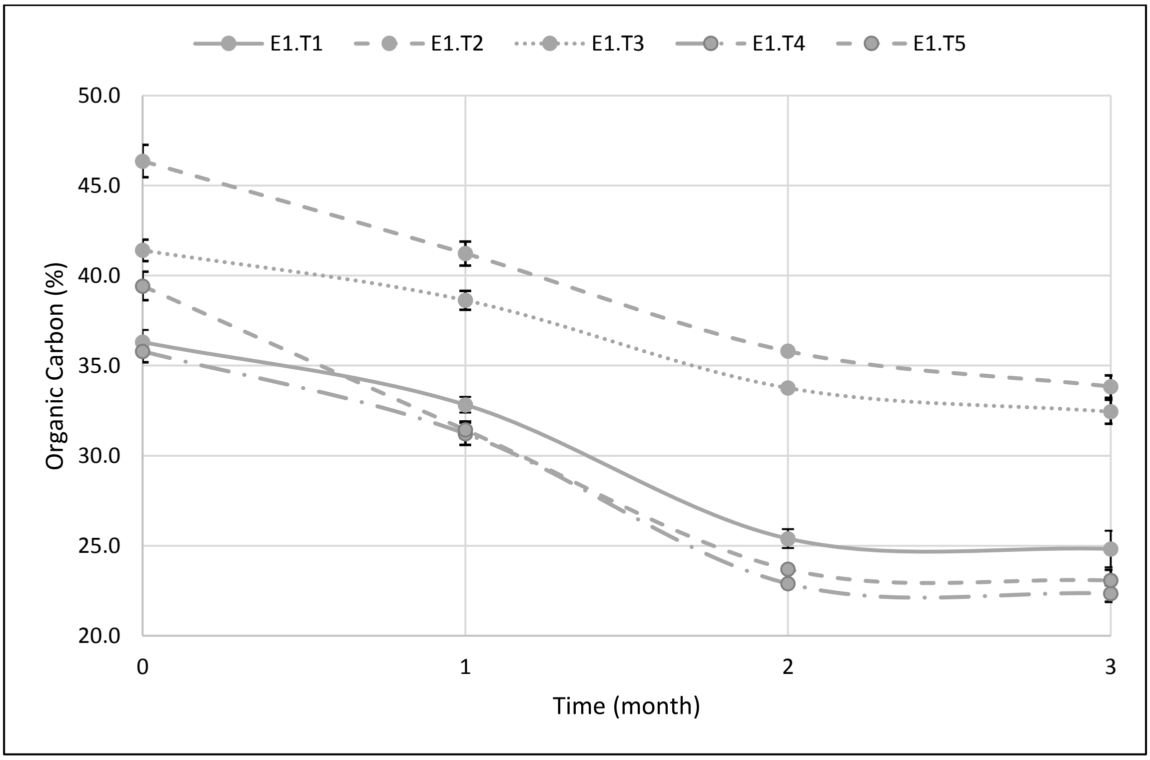


Figure 4.4: Changes in %organic carbon in different compost treatments in set of experiment # 1

The %OM and %OC values decreased during the composting process in all piles. The highest reduction was observed in E1.T5 (39.37%) followed by E1.T4 (35.76%), E1.T1 (29.79%), E1.T2 (22.75%), E1.T3 (18.9%) after 60 days. The percentage losses in OM and OC in the first set of experiments are presented in **Figure 4.5**.

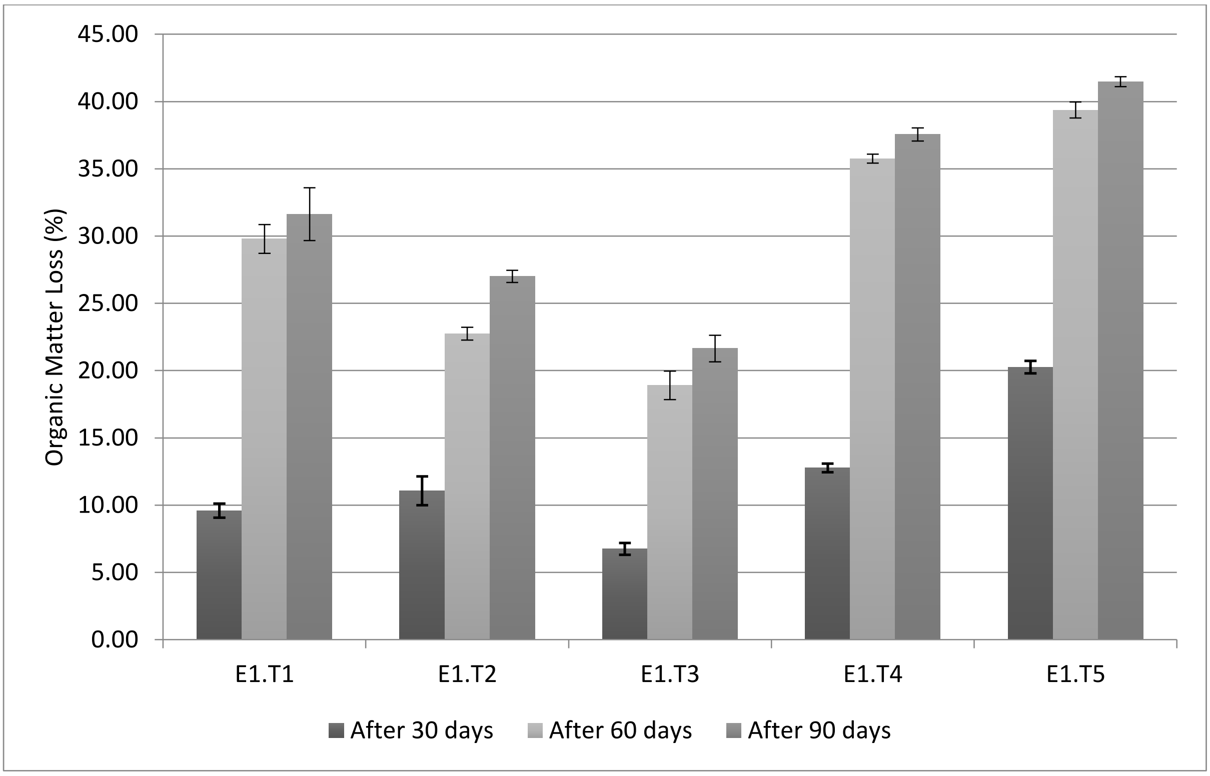


Figure 4.5: Percentage losses in organic matter and organic carbon in different compost treatments in set of experiment # 1

The reduction of OM and OC is mostly due to the degradation of easily degradable compounds such as proteins, cellulose, and hemi-cellulose, which are utilized by micro-organisms as carbon and nitrogen source and release of CO_2 during the composting process [165]. This means that treatments E1.T4 containing animal manure and E1.T5 containing animal manure and Chinese starter has the highest decomposition rate compared to other treatments. In other words, it could be concluded that these two treatments could have the highest content of easily decomposable substances compared to other treatments.

Also, the percent losses in OM and OC decreased with time; the percent losses are ranging from 2 to 5 % from 60days to 90days in all treatments. This is attributed to the fact that the thermophilic aerobic digestion has higher organic matter degradation compared to the mesophilic aerobic digestion [17].

Total nitrogen, ammonium and nitrate nitrogen in Experiment #1

The total nitrogen (TN), ammonium nitrogen (NH^{4+}) and nitrate nitrogen (NO^{3}) were measured for all piles, three measurements were taken for each pile. Detailed data and ANOVA results are presented in the **Appendix**. The average TN (%) values are presented in **Figure 4.6**. The total nitrogen has slightly increased in all treatments from 0.95, 0.78. 0.79. 0.85. 0.98 at the beginning of the composting process to 1.75, 1.47, 1.59. 1.11 and 1.24 after 60 days of composting for treatments E1.T1 to E1.T5 respectively. Also, the results show a slight increase in %TN from 60 days to 90 days compared to from the beginning of composting process to 60 days.

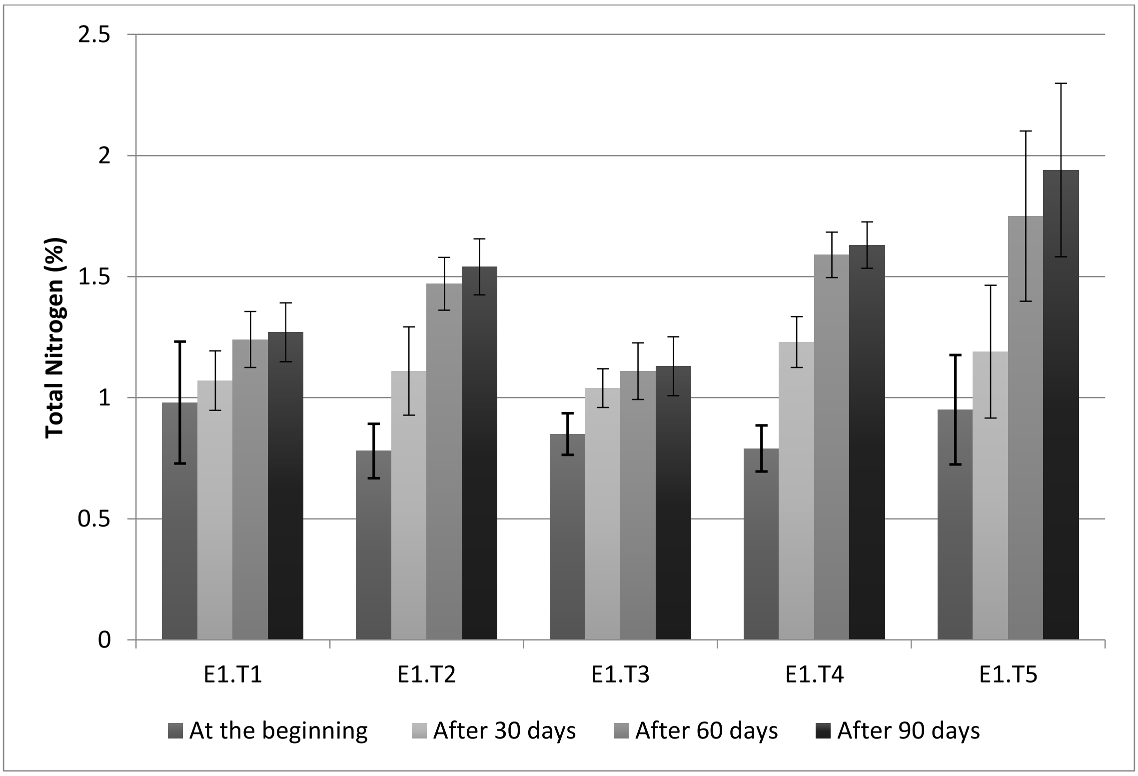


Figure 4.6: Total Nitrogen in different compost treatments in set of experiment # 1

Ammonium and nitrate nitrogen are of greater interest, as they have been used as maturity index for composting [166] [167]. The maximum values of ammonium nitrogen were observed at the beginning of the composting process to be 376, 314, 323, 410, 422 then decreased in all treatments to 36,62,65,33 and 46 for treatments E1.T1 to E1.T5 after 60 days respectively as shown in **Figure 4.7**.

While, nitrate nitrogen values increased with time as shown in **Figure 4.8**. The observed high values of ammonia nitrogen are due to mineralization of organic nitrogen present in composting mixture by ammonification reaction resulting from microbial activity. Then ammonia is transformed into nitrate by nitrifying bacteria. This transformation was reported to happen when the temperature of compost pile decreases below 40°C [167].

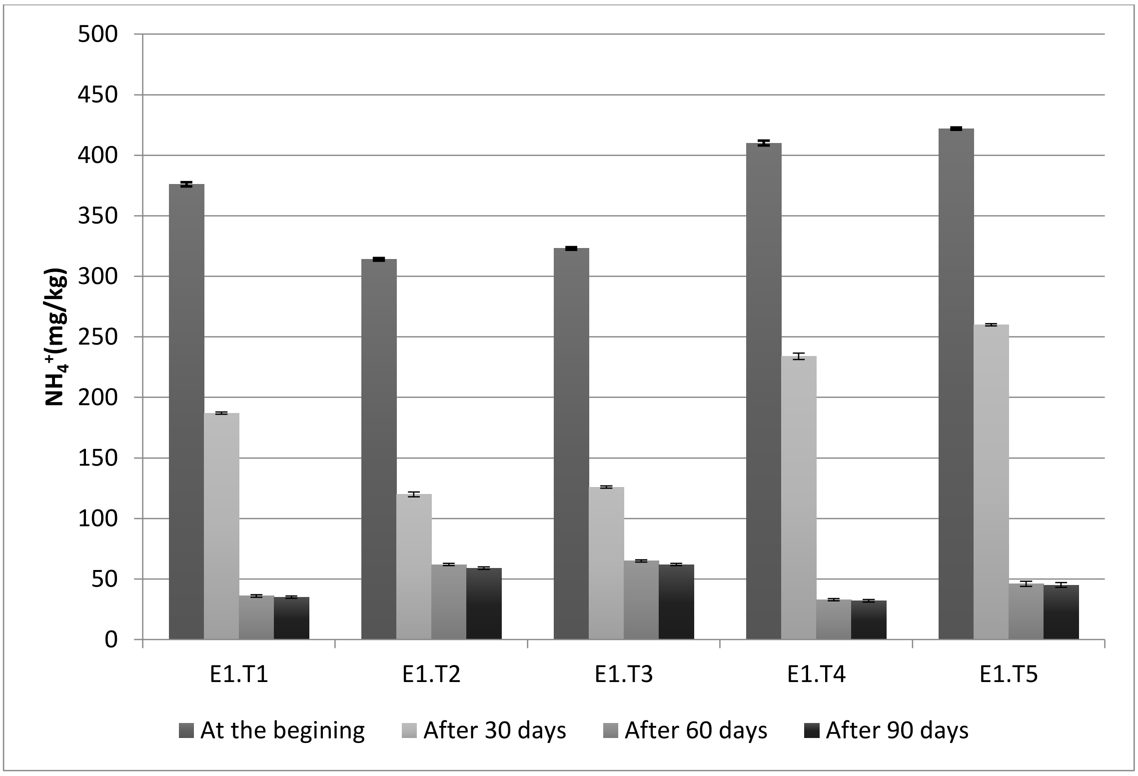


Figure 4.7: Ammonium Nitrogen in different compost treatments in set of experiment # 1

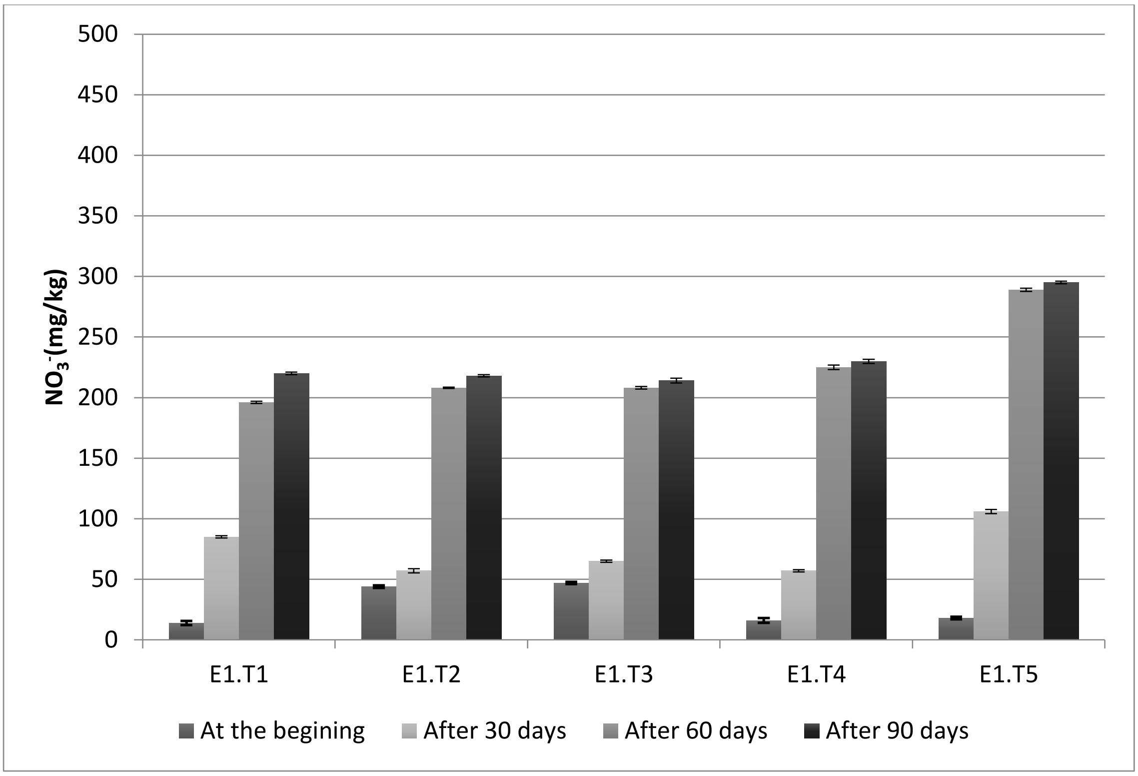


Figure 4.8: Nitrate Nitrogen in different compost treatments in set of experiment # 1

At the end of the process it was observed that the nitrate nitrogen is higher than ammonium nitrogen, which indicates that the process has been under adequate condition of aeration [167]. The nitrification ratios (NH_4/NO_3) of different treatments were calculated and presented in **Table 4.6**. According to Bernal *et al.*, the ratio should not exceed 0.16 to indicate maturity of the compost [168]. Other studies reported ratio values less than 1 at the end of composting process [166].

Table 4.6: NH4/NO3 for different treatments in set of experiment # 1

Treatments	Beginning of composting	After 30 days	After 60 days	After 90 days
E1.T1	26.86	2.20	0.18	0.16
E1.T2	7.14	2.11	0.30	0.27
E1.T3	6.87	1.94	0.31	0.29
E1.T4	25.63	4.11	0.15	0.14
E1.T5	23.44	2.45	0.16	0.15

Table 4.6 shows that nitrification ratios were high at the beginning of the treatments and decreased until maturity is reached. All treatments in set of experiment#1 have a nitrification ratio below 1. The treatments E1.T4 and E1.T5 have a nitrification ratio of 0.15 and 0.16 respectively. These results indicate that these piles reached maturity after 60 days. After 90 days also the pile inoculated Chinese starter only E1.T5 have a nitrification ratio below 0.16. These results indicate that these treatments have highest maturity compared to other treatments.

C/N ratio in Experiment # 1

The carbon to nitrogen ratio (C/N) is one of the most important factors that affect the composting process. Some studies showed that C/N ratio could be a reliable parameter for following the development of the composting process despite many pitfalls associated with this approach [169]. The C/N ratio was calculated and presented in **Figure 4.9**. It can be observed that C/N ratio decreased during the composting process. This decrease is due to the changes in the amount of nitrogen and loss of organic carbon during the composting process. These changes are an evidence that compost piles reached maturity stage. Many authors reported that C/N ratios below 20 are indicative of acceptable maturity [169, 170]. These results indicate that all treatments reached maturity. The C/N ratios after 60 days reached 20.5:1, 24.4:1, 30.4:1, 14.4:1, and 13.5:1 for treatments E1.T1 to E1.T5 respectively. This indicates that treatments E1.T4 and E1.T5 have reached acceptable maturity after 60 days compared to other treatments.

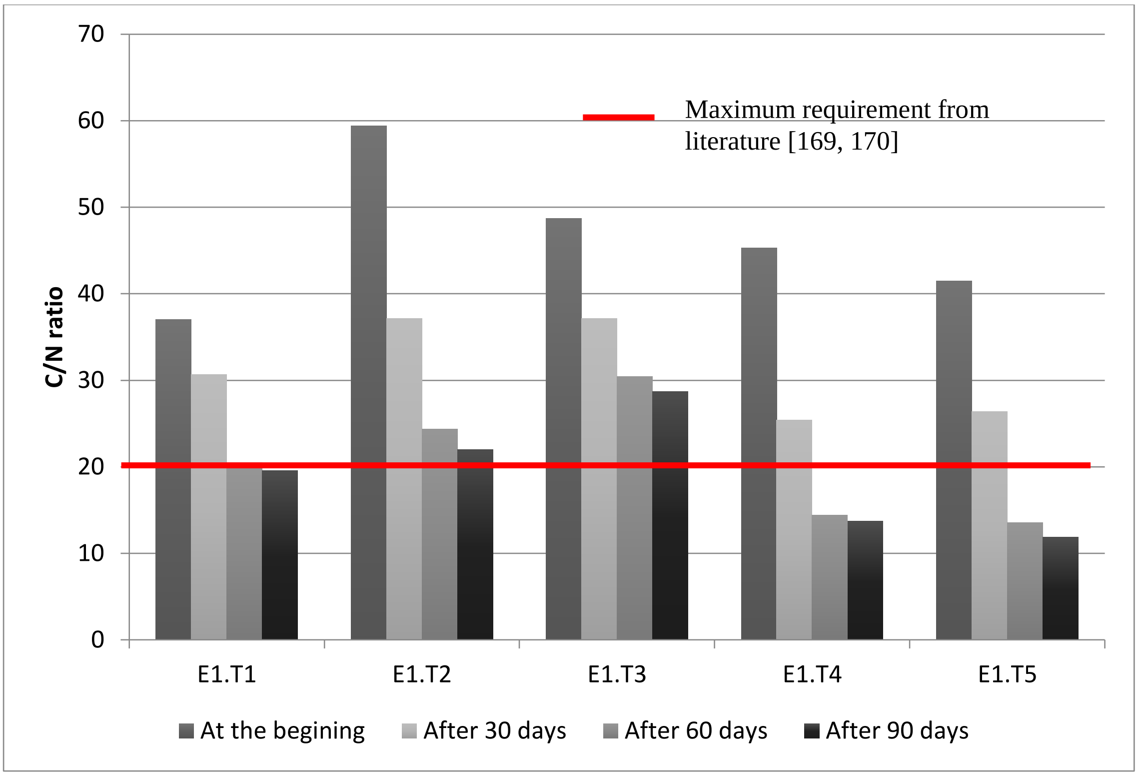


Figure 4.9: C/N ratio in different compost treatments in set of experiment # 1

Moisture content and bulk density in Experiment #1

The moisture content and bulk density were measured for all piles as presented in **Figures 4.10** and **4.11** respectively. The full data are presented in the **Appendix**.

The moisture content of all treatments initially ranged from 66-56% and decreased during the composting process to reach values in the range of 33 to 39% after 60 days and 32 to 38% after 90 days.

In the first set of experiments, the bulk densities were initially 218 kg/m^3, 180 kg/m^3, 170 kg/m^3, 170 kg/m^3 and 240 kg/m^{3}respectively. These values increased to 301 kg/m^3, 237 kg/m^3, 266 kg/m^3, 380 kg/m^3 and 431 kg/m^3, respectively after 60 days.

One-way ANOVA was performed on the data of bulk density after 90 days and results indicate that p-value of 0.00 less than 0.05 confidence interval, which means that there is a significant difference between the means of different treatments.

The piles inoculated with Chinese starter and animal manure (E1.T5) showed highest bulk density, followed by treatment having animal manure only (E1.T4), which is followed by treatment inoculated with Chinese starter only (E1.T1). High bulk density values indicate higher level of activities in the decomposition of organic material to break down the loosely combined raw materials into smaller pieces [17].

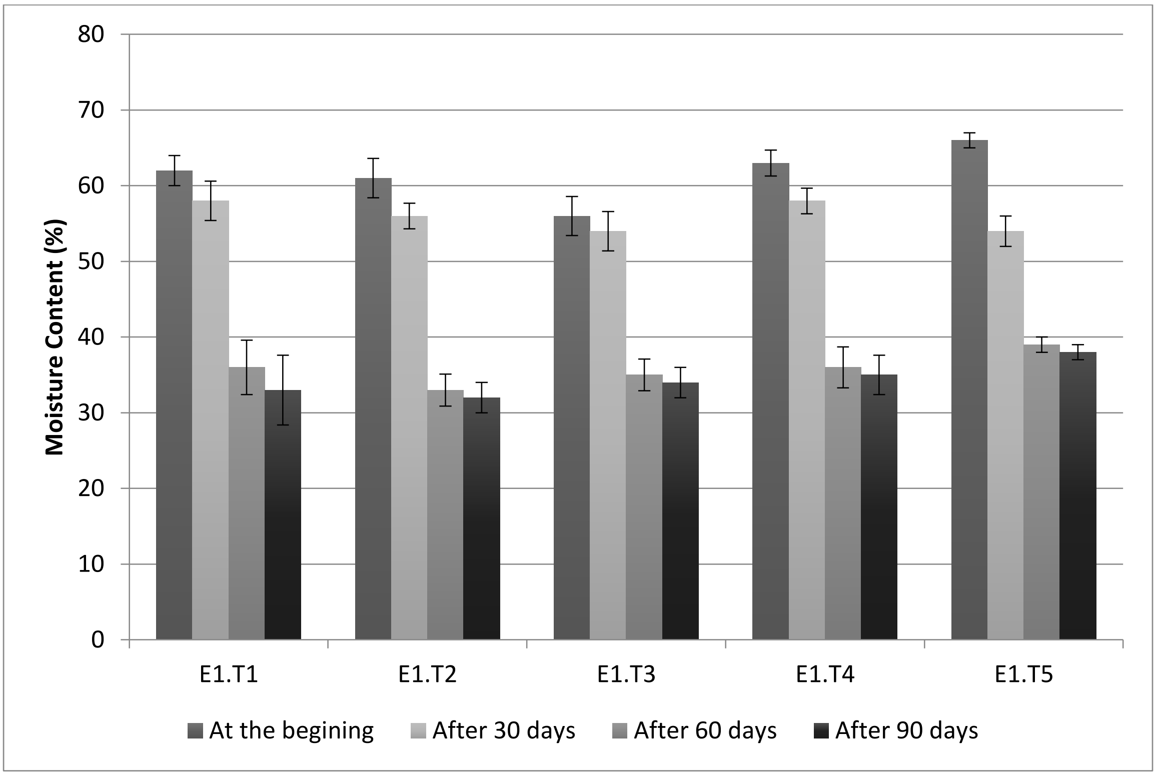


Figure 4.10: Moisture Content in different compost treatments in set of experiment # 1

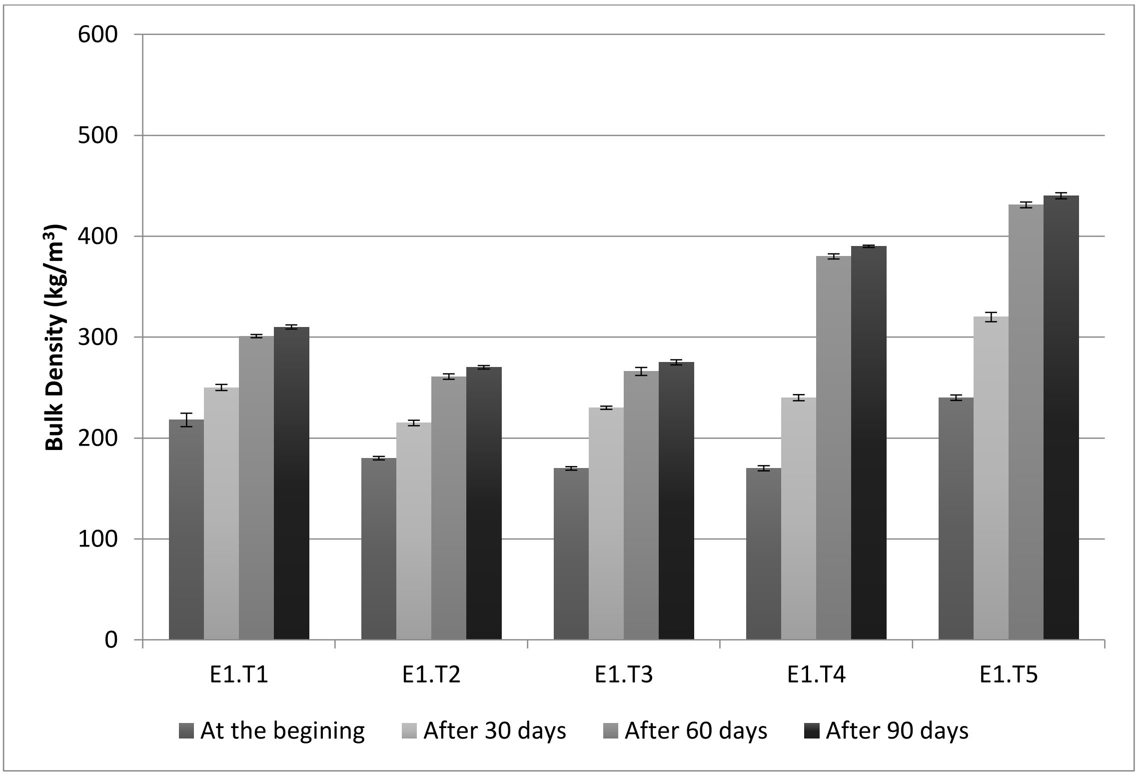


Figure 4.11: Bulk density in different compost treatments in set of experiment # 1

pH and Electrical conductivity (EC) in Experiment #1

The electrical conductivity (EC) and pH of all piles were measured and shown in **Figures 4.12** and **4.13** respectively.

EC is a good indicator of the safety and suitability of compost. The EC of the finished compost of all treatments are ranging between 2.3 to 3.12dS/m. Some studies showed that values ranging between 2.0 to 6.0ds/m are considered tolerable by plants [171, 172].

Also, the pH values of all piles were in the recommended range of good compost (pH 8.15 – 8.62). According to Makan *et al.* the pH of finished compost should range from 7.5 to 8.5 [164].

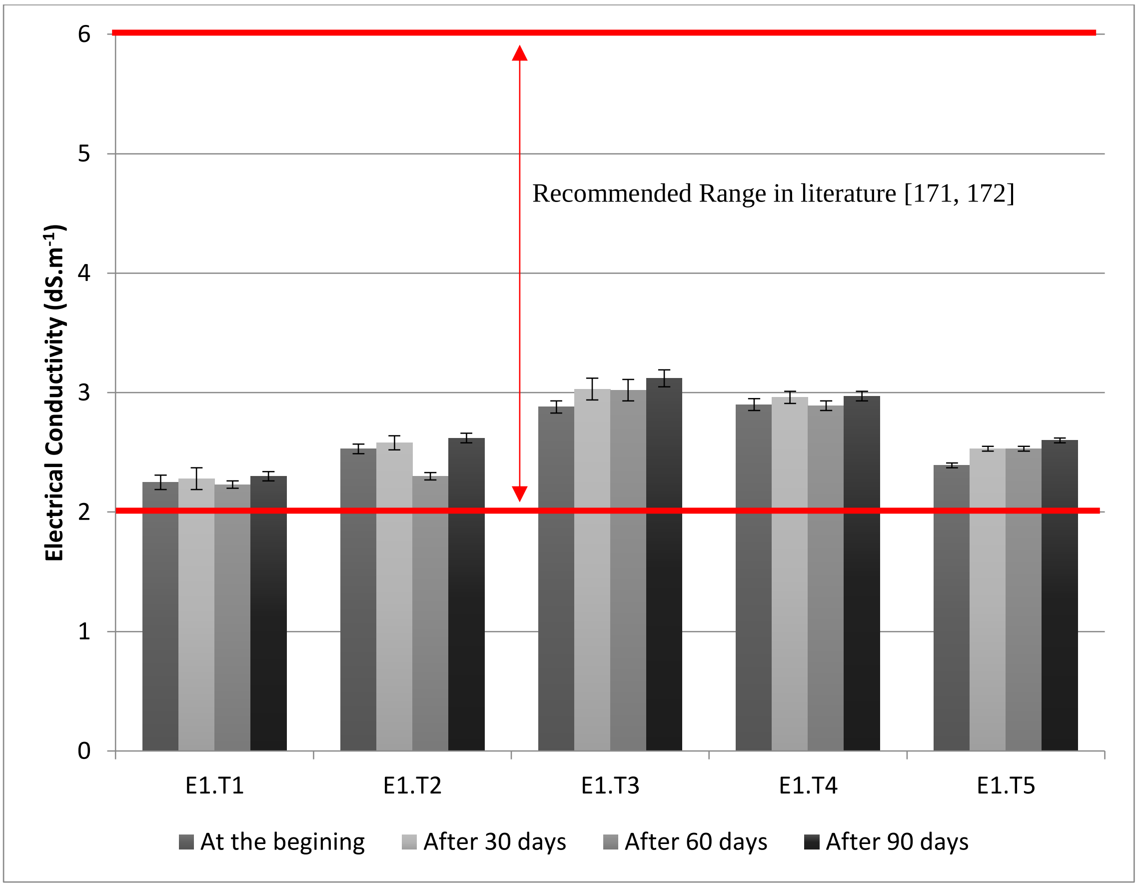


Figure 4.12: Electrical Conductivity in different compost treatments in set of experiment # 1

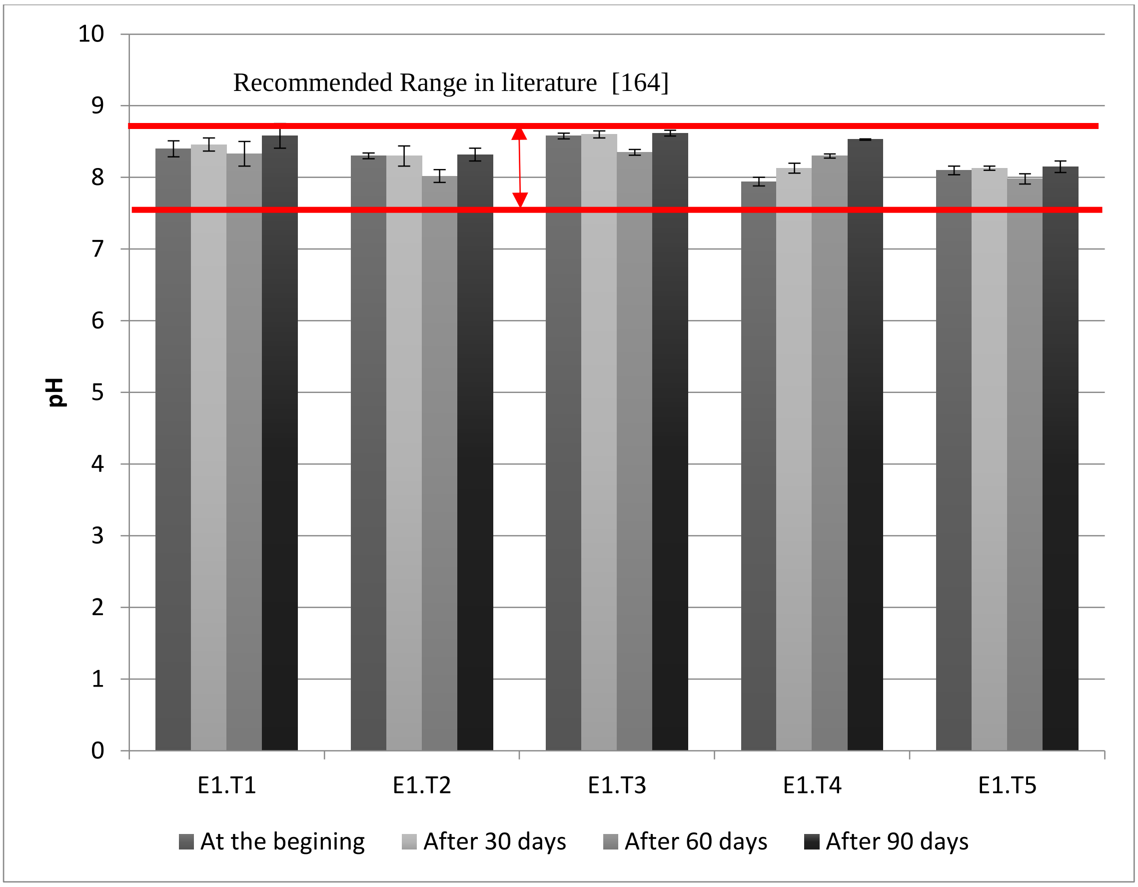


Figure 4.13: pH in different compost treatments in set of experiment # 1

Germination index (GI), pathogenic bacteria and humification index (HI) in Experiment #1

Germination index (GI) is a measure of phytotoxicity of compost; many studies reported that a GI higher than 80% indicates the absence of phytotoxins in composts [17, 166]. According to literature, GI ranging from 66 to 100 indicates absence of phytotoxicity. The GI of all treatments are presented in **Table 4.7.** GI of all treatments are ranging from 40 to 80. This results indicates that E1.T1 and E1.T5 treatments containing Chinese starter are free of phytotoxins. The humification index (HI) is the ratio of the humic acid to the fulvic acid and it is a measure of maturity of the compost. The recorded HI for all five treatments is less than 0.5 as shown in **Table 4.7**; therefore, composts could be considered stable and reached maturity [173].

All final compost treatments were found free of pathogenic bacteria, as presented in **Table 4.8**, indicating their biosafety.

Table 4.7: Germination Index and humification index for different treatments in set of experiment # 1 after 90 days of composting

	Treatments	After 60 days	After 90 days
Germination Index	E1.T1	60	80
	E1.T2	40	70
	E1.T3	40	70
	E1.T4	80	90
	E1.T5	80	90
Humification index	E1.T1	0.8	0.5
	E1.T2	1.1	0.8
	E1.T3	1.3	0.9
	E1.T4	0.5	0.4
	E1.T5	0.4	0.3

Table 4.8: Pathogenic bacteria for different treatments in set of experiment # 1

	Treatments	Beginning of composting	After 30 days	After 60 days	After 90 days
Total Coliform Count (cfu/g)	E1.T1	6.E+05	3.E+05	nd	nd
	E1.T2	5.E+05	4.E+05	nd	nd
	E1.T3	5.E+05	4.E+05	nd	nd
	E1.T4	6.E+05	3.E+05	nd	nd
	E1.T5	6.E+05	2.E+05	nd	nd
Fecal Coliform Count (cfu/g)	E1.T1	5.E+05	3.E+05	nd	nd
	E1.T2	3.E+05	1.E+05	nd	nd
	E1.T3	4.E+05	2.E+05	nd	nd
	E1.T4	4.E+05	1.E+05	nd	nd
	E1.T5	5.E+05	2.E+05	nd	nd
Salmonella and Shigella count (cfu/g)	E1.T1	2.E+05	nd	nd	nd
	E1.T2	4.E+05	2.E+05	nd	nd
	E1.T3	3.E+05	2.E+05	nd	nd
	E1.T4	3.E+05	1.E+05	nd	nd
	E1.T5	1.E+05	nd	nd	nd

Total phosphorous (TP) and Total Potassium (TK) in Experiment #1

TP and TK were measured for all piles, three measurements were taken for each pile. Detailed data are presented in the **Appendix**. The average TP(%) and TK(%) values are presented in **Figures 4.14** and **4.15** respectively. According to El-Haddad *et al*. [174], the recommended range of TP (%) is 0.4 to 1.1 and the recommended range of TK (%) is 0.6 to 1.7. The TP and TK of all treatments increased during the compost piles and were in final compost in the recommended range. In fact, TP values at the beginning of the composting process were 0.54, 0.29, 0.22. 0.53. and 0.55 and increased to 0.68, 0.38, 0.41, 0.73 and 0.79

for treatments E1.T1 to E1.T5 respectively.

The values of %TK at the beginning of the composting process were 0.58, 0.2, 0.34, 0.37, and 0.42 and increased to 0.82, 0.5, 0.72, 0.81, and 0.91 for treatments E1.T1 to E1.T5 respectively.

One-way ANOVA analysis of %TP and %TK after 90 days indicate that there is a significant difference between the means of different treatments, which means that each additive has a different effect on the final %TP and %TK of compost pile. In the first set of experiment the highest values were obtained in treatments E1.T5 containing Chinese starter and animal manure followed by E1.T4 containing animal manure only.

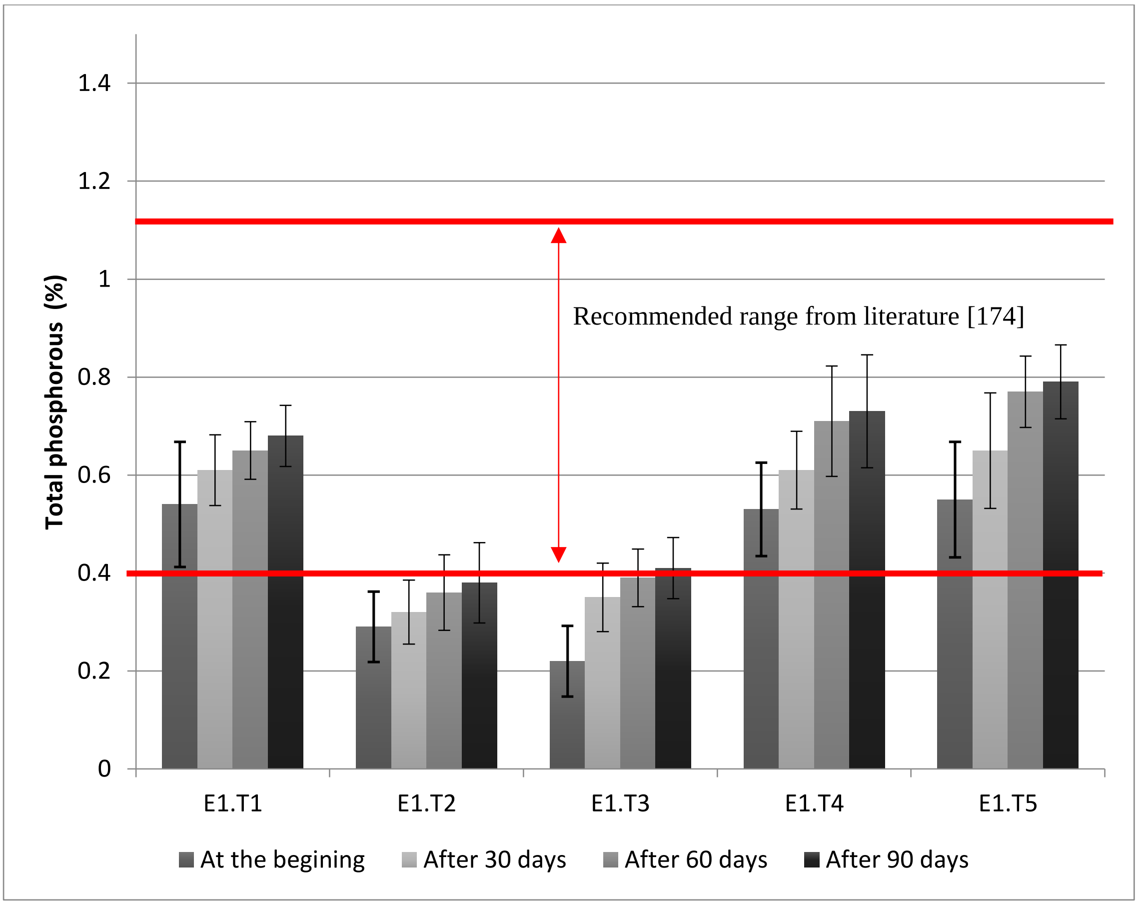


Figure 4.14: Total Phosphorous in different compost treatments in set of experiment # 1

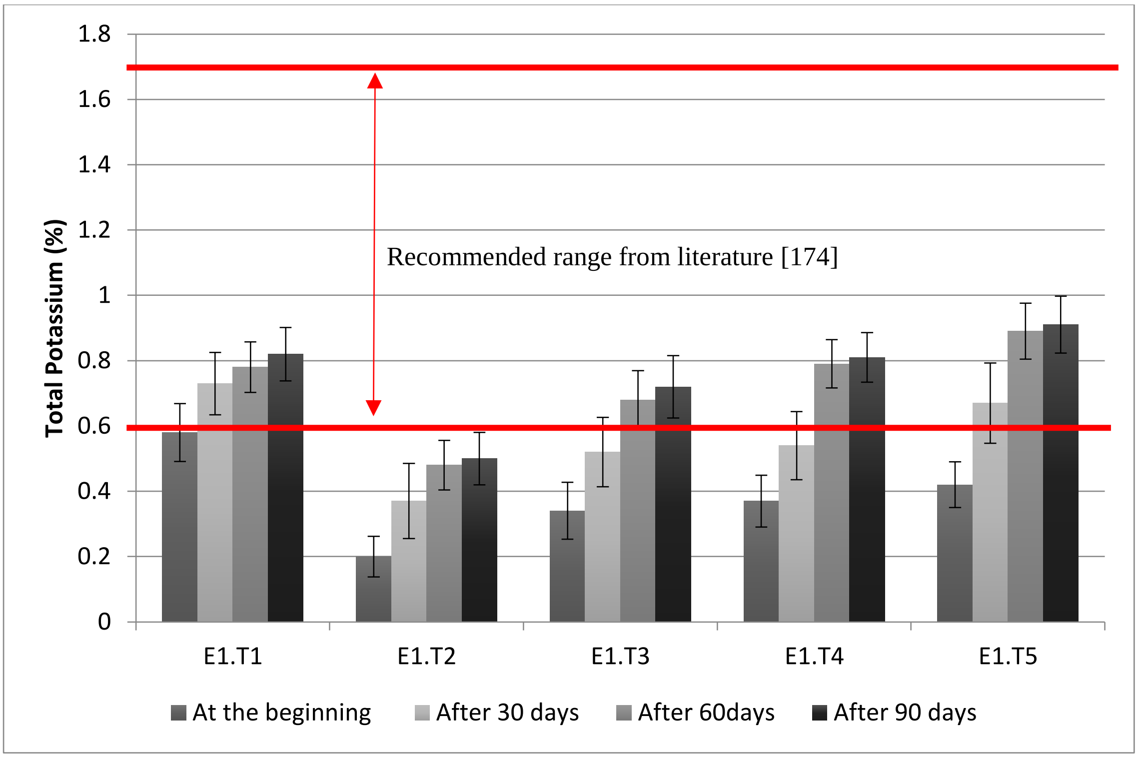


Figure 4.15: Total Potassium in different compost treatments in set of experiment # 1

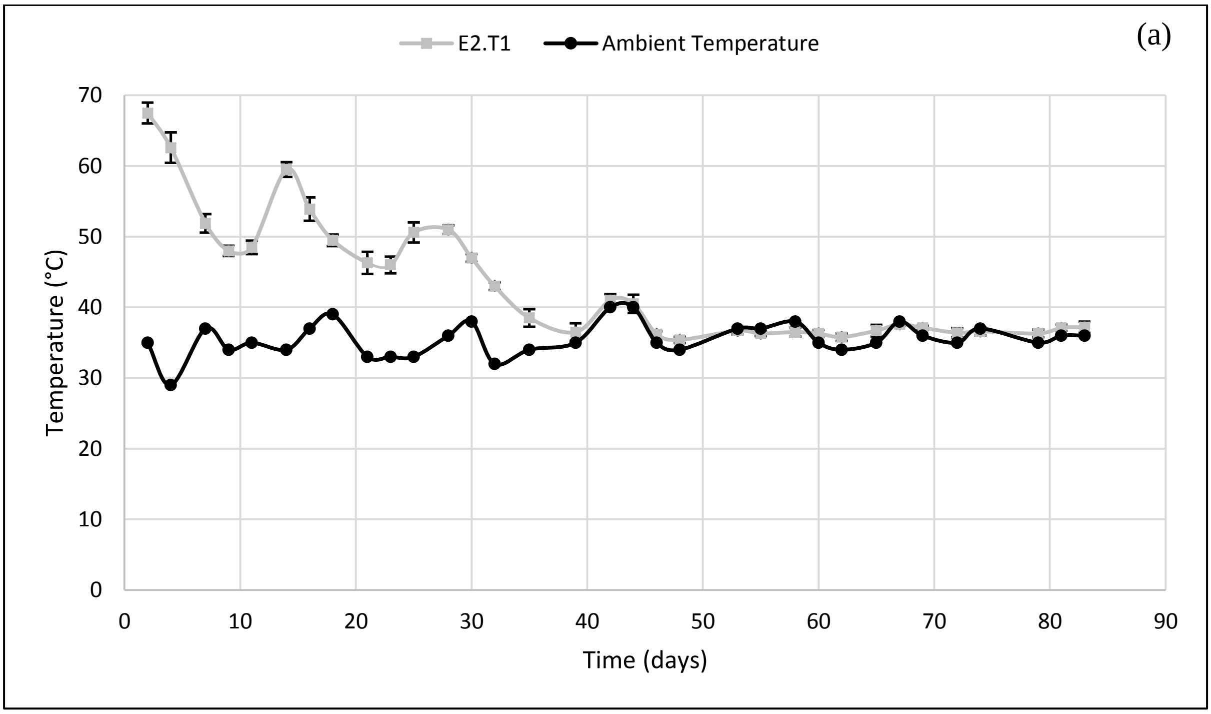
Conclusion of Experiment #1

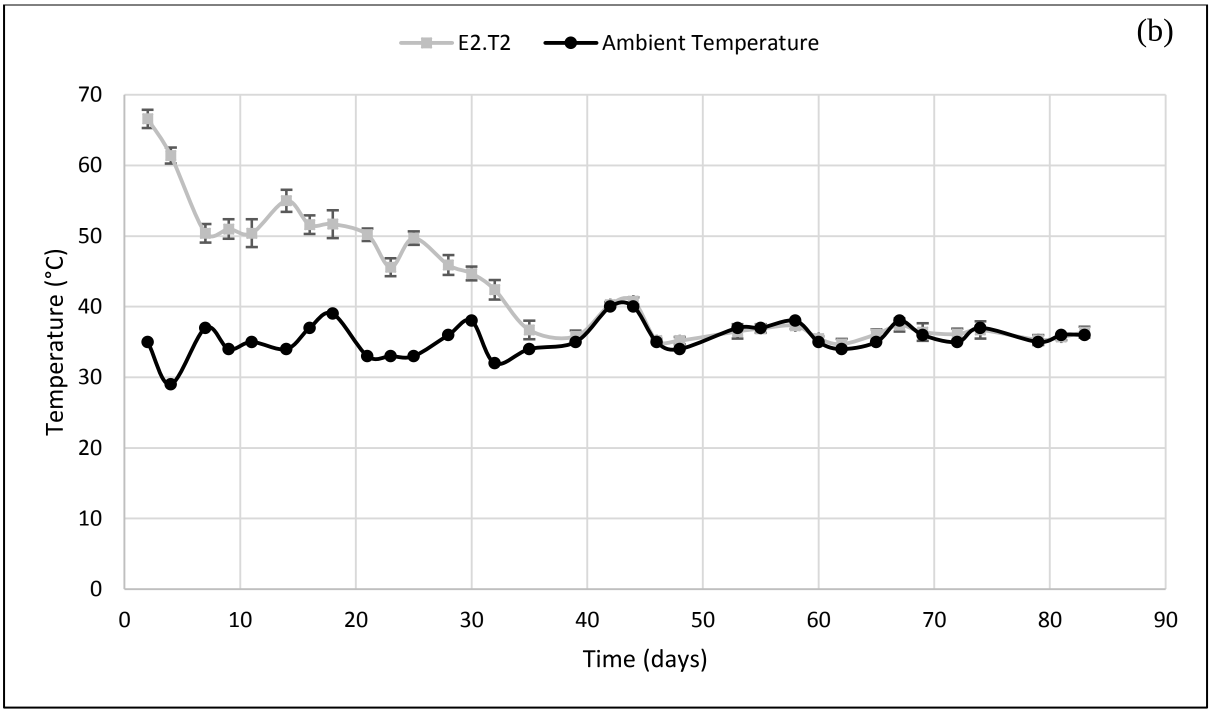
The results of the first set of experiments revealed that the application of different additives in composting of rice straw exhibited an effect on compost quality. The results of the first set of experiments revealed a higher decomposition rate of treatment having animal manure (E1.T4 and E1.T5), compared to other treatments. All analysis of the properties of the compost product indicated that these two treatments reached maturity after 60 days and can be used without any limitation. Hence, the second set of experiment has been conducted with substrate rice straw and animal manure inoculated with different types of additives and tested at the beginning of composting process, after30 days and after 60 days as presented in section 4.3.2.

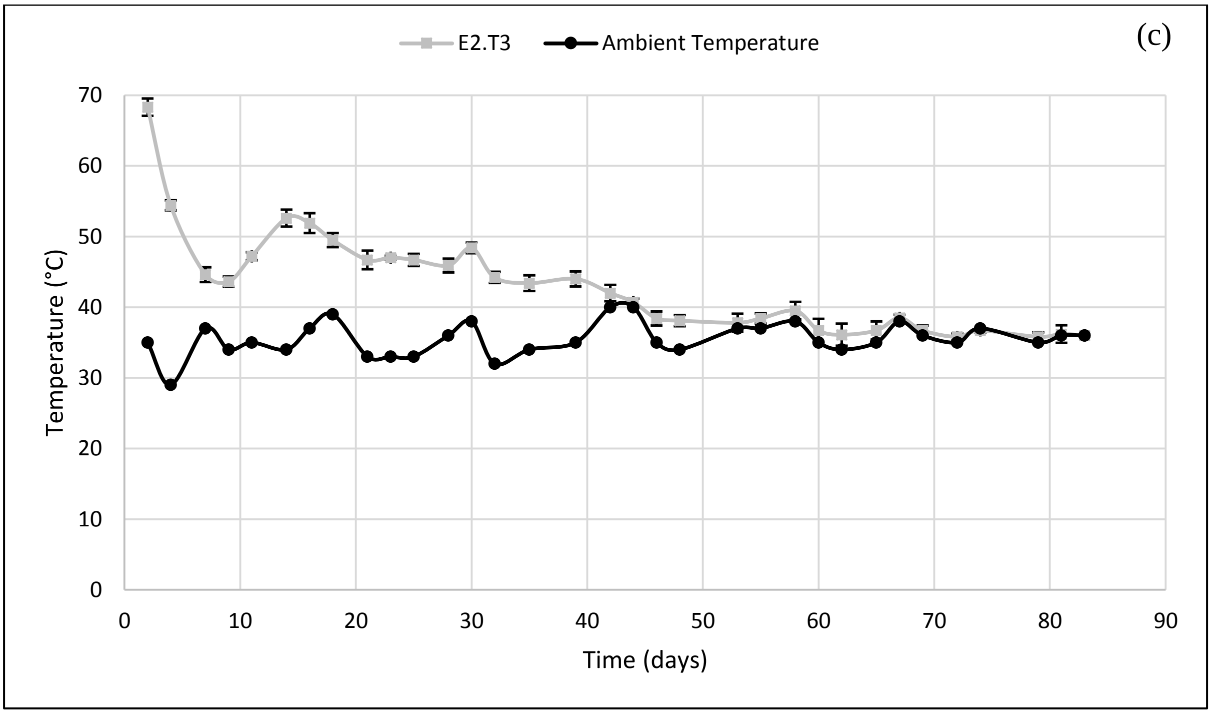
4.3.2. Bioconversion of organic waste into high quality organic fertilizer

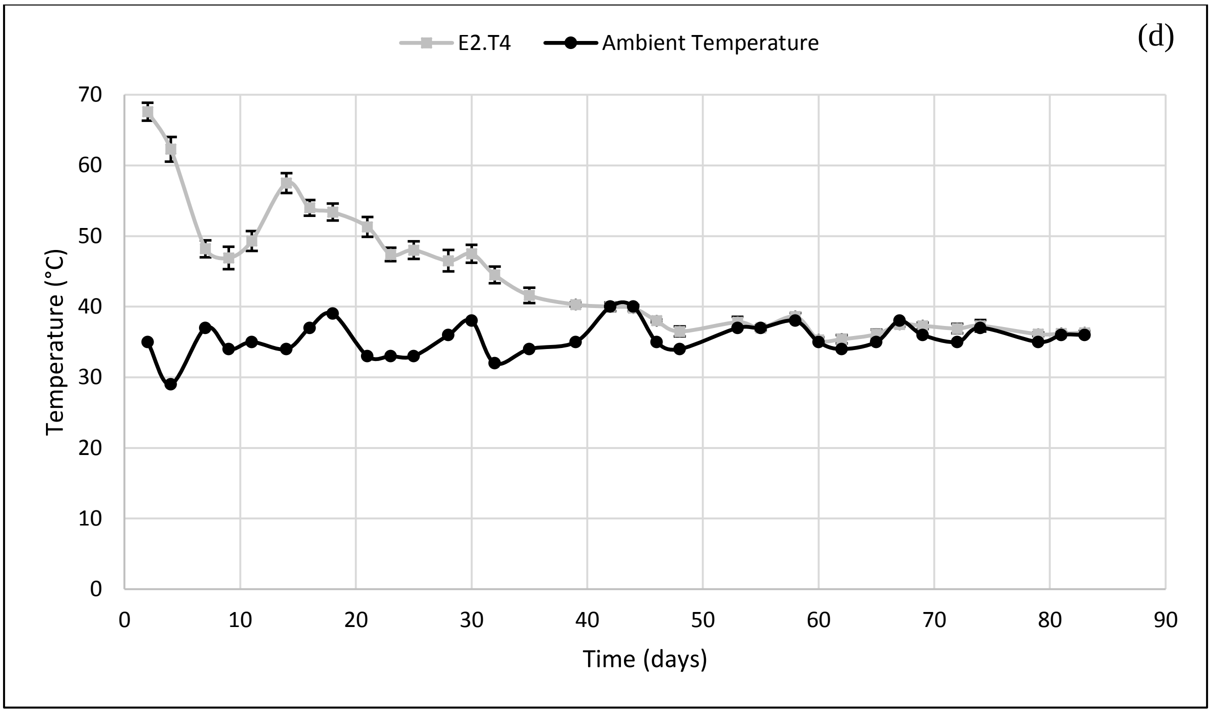
Temperature changes of Experiment # 2

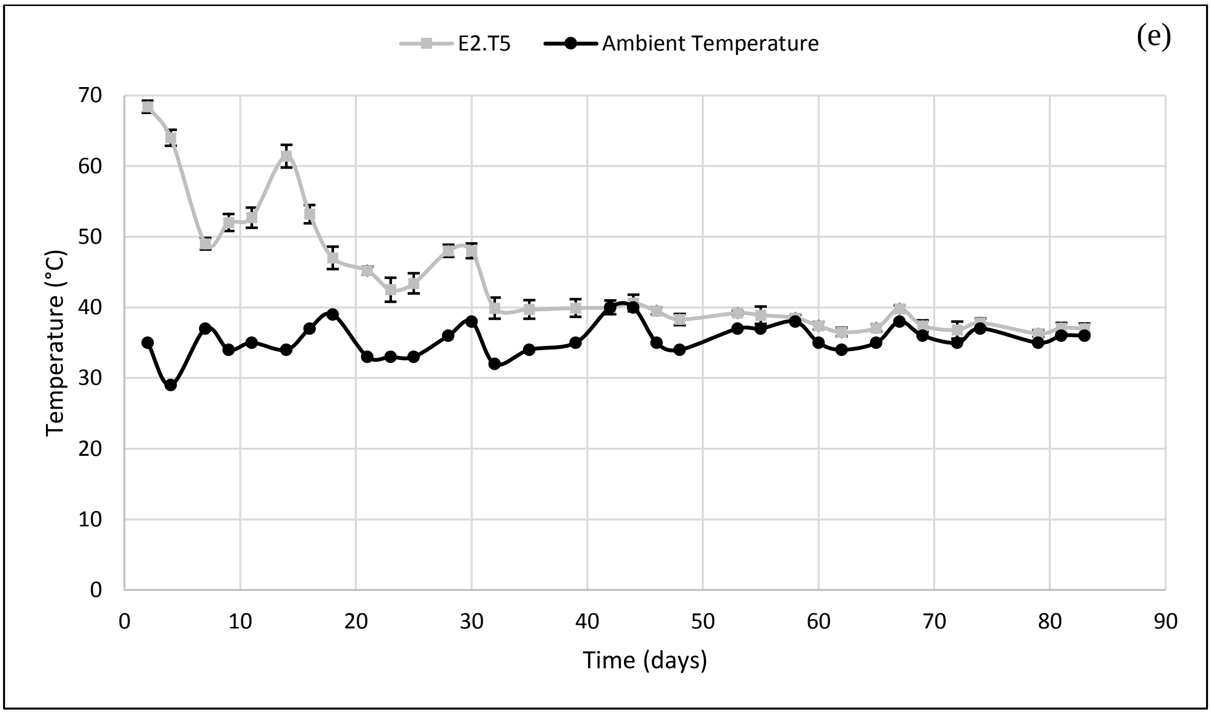
The temperature changes for the nine compost piles and corresponding ambient temperatures were recorded and summarized in **Figure 4.16**. All detailed data are presented in the **Appendix**. The ambient temperature variations throughout the composting period were between 29 and 40°C. An increase in piles temperatures was observed right after composting started.

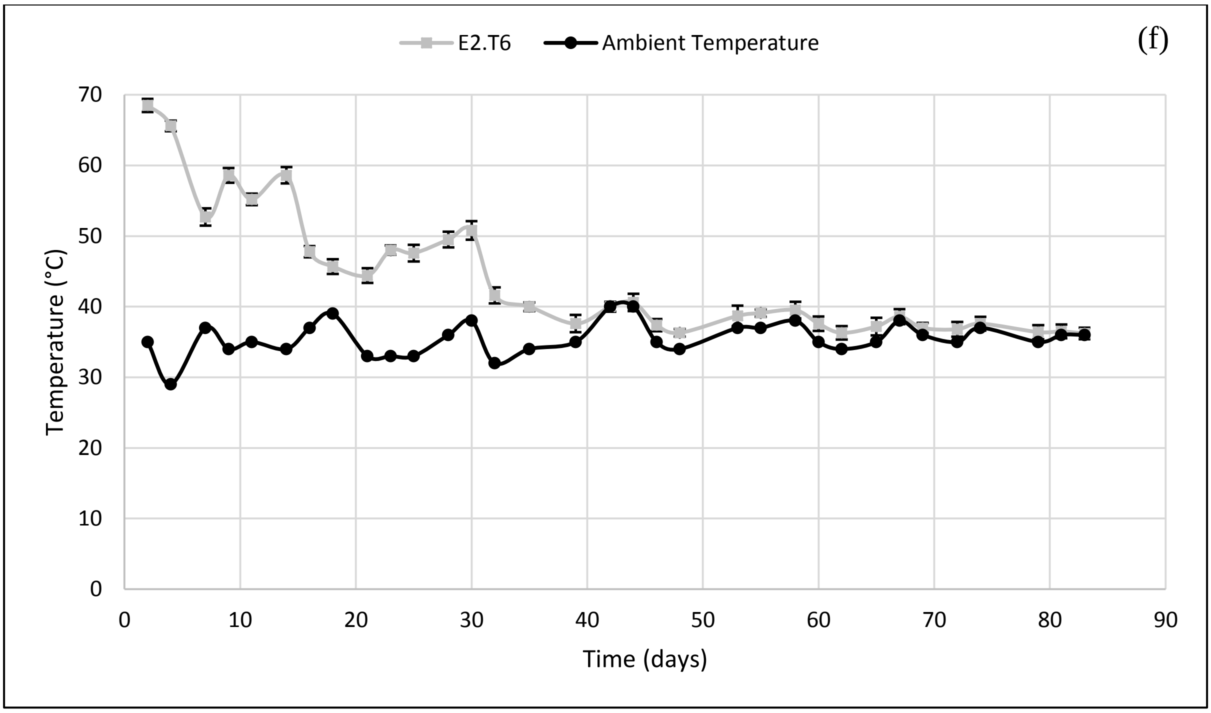


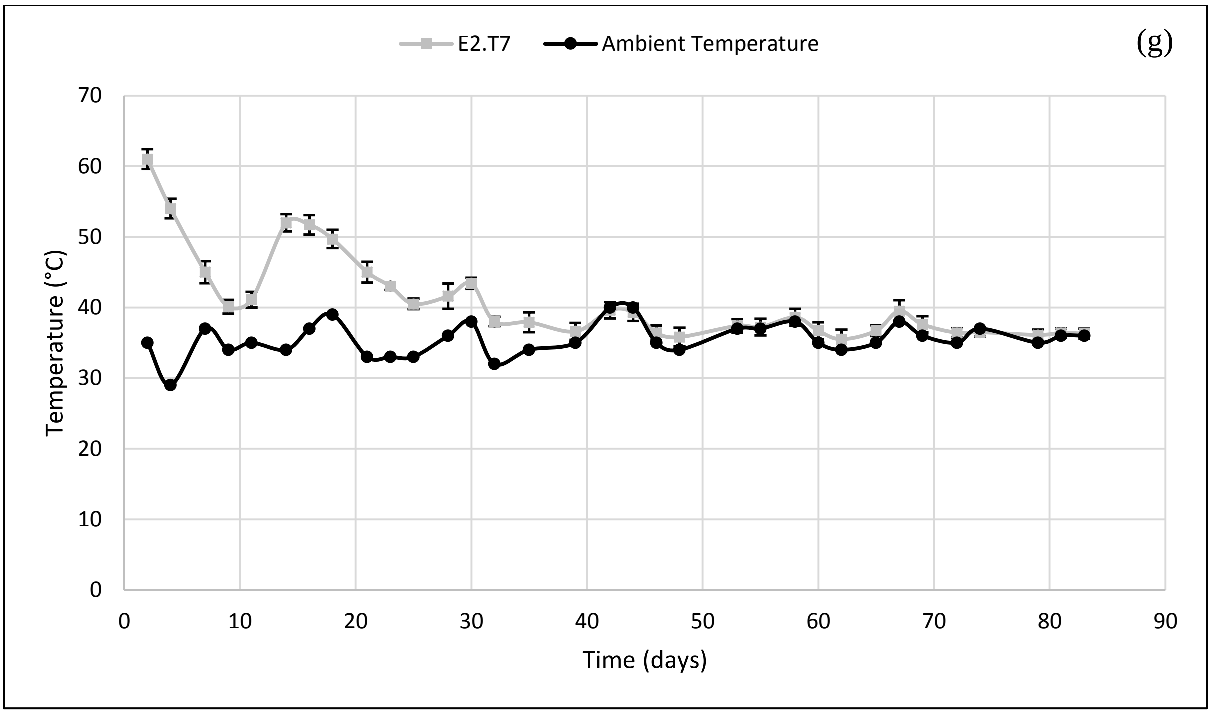

(b)
E2.T2
Ambient Temperature
Temperature (°C)
Time (days)
0
10
20
30
40
50
60
70
80
90

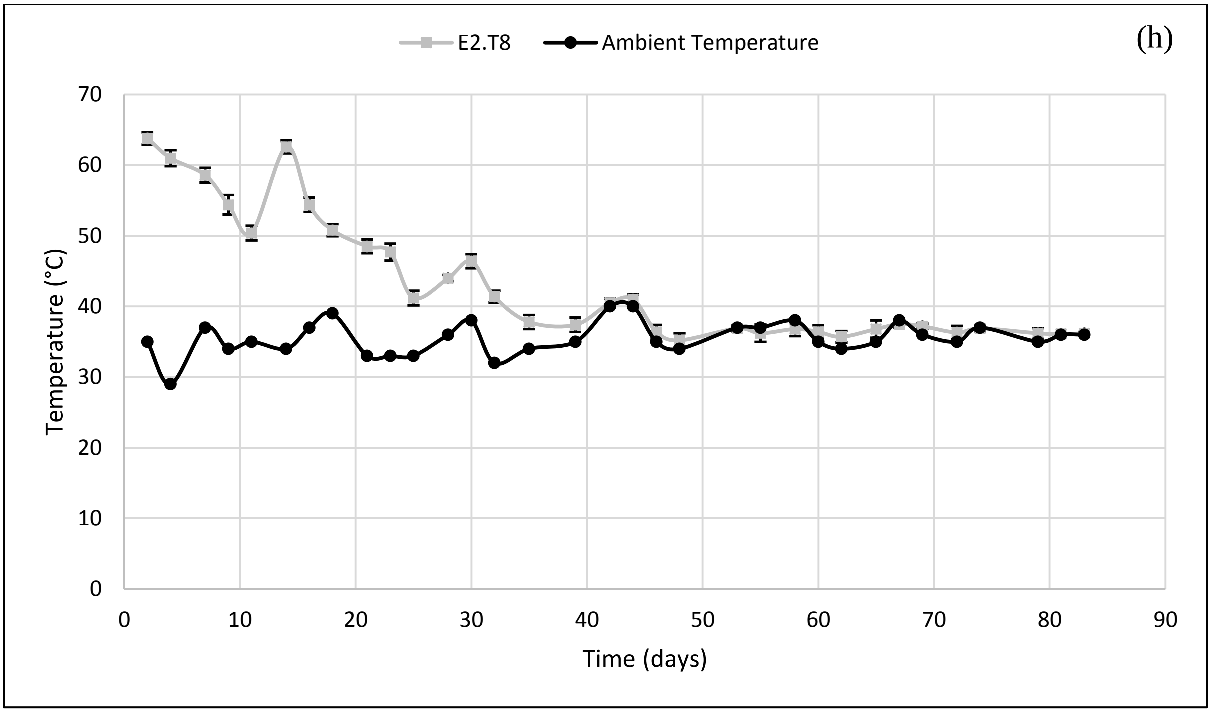

(c)
E2.T3
Ambient Temperature
Temperature (°C)
Time (days)
0
10
20
30
40
50
60
70
80
90


E2.T4
Ambient Temperature
(d)
Temperature (°C)
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
90
Time (days)


E2.T5
Ambient Temperature
(e)
Temperature (°C)
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
90
Time (days)


E2.T6
Ambient Temperature
(f)
Temperature (°C)
Time (days)
0
10
20
30
40
50
60
70
80
90


E2.T7
Ambient Temperature
(g)
Temperature (°C)
Time (days)
0
10
20
30
40
50
60
70
80
90



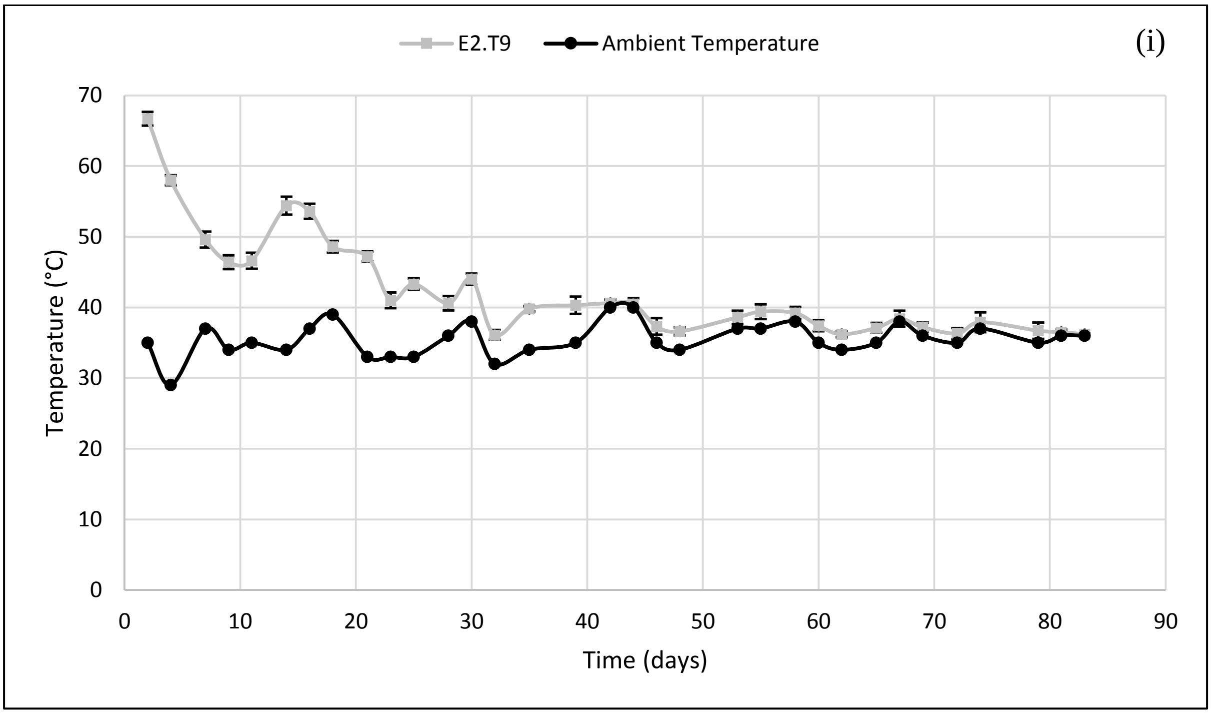


Figure 4.16: Changes in temperatures in compost piles with relation to ambient temperatures for (a) E2.T1, (b) E2.T2, (c) E2.T3, (d) E2.T4, (e) E2. T5, (f) E2.T6, (g) E2.T7, (h) E2.T8, (i) E2.T9

The temperatures increased rapidly to reach their maximum temperatures between 67.5°C, 66.6°C, 68.3°C, 67.6°C, 68.4°C ,68.5°C, 61°C, 63.8°C, 66.7°C for treatments E2.T1 to E2.T9 respectively after 2days, which marks the end of the initial mesophilic phase and beginning of thermophilic phase. After that, the temperatures started to decrease gradually, some increases in temperatures were recorded after turning the piles. Then the temperature gradually decreased to reach mesophilic phase. After that, it stabilized near the ambient temperature after 42 days.

The highest temperature where reached in E2.T3 containing EM, E2.T5 containing Chinese starter and 10% of biochar and E2.T6 containing EM and 10% of biochar. High temperature is attributed to higher microbial activity.

Organic Carbon (OC, %) and Organic Matter (OM, %) in Experiment #2

The %OM were measured for the nine piles; three measurements were taken for each pile and %OC were calculated from %OM. All data and ANOVA results are presented in the **Appendix**. The %OM was 61.2, 66.2,62.1, 63.2, 68.1, 65.3, 63.1, 67.2, 60.1% at the beginning of the composting process and decreased to 37.5%, 38.76%, 35.16%, 36.63%, 38.2%, 35.24%, 44.16%, 42.68%, 36.57% for treatments E2.T1 to E2.T9 respectively. One-way ANOVA was performed on the data of organic matter after 60 days and results indicate that p-value of 0.00 less than 0.05 confidence interval, which means that there is a significant difference between the means of different treatments. These values are much higher than the minimum required value of 16% for organic fertilizers made of agriculture waste from the Egyptian Specifications for Organic fertilizers [160].

The average %OM results of the second set of experiment are presented in **Figure 4.17**.

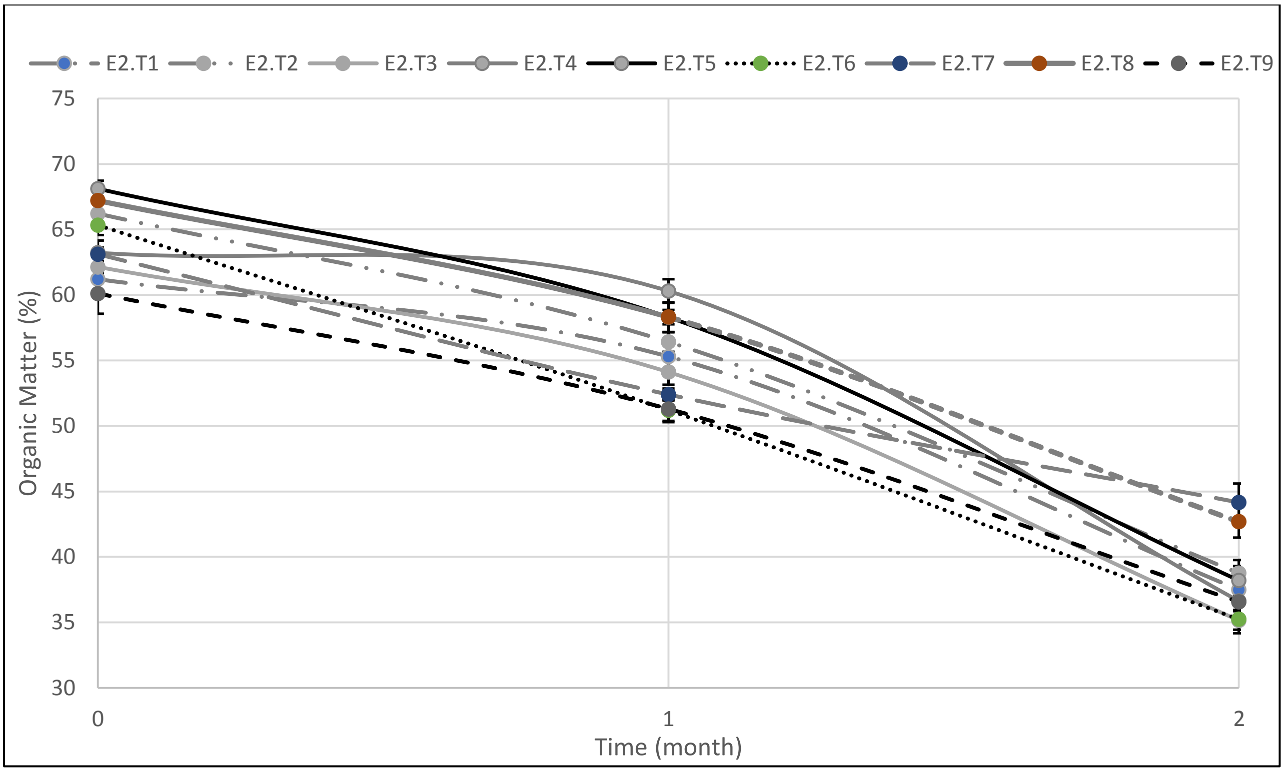


Figure 4.17: Changes in %organic matter in different compost treatments in set of experiment # 2

The %OC was 35.5, 38.4,36.0,36.7,39.5,37.9,36.6,39, 34.7% for treatments E2.T1 to E2.T9 respectively. The average %OC results of the second set of experiment are presented in **Figure 4.18**.

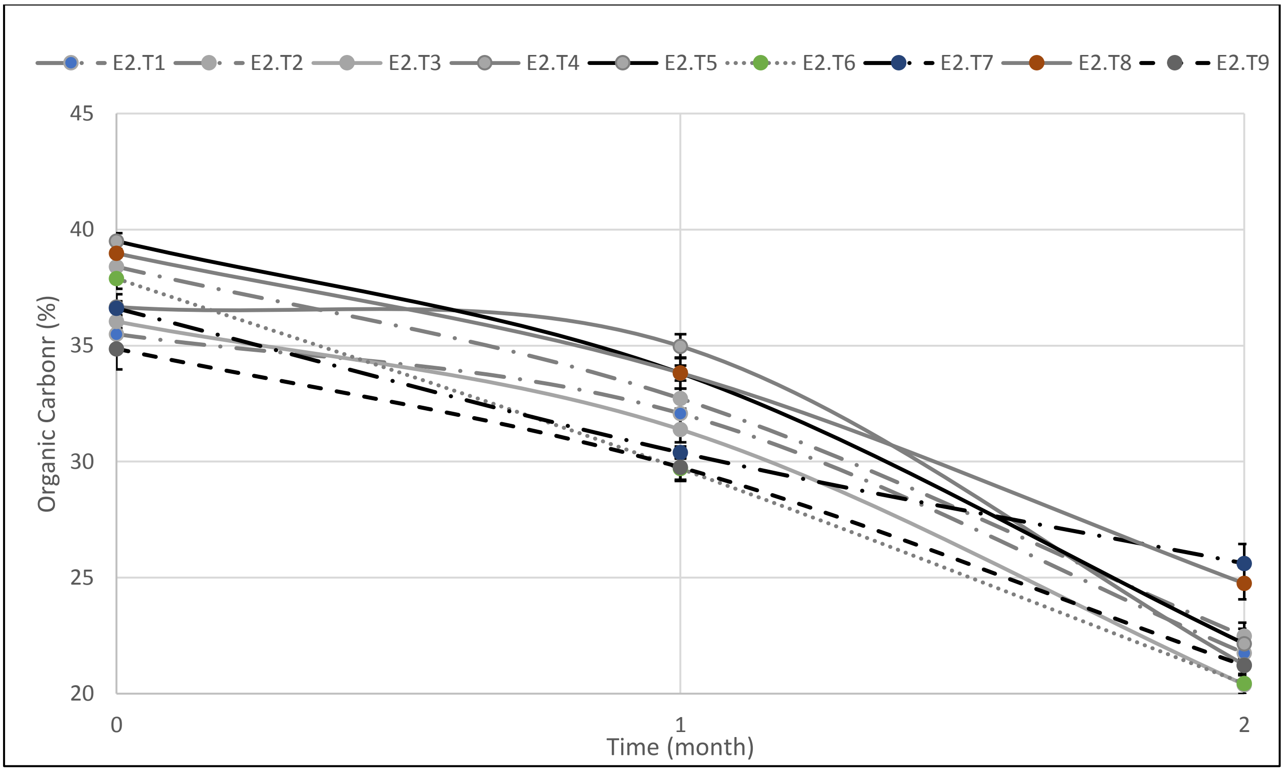


Figure 4.18: Changes in %organic carbon in different compost treatments in set of experiment # 2

The %OM and %OC values decreased during the composting process in all piles. The highest reduction was observed in E2.T6 (46.1%), E2.T5(43.9%), E2.T3(43.42%), E2.T4(42.1%), E2.T2 (41.5%), E2.T9 (39.9%), E2.T1 (38.7%), E2.T8 (36.49%), and E2.T7(30%). The percentage losses in OM and OC in the second set of experiments are presented in **Figure 4.19**.

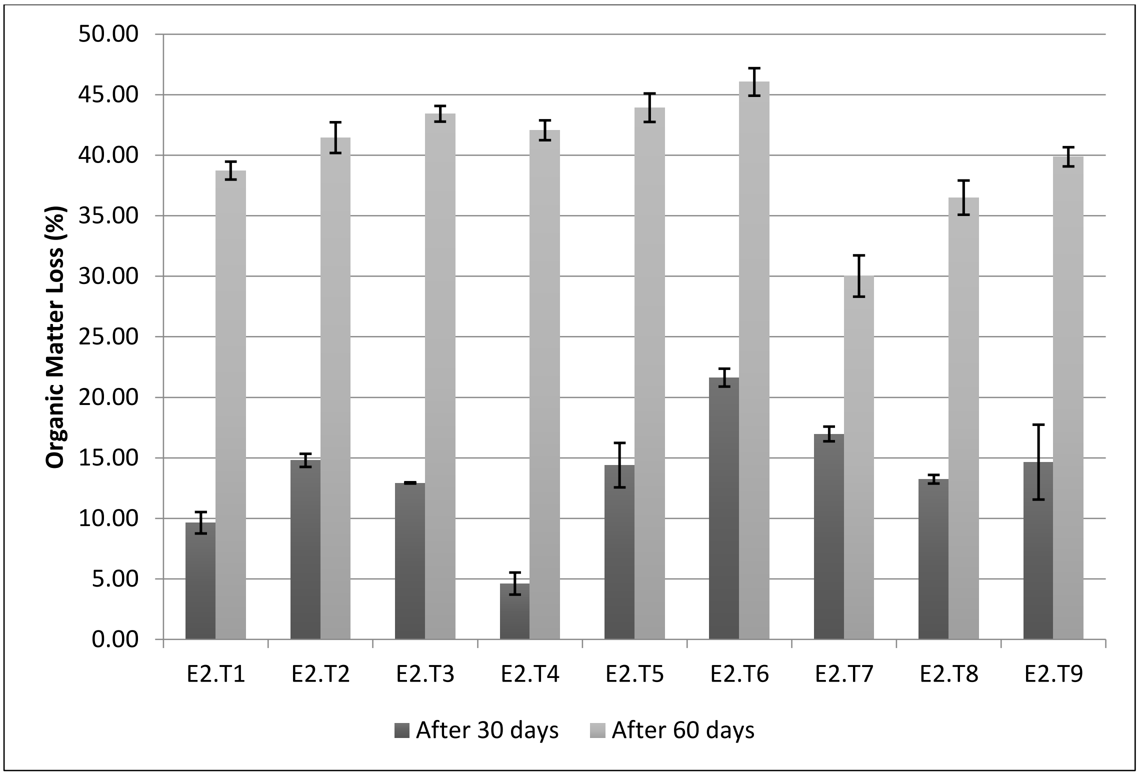


Figure 4.19: Percentage losses in organic matter and organic carbon in different compost treatments in set of experiment # 2

As previously discussed in the set of experiment 1, the observed decrease in OM and OC is due to the formation and release of CO_2 during the biodegradation of OM by aerobic microorganisms. The results indicate that the highest decomposition rate was observed in treatments E2.T6 containing EM and 10% biochar followed by E2.T5 containing Chinese starter and 10% biochar. This indicates that these treatments have high content of easily decomposable substances compared to other treatments.

Total nitrogen, ammonium and nitrate nitrogen in Experiment #2

The total nitrogen (TN), ammonium nitrogen (NH^{4+}) and nitrate nitrogen (NO^{3}) were measured for all piles, three measurements were taken for each pile. Detailed data are presented in the **Appendix**. The average TN (%) values are presented in **Figure 4.20**. The total nitrogen has slightly increased in all treatments from 0.95, 1.13, 0.87, 0.98, 1.11, 0.91, 1.1, 1.21, 0.85 at the beginning of the composting process to 1.22, 1.55, 1.09, 1.29, 1.21, 1.35, 1.22, 1.42, 1.01 after 60 days of composting for treatments E2.T1to E2.T9 respectively. One-way ANOVA was performed on the data of TN after 60 days and results indicate that p-value of 0.00 less than 0.05 confidence interval, which means that there is a significant difference between the means of different treatments. These values are much higher than the minimum required value of 0.5% for organic fertilizers made of agriculture waste from the Egyptian Specifications for Organic fertilizers [160].

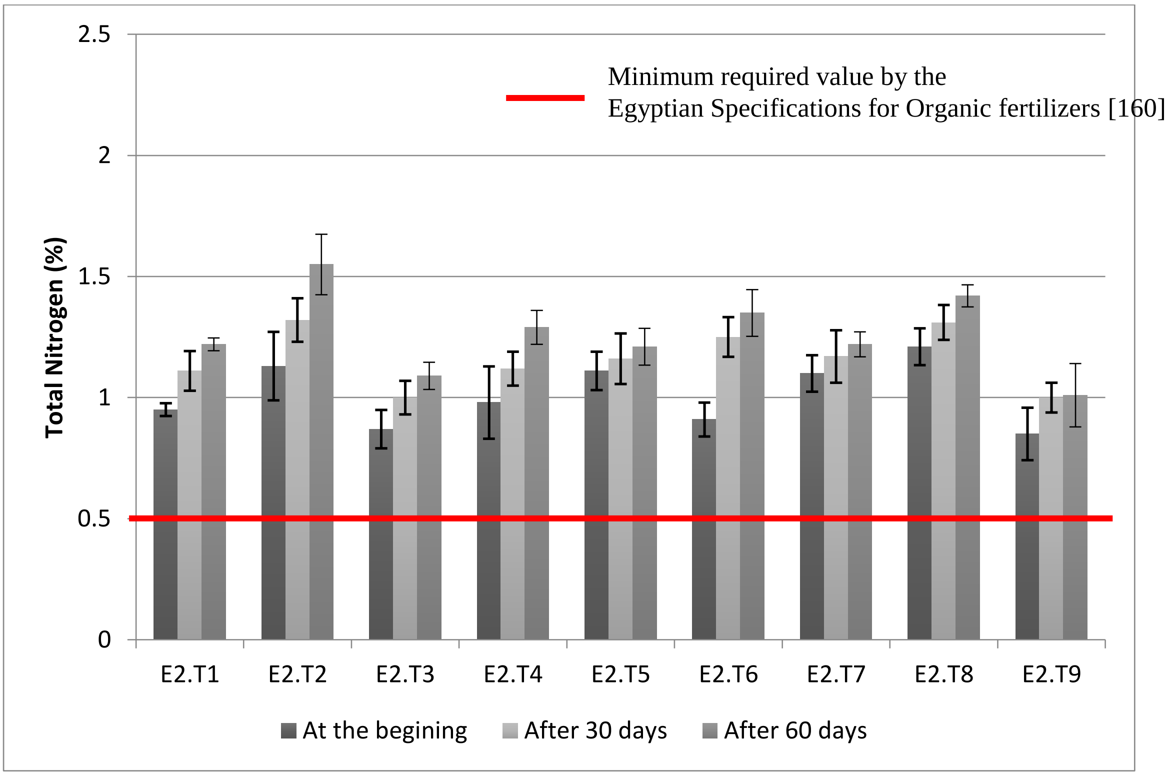


Figure 4.20: Total Nitrogen in different compost treatments in set of experiment # 2

As previously discussed in experiment #1, ammonium and nitrate nitrogen are of greater interest, as they have been used as maturity index for composting. The maximum values of ammonium nitrogen were observed after at the beginning of the composting process to be 376, 310, 425, 159, 480, 120, 295, 190, 432, 240 then decreased in all treatments to 38, 29, 38, 29, 28, 38, 30, 39, 38 for treatments E2.T1to E2.T9 respectively as shown in **Figure 4.21**. While, nitrate nitrogen values increased with time due ammonification and nitrification reactions resulting from microbial activity, as shown in **Figure 4.22.**

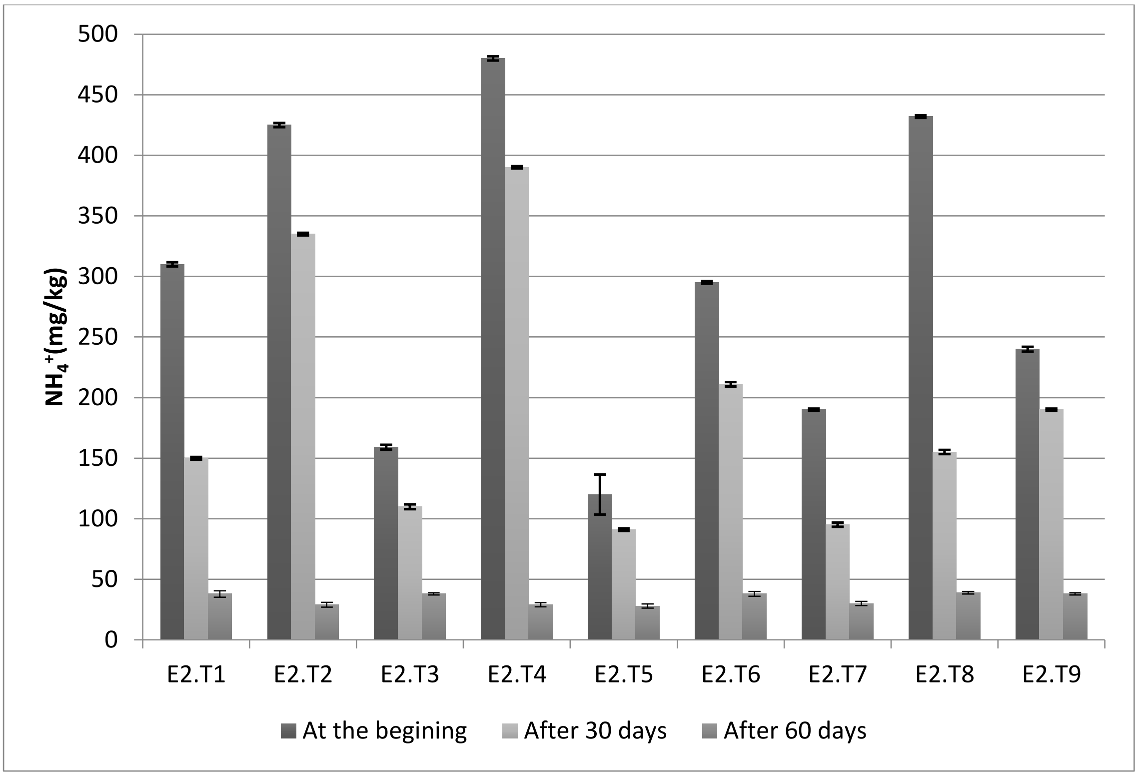


Figure 4.21: Ammonium Nitrogen in different compost treatments in set of experiment # 2

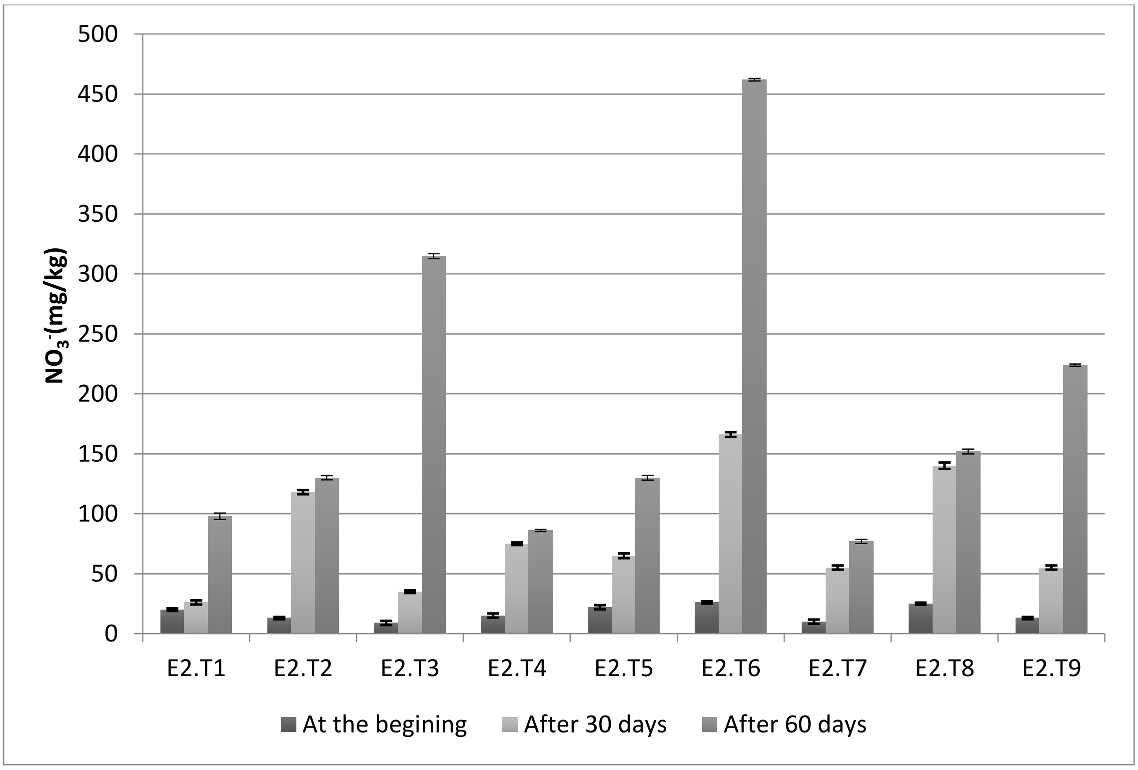


Figure 4.22: Nitrate Nitrogen in different compost treatments in set of experiment # 2

Table 4.9 shows that nitrification ratios were high at the beginning of the treatments and decreased until maturity is reached. All treatments in set of experiment#2 have a nitrification ratio below 1. Treatments inoculated with EM E2.T6, E2.T3, E2.T9 have a nitrification ratio below 0.16. These results indicate that these treatments have highest maturity compared to other treatments.

Table 4.9: NH4/NO3 for different treatments in set of experiment # 2

Treatments	Beginning of composting	After 30 days	After 60 days
E2.T1	15.50	5.77	0.39
E2.T2	32.69	2.84	0.22
E2.T3	17.67	3.14	0.12
E2.T4	32.00	5.20	0.34
E2.T5	5.45	1.40	0.22
E2.T6	11.35	1.27	0.08
E2.T7	19.00	1.73	0.39
E2.T8	17.28	1.11	0.26
E2.T9	18.46	3.45	0.17

C/N ratio in Experiment # 2

As previously discussed, the carbon to nitrogen ratio (C/N) is one of the most important factors that affect the composting process. The C/N ratio in this study was used as an indicator to follow the development of the composting process. The C/N ratio was calculated and presented in **Figure 4.23**. It can be observed that C/N ratio decreased during the composting process. The results show that C/N ratio of all piles are below or very close to 20 after 60 days of composting, which indicates that all treatments reached maturity. The C/N ratios after 60 days reached 17.8:1, 14.5:1, 18.7:1, 16.5:1, 18.3:1, 15.1:1, 10.9:1, 17.4:1, 21:1 for treatments E2.T1 to E2.9 respectively. Also, these values are within the required range of 18:1 to 22:1 required by Egyptian Specifications for Organic fertilizers [160].

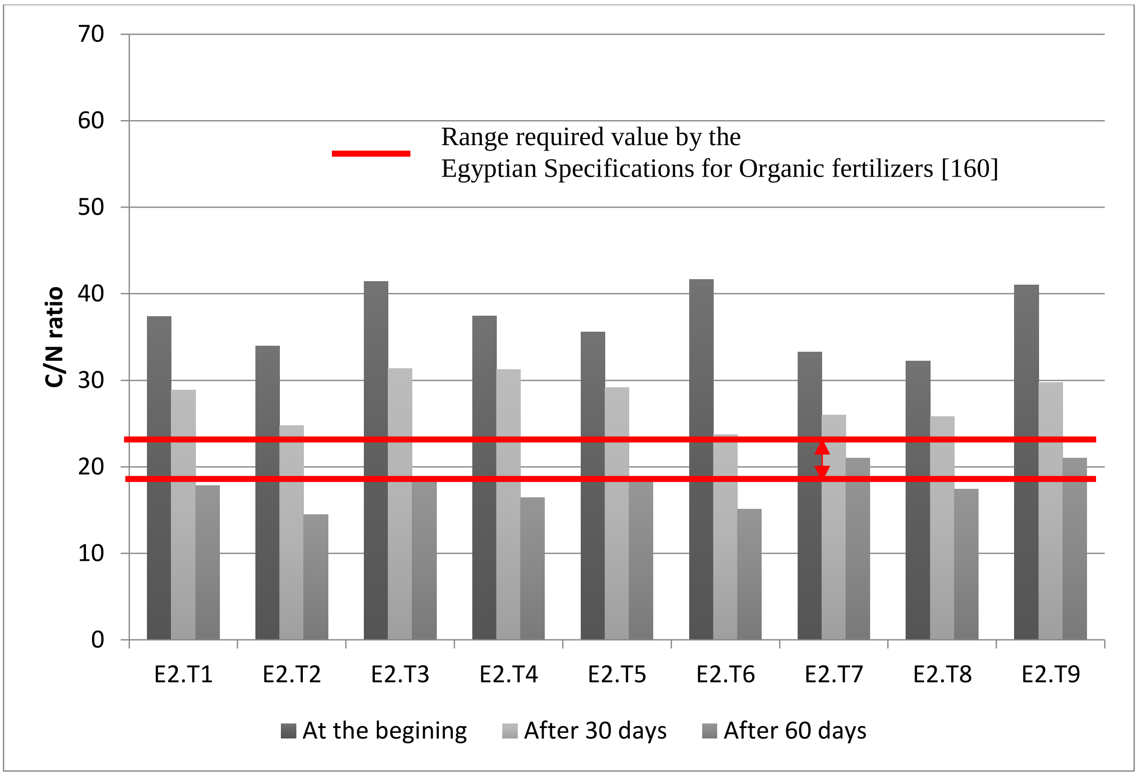


Figure 4.23: C/N ratio in different compost treatments in set of experiment # 2

Moisture content and bulk density in Experiment #2

The moisture content and bulk density were measured for all piles as presented in **Figures 4.24 and 4.25** respectively.

The moisture content of all treatments initially ranged from 67-60% and decreased during the composting process to reach values in the range of 30 to 38%. It is worth mentioning that treatments E2.T4, E2.T5 and E2.T6 contain 10% biochar compared to other treatments. This could be because biochar has high water holding capacities as recent studies indicated [116, 175].

In the first set of experiments, the bulk densities were initially 285 kg/m^3, 320 kg/m^3, 300 kg/m^3, 210 kg/m^3 and 290 kg/m^3 280 kg/m^3, 310 kg/m^3, 320 kg/m^3, 270 kg/m^3 respectively. These values increased to 445 kg/m^3, 533 kg/m^3, 470 kg/m^3, 420 kg/m^3, 536 kg/m^3, 480 kg/m^3, 494 kg/m^3, 552 kg/m^3, 466 kg/m^3 respectively.

One-way ANOVA was performed on the data of bulk density after 60 days and results indicate that p-value of 0.00 less than 0.05 confidence interval, which means that there is a significant difference between the means of different treatments.

It is important to mention that the pile inoculated with biochar (E2.T4 to E2.T9) showed lower bulk densities compared to other treatments. This is because biochar is porous in nature and this characteristic of biochar allow for better aeration [116, 175], which allow for higher microbial activity. This explains the increase in bulk density that is observed in **Figure 4.25**.

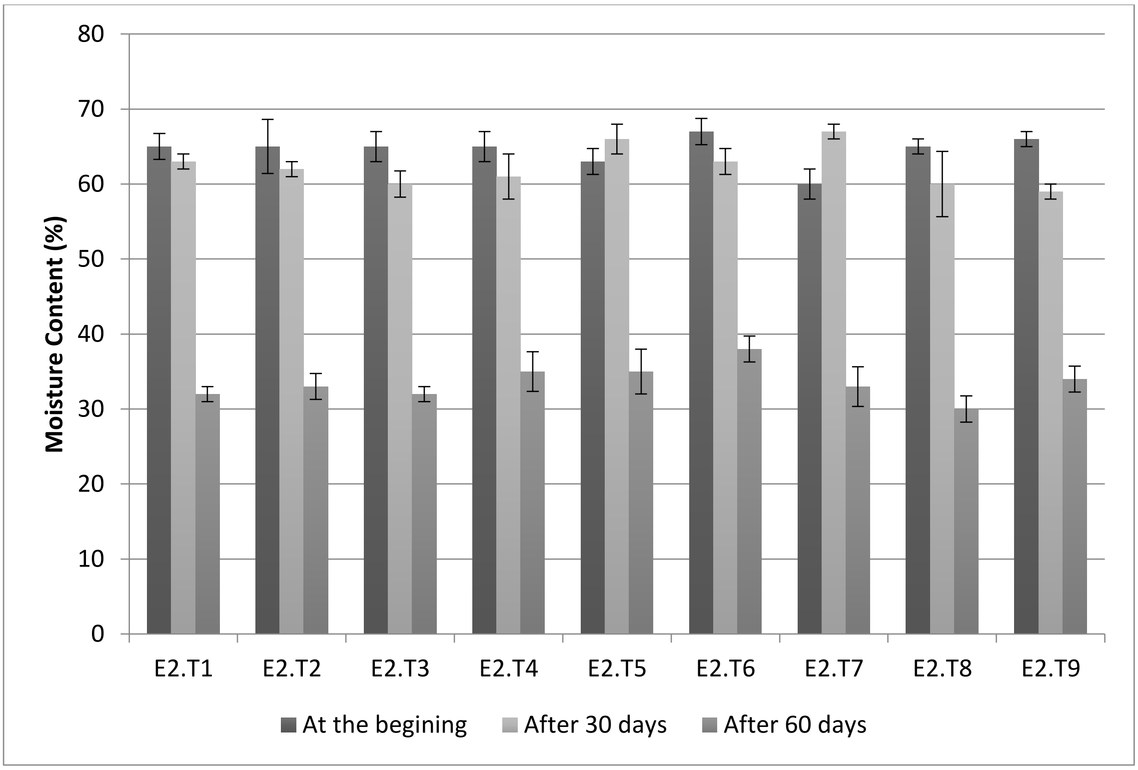


Figure 4.24: Moisture Content in different compost treatments in set of experiment # 2

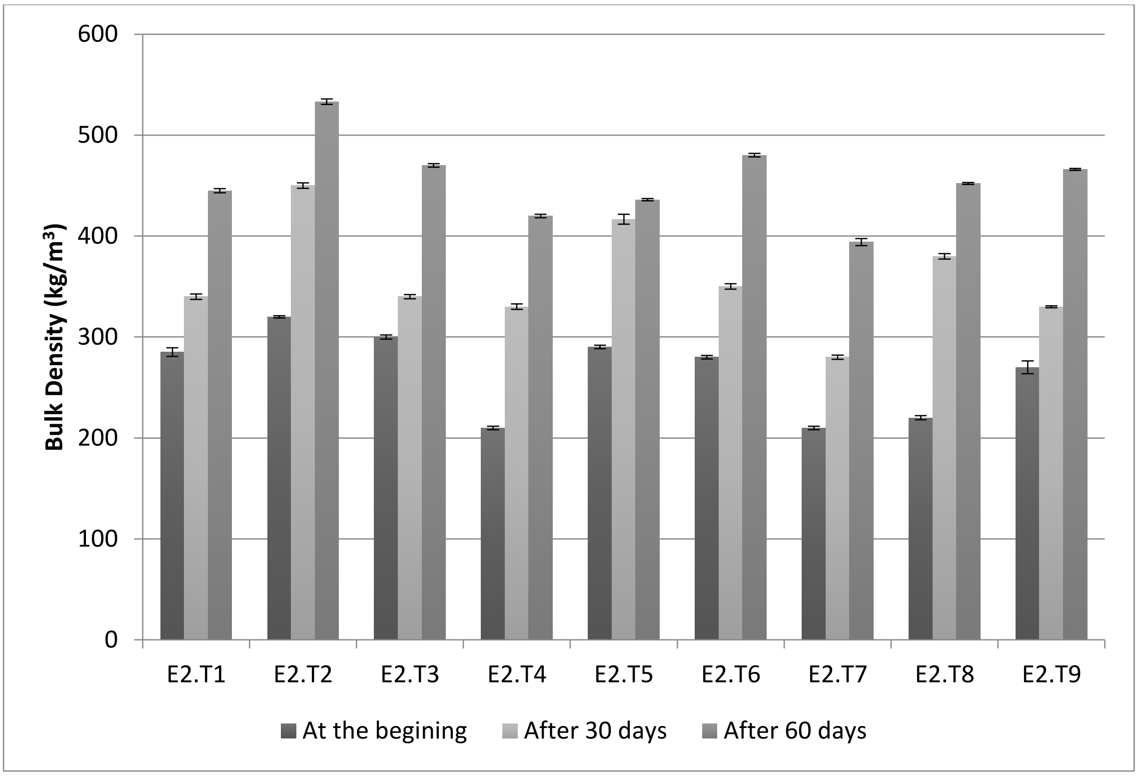


Figure 4.25: Bulk density in different compost treatments in set of experiment # 2

pH and Electrical conductivity (Ec) in Experiment #2

The electrical conductivity (EC) and pH of all piles were measured and shown in **Figures 4.26** and **4.27** respectively.

EC is a good indicator of the safety and suitability of compost. The EC of the finished compost of all treatments are ranging between 2.01 to 3.01dS/m, which is in the recommended range (2.0 to 6.0ds/m) as discussed in experiment #1.

Also, the pH values of all piles after 90 days were ranging from 7.74 to 8.69, which is in the recommended range from 7.5 to 8.5 as presented in experiment #1.

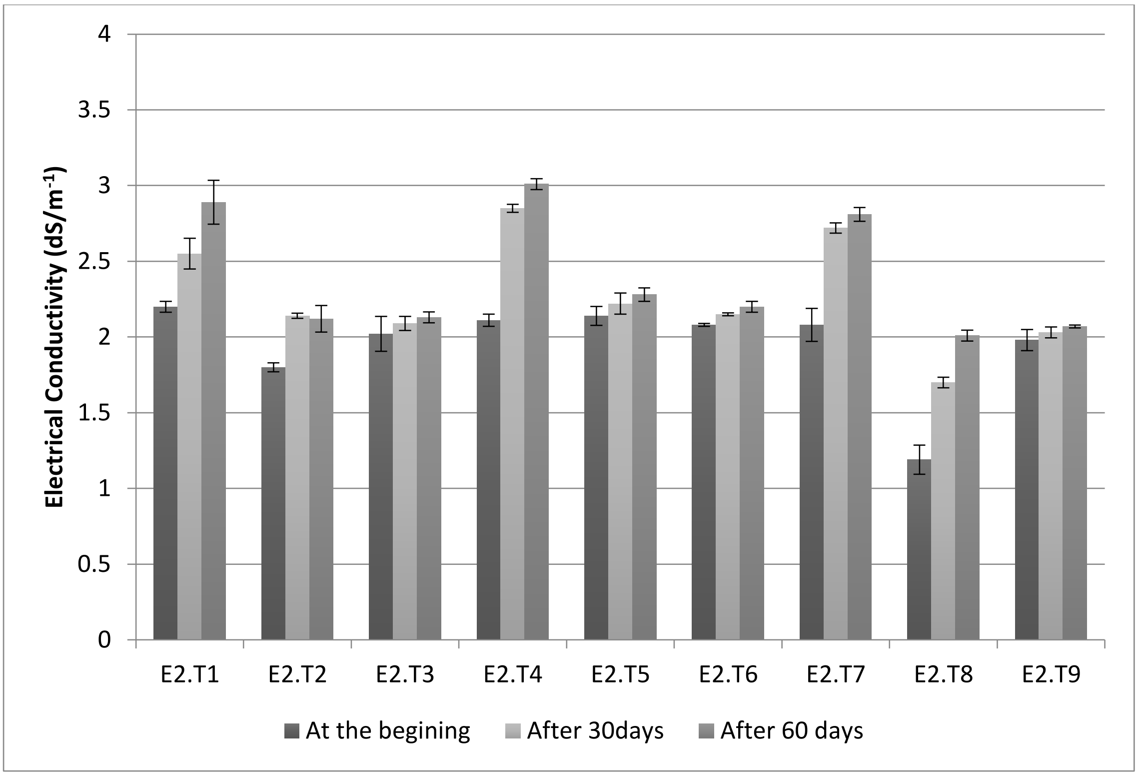


Figure 4.26: Electrical Conductivity in different compost treatments in set of experiment # 2

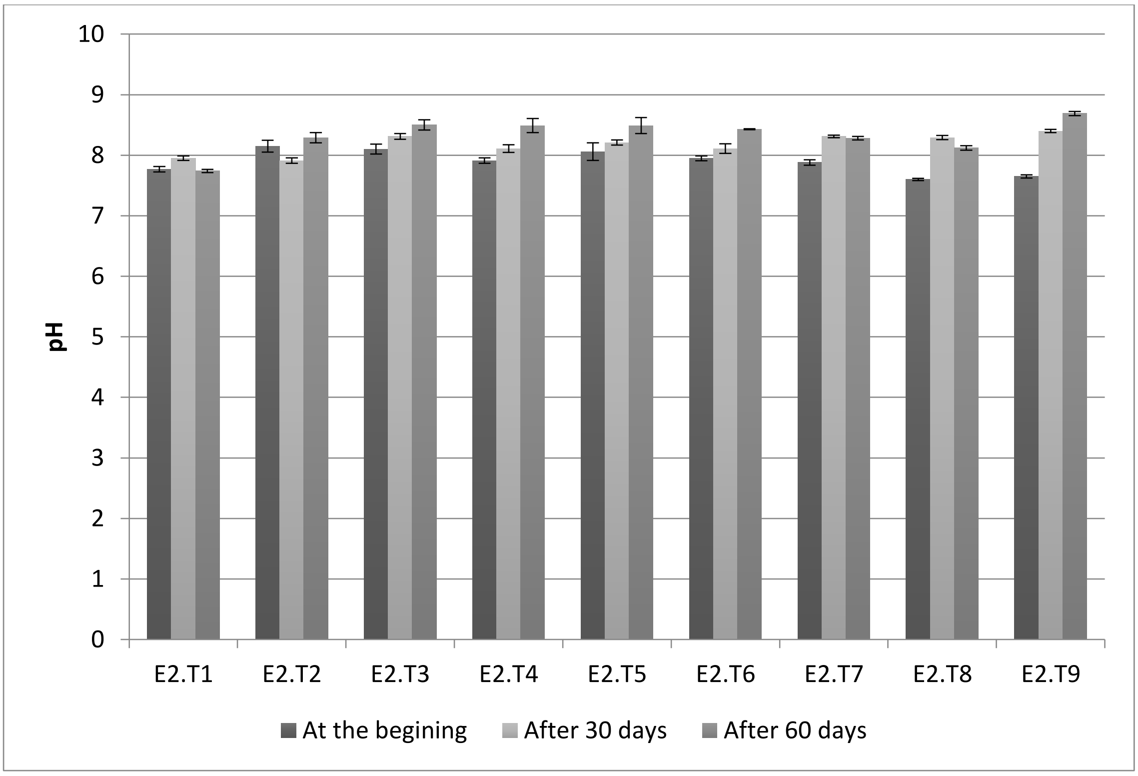


Figure 4.27: pH in different compost treatments in set of experiment # 2

Germination index (GI), pathogenic bacteria and humification index (HI) in Experiment #2

The GI of all treatments are presented in **Table 4.10.** GI of all treatments are ranging from 80 to 90, which indicates that all compost piles are free of phytotoxins as discussed in experiment#1.

The recorded HI are presented in **Table 4.10.** The recorded HI for all nine treatments are close to 0.5; therefore, all compost piles could be considered mature.

All final compost treatments were found free of pathogenic bacteria, as presented in **Table 4.11**, indicating their biosafety.

Table 4.10: Germination Index and humification index for different treatments in set of experiment # 2 after 90 days of composting

	Treatments	After 60 days
Germination Index	E2.T1	80
	E2.T2	80
	E2.T3	90
	E2.T4	80
	E2.T5	80
	E2.T6	90
	E2.T7	80
	E2.T8	80
	E2.T9	80
Humification index	E2.T1	0.6
	E2.T2	0.7
	E2.T3	0.6
	E2.T4	0.8
	E2.T5	0.5
	E2.T6	0.4
	E2.T7	1.0
	E2.T8	0.9
	E2.T9	1.1

Table 4.11 Pathogenic bacteria for different treatments in set of experiment # 2

	Treatments	Beginning of composting	After 30 days	After 60 days
Total Coliform Count (cfu/g)	E2.T1	9.E+05	3.E+05	nd
	E2.T2	6.E+05	2.E+05	nd
	E2.T3	5.E+05	2.E+05	nd
	E2.T4	8.E+05	4.E+05	nd
	E2.T5	7.E+00	3.E+05	nd
	E2.T6	4.E+05	2.E+05	nd
	E2.T7	6.E+05	3.E+05	nd
	E2.T8	8.E+05	5.E+05	nd
	E2.T9	6.E+05	3.E+05	nd
Fecal Coliform Count (cfu/g)	E2.T1	5.E+05	2.E+05	nd
	E2.T2	4.E+05	2.E+05	nd
	E2.T3	3.E+05	1.E+05	nd
	E2.T4	4.E+05	2.E+05	nd
	E2.T5	5.E+05	2.E+05	nd
	E2.T6	3.E+05	1.E+05	nd
	E2.T7	2.E+05	1.E+05	nd
	E2.T8	4.E+05	2.E+05	nd
	E2.T9	3.E+05	1.E+05	nd

	Treatments	Beginning of composting	After 30 days	After 60 days
Salmonella and Shigella count (cfu/g)	E2.T1	2.00E+05	1.E+05	nd
	E2.T2	4.00E+05	2.E+05	nd
	E2.T3	1.00E+05	nd	nd
	E2.T4	3.00E+05	2.E+05	nd
	E2.T5	3.00E+05	1.E+05	nd
	E2.T6	2.00E+05	1.E+05	nd
	E2.T7	2.00E+05	1.E+05	nd
	E2.T8	4.00E+05	2.E+05	nd
	E2.T9	3.00E+05	2.E+05	nd

Total phosphorous (TP) and Total Potassium (TK) in Experiment #2

TP and TK were measured for all piles, three measurements were taken for each pile. Detailed data are presented in the **Appendix**. The average TP(%) and TK(%) values are presented in **Figures 4.28** and **4.29** respectively. The TP and TK of all treatments increased during the compost piles and were in final compost in the recommended range TP (%) is 0.4 to 1.1 and TK (%) is 0.6 to 1.7 and meets the requirements of Egyptian Specifications for organic fertilizer as discussed in experiment#1. In fact, TP values at the beginning of the composting process were 0.75, 0.73, 0.78, 0.82, 0.9, 0.82, 0.9, 0.82, 0.63, 0.85, and 0.72 and increased to 0.92, 0.88, 1.09, 0.98, 1.15, 1.12, 0.81, 1.08, and 0.91 after 60 days for treatments E2.T1 to E2.T9 respectively. Also, TK values increased from 0.45, 0.51, 1.07, 0.51, 0.63, 1.12, 0.63, 1.49, 0.71 to 0.98, 0.91, 1.3, 1.14, 1.13, 1.6, 0.82, 0.79 and 0.94 respectively. It is clear that the values of TP and TK are higher than the ones obtained in experiment 1, this is due to the addition of natural rocks.

It is important to mention that piles containing 10% of biochar (E2.T4, E2.T5 and E2.T6) has higher %TP and %TK content. This is attributed to the fact that biochar is rich in phosphorous and potassium [116, 175].

In the second set of experiment the highest values were obtained in E2.T6 containing EM and 10% biochar. It is also important to notice that as increasing the percentage of biochar to 10% has increase quality of the compost. However, further increase of biochar to 20% decreased the quality of the compost. Similar results are observed by Xiao *et al.* [116] that reported that higher rates of biochar may hinder organic matter biodegradation.

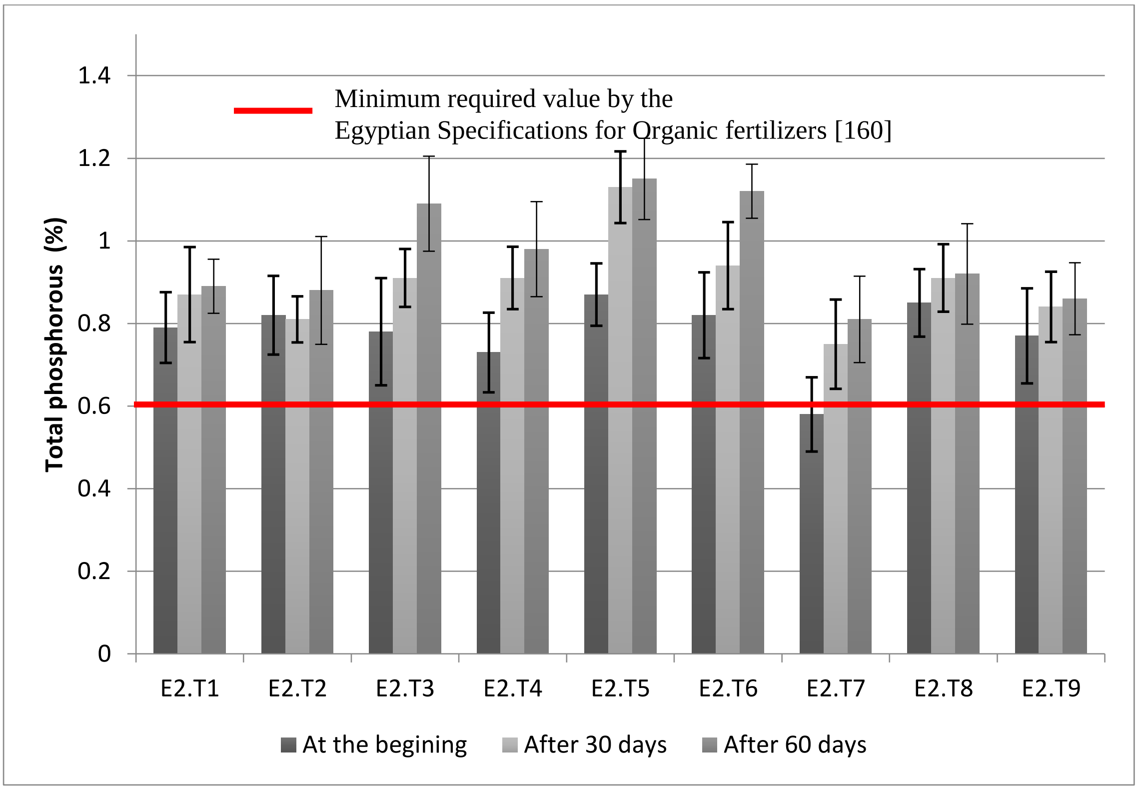


Figure 4.28: Total Phosphorous in different compost treatments in set of experiment # 2

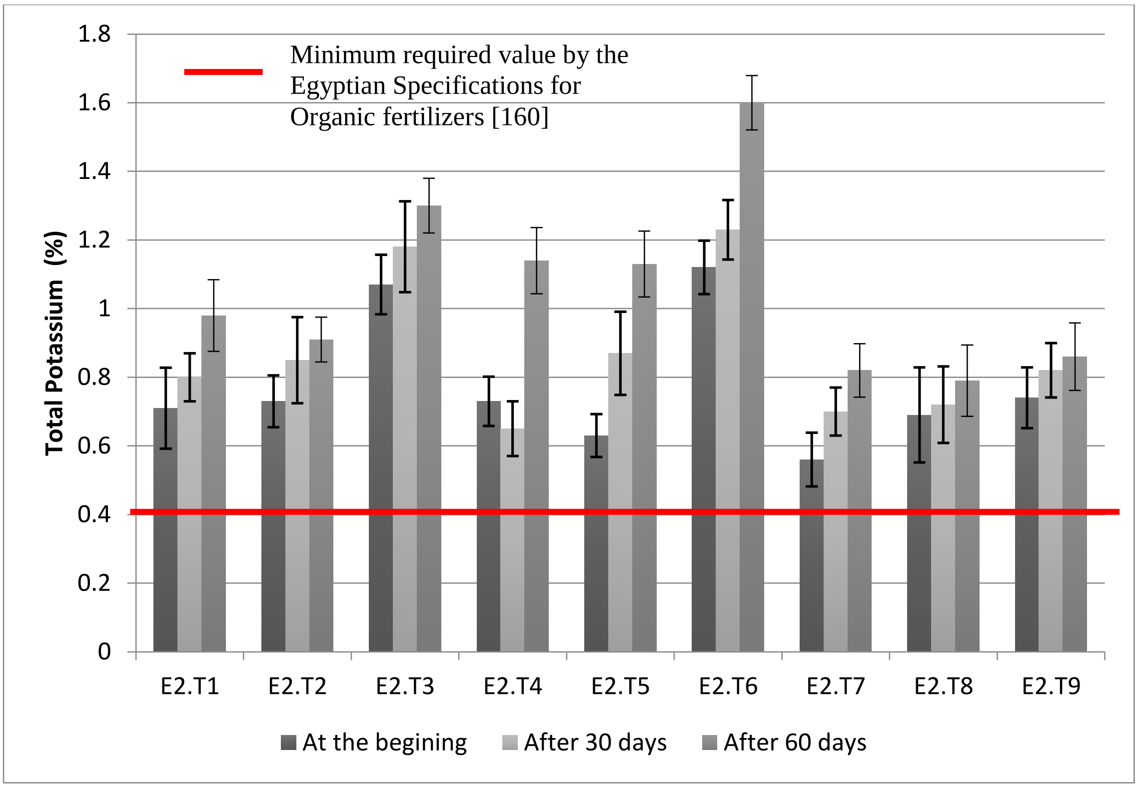


Figure 4.29: Total Potassium in different compost treatments in set of experiment # 2

Analysis of Odor and Color in Experiment #2

During the composting process the color of the compost was gradually darkening with time and this color is obvious by naked eye. The color of the final product is dark brown. The physical appearance of the best pile (E2.T6) at different composting stages is shown in **Figure 4.30**. The unpleasant odor of compost materials decreased with time. Finally, the odor was similar to the odor of earth at the end of the process. It is worth to mention, that the piles containing biochar have less unpleasant odor compared to other treatments.

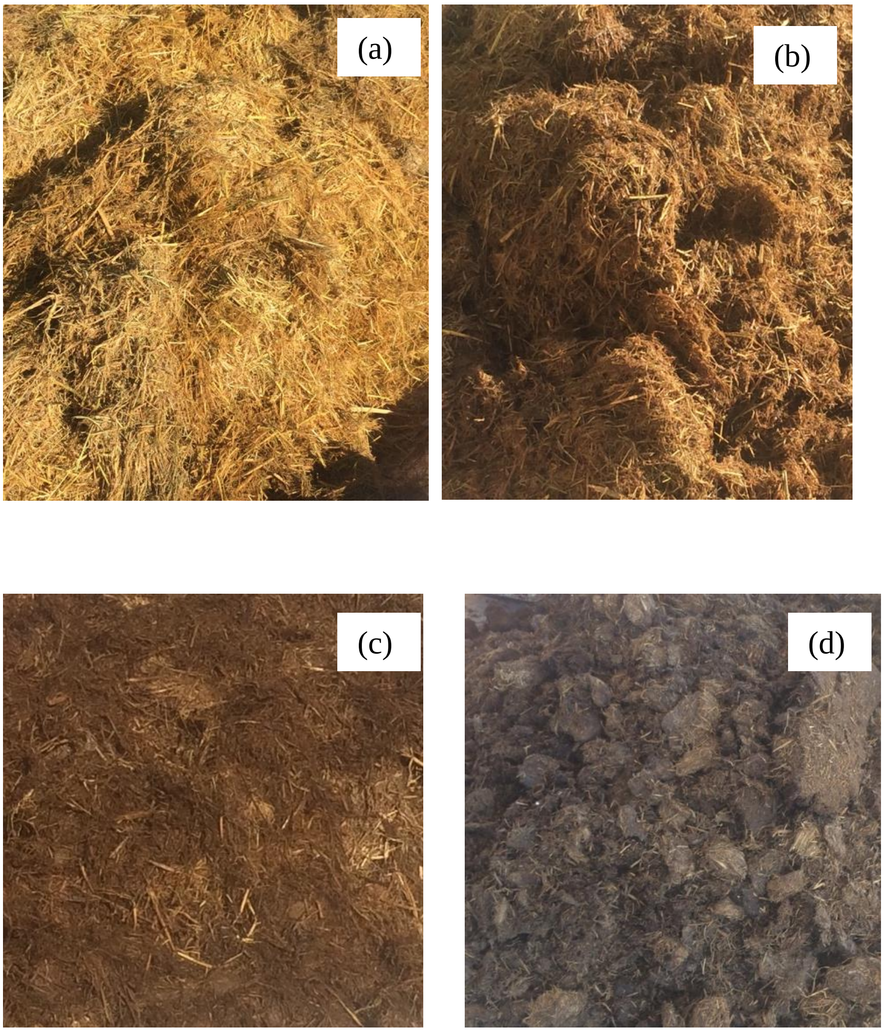


Figure 4.30: Physical appearance of E2.T6 (a) at the beginning of compost process, after (b) 30 days, (c) 60 days, and (c) 90 days

Conclusion of experiment # 2

In the second set of experiment natural rocks was added to rice straw and animal manure to enrich the nutritional value and produce high quality organic fertilizer. The effect of different additives to this substrate was studied and the results revealed that the application of different additives in composting of rice straw exhibit an improvement in maturation time and final product quality. In fact, all piles reached maturation after around 42 days. All analysis of the properties of the final products indicated that it was in the range of the matured level and can be used without any limitation as an organic fertilizer after 60 days. The highest decomposition rate and highest organic fertilizer quality was obtained in pile containing rice straw and 40% of animal manure mixed with natural rocks (2.5% of rock phosphate, 2.5% feldspar, 2.5% sulfur, 2.5% dolomite and 10% bentonite) and inoculated with 2% of EM and 10% biochar compared to other treatments. Also, the results showed that adding 20% biochar decreased the quality of the final compost compared to adding 10%.

4.4. From organic waste to sustainable green business opportunity in rural Egypt

Industry Analysis

Challenges facing the fertilizer Industry in Egypt

The tremendous increase in population in Egypt lead to an increase in food and agricultural production. Thus, many efforts are done to increase agricultural production and improve crop quality. In order to do that, better agricultural production methods are adopted to farm various types of yields. One of the most important factors to improve quality of agriculture production is the quality of the fertilizer used.

In Egypt, chemical fertilizers, also known as inorganic fertilizers, are composed of chemicals and/or minerals and are widely used as they allow fast and short-term plant growth. Chemical fertilizers can be divided into three main types:

1. Nitrogen Fertilizer (N): have high percentage of nitrogen and Urea and Ammonium nitrate are the main types of nitrogen fertilizers utilized in Egypt. There are several types including:
    a. urea (46.5 percent N)
    b. ammonium nitrate (33.5 percent N)
    c. ammonium sulphate (20.6 percent N)
    d. calcium nitrate (15.5 percent N)
2. Phosphate Fertilizers (P): the main constituent is Phosphorus. There are several types

including:

a. single superphosphate (15 percent P_2O_5)

b. concentrated superphosphate (37 percent P_2O_5)

3. Potassium fertilizers (K) is mainly made of potassium, there are several types including:

a. potassium sulphate (48 to 50 percent K_2O)

b. potassium chloride (50 to 60 percent K_2O)

In Egypt, mineral fertilizers, especially nitrogen, phosphate and potassium are being applied to an increasing extent. **Table 4.12** summarizes the quantities of chemical fertilizers produced in Egypt compared to the quantities required by the Egyptian farmers. The main causes of the increase in consumption of chemical fertilizers including:

- The increase in cropped area
- The farming of different types of crops at high rates required high rates of fertilizers.
- The quantity of suspended material deposited on soil which enrich the nutritional value of the soil decrease with the construction of the High Aswan Dam.

Table 4.12: Demand and Supply of chemical fertilizer in Egypt [176]

Type of chemical fertilizer	Quantity Produced in Egypt (Tons)	Quantities available for Egyptian market	Demand	Average Annual Shortage (ton)
Nitrogen fertilizer	5,045,300	5,400,000	8,300,000	2,900,000
Phosphate fertilizer	2,345,700	1,900,000	2,300,000	400,000
Potassium fertilizer	Not produced in Egypt	259,000	3,400,000	3,141,000

As indicated in **Table 4.12**, nitrogen fertilizer is the most widely used type of chemical fertilizer in Egypt as nitrogen, especially urea. The production of nitrogen fertilizers began in 1951 [176]. The difference between the quantity produced in Egypt and quantity available for the Egyptian market is imported.

As shown in **Table 4.12**, Egypt produces nitrogen and phosphate fertilizers. Phosphate fertilizer used to be imported until 1936 the local production of Phosphate started in Egypt. Large part of the produced phosphate fertilizer is exported as indicated in **Table 4.12**. No potassium fertilizers are produced in Egypt due to the lack of resources.

There are eight public sectors companies producing chemical fertilizer in Egypt including Abou Kir, Delta, and Helwan Al-Masriya. Also, there are five privet sector companies that sell half of their production to the government at subsidies price via the Principal Bank for Development & Agricultural Credit (PBDAC) and agricultural cooperatives.

The table indicates that there is an annual shortage of chemical fertilizer in the Egyptian market.

Challenges facing the demand side (farmers)

Although chemical fertilizers allow plants to grow fast, it has some disadvantages including the following [177]:

1. High price
2. Excessive use of chemical fertilizers that may lead to accumulation of heavy metals in soil and plant system. Also, chemical fertilizers are highly soluble in water. Plants absorb the fertilizers through the soil, they can enter the food chain. Thus, misuse of chemical fertilizers may lead to waterway contamination, chemical burn of crops, increase in air pollution, and acidification and mineral depletion of soil

The high cost and excessive use of chemical fertilizers is burden on the farmers. In fact, according to CAPMAS Egypt is ranked the second among the countries of the world in terms of the addition rate of a unit of area, which is estimated at 352kg of nitrogen per hectare [177].

Challenges facing the Supply side (government and producers)

As previously stated, there is a shortage in the amount of chemical fertilizers in Egypt. The chemical fertilizer crisis recurs every year and has a great impact on the Egyptian economy as the agricultural sector is one of the most important aspects of the Egyptian economy. Any increase in the price of chemical fertilizers is directly translated into an increase in price of agricultural commodities, which affects the level of living of Egyptian citizens. Therefore, in Egypt quota is provided by the state-owned Bank PBDAC to subsidized fertilizer to help poor farm owners. Yet, this system allows the creation of black market as producers, distributors and landlords buy the fertilizer at subsidized price and sell it at high price close to international market to make profits.

According to the CAPMAS report, in 2014 (before floating of the Egyptian pound) Public sector companies producing chemical fertilizers bear subsidy as the price is fixed to be 700LE/ton , while in companies in free-zones export the product at $230/ton which was equivalent to 1610LE/ton [177]. A strike in prices of chemical fertilizers occurred in past couple of years and the market price has reached LE5,200 per ton while subsidized fertilizers are sold at LE3,200 per ton. This leads to huge losses for the public-sector companies. At the same time, the price of producing chemical fertilizers is expected to increase as this industry utilize intensive amount of natural gas and electricity, which price is currently increasing.

Porter's Five Forces Model

The five forces model that can be used to assess the attractiveness of the industry are discussed below:

- Threat of Substitute
    - Chemical fertilizers are the main substitute to organic fertilizer. Farmers may oppose the idea of using organic fertilizer as they have already developed all the required skills to efficiently use chemical fertilizer so introducing a new product that they are not familiar with could threaten them. However, due to the shortage and rise of the price of chemical fertilizer, organic fertilizer is the future of agriculture
- Threat of new entrant

- The capital cost of this business is low so many people can enter the market and easily compete. However, this product is relatively new to rural Egypt and not many people have the know-how to optimize the composting process.

- Bargaining power of supplier:
    - Farmers currently burn most of their agricultural waste. Hence, buying the waste of famers could be an attractive alternative to farmers. Not taking the waste for free will ensure that farmers will stop burning their waste and sell it.
    - Chemical fertilizers can have harmful effects on soil
    - The price of chemical fertilizer is constantly increasing. Also, the shortage in chemical fertilizers (especially nitrogen) force farmers to buy from black market at high prices
- Bargaining power of buyer:
    - Organic fertilizer can be used by any farmer and at any scale
- Rivalry among existing firms:
    - Relatively new product in upper Egypt

Industry Trends

PEST (political, economic, social and technological) analysis is conducted to give an understanding of external factors affecting the fertilizer industry. Each factor could have negative and positive impact on the industry. Hence, it is important to have a detailed analysis as summarized below.

❖ Political trend:

- The Egyptian government aims to transform one and a half million acres of desert land into agricultural lands to fulfill the increasing high-quality food demand at an affordable price. The National Project for Reclamation and Cultivation will increase farmland in Egypt by 20%. Hence, the demand on fertilizers will tremendously increase.

- The government aim to use organic farming to improve the quality of food and life of Egyptians and increase the local production to increase exports and create more job opportunities.
- The government is also looking for solutions to resolve the conflict between subsidies, industrial production and local consumption needs
- The government of Egypt is aiming to achieve sustainable development that leads to transformational change and real improvements in people's lives. Therefore, the government is supporting any ideas to reduce pollution of water, soil and air caused by extensive utilization of chemical fertilizers.
- Also, the government is tending to make energy savings, particularly in intensive industries like fertilizers.
- The government is aiming to increase the amount of organic farming to be able to export more agricultural products.

❖ Economic Trend

- The government favors fertilizer industry as it facilitates the agricultural sector, which has direct impact on price of products utilized by citizens.
- Increase in demand for jobs opportunities
- Increase in demand of fertilizer to meet the demand for the Mega national agricultural projects

❖ Social Trend

- The extensive use of chemical fertilizers causes many environmental problems including water, soil and air pollution. These issues can cause many health problems.

- Also, the increase in the price of chemical fertilizer lead to increase in vegetables and fruits products, which directly negatively affects the life of citizens.

❖ Technological Trend

- Organic fertilizer production is an easy and relatively cheap technology as the raw material is agriculture waste and all what is requires is labor and water.

Triple Bottom Line

Economic Impact

❖ ***Direct Cost***

Table 4.13 summarizes the price of items used to produce high quality organic fertilizer. From the experimental analysis, it was concluded that the highest organic fertilizer was obtained in pile containing rice straw and 40% of animal manure mixed with natural rocks (2.5% of rock phosphate, 2.5% feldspar,2.5% dolomite, and 10% bentonite) and inoculated with 2% of EM and 10% of biochar.

Table 4.13: Price of raw material used in composting high quality organic fertilizer

Raw Material	*Quantity*	*Market Price*	*Cost (LE)*
Rice Straw	50kg	300LE/ton	15
EM	50mL	200LE/Liter	10
Biochar	5kg	100LE/ton	0.5
Animal Manure	20kg	300LE/ton	10
Rock phosphate	1.25kg	1200LE/ton	1.5
Feldspar	1.25kg	2200LE/ton	3
Sulfur	1.25kg	3300LE/ton	4
Dolomite	1.25kg	1250LE/ton	1.5
Bentonite	5kg	1000LE/ton	5.0
Total	135kg	-	50.5

Experiment has shown that there is around 40% loss in weight by the end of the compost pile. In other words, the initial weight of the pile is 135kg and it produced around 80kg of organic fertilizer. Hence, the total price is 635LE/ton of organic fertilizer. The price of labor and transportation was not added as farmers will be turning their compost piles manually in their lands so no extra charges for labor would be added. Also, this cost could be further decreased to be 330LE/ton if the farmer will be using the rice straw and animal manure produce from his land instead of burning it.

Studies conducted on Valencia Orange Trees in Egypt have indicated that on average using organic fertilizer in combination with other raw materials to increase its nutritional values would result in similar yield compared to using 100% chemical fertilizer [178, 179, 180]. However, Pradeepkumar *et al.* [181] conducted a study on ten tropical vegetable crops viz. amaranthus (Amaranthus tricolor L.), brinjal (Solanum melongena L.), chilli (Capsicum annuum L.), okra (Abelmoschus esculentus (L.) Moench), tomato (Solanum lycopersicon L.), bitter gourd (Momordica charantia L.), coleus (Solenostemon rotundifolius (L.) Codd.), cowpea (Vigna unguiculata (L.) Walp), snake gourd (Trichosanthes anguina L.), and cucumber (Cucumis sativus L.). This study showed that yields from the use of organic fertilizer is on average 98% of that obtained from the use of inorganic fertilizer.

Another study conducted by Seekem [182] showed that yields from cotton was 23% lower than those obtained from chemical fertilizer, yields from peppermint was 29% lower than the one obtained from chemical fertilizer, while no difference in yield production of dates was observed.

By using this information, this means the price of 1 ton of the produced organic fertilizer can be compared to the price of 1 ton of chemical fertilizer. **Table 4.14** compares the prices of produced organic fertilizer with market price of different fertilizers. The presented market price of chemical fertilizer are non-subsidized prices, nitrogen chemical fertilizers are subsidized and their price is around 40% less than market price.

According to CAPMAS is estimated that in Egypt 352kg of nitrogen chemical fertilizer is used per hectare [177], which is equivalent to 150kg per feddan. This means that 1 feddan will require 150kg of organic fertilizer. In other words, urea will cost 810LE/feddan (non-subsidized price) or 480LE/feddan (subsidized price), while organic fertilizer will cost 95LE/feddan or 50LE/feddan (if the farmer will be using his organic waste to produce the fertilizer). If the farmer will need labor to produce the fertilizer, according to Mohamed *et al*. [178], 1 feddan requires 2 labor for 120LE/feddan each. Therefore, the cost of organic fertilizer will be cost 335LE/feddan or 290LE/feddan. In other words, the use of organic fertilizer could be an attractive solution to farmers to substitute the expensive chemical fertilizer and at the same time could help the government remove the subsidy on chemical fertilizer.

Table 4.14: Comparison of price of organic and chemical fertilizer

Type of fertilizer	unit	Price (LE/ton)	Price (LE/feddan)
Organic Fertilizer			
Price of organic waste included labor not included	LE/ton	635	95
Price of organic waste and labor not included	LE/ton	330	50
Price of organic waste & labor included	LE/feddan	--	335
Price of organic waste not included & price of labor included	LE/feddan	--	290
Chemical Fertilizer Market Price (non-subsidized)			
Urea	LE/ton	5,400	810
Ammonium nitrate	LE/ton	5,600	840
Ammonium Sulphate	LE/ton	3,900	585
Calcium nitrate	LE/ton	6,000	900
Single superphosphate	LE/ton	1,700	255
Concentrated superphosphate	LE/ton	1,700	255
Potassium sulphate	LE/ton	12,000	1,800
Compound (19N, 19P, 10K)	LE/ton	8,400	1,260
Compound (6N,42P, 6K)	LE/ton	8,400	1,260

❖ ***Damage Cost***

In addition to the direct cost presented above, there is a hidden external cost that also must be considered that it will be referred to in this study as "Damage cost". The data presented is based on FAO report entitled Food wastage footprint Full-cost accounting – final report" [183] and Seekem report entitled Future of agriculture in Egypt [184]. There are two main types of damage cost as follows and their cost is listed in **table 4.15**:

1. Atmosphere damage cost via Greenhouse Gases Emission (GHG)

Several studies were conducted and showed that by applying compost to soil, carbon is stored in soil. This is due to the fact that composting partly results in the increased formation of stable carbon compounds, i.e. humus-like substances and aggregates. These are made of complex compounds that render them resistant to microbial attack. Thus, organic farming is used as carbon sequestration and GHG emission in organic farming is calculated to be zero. Carbon sequestration is defined as long-term storage for carbon dioxide. According to FAO report [183], the damage cost of GHG emission including deforestation and managed organic soils in the conventional farming is estimated to be $113 per ton CO_2 equivalent. These costs are determined by considering the six most important greenhouse gases: carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and Sulphur hexafluoride (SF_6). These are converted into CO_2 equivalents based on their global warming potential. The atmosphere damage cost is the cost of removing the main GHG from the atmosphere.

2. Water damage cost

According to Seekem report, water quality cost is determined based on the effect of use of fertilizer and pesticides in conventional and organic farming. This cost is estimated based on the cost of removing pesticide, nitrate and phosphate from drinking water. The table below summarizes the estimated cost for different type of crops. Conventional systems rely on pesticides many of which are toxic to humans and animals. For organic farming the cost of pesticides is assumed to be zero.

Table 4.15: Comparison of price of organic and chemical fertilizer [184]

Crop	GHG Emission (LE/feddan)	Water Damage Cost (LE/feddan)
Rice	2,868	1,575
Maize	1,762	1,709
Potatoes	3,846	6,094
Wheat	2,538	1,609
Cotton	1,261	2,295
Average	**2,455**	**2,656**

Social Impact

The production and use of organic fertilizer made from waste will have the following social impacts on rural communities:

- Create new types of job opportunities
- Famers will be able to use their waste, which will increase their revenues and at the same time will decrease their use of chemical fertilizer at high price
- Decrease the pollution and health problems from the use of chemical fertilizer
- Farmers and residents of rural areas will not be exposed to fumes created from burning of organic waste in field so the health problems will decrease.

Environmental Impact

The production and use of organic fertilizer made from waste will have the following social impacts on rural communities:

- Fertilizer consumption per cultivated area in Egypt is 10 times more than the average amount of whole world [176]. Many studies have shown that using enormous amounts of mineral fertilizers can accumulate harmful nitrate in food causing hazardous effects [185]. Also, excess use of chemical fertilizer leads to an efficiency of only 50% of nitrogen fertilizer and losses of nutrients by leaching, volatilization, denitrification as well as mobility of movement elements and most of phosphorous and potassium remain inert and only less than 10% of soil content [186]. Therefore, the use of organic fertilizer will result into a decrease in the pollution caused from the use of chemical fertilizer

- Decrease the pollution and health problems caused by burning the organic waste
- On the long term the use of organic fertilizer will enrich and rebuild the soil structure [179, 186].

Key Success Factors

Below is a list of the key elements that should be considered for successful business:

1. **Time of Collection from farmers:** Waste must be collected from the fields between the harvest and the planting of the new crop. In fact, farmers burn the waste in the field between harvest and planting seasons because of lack of storage space. Hence, any delay in collection could make famers not cooperate.
2. **Marketing and education:** it is important to educate and market about the benefits of organic fertilizer compared to chemical fertilizers. It is also important to explain to people what it is and how it is to be used.
3. **Time to apply organic fertilizer:** Organic fertilizer should be applied to the soil after the fermentation process is completed. The addition of organic fertilizer prior to completion of fermentation process could affect the seed and burn the roots and damage plantation process. It is imperative to make sure that the organic fertilizer used is stable and mature before using it, as if fermentation is incomplete the organic fertilizer will burn the soil and thus farmers will go be to the use of chemical fertilizer.
4. **Storage facility:** A storage facility is needed to store the collected waste as compost is seasonal product.

5. **Diverse type of raw material:** The type of waste used should be from different sources (food waste, different type of crops, etc.) so that the business is not dependent on the seasonality of the waste and ensure yearlong supply.
6. **Gradual shifting of use of organic fertilizer:** The shift from chemical to organic fertilizer must be done gradually.

4.5. Conclusion

The results of the first set of experiments revealed that the application of different additives in composting of rice straw exhibited an improvement of compost quality. In fact, all piles reached maturation time after around 60 days. All analysis of the properties of the final compost products indicated that it was in the range of the matured level and can be used without any limitation. Yet, the results of the first set of experiments revealed a higher decomposition rate of treatment having animal manure, compared to other treatments.

Therefore, a second set of experiment has been conducted with substrate rice straw and animal manure inoculated with different types of additives and mixture of natural rocks to produce organic fertilizer. The results revealed that the application of different additives in composting of rice straw exhibit an improvement in maturation time and final product quality. In fact, all piles reached maturation after around 42 days. All analysis of the properties of the final products indicated that it was in the range of the matured level and can be used without any limitation as an organic fertilizer. The highest decomposition rate and highest organic fertilizer quality was obtained in pile containing rice straw and 40% of animal manure mixed with natural rocks (2.5% of rock phosphate, 2.5% feldspar, 2.5% sulfur, 2.5% dolomite and 10% bentonite) and inoculated with 2% of EM and 10% biochar compared to other treatments. Also, the results showed that adding 20% biochar decreased the quality of the final compost compared to adding 10%.

Applying the Waste to Business (W_2B) model introduced in chapter 3 to organic waste in rural communities indicated that the price of the produced high-quality organic fertilizer is 330LE/ton, given that each farmer will use the organic waste generated from his land and will not need extra labor to produce the organic fertilizer compared to chemical fertilizer market price of 1,700LE/ton to 12,000LE/ton (non-subsidized price). In addition to the direct cost, the use of chemical fertilizer damages the atmosphere and the water. This damage has an unforeseen high cost. Therefore, organic fertilizer produced from organic waste can substitute expensive chemical fertilizer. In addition to economic benefits, reducing the use of chemical fertilizer will lead to the creation of new job opportunities in rural villages, reduction of soil, water and air pollution as farmers will sell their waste instead of burning it in the field. Also, application of organic fertilizer will re-establish the soil structure on the long run.

CHAPTER 5– APPROACHING FULL UTILIZATION OF MUNICIPAL SOLID WASTE – CASE STUDY OF REJECTS

5.1. Introduction

One of the major problems facing rural communities in Egypt is poor municipal solid waste (MSW) management, which contribute to the health, ecological and environmental problems facing rural communities. According to the country report on the solid waste management in Egypt in 2014 [11], Egypt generates 21million tons of MSW per year. Most of municipal solid wastes generated are either burnt or end up in open, public and random dumpsite or water canals, which contribute to the health, ecological and environmental problems facing rural communities [5, 6, 22]. More than 35% of waste generated every year in Egypt is thrown in streets, open dump sites and or water ways causing serious environmental and health problems [11]. A large amount of waste generated in Egypt is made out of unrecyclable waste known as rejects [5]. There are many types of rejects and this research focuses on the following types of rejects: (1) packaging materials, (2) thermosets, and (3) contaminated plastic bags.

Packaging material could be made of paper and cardboard, glass, aluminum, plastics or laminated packaging material. The laminated packaging material also known as multilayer packaging material are usually the ones referred to as rejects as they are hard to recycle because they are made of multilayer films of different materials bonded together. Multilayer packaging materials are commonly used to combine different performances of various materials. Hence, multilayer packaging is created to sufficiently protect sensitive food products and thus obtain extended shelf life. Usually multi-layer packaging materials are made of three-layers. The inner side facing the product provides sealability and is usually made of aluminum. The outer layer provides abrasion resistance, heat resistance, stiffness moisture and oxygen barrier and surface for printing and is usually made of polyester (PET), polypropylene (PP) and polyethylene (PE).

In the center an adhesive is needed to attach two dissimilar materials. Although multilayer packaging material provide high properties, they usually turn into waste immediately after using a product and most of them are usually incinerated or landfilled. Large amounts of packaging materials are generated every year. The Central Department of Solid Waste estimate that around 29% of MSW in Egypt could be made of packaging materials, which represents 6 million tons [11]. This is not a problem only in developing countries like Egypt, in fact, a study estimated that 1.89million tons of multi-layer packaging material are generated in Germany in 2009 and it is estimated that 40% of plastic produced in Germany in 2015 is used for packaging material [187]. It is reported that new law will enter into force in 2019 in Germany to increase recycling of packaging waste from 40% to 63% by 2022 [187, 188]. Therefore, innovative solutions to recycle packaging material is required. Most of literature describe recycling of multilayer packaging material via delamination process to recover either the plastic part and/or the aluminum side [145, 146, 143, 147, 148]. Some industries in developed countries use plasma process (around 15000°C) to recover aluminum from packaging material [145]. Other industries use microwave induces pyrolysis, which separates aluminum from plastic laminates by heating it to a temperature of 500°C [146]. However, because of the high cost and energy consumption of these techniques, they are not implemented in developing countries. Very few publications in the literature report mechanical recycling methods to recycle multi-layer packaging material to produce useful goods [151]. Thus, research is still needed in this area.

Another type of rejects is thermoset, which is a type of plastic that have many attractive properties (high hardness, thermal resistance, insulation, etc.) making it significantly used in many applications. All of these properties are attributed to the complex three-dimensional structure of the material. Yet, this cross-linked nature makes thermosets very challenging to recycle as they decompose and degrade when subject to heat. Therefore, most of the thermoset products end up in landfills or are incinerated at the end of their life, which causes serious environmental concerns due to the fact that plastic waste contains various toxic elements, which can pollute soil and water [23, 24]. Due to the increasing environmental concern, recycling of non-biodegradable thermoset wastes has been the major issue for researchers [25]. Therefore, the aim of this research is to develop easy and cheap technology to recycle rejects to produce useful goods. This part of the research will focus on recycling of melamine-formaldehyde (a hard thermoset), ethylene-propylene-diene- monomer rubber (an elastic thermoset) and multi-layer flexible packaging material to produce useful goods including interlock paving units and bricks.

5.2. Objectives

The main aim of this part is to propose solution to economically close the loop for rejects from municipal solid waste and approach full utilization of rejects. In this part of the research two innovative, efficient, simple and cheap technologies/products are proposed to recycle rejects:

Hot Technology

The objectives of this section are to:

- Produce an innovative composite material from rejects using compression molding technique. The composite material is made of multi-layer packaging material as the matrix and melamine-formaldehyde (one type of hard thermoset) as filling material.
- Measure the following mechanical properties of the new composite material:
    - Compressive strength in accordance with ASTM D 695 – "Standard Test Method for Compressive Properties of Rigid Plastics"
    - Density
    - Water Absorption in accordance with ASTM D 570 – "Standard Test Method for Water Absorption of Plastics"
    - Abrasion Resistance

- Abrasion Index
  - Flexural strength in accordance with ASTM D 790 – "Standard Test Method for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials"
  - Leachate
- Conduct full design of experiment using Design Expert 11 software to:
  - Identify the effect of three parameters of compression molding (temperature, percentage filling material, grain size of melamine-formaldehyde) on the properties of the produced composite material
  - Identify the parameter that has the most significant effect on material properties
  - Develop equations that will allow the prediction of properties for any combination of parameters
- Compare the measured properties with ASTM Specification requirements for interlock paving units
- Compare mechanical properties obtained if filling material (melamine-formaldehyde) is substituted with rubber or sand
- Compare mechanical properties obtained if packaging material is substituted with plastic bags
- Compare the cost of produced interlock from rejects and commercially available interlock paving unit

Cold Technology

The objectives of this section are to:

- Develop an innovative technique to produce bricks from waste rejects with minimal energy cost
- Measure the following mechanical properties:

- Compressive strength in accordance with ASTM C140
- Water Absorption in accordance with ASTM C140

- Compare the measure properties with ASTM C129 and the Egyptian code for non-load bearing masonry bricks
- Compare the cost of produced brick from rejects and commercially available brick

5.3. Development of an innovative composite material to produce interlock paving units from rejects using hot technology

5.3.1. Methodology

Material

Five types of waste rejects are used in these experiments:

- Multi-layer Packaging Material (MP) – MP are collected from Hay el Zabaleen in Cairo from municipal solid waste. These MP are mainly remaining from chips and chocolate packs, etc. They are mainly composed of three layers aluminum foil, adhesive and polymeric film usually made of polyethylene, polypropylene, polyamide, etc.
- Melamine-formaldehyde (MF) – Old plates made of MF are collected, cleaned and crushed into powder
- EPDM rubber – waste EPDM rubber in form of powder is received from the waste of ElShark Factory for Rubber – Dorgham.
- Sand
- Waste contaminated plastic bags

Experimental Procedure

- ***Experiment 1 – Multi-layer Packaging material (MP)+ melamine-formaldehyde (MF)***

MP is shredded into small pieces using a shredding machine as shown in **Figure 5.1**. MF was shredded and screened using wire mesh to the following particle sizes:

- Sieve 16 (1.18mm)

- Sieve 20 (850µm)
- Sieve 40 (425µm)

Shredding machine	Shredded MP	Screening
		
Sieve 16 (1.18mm)	Sieve 20 (850µm)	Sieve 40 (425µm)
		

Figure 5.1: Preparation of waste material

MF and MP are mixed together at different percentages using a mixer, shown in **Figure 5.2,** to make sure that material is well dispersed. Then material is poured inside a squared mold having dimensions of 100x100mm.

Figure 5.2: Mixer

Compression molding machine (**Figure 5.3**) is used to produce the composite material. In compression molding, the sample is subject to pressure and heat for a certain period of time for the material to melt and take the shape of the mold. The pressure is fixed at 50bar and time of molding is also fixed to be 30min. The effect of three factors are examined: (1) temperature, (2) percentage filling material, and particle size.

Figure 5.3: Compression Molding machine

As the exact composition of MP received form MSW is not known it is hard to determine the exact melting temperature of MP used. Therefore, pilot experiments are conducted to determine the temperature above which MP starts melting. Compression molding technique is used to melt packaging material only at different temperature (80°C, 100°C, 130°C, 140°C). These pilot experiments reveal that MP melts at about 135°C and if temperature is higher than 145°C the molten MP starts leaking from the mold.

Hence, a full design of experiment is planned to produce composite material made of MP and MF. **Figure 5.4** summarizes the hot technology procedure. As explained, there are three factors (1) temperature, (2) percentage of reinforcement material and (3) particle size and three levels for each of these factors are determined as follows:

- percentage reinforcement
    - 20 wt. %
    - 30 wt. %
    - 40 wt. %
- Temperature:
    - 145°C
    - 140°C
    - 135°C
- Particle Size
    - No 16 (1.18mm)
    - No 20 (850um)
    - No 40 (425um)

Therefore, there are 3^3 (=27) combinations that need to be tried and each combination is replicated three times. For higher accuracy samples are produced at random order using Design Expert software.

➢ ***Other composite materials***

The combination of particle size, % filling material and compression molding temperature that gives best mechanical properties is identified and other composite materials are produce using these parameters as follows:

- Experiment 2 – Multi-layer Packaging material (MP)+EPDM rubber – in this experiment MF is substituted with EPDM rubber.
- Experiment 3 – Multi-layer Packaging material (MP)+Sand – in this experiment MF is substituted with sand
- Experiment 4 – Waste Plastic bags+ Melamine formaldehyde (MF) – in this experiment MP is substituted with waste plastic bags

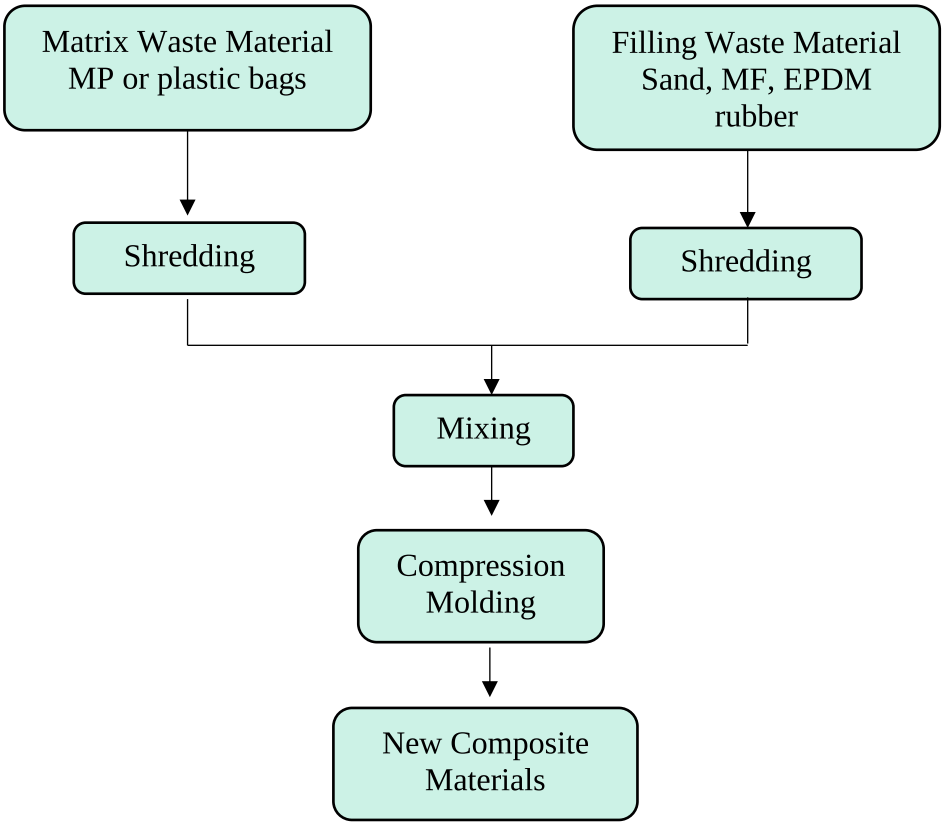


Figure 5.4: Schematic diagram for recycling of rejects using hot technology

5.3.2. *Measured Properties*

The following properties of composite materials are tested:

- **Compressive strength**

The universal testing machine (**Figure 5.5**) is used to measure the compressive strength of the samples. The compressive strength of specimens is measured according to ASTM standard test method D695 “Standard Test Method for Compressive Properties of Rigid Plastics”. All tests are performed at a constant displacement rate of 1.3 mm/min. The specimens are machined to have a rectangular shape of 12.7x12.7x25.4mm.

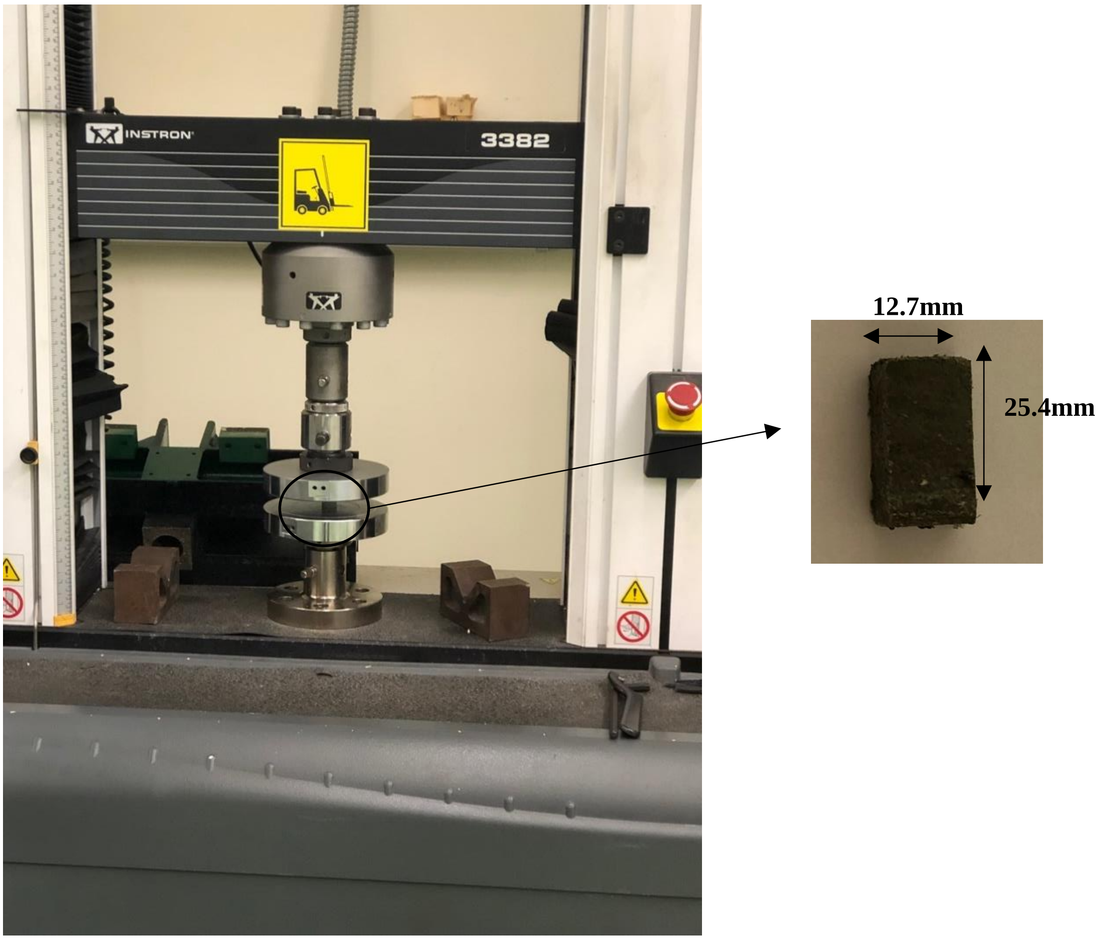


Figure 5.5: Compressive strength test apparatus

- **Moisture absorption**

The moisture absorption property of the materials is determined in accordance with ASTM D 570 – “Standard Test Method for Water Absorption of Plastics” using the 24-hour immersion procedure. The specimens are weighed on an analytical balance. The specimens are then entirely immersed in a container of water for 24 hours and then removed from water one at a time and surfaces are wiped off with dry cloth and weighted again.

The percentage of water absorbed is then calculated using the following equation:

- **Abrasion Resistance**

The abrasion resistance of the samples is measured, the obtained results are intended only for comparison purposes. The testing apparatus consists of a rotating disk and a load to hold the specimen in place and abrasive material as shown in **Figure 5.6**. The wear track diameter is 180mm. The test is carried out over a total distance of 16m. The wear test for all specimens was conducted under the normal loads of 50N and a sliding velocity of 73rpm. Before conducting the test, the surfaces of the samples were slides using emery paper (80 grit size) The initial and final weight and thickness of the samples are recorded. The weight and volume loss are then determined.

Figure 5.6: Abrasion test apparatus

➢ Abrasion Index

An important property of interlock paving units is abrasion as they are exposed to continuous abrasion by pedestrians and/or vehicles. ASTM C 902 lists two ways in which the abrasion resistance of brick pavers can be determined. The mostly reported and used method is to calculate the abrasion index as follows:

$$Abrasion\ Index = \frac{water\ absorption}{compressive\ strength\ (psi)} x100$$

➢ Flexural Strength

The flexural strength properties of the material are determined in accordance with ASTM D790– "Standard Test Method for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials" procedure A. A bar of rectangular cross section having dimensions of 100x10x5mm rests on two supports. The support span length is 80mm. The support span shall be 16 times the depth of the beam and the specimen width shall not exceed one fourth of the support span. The specimen shall be long enough to allow for overhanging on each end of at least 10 % of the support span, but in no case less than 6.4 mm. The specimen is loaded by means of a loading nose mid-way between the supports as shown in **Figure 5.7**. A strain rate of 0.01mm/mm/min is employed. The test ends when maximum strain in the outer surface of the test specimen reach 0.05mm/mm or at break, whichever happen first. The rate of crosshead motion is determined using the following equation:

$$R=ZL^2/6d$$

Where,
R=Rate of crosshead motion, mm
L=support span, mm
d=depth of beam,mm
Z=rate of straining of the outer fiber

$R=0.01(800)^2/(6x5)=1.63mm/min$

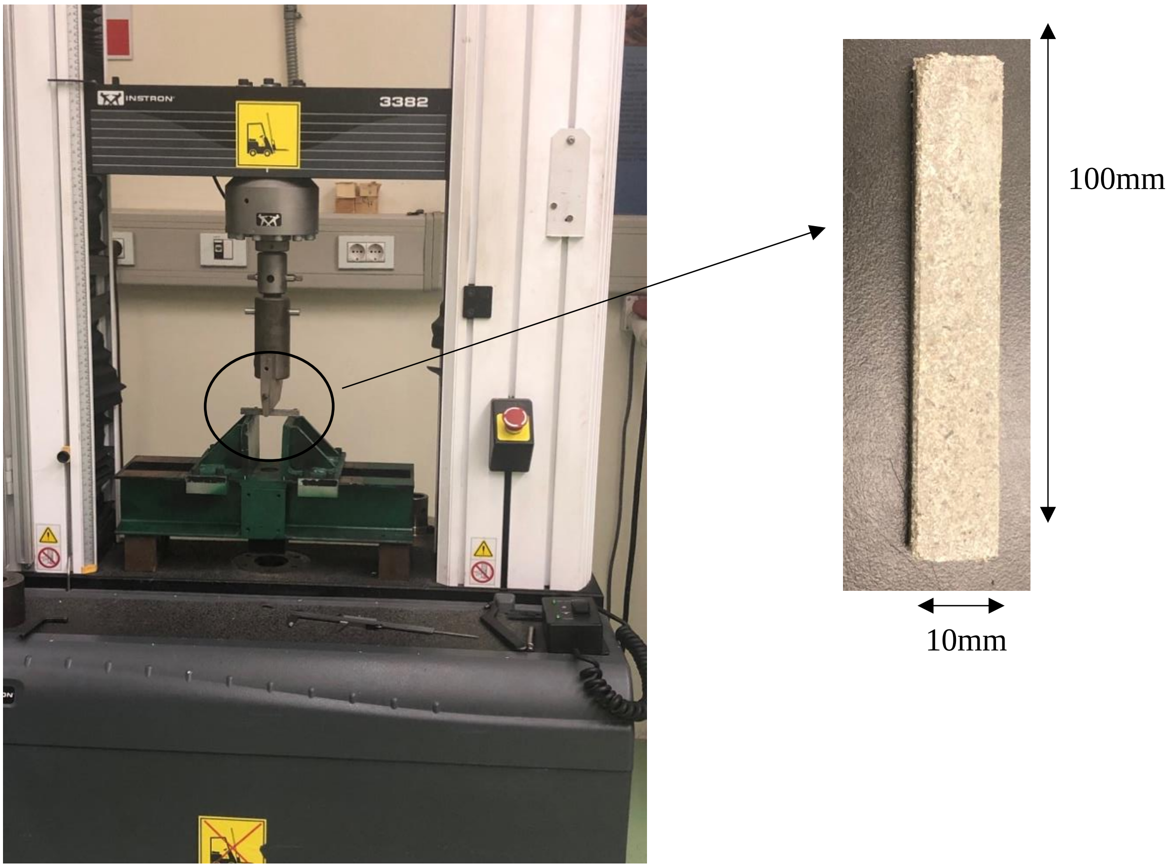


Figure 5.7: Flexural strength test apparatus

- **Density**

The weight of the specimen is recorded using a digital balance. The specimen dimensions were geometrically measured to calculate the volume. Density is then calculated by dividing the specimen's mass by its volume. The densities of three replicates were measured and the average was calculated accordingly.

- **Leachate test**

The health hazard of the investigated waste material is determined using the water leaching test DIN 38414-S4. In this test samples of 15g are immersed in 300ml of deionized water medium for 28 days. At the end of the immersion period the water is filtered using No. 50 filter paper and analyzed for the following:

- pH using a digital pH meter shown in **Figure 5.8**

Figure 5.8: Digital pH meter

- Total Suspended Solids (TSS) – glass fiber filter paper having pore size of 47mm is oven dried and then weighted using a digital balance (W_i). Then 100mL of water is poured through the filter paper. The filtered paper is oven dried for 2 hours at 105℃ to remove all water from filter. The filter paper is then weighted again (W_f). TSS can then be calculated as follows:

$$TSS = \frac{W_f(g) - W_i 9(g)}{mL\ of\ sample} x1{,}000{,}000$$

The apparatus used for measuring TSS are shown in **Figure 5.9**.

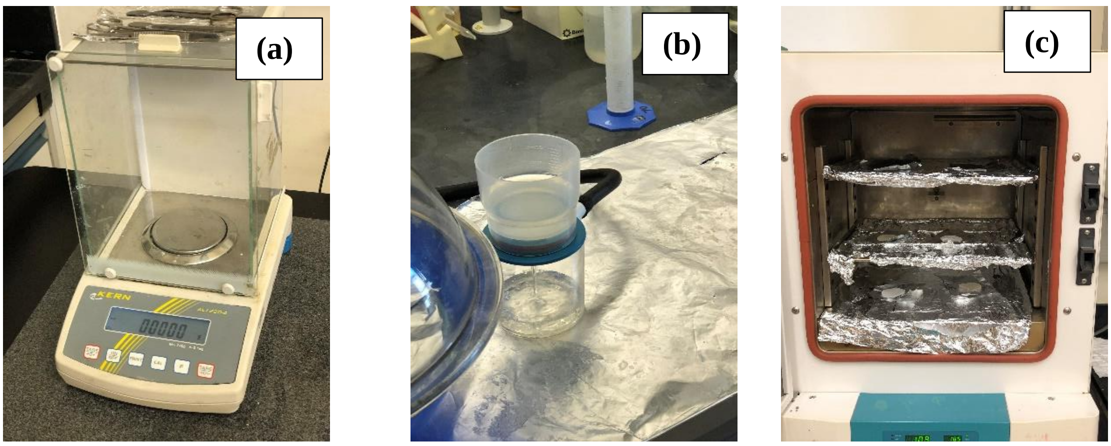


Figure 5.9: TSS measuring devices (a) digital balance, (b)filter paper, (c) oven

- Total Dissolved Solids (TDS) is measured using a TDS meter shown in **Figure 5.10**

Figure 5.10: TDS meter

- Nitrate is measured using nitrate method 8039 using Hack DR/ spectrophotometer 2000 (**Figure 5.11)**. A water sample of 25mL is placed inside the spectrophotometer as a reference. Then another sample is mixed and agitated with reagent for 1 min then left to react for 5min without agitation, which is then placed inside the spectrophotometer to take reading of nitrogen (mg/L). Then nitrate is determined by multiplying the obtained value by 4.4.

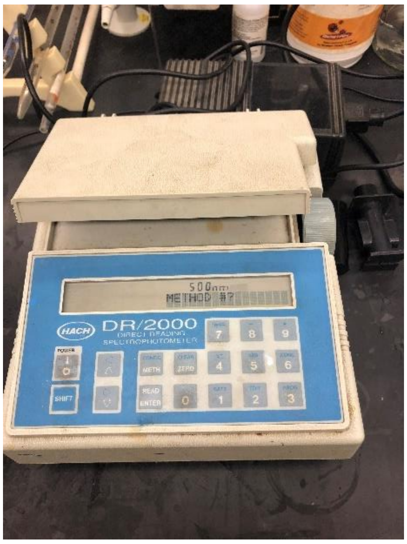


Figure 5.11: Nitrate spectrophotometer

- Chemical Oxygen Demand (COD) is determined by adding 2mL of water sample to oxidizing agent (potassium dichromate and sulfuric acid). Then the samples are placed in a reactor for 2hours at 160℃. The samples are then left to cool and a spectrophotometer shown in **Figure 5.12** is used to measure COD.

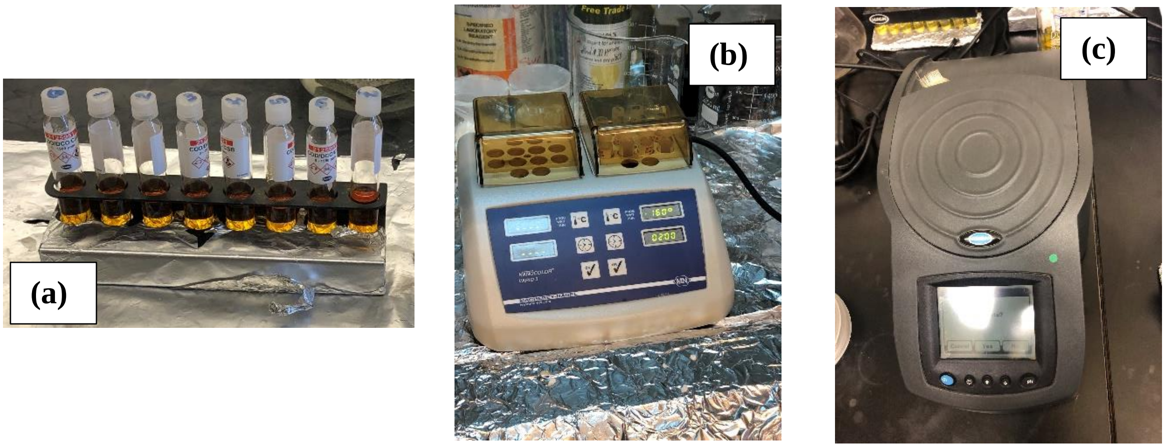


Figure 5.12: (a) water samples with reagent, (b) COD reactor, (c) Spectrophotometer

- Lead (Pb), Chromium (Cr) and cadmium (Cd) are measured suing atomic absorption spectrometer SensAA shown in **Figure 5.13**.

Figure 5.13: Atomic absorption spectrometer to measure heavy metals

5.3.3. Results and discussion

Properties of multi-layer flexible packaging and melamine-formaldehyde (MP+MF) composite

Compressive strength

The compressive strength was measured for all samples as reported in **Table 5.1**. Each sample was tested three times and average value is reported in **Table 5.1** and each sample was replicated three times. The results show that the average compressive strength of all samples range from 9.09 to 32.54MPa.

Table 5.1: Compressive strength of MP + MF composite material

Specimen No.	% MP	% MF	Temp. (°C)	Sieve No.	Compressive Strength (MPa) Replicate 1	Replicate 2	Replicate 3	Average
1M	80	20	135	No 16	7.73	9.05	10.98	9.25
2M	70	30	135	No 16	13.21	16.32	11.87	13.80
3M	60	40	135	No 16	12.23	6.34	9.02	9.20
4M	80	20	140	No 16	6.67	10.03	14.02	10.24
5M	70	30	140	No 16	10.04	13.87	18.21	14.04
6M	60	40	140	No 16	9.02	13.21	17.24	13.16
7M	80	20	145	No 16	15.3	19.81	23.08	19.40
8M	70	30	145	No 16	17.94	21.89	26.32	22.05
9M	60	40	145	No 16	13.65	18.76	23.87	18.76
10M	80	20	135	No 20	8.87	13.04	17.08	13.00
11M	70	30	135	No 20	11.34	15.03	18.87	15.08
12M	60	40	135	No 20	10.32	13.87	18.12	14.10
13M	80	20	140	No 20	16.89	22.02	24.95	21.29
14M	70	30	140	No 20	29.67	26.04	20.54	25.42
15M	60	40	140	No 20	14.87	18.84	25.32	19.68
16M	80	20	145	No 20	25.45	29.85	35.03	30.11
17M	70	30	145	No 20	28.54	32.04	37.05	32.54
18M	60	40	145	No 20	15.56	19.86	21.32	18.91
19M	80	20	135	No 40	7.7	11.13	14.74	11.19
20M	70	30	135	No 40	8.4	12.09	15.76	12.08
21M	60	40	135	No 40	5.5	9.45	12.32	9.09
22M	80	20	140	No 40	7.9	11.87	16.59	12.12
23M	70	30	140	No 40	11.34	13.89	18.65	14.63
24M	60	40	140	No 40	9.22	11.53	12.86	11.20
25M	80	20	145	No 40	13.54	17.43	19.67	16.88
26M	70	30	145	No 40	19.54	22.37	24.92	22.28
27M	60	40	145	No 40	13.44	16.98	19.04	16.49

By looking at the data it is obvious that the standard deviation (the deviation of the replicates from the mean) is quite high. This could be mainly due to the fact that the used packaging material is not from one single source (chocolate, chips packaging, etc,) and does not necessarily have the same composition.

Yet, before starting the Analysis of Variance (ANOVA), it is important to check the model adequacy. The first assumption is that the response variable residuals are normally distributed. This check is made by constructing a normal probability plot of the residuals as shown in **Figure 5.14(a)**. the normal probability plot resembles a straight line, which indicates that the normality assumption is met [189].

Also, the regression equation is fitted to the experimental values and model is considered valid only when the difference between the experimental and the calculated values (error) are uncorrelated and randomly distributed with a zero mean value and a common variance. To check these assumptions, the studendized residuals plots are constructed as shown in **Figures 5.14(b) and (c)**. These figures reveal that there are no outliers in the data and that the residuals do not follow any pattern. Therefore, the variance assumption is met [189].

The ANOVA table is presented in **Table 5.2**. P-values less than 0.05 indicate that the model terms are significant. In this case, B (Temperature), A^2 (particle size) and C^2 (%wt.) are significant model terms. The values of sum of squares indicates that temperature (B) has the highest effect on the compressive strength of the samples. In fact, the sum of squares of the temperature (B) represents 53% of the total sum of squares, followed by A^2 (32%) and C^2 (11%).

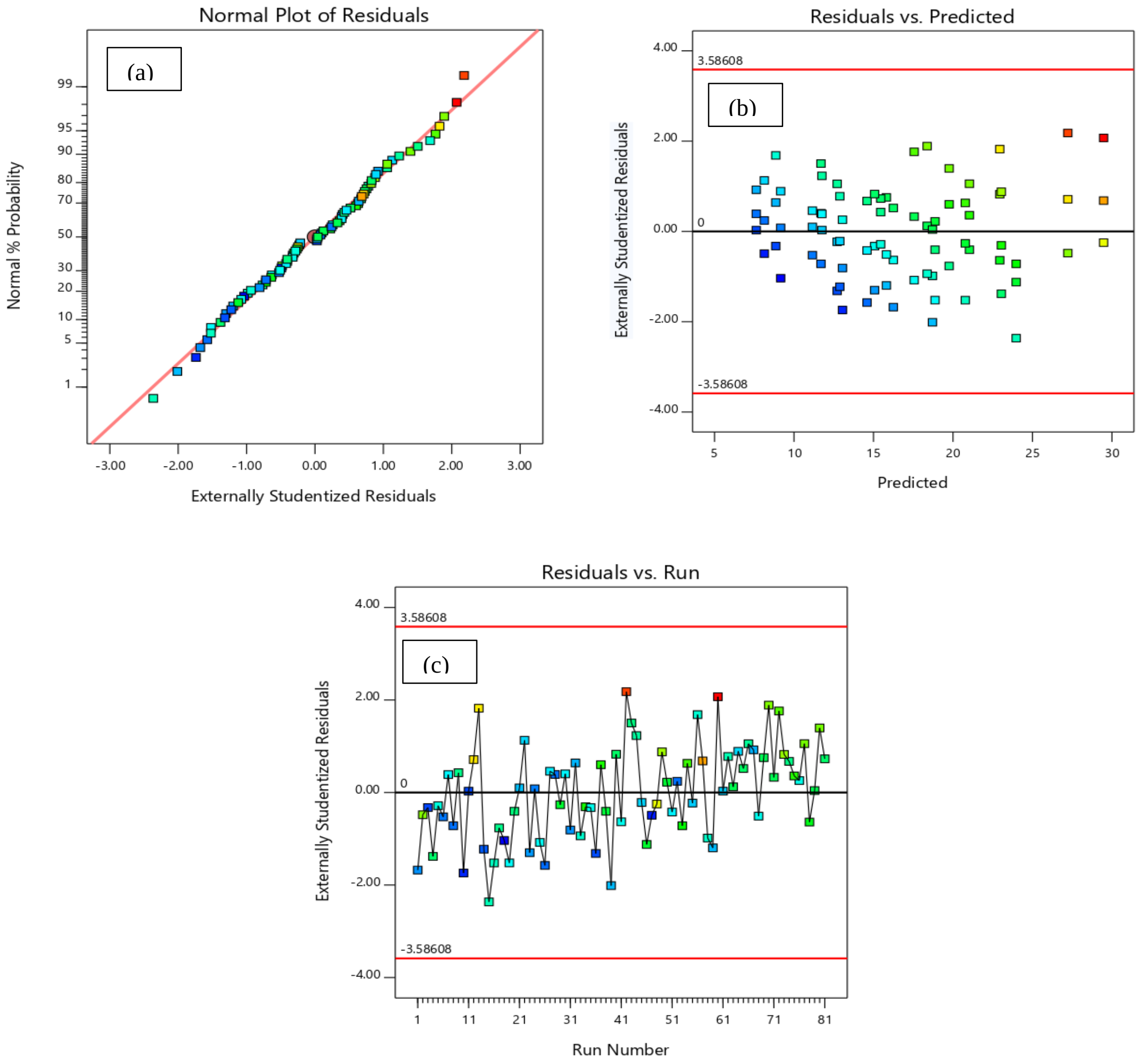


Figure 5.14: Model Adequacy checking for compressive strength response (a) normal probability plot, (b) Residuals versus predicted plots and (c) Residuals versus runs

Table 5.2: ANOVA table for compressive strength response

SOURCE	SUM OF SQUARES	DF	MEAN SQUARE	F-VALUE	P-VALUE	
MODEL	2570.92	9	285.66	17.92	< 0.0001	significant
A-PARTICLE SIZE	1.83	1	1.83	0.1147	0.7358	
B-TEMPERATURE	1354.31	1	1354.31	84.94	< 0.0001	
C-%WT.	19.76	1	19.76	1.24	0.2693	
AB	8.46	1	8.46	0.5305	0.4688	
AC	7.08	1	7.08	0.4444	0.5072	
BC	31.21	1	31.21	1.96	0.1661	
A^2	820.82	1	820.82	51.48	< 0.0001	
B^2	35.53	1	35.53	2.23	0.1399	
C^2	288.54	1	288.54	18.10	< 0.0001	
RESIDUAL	1132.00	71	15.94			
LACK OF FIT	356.11	17	20.95	1.46	0.1471	not significant
PURE ERROR	775.89	54	14.37			
COR TOTAL	3702.92	80				

Figure 5.15 shows 3D plot of the compressive strength at different particle sizes. The graphs indicate that sample M17 having 70% MP + 30% MF of sieve 20 and molded at a temperature of 145°C have the highest compressive strength of 32.54MPa.

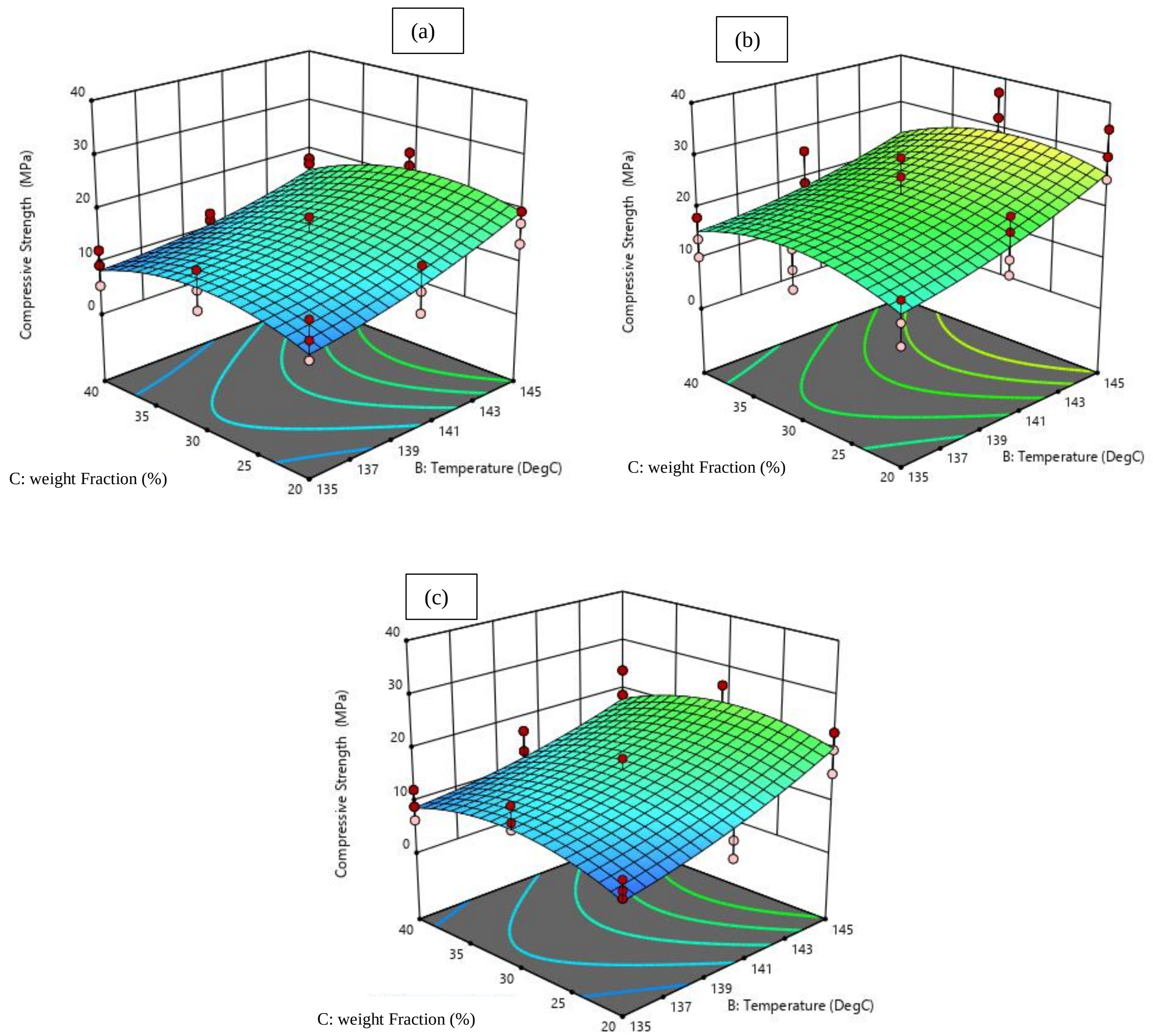


Figure 5.15: 3D plot for compressive strength response at (a) sieve 16, (b) sieve 20 and (c) sieve 40

The results reveal that highest compressive strength are achieved by increasing the temperature during compression molding. In fact, the highest compressive strength is obtained at temperature of 145°C compared to 140°C and 135°C. This is attributed to the fact that highest temperature allows the packaging material to melt more; therefore, packaging material wet the filling material more leading to better adhesion between the matrix and filling material.

The results show that there is a relationship between the compressive strength value and percentage of MF (C^2 from the ANOVA table). In fact, the compressive strength increased by increasing the percentage of MF from 20 to 30%. Many studies have reported that increasing %wt. improves the mechanical properties of the composite including compressive strength, tensile strength, fracture toughness, flexural strength etc. [190, 191, 192, 193, 194]. As MF (filling material) is harder compared to MP (matrix), adding MF to MP improves the strength of the material. This is due to increase in surface area of contact between the filler and the matrix, which allows better load transfer from matrix to particles [190]. Also, this observation agrees with the behavior experienced with filled elastomeric systems, where the filler particles reinforce the matrix by diverting the path of rupture and hence increasing the energy required to propagate a crack [5]. The highest compressive strength is observed at 30wt. % of MF. However, further increase in MF %wt. leads to a decrease in compressive strength. This could be due to poor adhesive bonding between particles and matrix [190].

Also, the results indicate that the particle size of MF has an effect on compressive strength (A^2 from ANOVA table). In fact, increasing the particle size decreases the compressive strength. Highest compressive strength values are obtained with sieve 20 compared to sieve 16 and 40. Large particle size (sieve 16-1.18mm) probably act as defects which leads to localized stress concentration. However, further decrease in particle size from sieve 20 to 40 cause a decrease in compressive strength. This suggests better dispersion and wetting characteristics associated with larger filler particles leading to stronger interfacial bonds. This could be because particles of small sizes form clusters that contain air gaps and voids and thus are weak points in the material. Also, these clusters usually contain entrapped air and it is established that strength decrease with the increase in the amount of entrapped air [195].

Design expert software compares different statistics including R-squared, adjusted Rsquared, and predicted R-squared before displaying the best fit as indicated in **Table 5.3**. The lack of fit shows that the quadratic interaction model does not display lack of fit (p-value=0.1471 > significance level). The variability in the data is relatively reduced (R^2=0.6555).

Table 5.3: Compressive Strength Response model fit statistics

Std. Dev.	3.99	**R^2**	0.6943
Mean	16.52	**Adjusted R^2**	0.6555
C.V. %	24.17	**Predicted R^2**	0.6076
		Adeq Precision	15.6229

The results show that the quadratic model can account for nearly all the variability in the response data and can, thus, be used to describe the compressive strength (Mpa) expressed as a function of compression molding temperature (°C), MF %wt. (%) and MF particle size (µm). Equation (5.1) is the final fitting equation:

$$\begin{aligned}\text{Compressive Strength} = \; & +873.02720 \\ & +0.038073 \cdot \text{Particle Size} \\ & -14.39798 \cdot \text{Temperature} \\ & +4.85416 \cdot \text{\%wt.} \\ & +0.000256 \cdot \text{Particle Size} \cdot \text{Temperature} \\ & +0.000119 \cdot \text{Particle Size} \cdot \text{\%wt.} \\ & -0.018622 \cdot \text{Temperature} \cdot \text{\%wt.} \\ & -0.000048 \cdot \text{Particle Size}^2 \\ & +0.056264 \cdot \text{Temperature}^2 \\ & -0.040050 \cdot \text{\%wt.}^2\end{aligned} \qquad \textbf{Eq. (5.1)}$$

Density

The average densities of all samples are presented in **Tables 5.4**. All samples have low densities ranging between 0.78 to 1.08 g/cm^3.

Table 5.4: Densities of MP + MF composite material

Specimen No.	% MP	% MF	Temp. (°C)	Sieve No.	Densities (g/cm^3)			
					Replicate 1	Replicate 2	Replicate 3	Average
1M	80	20	135	No 16	0.82	0.78	0.95	0.85
2M	70	30	135	No 16	0.89	0.82	1.05	0.92
3M	60	40	135	No 16	1.15	0.85	1.03	1.01
4M	80	20	140	No 16	0.83	0.92	1.13	0.96
5M	70	30	140	No 16	0.87	1.18	0.77	0.94
6M	60	40	140	No 16	0.79	1.07	1.2	1.02
7M	80	20	145	No 16	1.21	0.96	0.56	0.91
8M	70	30	145	No 16	1.08	0.76	1.16	1
9M	60	40	145	No 16	0.79	1.26	1.19	1.08
10M	80	20	135	No 20	0.72	1.08	0.63	0.81
11M	70	30	135	No 20	0.75	0.85	1.04	0.88
12M	60	40	135	No 20	1.22	0.89	1.04	1.05
13M	80	20	140	No 20	0.73	0.98	1.05	0.92
14M	70	30	140	No 20	0.88	1.21	0.64	0.91
15M	60	40	140	No 20	1.11	1.02	0.99	1.04
16M	80	20	145	No 20	0.86	0.96	1	0.94
17M	70	30	145	No 20	0.75	1.12	1.04	0.97
18M	60	40	145	No 20	1.2	0.97	1.01	1.06
19M	80	20	135	No 40	0.85	0.62	0.87	0.78
20M	70	30	135	No 40	0.75	0.92	0.91	0.86
21M	60	40	135	No 40	1.15	1.04	0.75	0.98
22M	80	20	140	No 40	0.95	0.63	0.88	0.82
23M	70	30	140	No 40	0.74	1.02	0.85	0.87
24M	60	40	140	No 40	1.16	0.89	0.98	1.01
25M	80	20	145	No 40	0.69	0.92	1.03	0.88
26M	70	30	145	No 40	1.05	0.86	0.88	0.93
27M	60	40	145	No 40	0.86	1.18	1.05	1.03

Before starting ANOVA analysis, the model adequacy is checked. The normal probability plot resembles to a straight line and the studendized residuals plots shows no outliers indicating that the normality assumption as well as variance assumption are met (**Figure 5.16**).

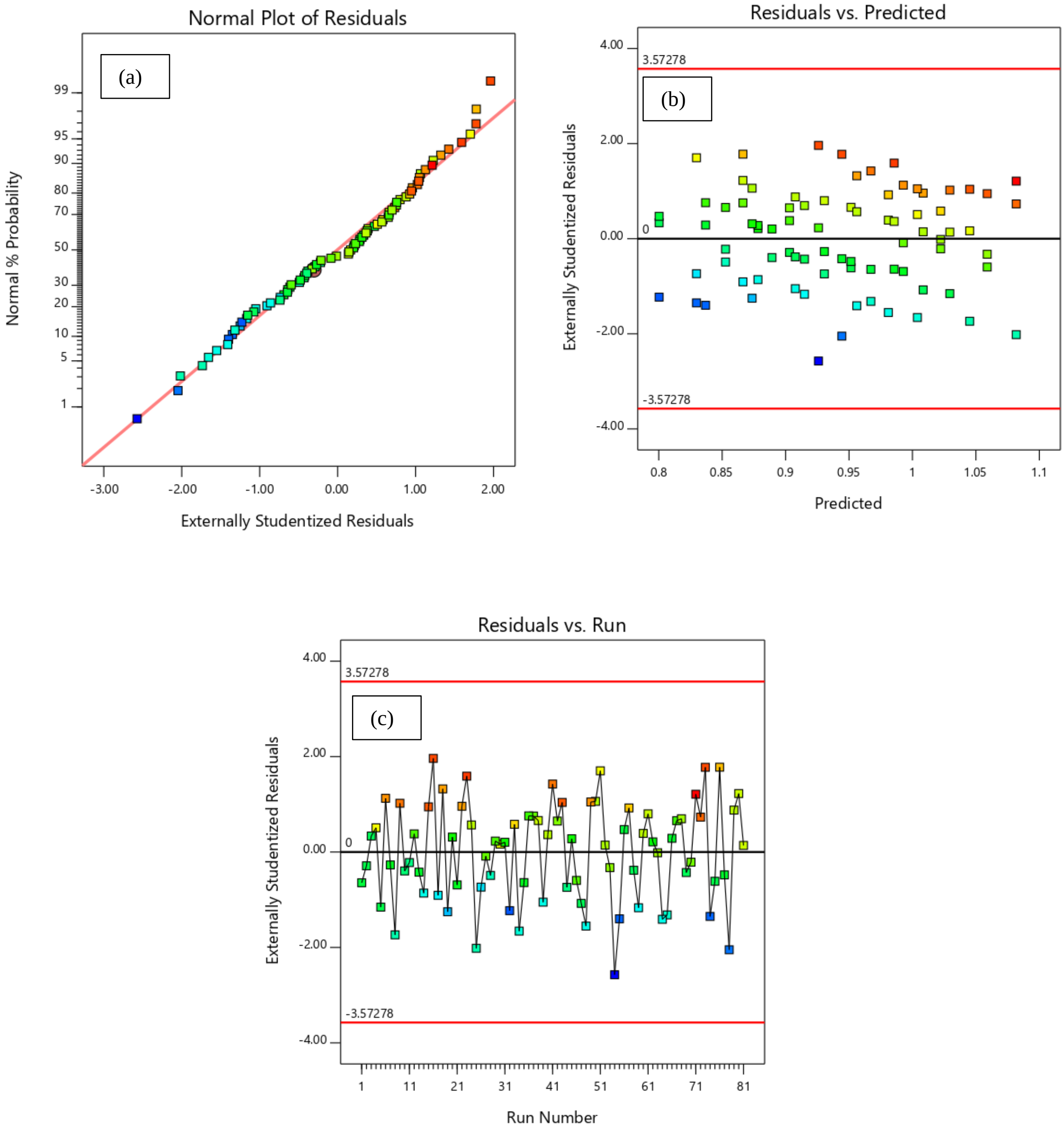


Figure 5.16: Model Adequacy checking for density response (a) normal probability plot, (b) Residuals versus predicted plots and (c) Residuals versus runs

The ANOVA table is presented in **Table 5.5**. P-values less than 0.05 indicate that the model terms are significant. In this case, C (%wt.) is the significant model term. The values of sum of squares indicates that MF % wt. has the highest effect on the density of the samples. In fact, the sum of squares of the %wt. represents 75% of the total sum of squares. This is due to the high density of MF compared to that of packaging material.

Table 5.5: ANOVA table for Density response

Source	Sum of Squares	DF	Mean Square	F-value	p-value	
Model	0.4405	3	0.1468	6.30	0.0007	significant
A-Particle Size	0.0365	1	0.0365	1.57	0.2143	
B-Temperature	0.0726	1	0.0726	3.12	0.0815	
C-%wt.	0.3277	1	0.3277	14.07	0.0003	
Residual	1.79	77	0.0233			
Lack of Fit	0.0888	23	0.0039	0.1223	1.0000	not significant
Pure Error	1.70	54	0.0316			
Cor Total	2.23	80				

The results show that the linear model can account for nearly all the variability in the response data and can, thus, be used to describe the density (g/cm^3) expressed as a function of compression molding temperature (°C), MF %wt. and MF particle size (μm). Equation (5.2) is the final fitting equation:

Density =
-0.374987
+0.000069 *Particle Size
+0.007333 *Temperature
+0.007791 *%wt.

Eq. (5.2)

Water absorption

The results also indicate that all samples have low water absorption percentages ranging from 0.32 to 9.67% (refer to **Table 5.6**).

Table 5.6: Water absorption of MP + MF composite material

Specimen No.	% MP	% MF	Temp. (°C)	Sieve No.	Water Absorption (%)			
					Replicate 1	Replicate 2	Replicate 3	Average
1M	80	20	135	No 16	4.78	7.23	10.32	7.6
2M	70	30	135	No 16	7.67	3.72	5.37	5.59
3M	60	40	135	No 16	8.96	2.32	6.3	5.8
4M	80	20	140	No 16	2.38	1.26	4.41	2.64
5M	70	30	140	No 16	0.57	3.11	1.81	1.88
6M	60	40	140	No 16	7.12	2.48	4.72	4.77
7M	80	20	145	No 16	1.19	2.43	1.97	1.87
8M	70	30	145	No 16	1.54	0.11	0.44	0.63
9M	60	40	145	No 16	2.42	1.65	3.21	2.34
10M	80	20	135	No 20	12.53	5.53	8.64	8.9
11M	70	30	135	No 20	6.68	3.76	4.76	4.99
12M	60	40	135	No 20	13.08	6.65	9.32	9.67
13M	80	20	140	No 20	1.04	2.24	0.48	1.26
14M	70	30	140	No 20	0.42	1.78	0.13	0.73
15M	60	40	140	No 20	3.78	2.03	4.65	3.42
16M	80	20	145	No 20	1.89	0.79	0.23	0.86
17M	70	30	145	No 20	0.25	0.98	0.12	0.32
18M	60	40	145	No 20	0.78	1.89	0.15	0.93
19M	80	20	135	No 40	9.43	4.13	6.57	6.71
20M	70	30	135	No 40	1.89	5.67	3.01	3.42
21M	60	40	135	No 40	11.52	5.89	8.74	8.75
22M	80	20	140	No 40	2.02	4.42	7.28	4.34
23M	70	30	140	No 40	0.25	1.03	2.12	1.08
24M	60	40	140	No 40	3.07	6.88	5.78	5.3
25M	80	20	145	No 40	0.14	0.21	1.65	0.52
26M	70	30	145	No 40	0.11	1.23	0.43	0.49
27M	60	40	145	No 40	0.62	0.76	0.69	0.69

The normal probability plot resembles to a straight line and the studendized residuals plots shows no outliers indicating that the normality assumption as well as variance assumption are met (**Figure 5.17**).

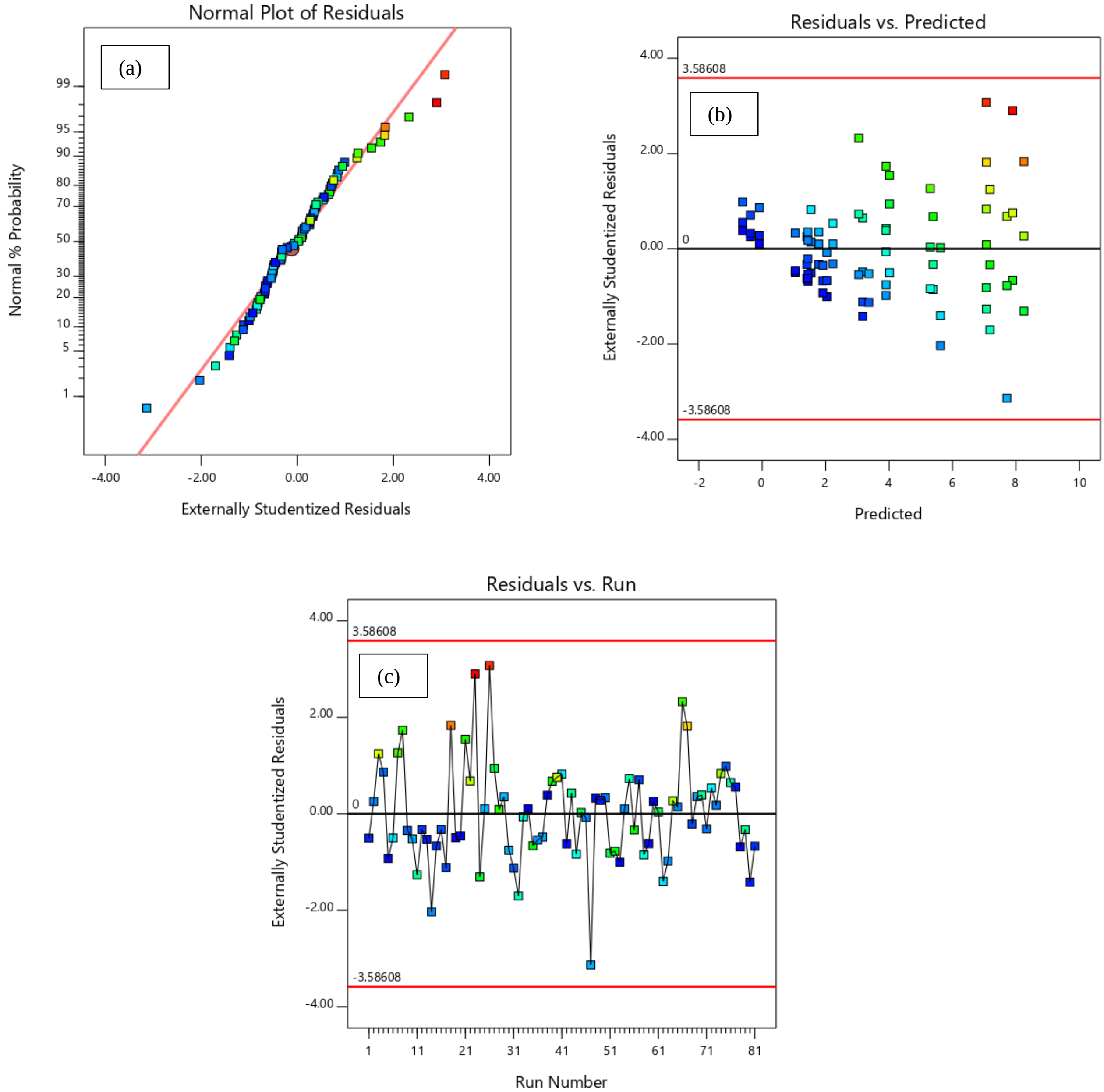


Figure 5.17: Model Adequacy checking for water absorption response (a) normal probability plot, (b) Residuals versus predicted plots and (c) Residuals versus runs

The ANOVA table is presented in **Table 5.7**. P-values less than 0.05 indicate that the model terms are significant. In this case, B (Temperature), B^2 and C^2(%wt.) are significant model terms. The values of sum of squares indicates that compression molding temperature (B) has the highest effect on the water absorption of the samples. In fact, the sum of squares of the temperature represents 80% of the total sum of squares.

Table 5.7: ANOVA table for water absorption

Source	Sum of Squares	DF	Mean Square	F-value	p-value	
Model	562.68	9	62.52	15.69	< 0.0001	significant
A-Particle Size	0.1392	1	0.1392	0.0349	0.8523	
B-Temperature	454.93	1	454.93	114.15	< 0.0001	
C-%wt.	7.73	1	7.73	1.94	0.1681	
AB	1.64	1	1.64	0.4106	0.5237	
AC	0.3977	1	0.3977	0.0998	0.7530	
BC	0.0920	1	0.0920	0.0231	0.8797	
A^2	0.0494	1	0.0494	0.0124	0.9116	
B^2	20.42	1	20.42	5.12	0.0267	
C^2	78.84	1	78.84	19.78	< 0.0001	
Residual	282.96	71	3.99			
Lack of Fit	88.64	17	5.21	1.45	0.1508	not significant
Pure Error	194.32	54	3.60			
Cor Total	845.64	80				

The results indicate that increasing the compression molding temperature leads to the decrease in water absorption. This could be because high temperature leads to samples with less defect and high compressive strength as previously discussed. The lowest water absorption percentage is obtained at temperature of 145°C, sieve 20 and % wt. of MF of 30% (sample 17M). These results are in line with compressive strength results. Some samples show higher water absorption compared to that of plastics, less than 1% **[5]**. This could be due to the presence of some sort of cavities or minor waste during the preparation of the specimen.

The results show that the quadratic model can account for nearly all the variability in the response data (R^2=0.67) and can, thus, be used to describe the density (g/cm^3) expressed as a function of compression molding temperature (°C), MF %wt. and MF particle size (µm). Equation (5.3) is the final fitting equation:

$$
\begin{aligned}
\text{Water Absorption} = \; & +944.35790 \\
& -0.015390 \, *\text{Particle Size} \\
& -12.58386 \, *\text{Temperature} \\
& -1.05409 \, *\%\text{wt.} \\
& +0.000113 \, *\text{Particle Size} * \text{Temperature} \\
& -0.000028 \, *\text{Particle Size} * \%\text{wt.} \\
& -0.001011 \, *\text{Temperature} * \%\text{wt.} \\
& +3.72365\text{E-}07 \, *\text{Particle Size}^2 \\
& +0.042652 \, *\text{Temperature}^2 \\
& +0.020935 \, *\%\text{wt}^2
\end{aligned}
\qquad \textbf{Eq. (5.3)}
$$

Flexural strength

The flexural strength was measured for all samples as reported in **Table 5.8**. Each sample was tested three times and the average values are reported in **Table 5.8** and each sample was replicated three times. The results show that the average flexural strength of all samples range from 8.41 to 18.42Mpa.

Table 5.8: Flexural Strength of MP – MF composite material

Specimen No.	% MP	% MF	Temp. (°C)	Sieve No.	Flexural Strength (Mpa)			
					Replicate 1	Replicate 2	Replicate 3	Average
1M	80	20	135	No 16	8.04	9.21	9.87	9.04
2M	70	30	135	No 16	11.38	10.16	9.78	10.44
3M	60	40	135	No 16	7.06	8.38	9.79	8.41
4M	80	20	140	No 16	8.67	9.25	12.22	10.05
5M	70	30	140	No 16	8.64	13.51	14.42	12.19
6M	60	40	140	No 16	8.18	11	11.99	10.39
7M	80	20	145	No 16	17.17	8.09	12.63	12.63
8M	70	30	145	No 16	13.58	16.87	12.76	14.40
9M	60	40	145	No 16	11.32	9.56	12.36	11.08
10M	80	20	135	No 20	8.19	11.67	9.96	9.94
11M	70	30	135	No 20	11.99	9.53	13.34	11.62
12M	60	40	135	No 20	9.63	6.7	11.69	9.34
13M	80	20	140	No 20	16.11	15.82	17.12	16.35
14M	70	30	140	No 20	18.76	16.77	15.87	17.13
15M	60	40	140	No 20	13.61	10.85	14.21	12.89
16M	80	20	145	No 20	15.76	18.86	17.34	17.32
17M	70	30	145	No 20	16.54	20.99	17.73	18.42
18M	60	40	145	No 20	15.47	11.81	14.46	13.91
19M	80	20	135	No 40	8.86	10.69	11.08	10.21
20M	70	30	135	No 40	14.83	11.56	12.19	12.86
21M	60	40	135	No 40	7.36	11.05	8.95	9.12
22M	80	20	140	No 40	7.09	9.87	11.76	9.57
23M	70	30	140	No 40	13.24	12.89	15.21	13.78
24M	60	40	140	No 40	8.23	12.45	10.07	10.25
25M	80	20	145	No 40	13.71	11.84	15.19	13.58
26M	70	30	145	No 40	11.56	12.06	14.35	12.66
27M	60	40	145	No 40	14.86	10.63	12.85	12.78

The normal probability plot resembles to a straight line and the studendized residuals plots shows no outliers indicating that the normality assumption as well as variance assumption are met (**Figure 5.18**).

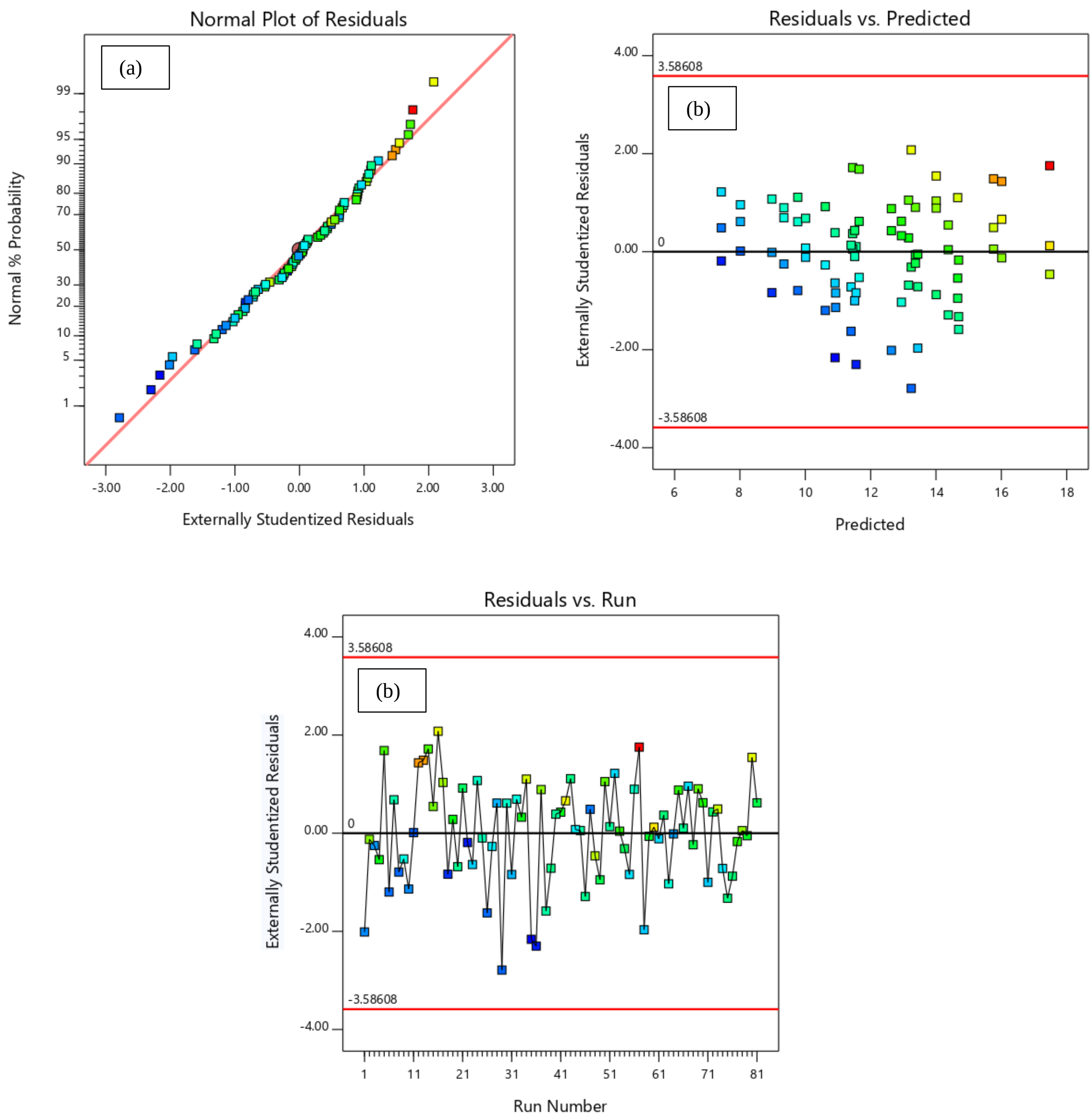


Figure 5.18: Model Adequacy checking for flexural strength response (a) normal probability plot, (b) Residuals versus predicted plots and (c) Residuals versus runs

The ANOVA table is presented in **table 5.9**. P-values less than 0.05 indicate that the model terms are significant. In this case, B (Temperature), A^2 (particle size) and C^2 (%wt.). The values of sum of squares indicates that compression molding temperature (B) has the highest effect on the flexural strength of the samples. In fact, the sum of squares of the temperature represents 44% of the total sum of squares.

Table 5.9: ANOVA table for flexural strength response

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	477.78	9	53.09	11.77	< 0.0001	significant
A-Particle Size	7.13	1	7.13	1.58	0.2128	
B-Temperature	209.97	1	209.97	46.55	< 0.0001	
C-%wt.	14.84	1	14.84	3.29	0.0739	
AB	4.51	1	4.51	0.9996	0.3208	
AC	0.1041	1	0.1041	0.0231	0.8797	
BC	2.95	1	2.95	0.6534	0.4216	
A^2	142.59	1	142.59	31.61	< 0.0001	
B^2	1.61	1	1.61	0.3567	0.5522	
C^2	94.09	1	94.09	20.86	< 0.0001	
Residual	320.24	71	4.51			
Lack of Fit	100.44	17	5.91	1.45	0.1498	not significant
Pure Error	219.81	54	4.07			
Cor Total	798.02	80				

Figure 5.19 shows 3D plot of the flexural strength at different particle sizes. The graphs indicate that sample having 70% MP + 30% MF of sieve 20 and molded at a temperature of 145°C (M17) showed the highest flexural strength of 18.42MPa.

The results indicate that low mixing temperature of 135°C leads to a decrease in flexural strength. The reason behind this could be explained the same way discussed earlier for compressive strength; higher mixing temperature results in a more homogeneous mix with fewer polymer segregates. Thus, the possibility of flaws and cracks decreases leading to an increase in flexural strength.

Also, increasing the MF content leads to a decrease in flexural strength. This decrease in the flexural strength with the increase in MF content is attributed to the stress concentrations induced by the filler particles. This stress concentration will promote failure upon load application.

It is also observed that sieve 20 results into highest flexural strength compared to sieve 16 and sieve 40. This result is in line with the results of compressive strength. In fact, large particle size of sieve 16 act as defects leading to localized stress concentration. Yet, further decrease in particle size from sieve 20 and 40 leading to the formation of filler clusters resulting into decrease in strength and modulus as discussed earlier for compressive strength.

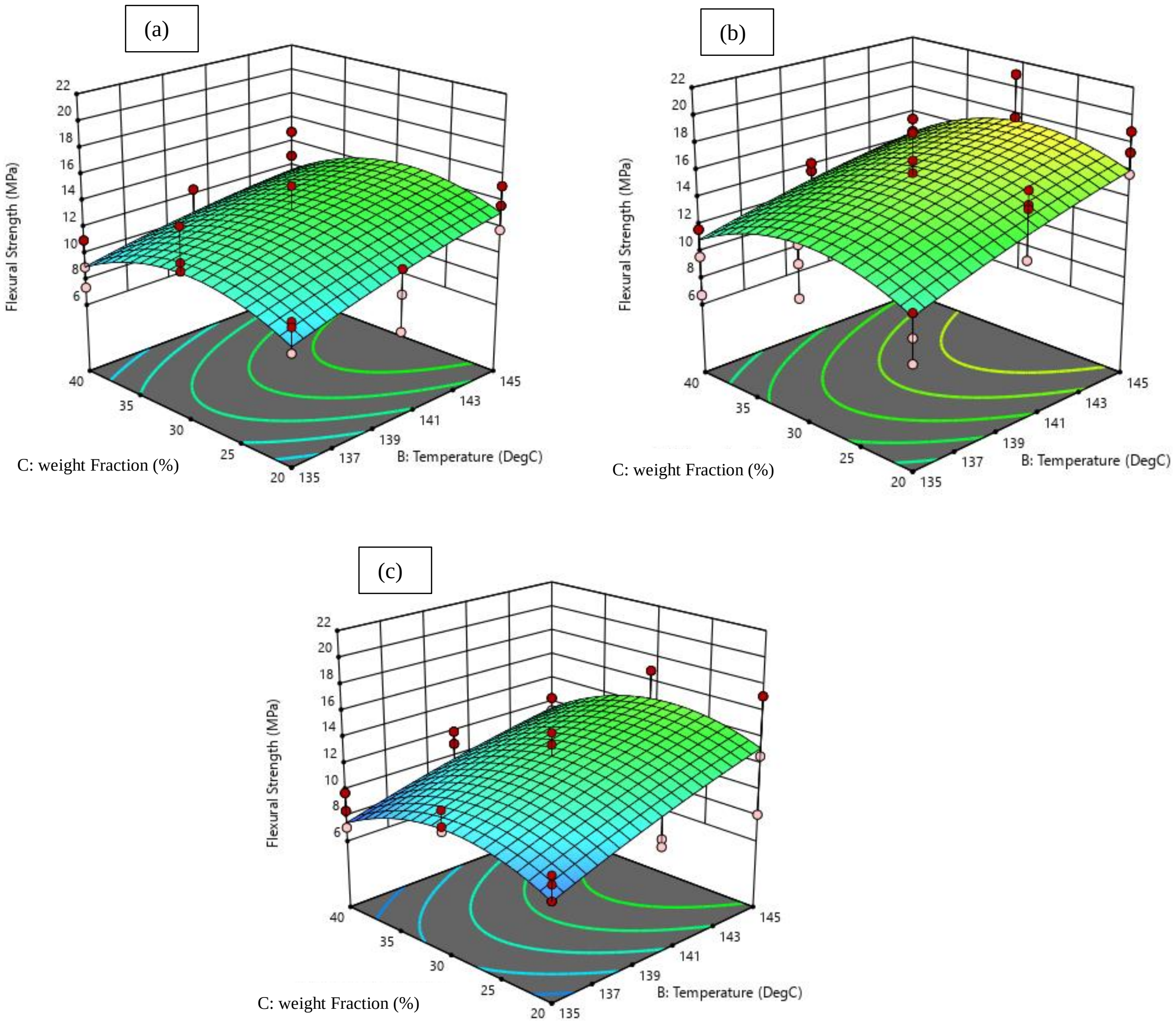


Figure 5.19: 3D plot for flexural strength response at (a) sieve 16, (b) sieve 20 and (c) sieve 40

The results show that the quadratic model can account for nearly all the variability in the response data (R^2=0.60) and can, thus, be used to describe the flexural strength (MPa) expressed as a function of compression molding temperature (°C), MF %wt. and MF particle size (µm). Equation (5.4) is the final fitting equation:

Flexural Strength =
-308.58995
+0.005375 Particle Size
+3.76907 Temperature
+2.13239 %wt.
+0.000187 Particle Size * Temperature
-0.000014 Particle Size * %wt.
-0.005722 Temperature * %wt.
-0.000020 Particle $Size^2$
-0.011973 $Temperature^2$
-0.022870 $\%wt.^2$

Eq. (5.4)

Abrasion Resistance

The abrasion resistance of all samples is measured, and results are presented in **Table 5.10**. The obtained results are intended only for comparison purposes. The lowest value is obtained for the sample molded at temperature of 145°C and containing 30 % wt. of sieve 20 MF (sample 17M). These results are in line with the compressive and flexural strength results. Low abrasion thickness losses are observed at high molding temperature, MF sieve 20 and moderate MF content. This is contributed to the fact that these conditions lead to strong adhesive bond between filling material and packaging material as discussed earlier in compressive and flexural strength.

Table 5.10: Abrasion of MP + MF composite material

Sample No.	Thickness Loss (mm)				Volume Loss (cm^3)				Weight Loss (g)			
	Rep. 1	Rep. 2	Rep. 3	Av.	Rep .1	Rep . 2	Rep . 3	Av.	Rep .1	Rep . 2	Rep . 3	Av.
1M	2.34	2.16	2.25	2.25	3.74	3.46	3.60	3.60	3.07	2.70	3.42	3.1
2M	1.52	1.35	1.36	1.41	2.43	2.16	2.18	2.26	2.16	1.77	2.28	2.1
3M	2.95	2.68	2.89	2.84	4.72	4.29	4.62	4.54	5.43	3.64	4.76	4.6
4M	1.94	1.62	1.87	1.81	3.10	2.59	2.99	2.90	2.58	2.38	3.38	2.8
5M	1.24	1.76	1.65	1.55	1.98	2.82	2.64	2.48	1.73	3.32	2.03	2.3
6M	2.15	1.85	2.63	2.21	3.44	2.96	4.21	3.54	2.72	3.17	5.05	3.6
7M	0.85	0.74	0.93	0.84	1.36	1.18	1.49	1.34	1.65	1.14	0.83	1.2
8M	0.72	0.53	0.61	0.62	1.15	0.85	0.98	0.99	1.24	0.64	1.13	1.0
9M	1.35	1.82	0.58	1.25	2.16	2.91	0.93	2.00	1.71	3.67	1.10	2.2
10M	0.27	0.43	0.23	0.31	0.43	0.69	0.37	0.50	0.31	0.74	0.23	0.4
11M	0.12	0.34	0.32	0.26	0.19	0.54	0.51	0.42	0.14	0.46	0.53	0.4
12M	0.19	0.38	0.42	0.33	0.30	0.61	0.67	0.53	0.37	0.54	0.70	0.6
13M	0.29	0.17	0.23	0.23	0.46	0.27	0.37	0.37	0.34	0.27	0.39	0.3
14M	0.23	0.08	0.14	0.15	0.37	0.13	0.22	0.24	0.32	0.15	0.14	0.2
15M	0.16	0.38	0.3	0.28	0.26	0.61	0.48	0.45	0.28	0.62	0.48	0.5
16M	0.25	0.09	0.23	0.19	0.40	0.14	0.37	0.30	0.34	0.14	0.37	0.3
17M	0.07	0.12	0.05	0.08	0.11	0.19	0.08	0.13	0.08	0.22	0.08	0.1
18M	0.18	0.34	0.2	0.24	0.29	0.54	0.32	0.38	0.35	0.53	0.32	0.4
19M	0.85	0.68	0.66	0.73	1.36	1.09	1.06	1.17	1.16	0.67	0.92	0.9
20M	0.42	0.59	0.61	0.54	0.67	0.94	0.98	0.86	0.50	0.87	0.89	0.7
21M	0.98	0.77	0.74	0.83	1.57	1.23	1.18	1.33	1.80	1.28	0.89	1.3
22M	0.49	0.63	0.47	0.53	0.78	1.01	0.75	0.85	0.74	0.64	0.66	0.7
23M	0.35	0.48	0.42	0.42	0.56	0.77	0.67	0.67	0.41	0.78	0.57	0.6
24M	0.78	0.56	0.73	0.69	1.25	0.90	1.17	1.10	1.45	0.80	1.14	1.1
25M	0.48	0.62	0.94	0.68	0.77	0.99	1.50	1.09	0.53	0.91	1.55	1.0
26M	0.38	0.75	0.64	0.59	0.61	1.20	1.02	0.94	0.64	1.03	0.90	0.9
27M	0.95	0.58	0.63	0.72	1.52	0.93	1.01	1.15	1.31	1.10	1.06	1.2

Abrasion Index

The abrasion index of all samples is calculated and presented in **Table 5.11**. The abrasion index of the samples ranges from 0.01 to 0.66. The lowest abrasion index is obtained for sample molded at temperature of 145°C and containing 30 % wt. of sieve 20 MF (17M). The results of the abrasion index are in line with results of obtained from the measured abrasion resistance.

Table 5.11: Abrasion Index of MP + MF composite material

Specimen No.	% MP	% MF	Temp. (°C)	Sieve No.	Abrasion Index
1M	80	20	135	No 16	0.57
2M	70	30	135	No 16	0.28
3M	60	40	135	No 16	0.43
4M	80	20	140	No 16	0.18
5M	70	30	140	No 16	0.09
6M	60	40	140	No 16	0.25
7M	80	20	145	No 16	0.07
8M	70	30	145	No 16	0.02
9M	60	40	145	No 16	0.09
10M	80	20	135	No 20	0.47
11M	70	30	135	No 20	0.23
12M	60	40	135	No 20	0.47
13M	80	20	140	No 20	0.04
14M	70	30	140	No 20	0.02
15M	60	40	140	No 20	0.12
16M	80	20	145	No 20	0.02
17M	70	30	145	No 20	0.01
18M	60	40	145	No 20	0.03
19M	80	20	135	No 40	0.41
20M	70	30	135	No 40	0.20
21M	60	40	135	No 40	0.66
22M	80	20	140	No 40	0.25
23M	70	30	140	No 40	0.05
24M	60	40	140	No 40	0.33
25M	80	20	145	No 40	0.02
26M	70	30	145	No 40	0.02
27M	60	40	145	No 40	0.03

Environmental Related test – leachate test

The results indicated that the highest mechanical properties are obtained from sample 17M. The sample is replicated three times and placed in deionized (DI) water for 28days and the water was analyzed. The used deionized water is also tested and also used melamine formaldehyde and packaging material are also placed in DI water and tested for comparison. The results are presented in **Table 5.12** and are compared to EPA surface water discharge criteria as well as the Egyptian law 48 for year 1982 and ministerial decree 92 for the year 2013 Required drainage standards before lifting to/or mixing with fresh surface water bodies.

The results indicate that water samples have TSS, TDS, nitrate, COD, and heavy metals lower than the ones required by EPA and the Egyptian standards. However, the water sample containing used packaging material is highly contaminated.

Table 5.12: Water Analysis results

Parameter	DI water	17M				MF	MP	EPA	Egyptian law
		R 1	R2	R 3	Average				
pH	6.9	7.59	7.34	7.55	7.49	7.83	7.38	6-9	7-8.5
TSS (mg/L)	0	0.016	0.002	0.029	0.02	--	--	--	500
TDS (mg/L)	1.8	241	245.6	256	247.53	62.9	339	--	--
Nitrate (mg/L)	4.4	8.36	6.6	7.56	7.51	7.48	--	10	Less than 45
COD	0	14	13	14	13.67	1071	--	200	Less than 15
Cadmium (mg/L)	0	0.000	0.005	0.000	0.000	0.014	--	0.04	Less than 0.01
Chromium (mg/L)	0	0.000	0.000	0.000	0.000	0.000	--	0.57	Less than 0.01
Lead (mg/L)	0	0.000	0.000	0.000	0.000	0.000	--	0.21	--

Figure 5.20 shows the color of the water samples after immersing samples for 28 days. The color of the water is still transparent. However, the color of the water samples having packaging material turned into black and rotten food is formed at the surface of water. All of these made it difficult to test the sample especially in spectrophotometer processes. In other words, the samples will not leachate contaminated water to the ground water compared to the packaging material if left in the streets.

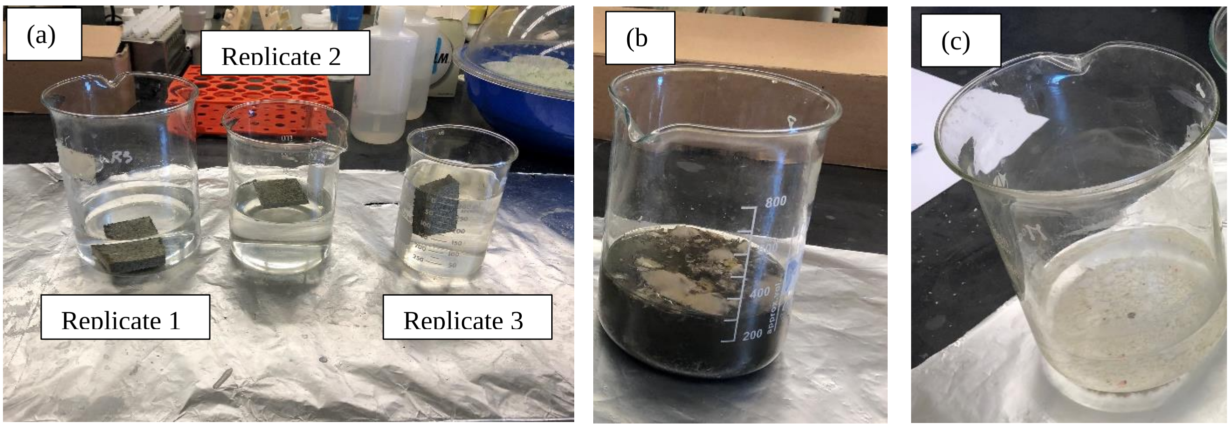


Figure 5.20: Water samples of (a) three replicates of 17M, (b) packaging material, (c) melamine formaldehyde

The results indicate that water samples are within required EPA and Egyptian law limits for discharged on surface water.

Conclusion of MP+MF composite experiment

A full design of experiment was conducted to study the effect of different compression molding parameters (temperature, %wt. fraction of filling and particle size of filling material. The results indicated that highest mechanical properties are obtained using molding temperature of 145°C, sieve 20 and 30%wt.

Recycling of alternative rejects

Based on the results obtained with MP+MF composite material, the best results are obtained using molding temperature of 145°C, sieve 20 and 30%wt. fraction of MF. These conditions are used to produce other composite materials as follows:

- Multi-layer Packaging material (MP)+EPDM rubber – in this experiment MF is substituted with EPDM rubber
- Multi-layer Packaging material (MP)+Sand – in this experiment MF is substituted with sand
- Waste Plastic bags (PB)+ Melamine formaldehyde (MF) – in this experiment MP is substituted with waste plastic bags

Table 5.13 summarizes the results for the three composites listed above. The values presented in the table are average of three replicates.

Table 5.13: Summary of the mechanical properties of the three produced composite materials

Test	70%MP+30%EPDM	70%MP+30%Sand	70PB+30%MF
Compressive strength (MPa)	24.85	27.84	21.23
Flexural Strength (MPa)	16.27	17.47	14.31
Water Absorption (%)	0.37	0.41	0.39
Density (g/cm^3)	0.75	0.92	0.65
Abrasion			
Thickness loss (mm)	0.15	0.24	0.32
Volume loss (cm^3)	0.24	0.38	0.41
Weight loss (g)	0.2	0.4	0.6
Abrasion Index	0.010	0.010	0.013

The results indicate that the properties of the material produced are very close to the ones obtained with 70%MP+30%MF. The flexural and compressive strength of material containing packaging material are found to be higher than that using plastic bags and MP contains a percentage of aluminum that gives higher mechanical performances compared to plastic. Also, using MF gives higher strength compared to using sand and EPDM rubber as MF has higher strength compared to the two other types of filling material.

5.3.4. Possible Application

One possible application of produced composite material is interlock paving units. Roads in many rural villages in developing countries like Egypt are left unpaved. These causes several problems throughout the year. During winter and rainy season, the roads become waterlogged and impassible. During the dry season, dust raised by wheels of passing vehicles becomes a major environmental and health hazard [196]. Even paved areas are seldom properly designed causing same problems. One way to eliminate these problems is to use paving blocks (pavers). This has been introduced in Egypt in footpaths, parking areas and now being adopted extensively in different uses where the conventional construction of pavement using bituminous mix or cement concrete is not feasible or desirable. Many codes and standard sallow the use of recycled material in the interlock production [197]. Several researchers have studied the use of waste materials in concrete such as coal, fly ash, plastic waste, industrial waste fiber, rubber pads, marbles etc. The use of recycled material allows to reduce the cost of final product as well as conserve natural resources. According to ASTM standards there are two major classifications of interlocks (1) Pedestrian and Light Traffic Paving Brick (ASTM C902) and (2) Heavy Vehicular Paving Brick each one has several sub-classifications (ASTM C1272). This research focuses on Pedestrian and Light Traffic Paving Brick, which can be sub-divided into other classifications based on the type of weather and traffic as follows:

- Weather:
    - SX – Brick that maybe frozen while saturated with water
    - MX – Brick intended for exterior with no freezing conditions
    - NX – Brick intended for interior use with no freezing conditions
- Traffic:
    - Type I – Pavers subjected to extensive abrasion, such as public sidewalks and driveways
    - Type II – Pavers subjected to intermediate abrasion, such as residential walkways and residential driveways
    - Type III – Pavers subjected to low abrasion, such as floors or patios in single family Homes

According to ASTM specification C902 -15 – Standard Specification for Pedestrian and Light Traffic Paving Brick – the acceptable properties for interlocks are summarized in **Table 5.14** and **5.15**.

Table 5.14: Properties of Light Traffic Paving Units based on ASTM C902

Type	Min. Compressive Strength (MPa)	Water absorption (%)
SX	55.2	8
MX	20.7	14
NX	20.7	No limits

Table 5.15: Abrasion index of Light Traffic Paving Units based on ASTM C902

Type	Max. Abrasion Index
Type I	0.11
Type II	0.25
Type III	0.5

As illustrated in **Figure 5.21** and based on compressive strength results, several mixes could be used to make Type MX and NX paving units (20.7MPa). In fact, samples produced with MF wt. of 30% at molding temperature of 145°C all three particle sizes (8M,14M,17M, 26M) have compressive strength higher than 20.7MPa as well as mixes 13 and 16.

Also, the maximum required water absorption by ASTM C902 is 8% for type SX and 14% for type MX. It is clear from **Figure 5.22** that all samples satisfy the standard requirement for type MX. Most of the samples also satisfies the standard requirements for type SX except sampled 10M, 12M and 21M those having 40% of MF and/or produced at temperature of 135°C.

According to ASTM C 902, in addition to the classification based on weather, there are three classes of pavers based on the type of traffic to use the roads. Type I pavers are appropriate for areas receiving extensive abrasion, such as commercial driveways and entrances and requires an abrasion index of 0.11. Type II pavers are intended for walkways and floors in restaurants and stores and requires an abrasion index of 0.25. Type III pavers are used for residential floors and patios and requires an abrasion index of 0.5. As illustrated in **Figure 5.23**, all samples made using temperature of 140°C and 145°C and sieve 20 (samples from 13M to 18M) satisfies the requirements for the three types of paving units.

Hence, from the above discussion it could be concluded that the sample molded at temperature of 145°C and containing 30 % wt. of sieve 20 MF (17M) could be used to produce MX and NX types of Light Traffic Paving units with highest mechanical properties.

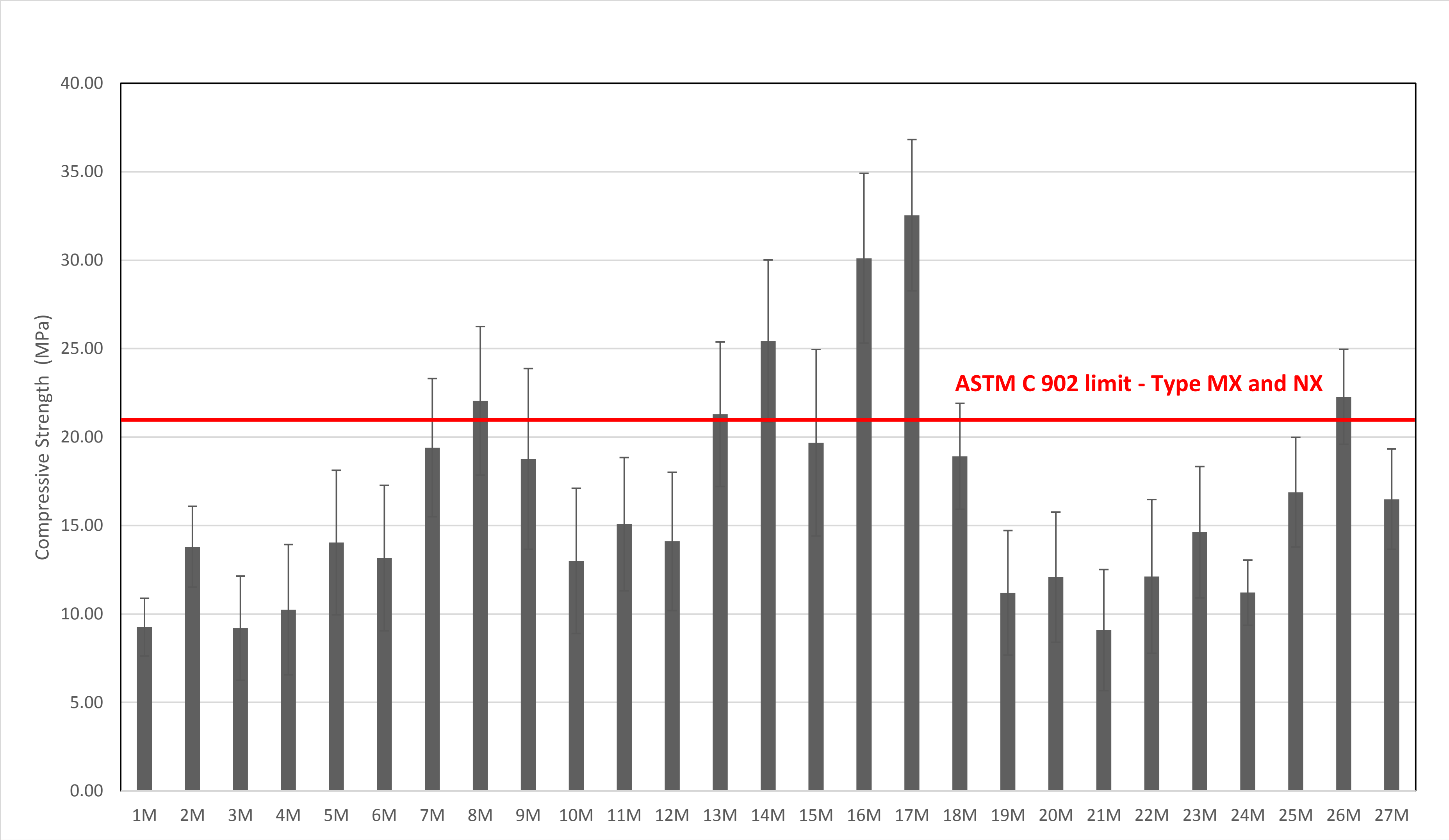


Figure 5.21: Compressive Strength of MP – MF composite material

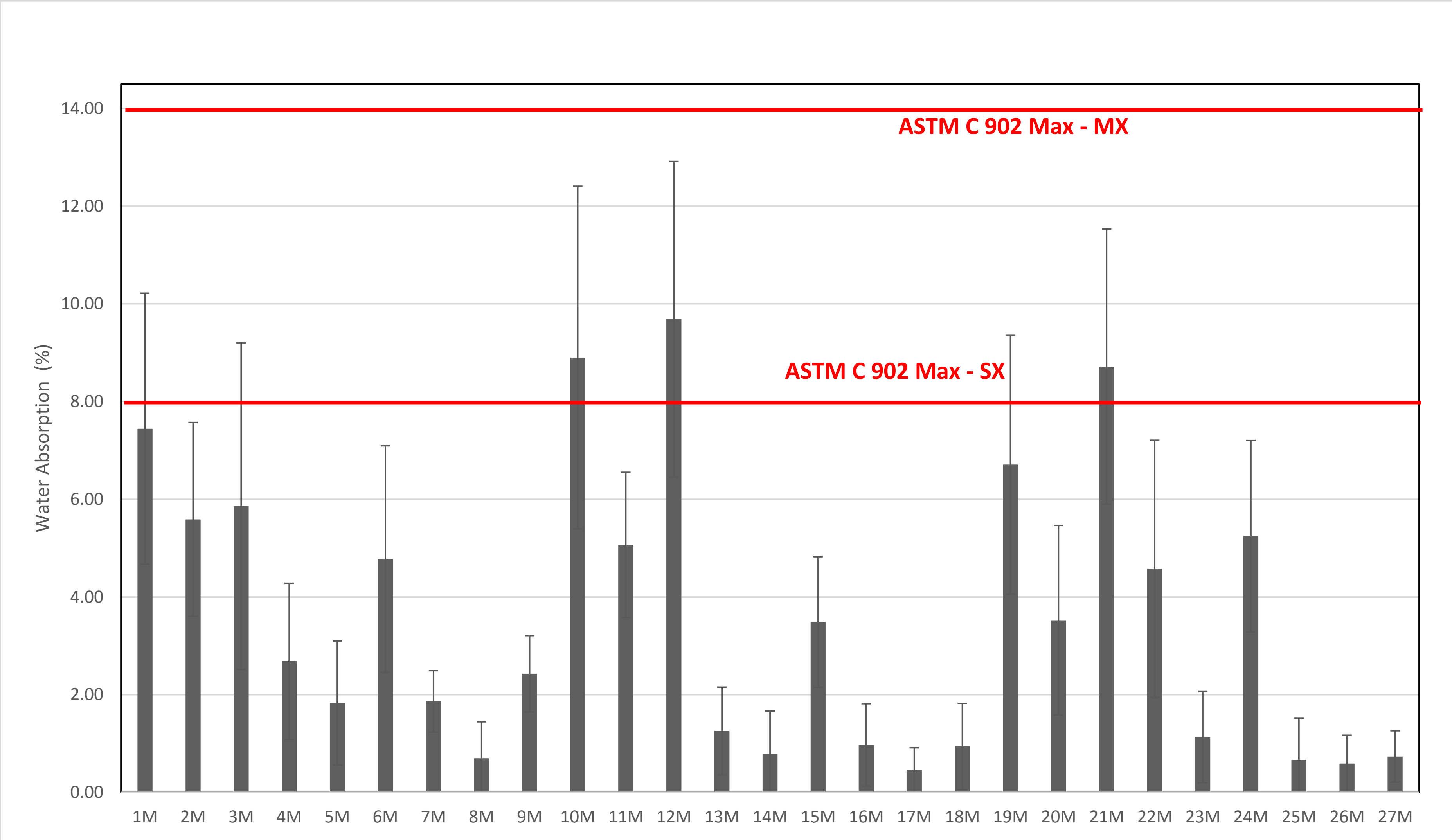


Figure 5.22: Water absorption of MP – MF composite material

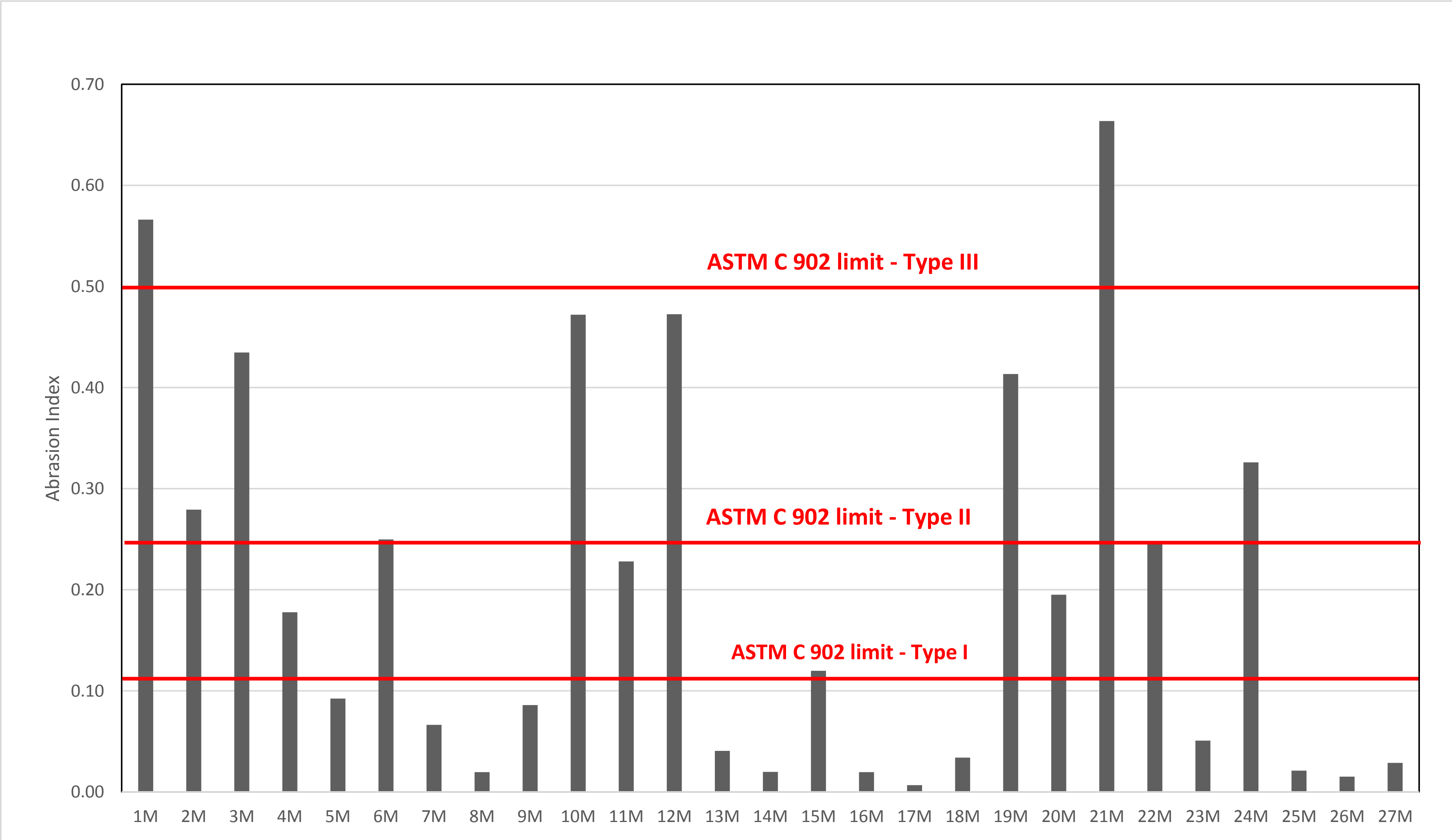


Figure 5.23: Abrasion Index of MP – MF composite material

5.3.5. *Cost Analysis*

Table 5.16 summarizes the price of items used to produce the products out of rejects. From the experimental analysis, it was concluded that the sample molded at temperature of 145°C and containing 30 % wt. of sieve 20 melamine-formaldehyde and 70% packaging material could be used to produce MX and NX types of Light Traffic Paving Units as well as replace fiber cement board with highest mechanical properties. As **Table 5.10** indicates the price of produced sample is 1.2LE per sample, which means that the cost of the new material is 120LE/m^2 compared to 150LE/m^2 of commercially available interlocks. It is obvious that making one interlock unit at a time is not economical. Thus, it is suggested to have a large mold having dimension of 1000x1000mm and that is divided into the preferred shape of interlocks required. By doing that, several interlock units can be produced at a time. This will decrease the cost of the produced interlock unit from 120LE/m^2 to 1.2LE/m^2.

Table 5.16: Cost calculation and comparison with commercial prices

Cost of process				
Process	**Power (kW)**	**Time of process (min)**	**Cost of energy (LE/kW)**	**Cost of Energy LE per sample**
Shredding	1.5	4	1.6	0.16
Mixing	1	2	1.6	0.05
Compression molding	7.5	1	1.6	0.2
Heating	0.3	30	1.6	0.24
Cost of Equipment				
Equipment	Market price	Expected Useful Life	No. of samples per day	Cost of equipment LE/sample
Mold	500	5	16	0.025
Heater	150	5	16	0.007
Hydraulic press (50ton)	50,000	25	16	0.5
Cost of one sample (100x100mm)				**1.2 LE**
Cost of new composite material if mold is (100x100mm)				**120LE/m^2**
Cost of new material if mold is (1000x1000mm)				**1.2LE/m^2**
Market price of interlock				**150LE/m^2**

5.3.6. Conclusion

Compression molding technique is used to produce the composite material from waste multi-layer packaging material as the matrix and melamine-formaldehyde as the filling material. In compression molding, the sample is subject to 50bar pressure and heat for 30min. The effect of the following three factors are examined: (1) temperature, (2) %wt. of filling material, and (3) particle size of filling material. Pilot experiments are conducted first to determine the different levels that will be tested for each factors. The pilot experiments indicated that good samples are obtained using volume fraction ranging from 20% to 40% of filling material, heating temperature ranging from 135 to 145℃, and particle size ranging from sieve 16 to sieve 40. Three levels for each factor are determined and a full design of experiment is conducted. Hence, 27 combinations are tested, and each combination is replicated 3 times. For higher accuracy samples are produced at random order using Design Expert software. The following tests are conducted on all 81 samples: compressive strength, moisture absorption, abrasion resistance, flexural strength and density. Also, abrasion index of all samples is calculated from water absorption and compressive strength values. Finally, leachate test is conducted to make sure that the produced material can be safely used without adverse effect on the environment.

The experimental results indicated that compression molding temperature has the highest significant effect on the compressive and flexural strength of the samples. The results reveal that highest compressive and flexural strength are achieved by increasing the temperature during compression molding. This is attributed to the fact that highest temperature allows the packaging material to melt more; therefore, packaging material wet the filling material more leading to better adhesion between the matrix and filling material. The results show that the compressive strength as well as the flexural strength can be described by a quadratic model expressed as a function of compression molding temperature (°C), MF %wt., and MF particle size (µm). Also, the results reveal that all samples have low densities, low water absorption properties and high abrasion resistance.

The experimental results indicate that the highest mechanical properties are obtained in samples produced using molding temperature of 145°C, melamine-formaldehyde having a particle size of sieve 20 and 30%wt. fraction of melamine-formaldehyde. In fact, the produced material is found to have compressive strength of 32.54MPa, flexural strength of 18.42MPa, water absorption of 0.32%, density of 0.97g/cm^3 and abrasion index of 0.01. The resulting product is found to be competitive to commercial MX and NX types of Light Traffic Paving Units in terms of cost and mechanical performance. In fact, the cost of produced material is 1.2LE/m^2 compared to 150LE/m^2 for interlock market price.

Also, substituting melamine-formaldehyde with other filling material like EPDM rubber waste or sand and substituting the packaging material with plastic bags waste showed to produce material slightly lower mechanical properties but can still be a competitive substitute to produce interlocks and substitute cement board.

The application of Waste to Business (W_2B) model introduced in chapter 3, in recycling of rejects to produce marketable products are beneficial for the rural communities not only from an economic point of view, but also will allow rural areas to convert the piles of unrecyclable waste – piling up in streets, waterways and dumpsites and causing environmental and health problem – into paving units that give aesthetic views to rural villages.

5.4. Development of innovative cold technology to produce bricks from rejects

4.5.1. Methodology

Materials

Four types of waste rejects are used in this experiment:

- Contaminated plastic bags waste

- Melamine-formaldehyde (MF) – Old plates made of MF are collected, cleaned and crushed into powder
- Waste Marble powder (WMP)
- Sand

Traditional cement bricks are made of cement, sand, gravel and other fine and coarse aggregates. Then water is added to activate the cement which is the element responsible for binding the mix together to form one solid object. Several studies have been conducted to study the effect of replacing cement or sand with waste material.

Some studies have been conducted to partially replace cement with marble powder or substitute limestone in cement. During the production of marble studies indicated that 25% of the original marble mass is lost in the form of powder, which causes many environmental problems if not disposed of properly.

Sharma *et al.* [198], studied the effect of partially replacing sand with waste marble powder and reported that adding waste marble powder with up to 5% by weight of sand increases the strength properties of the brick. Vigneshpandian *et al.* [199], studied replacing cement with waste marble powder with different proportions (25%, 50% and 100%) of the weight of cement. The study revealed that optimum replacement rate by marble powder to sand in concrete was 50%. Several other studies have been conducted and showed that marble powder can be used as a replacement material for cement. These studies revealed that adding 10% marble powder with cement gives high strength to the material compared to the control concrete [200].

Very few studies reported the effect of partially replacing cement with waste plastics. Kumar and Gomathi [201], studied the effect of mixing high-density polyethylene (HDPE) and polyethylene (PE) plastic bottles and bags with sand, lime, fly ash and gypsum to produce a brick. The test results showed that the partial replacement of natural sand by crushed waste plastics at the levels of 5 to 10% has good effects on compressive strength of the bricks and reduced the weight of the brick. Other studies have been done to study the effect of other types of plastic waste in concrete and construction material like polyethylene terephthalate (PET), glass fiber reinforced plastic, polyurethane (PUR) foam, polycarbonate (PC), polyvinyl chloride (PVC) [202, 203, 204, 205].

However, very few studies have been reported on the recycling of thermosetting plastic waste in lightweight concrete [23]. Thus, it would be very interesting to recycle thermosetting plastic waste to produce cement composites, which might be one of the best solutions for disposing of rejects of economic advantages and environmentally friendly methods.

In this study contaminated plastic bags waste are used as coarse aggregates and marble powder and MF are used as fine aggregate. **Table 5.17** summarizes the particle sizes distribution by mass of each material:

Table 5.17: Particle gradation by mass

Sieve	Particle size (mm)	Plastic bags	MF	Marble Powder
10	2	69.3%	-	-
12	1.7	17.3%	5.9%	-
16	1.18	13.4%	14.7%	-
170	0.090	-	79.4%	100%

Experimental Procedure

MF and plastic bags are shredded into small pieces using a shredding machine. **Figure 5.24** summarizes the steps of the proposed cold technology. The mixture of material is mixed and poured inside a mold having dimensions of 25cmx12cmx6cm and pressed using a manual pressing machine to take the shape of the mold. Then the brick is left to cure at ambient conditions for 28days, water is added to the bricks every day for the material to cure.

Table 5.18 summarizes different mixes produced.

Table 5.18: Mixes used in cold technology

Mix No.	Cement	Plastic bags	Sand	Marble Powder	MF	Cement to water ratio
M1	25	30	15	25	5	0.5
M2	20	30	15	30	5	0.5
M3	25	30	15	15	15	0.5
M4	20	30	15	20	15	0.5
M5	25	30	15	20	10	0.5
M6	20	30	15	25	10	0.5

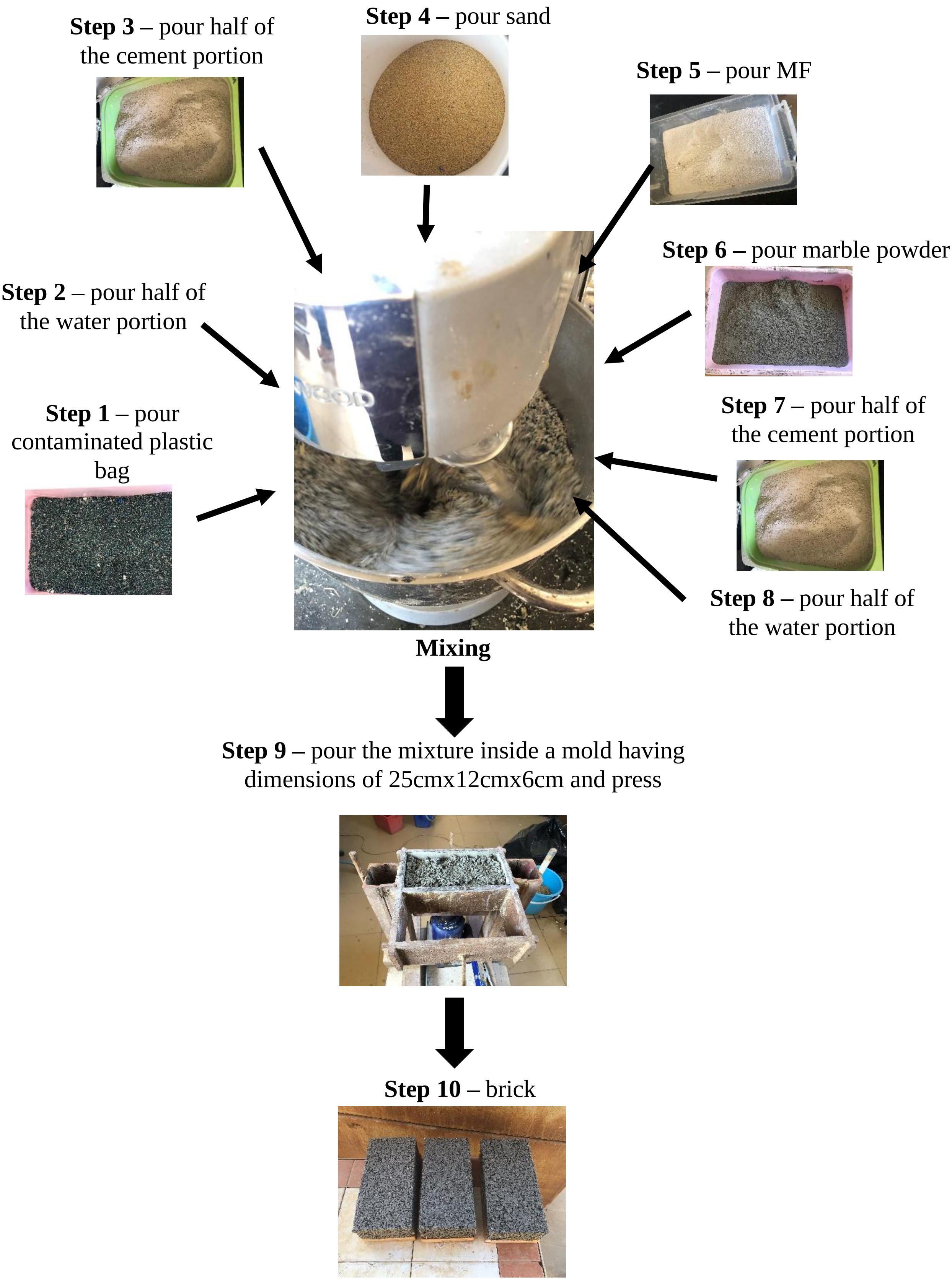


Figure 5. 24: Summary of recycling of rejects using cold technology

Statistical Analysis

All results were presented as the average of three replicates, and the means among different treatments were compared using one-way ANOVA using SPPS version 23. The null hypothesis states that the population means are all equal. A significance level α =0.05 is used.

4.5.2. Measured Properties

Compressive Strength

The compression machine (**Figure 5.25**) is used to measure the compressive strength of the bricks. The compressive strength of bricks is measured according to ASTM standard test method C140 "Sampling and Testing Concrete Masonry Units". The surface of the sample is cleaned and leveled, then the sample is placed in the machine and the gate of the machine is closed. The machine record automatically the load at which the brick fails in kilo Newton (kN). The compressive strength of the sample is calculated using the following equation:

Figure 5.25: Compression Machine

Water Absorption Test

The absorption test is conducted on all bricks after they cured for 28 days. This test is conducted to amount of moisture absorbed if the brick is subject to extreme conditions. The bricks are first oven dried at 110℃ for 24 hours and their weight are recorded as W_d. The samples are then immersed in water for 24 hours in a way that the top of the sample is below water level by 150mm as shown in **Figure 5.26**. Finally, the samples are removed from water and dried using a dry cloth and are weighted and the weights are recorded as W_s.

The percentage of water absorption is determined using the following equation:

$$Water\ absorption = \frac{W_s - W_d}{W_d} x100$$

Figure 5.26: Water Absorption test

Density

The weight of the specimen is recorded using a digital balance. Density is calculated by dividing the specimen's mass by its volume. The densities of the three replicates of the six mixes are calculated and the average was calculated accordingly.

4.5.3. Results and Discussion

Compressive Strength

Different mixtures of concrete, marble powder, melamine formaldehyde, sand and contaminated plastic bags are molded and left to dry. The compression test was conducted on the mixes after 7 days, 14 days and 28 days to study the effect of time on compressive strength. Each mix is replicated three times and the results are shown in **Table 5.19** and **Figure 5.27**.

Table 5.19: Compressive strength of different bricks

Mix No.	Compression Load (kN)				Compressive Strength (MPa)			
After 7days								
	R1	**R2**	**R3**	**Mean**	**R1**	**R2**	**R3**	**Mean**
M1	52.3	51.9	52.8	52.3	1.74	1.73	1.76	1.74
M2	46.4	46.8	45.9	46.4	1.55	1.56	1.53	1.55
M3	56.7	56.1	56.5	56.4	1.89	1.87	1.88	1.88
M4	48.3	47.8	48.6	48.2	1.61	1.59	1.62	1.61
M5	54.3	54.7	54.2	54.4	1.81	1.82	1.81	1.81
M6	49.2	48.7	48.4	48.8	1.64	1.62	1.61	1.63
After 14days								
Mix No.	**Compression Load (kN)**				**Compressive Strength (MPa)**			
	R1	**R2**	**R3**	**Mean**	**R1**	**R2**	**R3**	**Mean**
M1	73.8	74.7	74.4	74.3	2.46	2.49	2.48	2.48
M2	67.9	68.5	68.7	68.4	2.26	2.28	2.29	2.28
M3	76.5	77.5	79.6	77.9	2.55	2.58	2.65	2.60
M4	69.2	69.6	71.1	70.0	2.31	2.32	2.37	2.33
M5	75.6	74.8	75.2	75.2	2.52	2.49	2.51	2.51
M6	71.9	71.3	71.4	71.5	2.40	2.38	2.38	2.38
After 28days								
Mix No.	**Compression Load (kN)**				**Compressive Strength (MPa)**			
	R1	**R2**	**R3**	**Mean**	**R1**	**R2**	**R3**	**Mean**
M1	123.6	123.9	124.3	123.9	4.12	4.13	4.14	4.13
M2	96.5	102.1	98.5	99	3.22	3.40	3.28	3.30
M3	125.3	125.7	124.9	125.3	4.18	4.19	4.16	4.18
M4	102.5	99.2	98.7	100.1	3.42	3.31	3.29	3.34
M5	124.2	124.9	125.3	124.8	4.14	4.16	4.18	4.16
M6	120.9	121.3	121.6	121.3	4.03	4.04	4.05	4.04

The results in **Table 5.19** indicate that the compressive strength of the bricks increase until 28 days. The highest compressive strength is obtained in M3 containing 25% cement, 15% sand, 15% marble powder, 15% MF and 30% contaminated plastic bags.

One-way ANOVA has been conducted and the results are presented in **Table 5.20**. The results indicate that the p-value is less than 0.05, which means that there is a significant difference between the compressive strength of each mix.

Table 5.20: One Way ANOVA for Compressive Strength

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2.639	5	.528	224.036	.000
Within Groups	.028	12	.002		
Total	2.667	17			

However, the one-way ANOVA alone cannot tell which means are significantly different from each other and which are not. In order to compare the means of every mix to the mean of every other mix the Tukey's honest significance test has been conducted and the results are presented in **Table 5.21**.

The first comparison is made between M1 and M2 where all ingredients are fixed except cement and marble powder content in M1 cement is 25% and marble powder in 25% compared to M2 where cement is 20% and marble powder is 30%. The Tukey test indicates that the means of M1 and M2 are significantly different as p value is 0.000 <0.05. In other words, it is with 95% confidence that the mean compressive strength of M2 is lower than mean compressive strength of M1.

The same comparison is done between mixes M3 and M4 where again all ingredients are fixed except cement and marble powder content, In M3 cement is 25% and marble powder is 15% and in M4 cement is 20% and marble powder is 20%. Again, the Tukey test indicates that the means of M1 and M2 are significantly different as p value is 0.000 <0.05. In other words, it is with 95% confidence that the mean compressive strength of M4 is lower than mean compressive strength of M3.

The same comparison is done between mixes M5 and M6 where again all ingredients are fixed except cement and marble powder content, In M3 cement is 25% and marble powder is 20% and in M4 cement is 20% and marble powder is 25%. This time the Tukey test indicates that the means of M5 and M6 are not significantly different as p value is 0.086 >0.05.

In other words, changes in percentage of cement and marble powder in mixes having 10% MF does not have a significant impact on the compressive strength of the produced bricks. Unlike changes in percentage of cement and marble in mixes having 5% MF (M1 and M2) and 15% MF (M3 and M4).

Another comparison can be done between M1, M3 and M5 in which all ingredients are the same except MF and marble powder. In M1 there is 25% marble powder and 5% MF, in M2 there is 15% marble powder and 15% MF and in M3 there is 20% marble powder and 10% MF. The Tukey test indicates that the means of M1 and M3 have a p-value of 0.839 and M1 and M5 have a p-value of 0.97 and M3 and M5 have a p-value of 0.998, which are more than 0.05 meaning that there are not significantly different in means. In other words, having 25% cement any changes in percentages of marble powder and MF does not have an effect on the compressive strength of the produced brick.

The last comparison can be done between M2, M4 and M6 in which all ingredients are the same except MF and marble powder. In M2 there is 30% marble powder and 5% MF, in M4 there is 20% marble powder and 15% MF and in M6 there is 25% marble powder and 10% MF. The Tukey test indicate that the means of M2 and M4 have a p-value of 0.906 which is more than 0.05. While, the means of M2 and M4 and M 4 and M6 are 0.000 <0.05, which means that there is a significant difference between means. In other words, at 20% cement changing the percentage of marble powder to 25% and MF to 10% (M6) results into the highest compressive strength values of the bricks.

Table 5.21: Tukey's HSD test for Compressive Strength

(I) Mix	(J) Mix	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
M1	M2	.83000*	.03963	.000	.6969	.9631
	M3	-.04667	.03963	.839	-.1798	.0864
	M4	.79000*	.03963	.000	.6569	.9231
	M5	-.03000	.03963	.970	-.1631	.1031
	M6	.09000	.03963	.276	-.0431	.2231
M2	M1	-.83000*	.03963	.000	-.9631	-.6969
	M3	-.87667*	.03963	.000	-1.0098	-.7436
	M4	-.04000	.03963	.906	-.1731	.0931
	M5	-.86000*	.03963	.000	-.9931	-.7269
	M6	-.74000*	.03963	.000	-.8731	-.6069
M3	M1	.04667	.03963	.839	-.0864	.1798
	M2	.87667*	.03963	.000	.7436	1.0098
	M4	.83667*	.03963	.000	.7036	.9698
	M5	.01667	.03963	.998	-.1164	.1498
	M6	.13667*	.03963	.043	.0036	.2698
M4	M1	-.79000*	.03963	.000	-.9231	-.6569
	M2	.04000	.03963	.906	-.0931	.1731
	M3	-.83667*	.03963	.000	-.9698	-.7036
	M5	-.82000*	.03963	.000	-.9531	-.6869
	M6	-.70000*	.03963	.000	-.8331	-.5669
M5	M1	.03000	.03963	.970	-.1031	.1631
	M2	.86000*	.03963	.000	.7269	.9931
	M3	-.01667	.03963	.998	-.1498	.1164
	M4	.82000*	.03963	.000	.6869	.9531
	M6	.12000	.03963	.086	-.0131	.2531
M6	M1	-.09000	.03963	.276	-.2231	.0431
	M2	.74000*	.03963	.000	.6069	.8731
	M3	-.13667*	.03963	.043	-.2698	-.0036
	M4	.70000*	.03963	.000	.5669	.8331
	M5	-.12000	.03963	.086	-.2531	.0131

The compressive strength of the produced bricks is compared against the compressive strength required by ASTM C129-17 for non-load bearing concrete Masonry Units and the

Egyptian Standard value for the non-load bearing clay masonry units as shown in **Table 5.22** and **Figure 5.27**.

Table 5.22: Compression Strength (MPa) for non-load bearing concrete masonry units

No. of units	ASTM C129-17 For non-load bearing concrete masonry units
Average of 3units	4.14
Individual Units	3.45
No. of units	**Egyptian Standard for non-load bearing clay masonry units**
Average of 5units	Not less than 4
Individual Units	Not less than 3.5

The results indicate that bricks composed of 25% cement, 15% san, 30% contaminated plastic bags and any mixture of MF and marble powder can be a potential replacement for non-load bearing bricks.

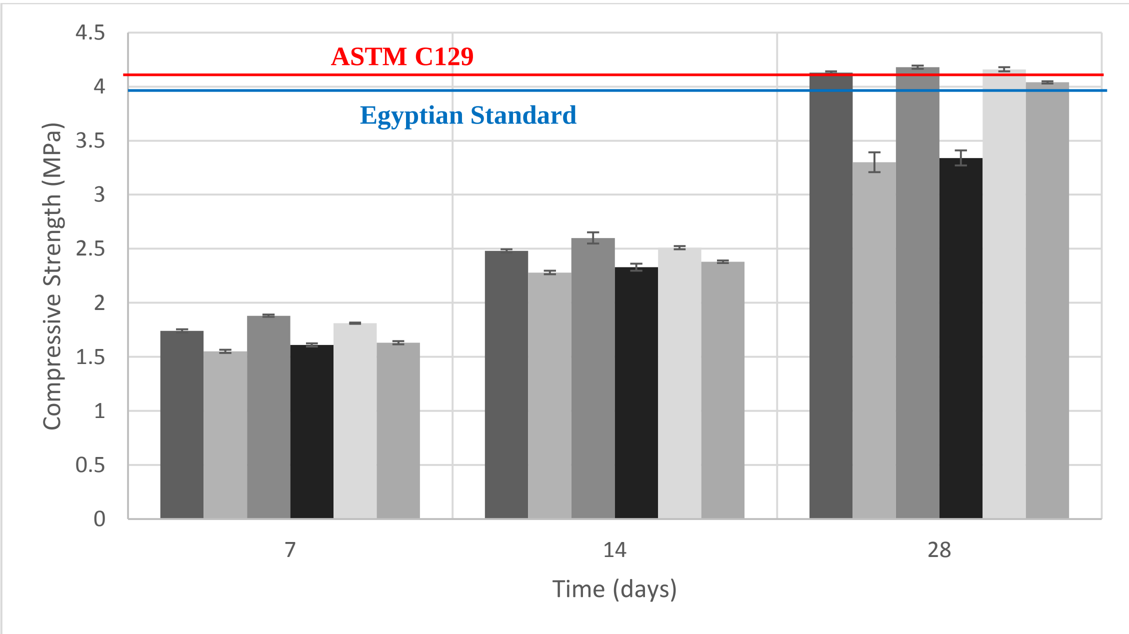


Figure 5.27: Compressive Strength of produced bricks after 7, 14 and 28 days

Water Absorption

The water absorption of the produced bricks is measured after 28 days, and data are presented in **Table 5.23**.

Table 5.23: Water absorption of produced bricks

Mix No.	Replicate 1			Replicate 2			Replicate 3			Average %
	W_d	W_s	%	W_d	W_s	%	W_d	W_s	%	
M1	1891.5	2198.5	14.0%	1898.2	2237.9	15.2%	1847.1	2216.5	16.7%	15.3%
M2	1829.9	2215.3	17.4%	1871.4	2256.2	17.1%	1893.9	2306.4	17.9%	17.4%
M3	1904.3	2193.1	13.2%	1899.8	2185.6	13.1%	1913.1	2189.3	12.6%	13.0%
M4	1866.4	2244.5	16.8%	1871.6	2259.3	17.2%	1915.2	2305.6	16.9%	17.0%
M5	1875.8	2245.6	16.5%	1895.6	2253.1	15.9%	1888.1	2289.5	17.5%	16.6%
M6	1892.1	2264.4	16.4%	1859.5	2235.2	16.8%	1886.4	2228.7	15.4%	16.2%

Note:
* Wd is the initial weight of the dry brick
* Ws is the final weight after the brick was placed in water for 24 hours
* % is the Water absorption in %

The results indicate that all samples have water absorption properties less than that required by the Egyptian standard non-load bearing clay masonry units of 20%. Water absorption is a key factor affecting the brick properties. The less water infiltration into the brick, the more durable the brick is and the more resistant to the natural environment [206].

Density

The density of the samples is calculated and presented in **Table 5.24**. The results indicate that the samples have a density that is comparable to light weight non-load bearing masonry bricks as defined by ASTM C129-17 and the Egyptian standard as presented in **Table 5.25**. This is mainly because 30% of the brick is composed of contaminated plastic bags. It is obvious that samples made of 25% cement have higher densities than the ones made of 20% cement.

Table 5.24: Density of produced bricks

Mix No.	Density (kg/m^3)			
	Replicate 1	Replicate 2	Replicate 3	Average
M1	1050.8	1054.6	1026.2	1043.9
M2	1016.6	1039.7	1052.2	1036.1
M3	1057.9	1055.4	1062.8	1058.7
M4	1036.9	1039.8	1064.0	1046.9
M5	1042.1	1053.1	1048.9	1048.1
M6	1051.2	1033.1	1048.0	1044.1

Table 5.25: Standard requirement of oven dry density of concrete

No. of units	Egyptian Standard for non-load bearing clay masonry units
Light weight	Light weight 900-1200
Medium weigh and normal weight	not less than 1600
No. of units	**ASTM C129-17 For non-load bearing concrete masonry units**
Light weight	1680
Medium weight	1680-2000
Normal weight	2000 or more

4.5.4. Cost Analysis

Table 5.26 summarizes the price of items used to produce bricks out of rejects using cold technology.

Table 5.26: Cost calculation and comparison with commercial prices for cold technology

Cost of process				
Process	**Power (kW)**	**Time of process (min)**	**Cost of energy (LE/kW)**	**Cost of Energy LE per sample**
Shredding	1.5	4	1.6	0.16
Mixing	1	2	1.6	0.05
Cost of Equipment				
Equipment	Market price	Expected Useful Life	No. of samples per day	Cost of equipment LE/sample
Mold	500	5	40	0.01
Manual press	1,000	10	40	0.01
Cost of cement – 800LE/ton				0.36LE/brick
Cost of one brick				**0.6 LE**
Market price of cement bricks (900LE/1000brick)				**0.9LE/brick**
Market price of red brick (700LE/1000brick)				**0.7LE/brick**

It is worth mentioning that all calculations are based on cost of raw materials only excluding transportation and labor wages. Also, the costs of landfilling, conservation of natural resources and environmental impact of dumping rejects in streets and waterways are not included.

4.5.5. Conclusion

In this section an innovative technique is proposed to produce bricks from waste rejects with minimal energy cost. This technique consists mixing contaminated plastic bags as coarse aggregates with sand, marble powder and melamine-formaldehyde as fine aggregates with cement. The mix is then pressed using a manual pressing machine without applying heat for few minutes to take the shape of the mold. Then the brick is left to cure at ambient conditions and water is added every day.

The experimental results indicated that the highest properties is obtained after 28days of curing in the mix made of 25%cement, 30% contaminated plastic bags, 15%sand, 15% marble powder, 15% melamine-formaldehyde. The produced brick is found to have a compressive strength of 4.18MPa and a water absorption of 13%. The density of the sample is found to be 1058.7kg/m3, which is considered light weight brick. The resulting product is found to be competitive to the commercial non-load bearing masonry brick in terms of mechanical performance and cost. In fact, the cost of produced material is 0.6LE/brick compared to 0.9 LE/brick for cement brick.

The application of Waste to Business (W_2B) model introduced in chapter 3 , in recycling of rejects to produce marketable products are beneficial for the rural communities not only from an economic point of view, but also will allow rural areas to convert the piles of unrecyclable waste – piling up in streets, waterways and dumpsites and causing environmental and health problem – into cement bricks that give aesthetic views to houses and buildings of rural villages.

5.5. Conclusion

In this chapter two methods have been proposed to recycle rejects: (1) hot technology and (2) cold technology. By using the hot technology, a new composite material is produced from rejects and can be used to produce Light Traffic interlock paving units. Also, the cold technology can be used to produce material that can be used to produce non-load bearing masonry brick. In other words, these proposed technologies can be used to produce competitive products in terms of mechanical properties and cost from rejects.

In addition to the economic benefit, the production of new material from rejects will also have positive social and environmental impact as follows:

- Reduce the amount of rejects and garbage in streets and waterways and thus reduce health hazard associated with it.
- Create new types of job opportunities
- Gives the micro-entrepreneurial opportunity to residents of rural areas
- Help residents of rural communities have aesthetic spaces by removing the unrecycled materials from streets and replacing them with cheap interlocks paving units and masonry bricks for buildings. This will also help protect rural landscape, protect air and water quality as well as create touristic attractions that can be beneficial for the economy of the rural areas as well as the economy of the country as a whole.

CHAPTER 6– CONCLUSION AND RECOMMENDATIONS

Rural communities in Egypt are confronted with many environmental issues due to the huge amount of waste generated every year including municipal solid waste (such as metals, glass, plastics, rejects, ...), wastewater, organic waste (such as agricultural waste and animal manure, ...) etc. These wastes are poorly disposed of and managed causing serious problems and burden to the country. These problems cause environmental, ecological, economic and health pressures. The tragic situation facing rural villages in developing countries cannot be ignored anymore.

The main goal of this research work is to develop and propose a concept to help rural communities in Egypt approach full utilization of all types of wastes generated. This research is divided into three parts. In the first part the concept of Waste to Business (W_2B) model is proposed to help rural communities approach full utilization of their waste. Then, the second part of this research focuses on recycling of organic waste and rice straw is taken as a case study. The third part focuses on recycling of municipal solid waste and reject is taken as a case study.

6.1. Conclusions

6.1.1. Waste to business Model for Sustainable Rural Communities

The object of the first part of this research work is to develop a concept to help rural communities in Egypt approach full utilization of their different waste streams. In order to achieve this object, desk research method is used in which secondary data are collected from different sources including books, journal papers, conference papers, governmental reports, international organizations' statistics and websites. In order to gather relevant information to the problem, some research questions are developed from which a list of key words is generated. These key words are then used to search for relevant sources. The main limitation encountered during the research is the absence of accurate data regarding the exact amounts and types of waste generated in rural areas. Most of the published studies focus on waste management in Great Cairo and very few studies are conducted in rural areas. This lack of data makes it difficult to estimate numbers such as uncollected waste by geographical location and the exact amount of waste generated by types.

After thorough study of the gathered literature, the collected data are discussed to reply to the above questions. Then the limitations of the disposal methods and recycling techniques for rural villages are identified and the concept of W_2B is developed and proposed to help rural areas in Egypt reach Sustainable Rural Communities.

It is proposed that the government, the rural community, business community and academic institutions and research centers collaborate to implement W_2B model in rural communities. The W_2B model consists of having a facility in each rural community that groups simple and obtainable technologies. This facility will receive all types of wastes generated in rural areas, which will be sorted manually and distributed among different units to fully utilize all types of wastes generated in rural village and produce useful products. Wastewater is stored in a tank and then used to produce biogas. The slurry from the biogas digester along with agricultural waste, food waste and animal manure are used in composting process to produce high quality fertilizer. Yet research is still needed to understand the effect of different additives on the composting process and to accelerate the process. MSW is then sorted manually and distributed among different units to produce useful goods depending on the market need of the village. One type of MSW is reject, material that are hard to recycle, still research is needed to fully utilize rejects to produce useful good at an affordable manner. Consequently, this facility will collect all type of wastes generated in the rural village and will recycle them to produce useful products. By applying this approach, the village will be able to conserve natural resources, reduce the environmental, health, economic and social problems facing these remote areas due to burning and dumping waste. It will also help in creating new job opportunities and reduce the cost of goods.

While reviewing different waste streams it became obvious that there are two main important problems in rural villages in Egypt that need to be studied in depth: (1) recycling of organic waste, and (2) Recycling or rejects

6.1.2. Sustainable bio-conversion of agricultural waste into high quality organic fertilizer: case study of rice straw

One of the utmost important problems facing rural villages in Egypt is the huge amount of organic waste generated every year that are estimated to be 133million tons/year. There are several types of organic waste and this research focuses on agricultural waste as a type of organic waste. Egypt generates up to 30 million ton/year of agricultural waste, from which 52% are directly burnt in the fields. One of the main types of agricultural waste generated in Egypt is rice straw, it is estimated that today around 2.5million tons of rice straw are generated per year.

Composting is one of the useful methods that can convert large amounts of agricultural waste into a valuable product that can be used as a source amendement to improve soil structure, increase its organic matter, and enhance plant growth. However, this method is not widely practiced in developing countries because it is time consuming and quality of product received can be unstable. Some studies showed that the use of additives is a beneficial option to improve nutritional value of compost and accelerate the degradation process. Some of these amendments include biochar, effective micro-organisms (EM), cellulose decomposing bacteria, starters containing bacillus, fungi, yeast, lactic acid bacteria, and animal manure. Several producers of these additives claim that they can generate higher quality compost during short period of time. Yet, the effect of these additives on the composting process is not fully studied and understood. The aim of these experiments is to evaluate the effect of different additives on the quality of rice straw compost and to produce high quality soil amendments and organic fertilizers by composting of rice straw. This part is divided into two sets of experiments as follows:

The objective of the first set of experiment is to transform rice straw into soil amendment and evaluate the effect of different additives on the produced compost. In the first set of experiment rice straw is inoculated with animal manure, Chinese starter, cellulose decomposer and starter from the Egyptian Ministry of agriculture. The results of the first set of experiments revealed that the application of different additives in composting of rice straw exhibited an improvement of compost quality. The results of the first set of experiments revealed a higher decomposition rate of treatment having animal manure, compared to other treatments. All analysis of the properties of the final compost products containing animal manure indicated that it was in the range of the matured level after 60 days and can be used without any limitation

Therefore, a second set of experiment has been conducted with substrate rice straw, animal manure and mixture of natural rocks inoculated with different types of additives (including (effective micro-organisms, biochar and Chinese starter) to produce high quality organic fertilizer. The results revealed that the application of different additives in composting of rice straw exhibit an improvement in maturation time and final product quality. In fact, all piles reached maturation after around 42 days. All analysis of the properties of the final products indicated that it was in the range of the matured level and can be used without any limitation as an organic fertilizer. The highest decomposition rate and highest organic fertilizer quality was obtained in pile containing rice straw and 40% of animal manure mixed with natural rocks (2.5% of rock phosphate, 2.5% feldspar, 2.5% sulfur, 2.5% dolomite and 10% bentonite) and inoculated with 2% of EM and 10% biochar compared to other treatments. Also, the results showed that adding 20% biochar decreased the quality of the final compost compared to adding 10%. The cost of the produced high-quality organic fertilizer is estimated to be 330LE/ton, given that each farmer will use the organic waste generated from his land and will not need extra labor to produce the organic fertilizer compared to chemical fertilizer market price of 1,700LE/ton to 12,000LE/ton (non-subsidized price). In addition to the direct cost, the use of chemical fertilizer damages the atmosphere and the water. This damage has an unforeseen high cost. Therefore, organic fertilizer produced from organic waste can substitute expensive chemical fertilizer. In addition to economic benefits, reducing the use of chemical fertilizer will lead to the creation of new job opportunities in rural villages, reduction of soil, water and air pollution as farmers will sell their waste instead of burning it in the field. Also, application of organic fertilizer will re-establish the soil structure on the long run.

6.1.3. Approaching full utilization of Municipal Solid Waste: case study of rejects

Another major problems facing rural communities in Egypt is poor municipal solid waste (MSW) management, which contribute to the health, ecological and environmental problems facing rural communities. Egypt generates around 21million tons of MSW per year. More than 35% of waste is either burnt or end up in open, public and random dumpsite causing many environmental and health problem to rural villages in Egypt. A large part of MSW is made out of unrecyclable waste known as rejects. There are many types of rejects and this research focuses on the following types of rejects: (1) packaging materials, (2) thermosets, and (3) contaminated plastic bags.

The main aim of this part is to propose solution to close the loop for rejects from municipal solid waste and approach full utilization of rejects.

This part of the research work proposes two techniques to recycle rejects: (1) hot technology and (2) a cold technology.

In the hot technology compression molding technique is used to produce the composite material from waste multi-layer packaging material as the matrix and melamine-formaldehyde as the filling material. In compression molding, the sample is subject to 50bar pressure and heat for 30min. The effect of the following three factors are examined: (1) temperature, (2) %wt. of filling material, and (3) particle size of filling material. Pilot experiments are conducted first to determine the different levels that will be tested for each factors. The pilot experiments indicated that good samples are obtained using volume fraction ranging from 20% to 40% of filling material, heating temperature ranging from 135 to 145℃, and particle size ranging from sieve 16 to sieve 40. Three levels for each factor are determined and a full design of experiment is conducted. Hence, 27 combinations are tested, and each combination is replicated 3 times. For higher accuracy samples are produced at random order using Design Expert software. The following tests are conducted on all 81 samples: compressive strength, moisture absorption, abrasion resistance, flexural strength and density. Also, abrasion index of all samples is calculated from water absorption and compressive strength values. Finally, leachate test is conducted to make sure that the produced material can be safely used without adverse effect on the environment.

The experimental results indicated that compression molding temperature has the highest significant effect on the compressive and flexural strength of the samples. The results reveal that highest compressive and flexural strength are achieved by increasing the temperature during compression molding. This is attributed to the fact that highest temperature allows the packaging material to melt more; therefore, packaging material wet the filling material more leading to better adhesion between the matrix and filling material. The results show that the compressive strength as well as the flexural strength can be described by a quadratic model expressed as a function of compression molding temperature (°C), MF %wt., and MF particle size (μm). Also, the results reveal that all samples have low densities, low water absorption properties and high abrasion resistance.

The experimental results indicate that the highest mechanical properties are obtained in samples produced using molding temperature of 145°C, melamine-formaldehyde having a particle size of sieve 20 and 30%wt. fraction of melamine-formaldehyde. In fact, the produced material is found to have compressive strength of 32.54MPa, flexural strength of 18.42MPa, water absorption of 0.32%, density of 0.97g/cm^3 and abrasion index of 0.01. The resulting product is found to be competitive to commercial MX and NX types of Light Traffic interlock paving units in terms of cost and mechanical performance. In fact, the cost of produced material is 1.2LE/m^2 compared to 150LE/m^2 for interlock market price.

Also, substituting melamine-formaldehyde with other filling material like EPDM rubber waste or sand and substituting the packaging material with plastic bags waste showed to produce material slightly lower mechanical properties but can still be a competitive substitute to produce interlocks and substitute cement board.

Recycling of rejects are beneficial for the rural communities not only from an economic point of view, but also will allow rural areas to convert the piles of unrecyclable waste – piling up in streets, waterways and dumpsites and causing environmental and health problem – into interlocks that give aesthetic views to rural villages.

In the second part, an innovative cold technology is proposed to produce cement bricks from rejects. This technique consists mixing contaminated plastic bags as coarse aggregates with sand, marble powder and melamine-formaldehyde as fine aggregates with cement. The mix is then pressed using a manual pressing machine without applying heat for few minutes to take the shape of the mold. Then the brick is left to cure at ambient conditions and water is added every day.

The experimental results indicated that the highest properties are obtained after 28days of curing in the mix made of 25%cement, 30% contaminated plastic bags, 15%sand, 15% marble powder, 15% melamine-formaldehyde. The produced brick is found to have a compressive strength of 4.18MPa and a water absorption of 13%. The density of the sample is found to be 1058.7kg/m^3, which is considered light weight brick. The resulting product is found to be competitive to the commercial non-load bearing masonry brick in terms of mechanical performance and cost. In fact, the cost of produced material is 0.6LE/brick compared to 0.9LE/brick for cement brick.

Recycling of rejects to produce marketable products are beneficial for the rural communities not only from an economic point of view, but also will allow rural areas to convert the piles of unrecyclable waste – piling up in streets, waterways and dumpsites and causing environmental and health problem – into cement bricks that will allow resident of rural areas build their homes in a more affordable way.

6.1.4. Closing the loop and clearing the path towards sustainable rural communities

The concept of W_2B is proposed to help the government, the rural community, business community and academic institutions and research centers collaborate to help rural communities approach full utilization of wastes. While studying different waste streams two gaps were identified: (1) recycling of agricultural waste to produce high quality organic fertilizer in short period of time, and (2) recycling rejects that are perceived as impossible to recycle and have no value. By tackling these two problems in this research the W_2B model proposed in chapter 3 can be modified and completed as shown in **Figure 6.1**.

Applying the concept of W_2B can contribute to the Egyptian Sustainable Development Strategy: Egypt Vision 2030 as well as to 4 of the 17 United Nations Sustainable Development Goals for 2030 which are:

(1) *Good health and well-being* as by reducing the amount of waste dumped in streets and water ways all the health problems associated with pollution will be alleviate allowing people to live a better life,

(2) *Decent work and economic growth* as different small and simple technologies are proposed which will create new job opportunities, give the micro-entrepreneurial

opportunity to residents of rural areas and produce useful products that have economic value and reduce the amount of imported products

(3) *Sustainable cities and communities:* by having the W2B facility in each rural village, each village will be able to eliminate waste and produce out it useful products based on the village needs

(4) *Responsible consumption and production:* by having this facility resident of rural areas will start being introduced and familiar with the concept of recycling and will start learning how to reduce the use of material that are hard to recycle and find innovative ways to recycle their waste

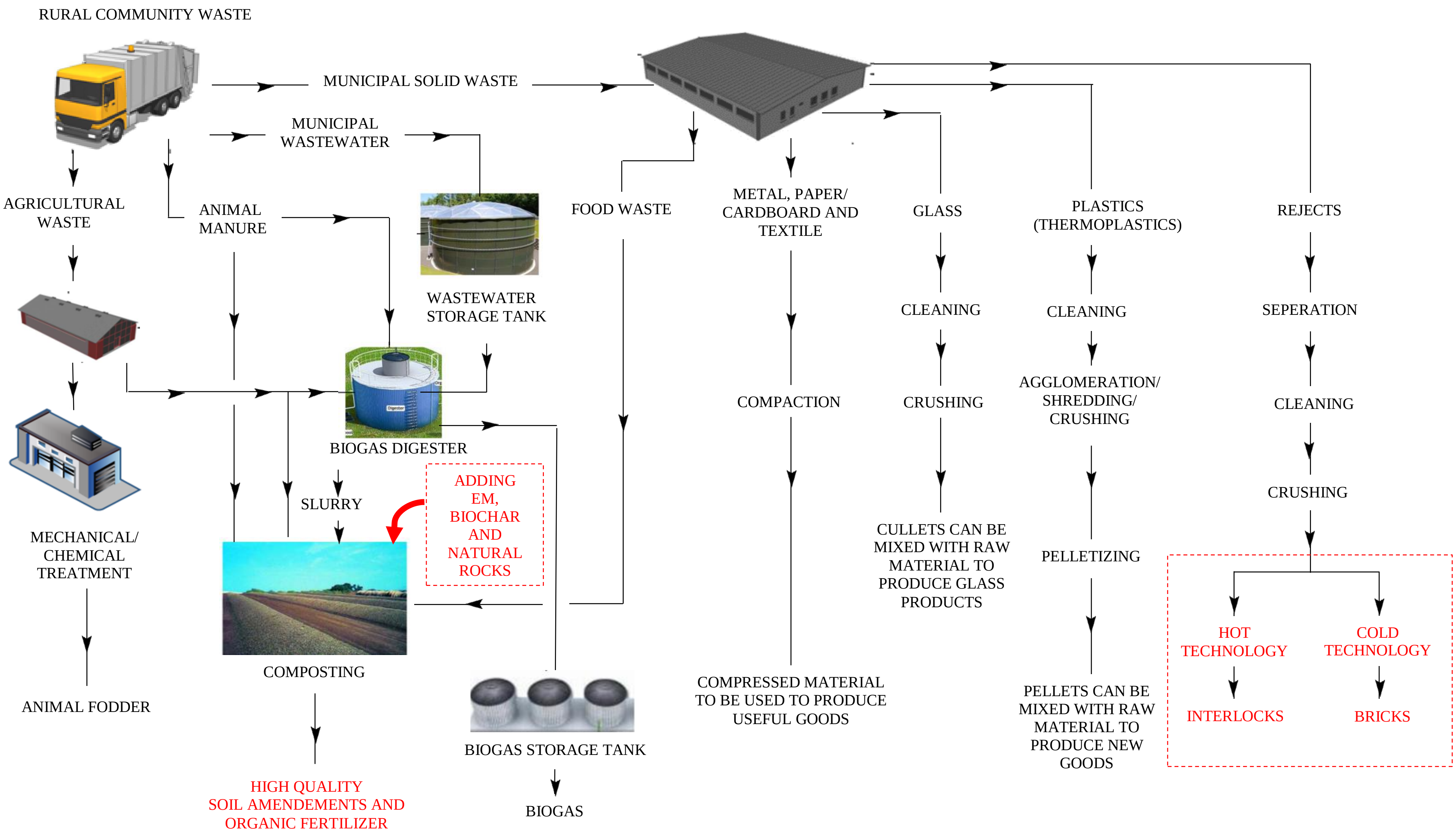


Figure 6.1: Complete Waste to Business Model (W_2B)

6.2. Recommendations

6.2.1. Sustainable bio-conversion of agricultural waste into high quality organic fertilizer: case study of rice straw

The second part of this research work focuses on recycling of organic waste. One type of organic waste is agriculture waste. Experimental results indicated that by having additives like animal manure, biochar, Effective micro-organisms and natural rocks, rice straw can be transformed into high quality organic fertilizer that meets the Egyptian specifications and can replace the use of expensive chemical fertilizer. The following are recommendations for future possible work for this part:

- Evaluate the GHG emission from the production of organic fertilizer from waste using biochar and EM
- Evaluate yield from different types of crops (vegetable, fruits, trees) using the produced organic fertilizer
- Develop a mathematical model for the composting process to predict the properties of organic fertilizer produced and for process optimization
- Figure out the optimal addition rate of biochar for successful composting practice
- Large scale trial should be done to confirm that the various benefits found from this pilot- scale study can be repeated in large scale

6.2.2. Approaching full utilization of Municipal Solid Waste: case study of rejects

The third part of the research work focuses on recycling of rejects. Two technologies are introduced to produce valuable products from rejects: (1) hot technology and (2) cold technology. The hot technology was shown to be an effective way to produce interlocks from multi-layer packaging material and melamine-formaldehyde and the cold technology was proven to be an effective way to produce non-load bearing bricks.

The aim of this research was to check the possibility of producing cement bricks using the cold technology. Based on the literature and the pilot experiments, six mixes were proposed to produce bricks and were tested. In the future work it is proposed to conduct a full design of experiment in order to

- Identify the effect of different components on the properties of the produced composite material
- Identify the parameter that has the most significant effect on material properties
- Develop equations that will allow the prediction of properties for any combination of parameters

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APPENDIX

SUSTAINABLE BIO-CONVERSION OF RICE STRAW INTO HIGH QUALITY ORGANIC FERTILIZER

Temperature changes of Experiment # 1

E1.T1						
Days	**Mean daily temperature**	**Average**	**Reading # 1**	**Reading # 2**	**Reading # 3**	**Standard Deviation**
5	14	50	49.5	51.3	49.2	1.136
8	14	45	44.2	45.8	45	0.800
10	12	52	52.8	50.4	52.8	1.386
12	12	56.3	57.9	55.8	55.2	1.418
15	14	39.7	38.2	39.1	41.8	1.873
17	15	38.5	37.3	40.1	38.1	1.442
19	14	39.2	38.2	40.4	39	1.114
24	14	40	41	39.3	39.7	0.889
27	16	35.7	36.2	33.8	37.1	1.706
31	12	23.6	22.4	22.9	25.8	1.836
33	14	23.7	22.7	23.2	25.2	1.323
35	13	23	22.1	22.9	24	0.954
37	13	21	19.7	21.5	21.8	1.136
39	16	20.1	19.2	19.8	21.3	1.082
42	16	28.7	29.3	28.7	28.1	0.600
44	16	35	34.9	35.1	35	0.100
46	16	27	26.7	25.9	28.4	1.277
48	14	27	26.5	27.1	27.4	0.458
53	15	23.8	23.8	23	24.7	23.7
55	16	25.4	25.4	23.5	24.5	28.2
58	18	26.6	26.6	27.5	25.4	26.9
60	20	29.1	29.1	30.7	27.9	28.7
62	20	27.1	27.1	25.4	28.5	27.4
65	17	25	25	23.2	25.4	26.4
67	18	25.7	25.7	26.8	23.5	26.8
69	21	25	25	24.8	26.2	24
72	19	23.5	23.5	22.8	23.6	24.1
74	19	24.6	24.6	24.5	24.8	24.5
79	19	24	24	24.6	23.8	23.6
81	19	24	24	23.8	23.6	24.6
83	22	24.3	24.3	24.2	24.6	24.1

E1.T2						
Days	**Mean daily temperature**	**Average**	**Reading # 1**	**Reading # 2**	**Reading # 3**	**Standard Deviation**
5	40	38.7	42.1	39.2	1.84	40
8	50	52.3	49.8	47.9	2.21	50
10	52.6	53.8	51.8	52.2	1.06	52.6
12	48.6	49.1	47.6	49.1	0.87	48.6
15	45	44.3	45.6	45.1	0.66	45
17	41	40.8	41.2	41	0.20	41
19	42.5	42.1	42.6	42.8	0.36	42.5
24	36.7	36.5	37.9	35.7	1.11	36.7
27	30.7	31.2	30.4	30.5	0.44	30.7
31	23.2	23.4	25.2	21	2.11	23.2
33	35.6	36.7	34.9	35.2	0.96	35.6
35	31.3	31.5	30.9	31.5	0.35	31.3
37	31.6	31.8	30.8	32.2	0.72	31.6
39	27.2	28.2	27.3	26.1	1.05	27.2
42	32	32.3	31.7	32	0.30	32
44	22	22.4	21.3	22.3	0.61	22
46	36	35.8	36.1	36.1	0.17	36
48	26.8	27.7	26.9	25.8	0.95	26.8
53	23.2	24.1	23.8	21.7	1.31	23.2
55	21.6	20.8	21.3	22.7	0.98	21.6
58	27	26.9	27.8	26.3	0.75	27
60	29	29.2	28.4	29.4	0.53	29
62	32	31.6	32.4	32	0.40	32
65	31.2	31.2	32.4	30	1.20	31.2
67	28	27.7	28.1	28.2	0.26	28
69	26.4	26.3	26.9	26	0.46	26.4
72	27.6	27.1	27.9	27.8	0.44	27.6
74	26	25.8	25.5	26.7	0.62	26
79	24.2	24.3	25	23.3	0.85	24.2
81	23.6	24.3	23.1	23.4	0.62	23.6
83	24	24.1	24.6	23.3	0.66	24

E1.T3						
Days	**Mean daily temperature**	**Average**	**Reading # 1**	**Reading # 2**	**Reading # 3**	**Standard Deviation**
5	40	50	50.1	51.3	48.6	1.35
8	50	55	56.1	54.8	54.1	1.01
10	52.6	51.7	52.6	51.3	51.2	0.78
12	48.6	48.7	49.8	50.1	46.2	2.17
15	45	43.6	43.7	42.7	44.4	0.85
17	41	49	48.6	49.4	49	0.40
19	42.5	45.7	45.1	46.2	45.8	0.56
24	36.7	42.4	41.5	42.8	42.9	0.78
27	30.7	36.3	35.8	36.7	36.4	0.46
31	23.2	24.2	25.3	24.3	23	1.15
33	35.6	30.1	29.8	30.6	29.9	0.44
35	31.3	26	26.8	25.6	25.6	0.69
37	31.6	35	35.7	36.4	32.9	1.85
39	27.2	32	31.2	32.8	32	0.80
42	32	25.6	24.7	25.7	26.4	0.85
44	22	32	31.5	32.4	32.1	0.46
46	36	35.2	35.2	36.4	34	1.20
48	26.8	29.3	29.1	28.9	29.9	0.53
53	23.2	23	22.1	24.3	22.6	1.15
55	21.6	25.8	24.9	25.3	27.2	1.23
58	27	26.9	26.1	25.4	29.2	2.02
60	29	29.3	30.4	28.9	28.6	0.96
62	32	29.4	30.2	29.5	28.5	0.85
65	31.2	28.1	27.5	28.6	28.2	0.56
67	28	25.9	24.6	26.1	27	1.21
69	26.4	28	28.5	29.4	26.1	1.71
72	27.6	23	22.9	23.4	22.7	0.36
74	26	24	23.8	24.5	23.7	0.44
79	24.2	22	21.3	21.2	23.5	1.30
81	23.6	22	19.4	22.3	24.3	2.46
83	24	22.6	23.4	21.6	22.8	0.92

E1.T4						
Days	**Mean daily temperature**	**Average**	**Reading # 1**	**Reading # 2**	**Reading # 3**	**Standard Deviation**
5	40	40	40.1	39.7	40.2	0.26
8	50	58	58.6	59.3	56.1	1.68
10	52.6	59	59.8	58.8	58.4	0.72
12	48.6	52	50.7	51.3	54	1.76
15	45	44.4	44.1	45.3	43.8	0.79
17	41	46	45.4	46.5	46.1	0.56
19	42.5	46.4	45.2	46.7	47.3	1.08
24	36.7	39.6	38.4	39.4	41	1.31
27	30.7	43.4	43.5	43	43.7	0.36
31	23.2	41	40.3	41.6	41.1	0.66
33	35.6	36.4	35.3	36.4	37.5	1.10
35	31.3	40	40.5	41.8	37.7	2.10
37	31.6	43	42.3	43.7	43	0.70
39	27.2	38.6	38.1	39.4	38.3	0.70
42	32	31.1	31.2	30.2	31.9	0.85
44	22	29.1	28.7	29.6	29	0.46
46	36	25.3	24.9	25.8	25.2	0.46
48	26.8	21.4	20.4	21.2	22.6	1.11
53	23.2	20.7	21.3	20.3	20.5	0.53
55	21.6	23.7	24.3	22.8	24	0.79
58	27	23	22.4	23.7	22.9	0.66
60	29	26	25.3	26.8	25.9	0.75
62	32	27.4	26.3	28	27.9	0.95
65	31.2	26.7	27.3	25.9	26.9	0.72
67	28	26.9	25.8	27.1	27.8	1.01
69	26.4	27.7	28	27.3	27.8	0.36
72	27.6	25	23.5	25.8	25.7	1.30
74	26	24.7	24.5	23.5	26.1	1.31
79	24.2	23	24.2	22.4	22.4	1.04
81	23.6	22.7	21.4	23.5	23.2	1.14
83	24	24	23.9	24.7	23.4	0.66

E1.T5						
Days	**Mean daily temperature**	**Average**	**Reading # 1**	**Reading # 2**	**Reading # 3**	**Standard Deviation**
5	40	45	44.6	45.3	45.1	0.36
8	50	60	61.3	59.7	59	1.18
10	52.6	55	54.5	55.4	55.1	0.46
12	48.6	46.1	45.3	46.9	46.1	0.80
15	45	41.7	42.3	43.6	39.2	2.26
17	41	49.2	50.2	49.3	48.1	1.05
19	42.5	42.7	42.3	43.1	42.7	0.40
24	36.7	44	43.5	45.3	43.2	1.14
27	30.7	46	45.7	46.4	45.9	0.36
31	23.2	43	44.2	43.5	41.3	1.51
33	35.6	37.7	38.4	37.3	37.4	0.61
35	31.3	34	33.4	34.4	34.2	0.53
37	31.6	33.5	34.6	33.1	32.8	0.96
39	27.2	34	33.6	34.6	33.8	0.53
42	32	30.2	29.5	31.2	29.9	0.89
44	22	27.6	26.4	28.4	28	1.06
46	36	23	22.3	23.5	23.2	0.62
48	26.8	21.7	20.3	22.3	22.5	1.22
53	23.2	24.2	24.3	25.4	22.9	1.25
55	21.6	25.6	25.5	25.8	25.5	0.17
58	27	25	24.3	25.4	25.3	0.61
60	29	26.3	26.4	27.5	25	1.25
62	32	28.3	29.1	28	27.8	0.70
65	31.2	27.2	26.7	27.4	27.5	0.44
67	28	25	24.3	25.7	25	0.70
69	26.4	24	23.6	24.3	24.1	0.36
72	27.6	24	23.3	25.1	23.6	0.96
74	26	23.9	23.4	24	24.3	0.46
79	24.2	23.1	22.8	23.5	23	0.36
81	23.6	22	23.1	21.9	21	1.05
83	24	23	22.9	23.5	22.6	0.46

%OC changes of Experiment # 1

		Average	Reading # 1	Reading # 2	Reading # 3	Standard Deviation	%Losses
E1.T1	Initial	36.3	35.7	37.0	36.3	0.67	9.58
	After 30 days	32.8	32.4	33.2	32.9	0.44	29.01
	After 60 days	25.8	25.2	26.0	26.2	0.53	31.63
	After 90 days	24.8	23.7	25.3	25.5	1.01	
E1. T2	Initial	46.4	45.4	47.1	46.6	0.90	11.06
	After 30 days	41.2	40.8	42.0	40.9	0.67	22.81
	After 60 days	35.8	34.8	36.4	36.2	0.88	27.00
	After 90 days	33.8	33.1	34.2	34.2	0.62	
E1. T3	Initial	41.4	40.9	42.1	41.3	0.59	6.74
	After 30 days	38.6	38.0	39.1	38.7	0.53	18.46
	After 60 days	33.8	33.0	34.1	34.1	0.63	21.64
	After 90 days	32.4	31.7	32.9	32.8	0.67	
E1.T4	Initial	35.8	35.1	36.2	36.1	0.61	12.77
	After 30 days	31.2	30.5	31.6	31.6	0.62	36.08
	After 60 days	22.9	22.4	23.3	23.0	0.41	37.56
	After 90 days	22.4	21.9	22.8	22.4	0.47	
E1.T5	Initial	39.4	38.5	39.9	39.9	0.79	20.26
	After 30 days	31.4	30.9	31.7	31.7	0.45	39.89
	After 60 days	23.7	22.9	24.2	24.0	0.69	41.47
	After 90 days	23.1	22.4	23.5	23.3	0.60	9.58

%OM changes of Experiment # 1

		Average	Reading # 1	Reading # 2	Reading # 3	Standard Deviation	%Losses
E1.T1	Initial	62.6	61.5	63.8	62.5	1.15	
	After 30 days	56.6	55.8	57.3	56.7	0.75	9.58
	After 60 days	44.4	43.4	44.8	45.1	0.92	29.01
	After 90 days	42.8	40.8	43.7	43.9	1.73	31.63
E1. T2	Initial	79.92	78.2	81.2	80.36	1.55	
	After 30 days	71.08	70.3	72.4	70.54	1.15	11.06
	After 60 days	61.68921333	60.0	62.7	62.4	1.51	22.81
	After 90 days	58.34	57.1	58.9	59.02	1.08	27.00
E1. T3	Initial	71.38	70.5	72.5	71.14	1.02	
	After 30 days	66.57	65.6	67.4	66.7	0.91	6.74
	After 60 days	58.20	56.9	58.8	58.9	1.09	18.46
	After 90 days	55.93	54.6	56.7	56.49	1.16	21.64
E1.T4	Initial	61.72	60.5	62.4	62.26	1.06	
	After 30 days	53.84	52.6	54.4	54.52	1.08	12.77
	After 60 days	39.45	38.7	40.1	39.6	0.71	36.08
	After 90 days	38.54	37.7	39.3	38.62	0.80	37.56
E1.T5	Initial	67.97	66.4	68.8	68.71	1.36	
	After 30 days	54.2	53.3	54.7	54.6	0.78	20.26
	After 60 days	40.86	39.5	41.7	41.4	1.20	39.89
	After 90 days	39.78	38.6	40.5	40.24	1.03	41.47

One-Way ANOVA

All results were presented as the average of three replicates, and the means among different treatments were compared using one-way ANOVA using SPPS version 23. The null hypothesis states that the population means are all equal. A significance level α =0.05 is used.

%OM					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1048.950	4	262.238	181.844	.000
Within Groups	14.421	10	1.442		
Total	1063.371	14			

The ANOVA results indicate that the p-value is less than the significance level; therefore, the null hypothesis is rejected, and it can be concluded that there is a significant difference between the means. This indicates that each additive has a different effect on the compost pile in terms of organic matter.

%TN changes of Experiment # 1

		Average	**Reading # 1**	**Reading # 2**	**Reading # 3**	**Standard Deviation**
E1.T1	Initial	0.98	0.86	1.27	0.81	0.25
	After 30 days	1.07	0.93	1.16	1.12	0.12
	After 60 days	1.24	1.11	1.32	1.30	0.12
	After 90 days	1.27	1.13	1.35	1.33	0.12
E1. T2	Initial	0.78	0.65	0.84	0.85	0.11
	After 30 days	1.11	1.01	1.32	1	0.18
	After 60 days	1.47	1.43	1.59	1.39	0.11
	After 90 days	1.54	1.5	1.67	1.45	0.12
E1. T3	Initial	0.85	0.76	0.93	0.86	0.09
	After 30 days	1.04	0.96	1.12	1.04	0.08
	After 60 days	1.11	1.00	1.23	1.08	0.12
	After 90 days	1.13	1.02	1.26	1.11	0.12
E1.T4	Initial	0.79	0.68	0.85	0.84	0.10
	After 30 days	1.23	1.12	1.33	1.24	0.11
	After 60 days	1.59	1.53	1.69	1.53	0.09
	After 90 days	1.63	1.58	1.74	1.57	0.10
E1.T5	Initial	0.95	0.89	1.2	0.76	0.23
	After 30 days	1.19	0.98	1.5	1.09	0.27

	After 60 days	1.89	1.83	2.26	1.56	0.35
	After 90 days	1.94	1.89	2.32	1.61	0.36

One-Way ANOVA

%TN

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1.206	4	.301	8.382	.003
Within Groups	.360	10	.036		
Total	1.565	14			

The ANOVA results indicate that the p-value is less than the significance level; therefore, the null hypothesis is rejected, and it can be concluded that there is a significant difference between the means. This indicates that each additive has a different effect on the compost pile in terms of TN.

%NO_3^- changes of Experiment # 1

		Average	**Reading # 1**	**Reading # 2**	**Reading # 3**	**Standard Deviation**
E1.T1	Initial	14	13	15	14	1.00
	After 30 days	85	85	86	84	1.00
	After 60 days	214	214	215	213	0.91
	After 90 days	220	221	220	219	1.00
E1. T2	Initial	44	45	43	44	1.00
	After 30 days	57	58	55	58	1.73
	After 60 days	207	208	207	207	0.51
	After 90 days	218	219	218	217	1.00
E1. T3	Initial	47	46	48	47	1.00
	After 30 days	65	66	64	65	1.00
	After 60 days	208	209	208	207	1.10
	After 90 days	214	216	214	212	2.00
E1.T4	Initial	16	16	14	18	2.00
	After 30 days	57	56	58	57	1.00

	After 60 days	225	227	223	225	1.94
	After 90 days	230	231	228	231	1.73
E1.T5	Initial	18	17	18	19	1.00
	After 30 days	106	107	104	107	1.73
	After 60 days	289	290	287	289	1.30
	After 90 days	295	295	294	296	1.00

%NH_4^+ changes of Experiment # 1

		Average	**Reading # 1**	**Reading # 2**	**Reading # 3**	**Standard Deviation**
E1.T1	Initial	376	374	377	377	1.7
	After 30 days	187	186	188	187	1.0
	After 60 days	36	36	37	35	1.0
	After 90 days	35	35	36	34	1.0
E1. T2	Initial	314	313	314	315	1.0
	After 30 days	120	118	120	122	2.0
	After 60 days	62	61	63	61	0.9
	After 90 days	59	58	60	59	1.0
E1. T3	Initial	323	322	324	323	1.0
	After 30 days	126	125	126	127	1.0
	After 60 days	65	64	66	64	0.9
	After 90 days	62	61	63	62	1.0
E1.T4	Initial	410	408	410	412	2.0
	After 30 days	234	235	236	231	2.6
	After 60 days	33	33	34	32	1.0
	After 90 days	32	32	33	31	1.0
E1.T5	Initial	422	421	422	423	1.0
	After 30 days	260	261	260	259	1.0

	After 60 days	46	46	48	44	2.1
	After 90 days	45	45	47	43	2.0

%TP changes of Experiment # 1

		Average	**Reading # 1**	**Reading # 2**	**Reading # 3**	**Standard Deviation**
E1.T1	Initial	0.54	0.43	0.68	0.51	0.13
	After 30 days	0.61	0.53	0.67	0.63	0.07
	After 60 days	0.65	0.60	0.71	0.63	0.06
	After 90 days	0.68	0.63	0.75	0.66	0.06
E1. T2	Initial	0.29	0.21	0.35	0.31	0.07
	After 30 days	0.32	0.26	0.39	0.31	0.07
	After 60 days	0.36	0.30	0.45	0.35	0.08
	After 90 days	0.38	0.31	0.47	0.36	0.08
E1. T3	Initial	0.22	0.14	0.28	0.24	0.07
	After 30 days	0.35	0.28	0.42	0.35	0.07
	After 60 days	0.39	0.32	0.44	0.41	0.06
	After 90 days	0.41	0.34	0.46	0.43	0.06
E1.T4	Initial	0.53	0.43	0.62	0.54	0.10
	After 30 days	0.61	0.64	0.52	0.67	0.08
	After 60 days	0.71	0.59	0.81	0.72	0.11
	After 90 days	0.73	0.61	0.84	0.74	0.12
E1.T5	Initial	0.55	0.45	0.68	0.52	0.12
	After 30 days	0.65	0.78	0.55	0.62	0.12
	After 60 days	0.77	0.85	0.70	0.76	0.07
	After 90 days	0.79	0.87	0.72	0.78	0.08

One-Way ANOVA

%TP					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.432	4	.108	16.106	.000
Within Groups	.067	10	.007		
Total	.499	14			

The ANOVA results indicate that the p-value is less than the significance level; therefore, the null hypothesis is rejected, and it can be concluded that there is a significant difference between the means. This indicates that each additive has a different effect on the compost pile in terms of TP.

%TK changes of Experiment # 1

		Average	**Reading # 1**	**Reading # 2**	**Reading # 3**	**Standard Deviation**
E1.T1	Initial	0.58	0.51	0.68	0.55	0.09
	After 30 days	0.73	0.63	0.82	0.74	0.10
	After 60 days	0.78	0.71	0.86	0.76	0.08
	After 90 days	0.82	0.75	0.91	0.8	0.08
E1. T2	Initial	0.2	0.15	0.27	0.18	0.06
	After 30 days	0.37	0.24	0.46	0.41	0.12
	After 60 days	0.48	0.40	0.55	0.48	0.076
	After 90 days	0.5	0.42	0.58	0.5	0.08
E1. T3	Initial	0.34	0.28	0.44	0.3	0.09
	After 30 days	0.52	0.48	0.64	0.44	0.11
	After 60 days	0.68	0.58	0.74	0.73	0.089
	After 90 days	0.72	0.61	0.78	0.77	0.10
E1.T4	Initial	0.37	0.28	0.43	0.4	0.08
	After 30 days	0.54	0.42	0.59	0.61	0.10
	After 60 days	0.79	0.71	0.85	0.80	0.074
	After 90 days	0.81	0.73	0.88	0.82	0.08
E1.T5	Initial	0.42	0.34	0.47	0.45	0.07

	After 30 days	0.67	0.53	0.76	0.72	0.12
	After 60 days	0.89	0.79	0.95	0.93	0.086
	After 90 days	0.91	0.81	0.97	0.95	0.09

One-Way ANOVA

%TK					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.292	4	.073	10.297	.001
Within Groups	.071	10	.007		
Total	.363	14			

The ANOVA results indicate that the p-value is less than the significance level; therefore, the null hypothesis is rejected, and it can be concluded that there is a significant difference between the means. This indicates that each additive have a different effect on the compost pile in terms of TK.

Moisture Content changes of Experiment # 1

		Average	**Reading # 1**	**Reading # 2**	**Reading # 3**	**Standard Deviation**
E1.T1	Initial	62	60	64	62	2
	After 30 days	58	56	61	57	2.6
	After 60 days	36	35	33	40	3.6
	After 90 days	33	32	29	38	4.6
E1. T2	Initial	61	60	59	64	2.6
	After 30 days	56	55	58	55	1.7
	After 60 days	32.96	31	33	35	2.1
	After 90 days	32	30	32	34	2
E1. T3	Initial	56	57	53	58	2.6
	After 30 days	54	52	57	53	2.6
	After 60 days	35	33	37	35	2.1
	After 90 days	34	32	36	34	2

E1.T4	Initial	63	61	64	64	1.7
	After 30 days	58	56	59	59	1.7
	After 60 days	36	34	35	39	2.7
	After 90 days	35	33	34	38	2.6
E1.T5	Initial	66	64	67	67	1.7
	After 30 days	54	54	56	52	2
	After 60 days	39	38	40	39	1.0
	After 90 days	38	37	39	38	1

Bulk Density changes of Experiment # 1

		Average	Reading # 1	Reading # 2	Reading # 3	Standard Deviation
E1.T1	Initial	218	219	211	224	6.56
	After 30 days	250	250	253	247	3
	After 60 days	301	303	301	299	1.6
	After 90 days	310	312	308	310	2
E1. T2	Initial	180	181	178	181	1.73
	After 30 days	215	212	217	216	2.65
	After 60 days	261	261	258	263	2.7
	After 90 days	270	271	268	271	1.73
E1. T3	Initial	170	172	169	169	1.73
	After 30 days	230	228	231	231	1.73
	After 60 days	266	262	269	269	3.9
	After 90 days	275	272	276	277	2.65
E1.T4	Initial	170	171	172	167	2.65
	After 30 days	240	240	243	237	3
	After 60 days	380	382	378	378	2.4
	After 90 days	390	391	389	390	1
E1.T5	Initial	240	243	239	238	2.65

	After 30 days	320	321	324	315	4.58
	After 60 days	431	434	429	429	2.9
	After 90 days	440	443	437	440	3

One-way ANOVA

Bulk Density					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	67440.000	4	16860.000	3512.500	.000
Within Groups	48.000	10	4.800		
Total	67488.000	14			

The ANOVA results indicate that the p-value is less than the significance level; therefore, the null hypothesis is rejected, and it can be concluded that there is a significant difference between the means. This indicates that each additive has a different effect on the compost pile in terms of bulk density.

pH changes of Experiment # 1

		Average	**Reading # 1**	**Reading # 2**	**Reading # 3**	**Standard Deviation**
E1.T1	Initial	8.4	8.28	8.42	8.5	0.11
	After 30 days	8.46	8.36	8.48	8.54	0.09
	After 60 days	8.33	8.14	8.43	8.42	0.17
	After 90 days	8.58	8.39	8.63	8.72	0.17
E1. T2	Initial	8.3	8.27	8.35	8.28	0.04
	After 30 days	8.3	8.23	8.21	8.46	0.14
	After 60 days	8.02	7.94	7.99	8.12	0.09
	After 90 days	8.32	8.24	8.31	8.41	0.09
E1. T3	Initial	8.58	8.62	8.54	8.58	0.04
	After 30 days	8.6	8.54	8.63	8.63	0.05
	After 60 days	8.35	8.31	8.36	8.39	0.04

	After 90 days	8.62	8.63	8.58	8.65	0.04
E1.T4	Initial	7.94	8.01	7.92	7.89	0.06
	After 30 days	8.13	8.06	8.13	8.2	0.07
	After 60 days	8.30	8.33	8.30	8.27	0.03
	After 90 days	8.53	8.52	8.54	8.53	0.01
E1.T5	Initial	8.1	8.03	8.15	8.12	0.06
	After 30 days	8.13	8.1	8.15	8.14	0.03
	After 60 days	7.98	7.90	8.02	8.01	0.07
	After 90 days	8.15	8.06	8.17	8.22	0.08

EC changes of Experiment # 1

		Average	**Reading # 1**	**Reading # 2**	**Reading # 3**	**Standard Deviation**
E1.T1	Initial	2.25	2.28	2.18	2.29	0.06
	After 30 days	2.28	2.18	2.31	2.35	0.09
	After 60 days	2.23	2.27	2.21	2.22	0.03
	After 90 days	2.3	2.34	2.26	2.3	0.04
E1. T2	Initial	2.53	2.54	2.49	2.56	0.04
	After 30 days	2.58	2.56	2.53	2.65	0.06
	After 60 days	2.53	2.52	2.56	2.50	0.03
	After 90 days	2.62	2.61	2.66	2.59	0.04
E1. T3	Initial	2.88	2.89	2.83	2.92	0.05
	After 30 days	3.03	2.93	3.08	3.08	0.09
	After 60 days	3.02	2.93	3.10	3.05	0.09
	After 90 days	3.12	3.04	3.18	3.14	0.07
E1.T4	Initial	2.9	2.94	2.85	2.91	0.05
	After 30 days	2.96	2.91	2.97	3	0.05
	After 60 days	2.89	2.89	2.94	2.85	0.04

	After 90 days	2.97	2.95	3.02	2.94	0.04
E1.T5	Initial	2.39	2.41	2.37	2.39	0.02
	After 30 days	2.53	2.51	2.54	2.54	0.02
	After 60 days	2.55	2.57	2.53	2.54	0.02
	After 90 days	2.6	2.62	2.58	2.6	0.02

Temperature changes of Experiment # 2

E2.T1						
Days	**Mean daily temperature**	**Average**	**Reading # 1**	**Reading # 2**	**Reading # 3**	**Standard Deviation**
5	35	67.50	65.9	67.8	68.8	1.47
8	29	62.60	60.5	62.5	64.8	2.15
10	37	51.90	52.5	50.4	52.8	1.31
12	34	48.00	47.8	47.4	48.8	0.72
15	35	48.50	47.6	48.4	49.5	0.95
17	34	59.50	60.3	58.3	59.9	1.06
19	37	53.90	52.4	53.6	55.7	1.67
24	39	49.50	48.6	49.7	50.2	0.82
27	33	46.30	44.7	46.4	47.8	1.55
31	33	46.00	44.7	46.3	47	1.18
33	33	50.60	50.2	52.2	49.4	1.44
35	36	51.00	51.7	50.6	50.7	0.61
37	38	47.00	47.6	46.8	46.6	0.53
39	32	43.00	42.5	43.6	42.9	0.56
42	34	38.50	37.2	38.6	39.7	1.25
44	35	36.50	35.1	36.9	37.5	1.25
46	40	41	40	41.4	41.6	0.87
48	40	40.5	39.4	40.2	41.9	1.28
53	35	36.2	35.7	36.5	36.4	0.44
55	34	35.4	34.9	35.6	35.7	0.44
58	37	36.7	36.1	36.9	37.1	0.53
60	37	36.3	35.9	36.4	36.6	0.36
62	38	36.5	36.2	37.2	36.1	0.61
65	35	36.3	35.7	36.6	36.6	0.52
67	34	35.8	35.2	36.1	36.1	0.52
69	35	36.7	35.8	36.9	37.4	0.82
72	38	37.6	37.9	37.4	37.5	0.26
74	36	37.1	37.4	36.8	37.1	0.30
79	35	36.4	35.8	36.3	37.1	0.66
81	37	36.6	36.1	37.2	36.5	0.56
83	35	36.3	36.1	35.9	36.9	0.53

E2.T2						
Days	**Mean daily temperature**	**Average**	**Reading # 1**	**Reading # 2**	**Reading # 3**	**Standard Deviation**
5	35	66.6	65.1	67.3	67.4	1.30
8	29	61.4	60.9	62.7	60.6	1.14
10	37	50.4	49.2	51.8	50.2	1.31
12	34	51	50.3	52.6	50.1	1.39
15	35	50.4	48.3	50.7	52.2	1.97
17	34	55	54.3	56.8	53.9	1.57
19	37	51.6	50.2	51.8	52.8	1.31
24	39	51.7	52.3	53.3	49.5	1.97
27	33	50.2	49.2	50.5	50.9	0.89
31	33	45.6	44.2	45.9	46.7	1.28
33	33	49.7	49.2	50.8	49.1	0.95
35	36	45.9	44.3	46.8	46.6	1.39
37	38	44.7	43.6	45.5	45	0.98
39	32	42.4	41.2	43.9	42.1	1.37
42	34	36.7	35.3	36.9	37.9	1.31
44	35	35.8	34.9	36	36.5	0.82
46	40	40.3	40.7	40	40.2	0.36
48	40	40.8	41	40.2	41.2	0.53
53	35	35.2	35	35.5	35.1	0.26
55	34	35.2	34.6	35.4	35.6	0.53
58	37	36.5	37.4	36.7	35.4	1.01
60	37	36.9	37.3	36.2	37.2	0.61
62	38	37.3	37.8	36.9	37.2	0.46
65	35	35.5	35.2	35.8	35.5	0.30
67	34	34.7	34	35.5	34.6	0.75
69	35	36.1	35.3	36.4	36.6	0.70
72	38	37.4	38.2	36.4	37.6	0.92
74	36	36.4	36.3	37.7	35.2	1.25
79	35	36.1	35.3	36.1	36.9	0.80
81	37	36.7	36.9	35.4	37.8	1.21
83	35	35.3	35	34.8	36.1	0.70

E2.T3						
Days	**Mean daily temperature**	**Average**	**Reading # 1**	**Reading # 2**	**Reading # 3**	**Standard Deviation**
5	35	68.3	69.7	67.8	67.4	1.23
8	29	54.4	55.2	53.9	54.1	0.70
10	37	44.6	43.4	45.3	45.1	1.04
12	34	43.6	44.2	42.8	43.8	0.72
15	35	47.2	47.8	46.7	47.1	0.56
17	34	52.6	51.2	53.4	53.2	1.22
19	37	51.9	50.3	52.4	53	1.42
24	39	49.5	48.7	50.6	49.2	0.98
27	33	46.7	45.2	47.3	47.6	1.31
31	33	47	46.7	47.3	47	0.30
33	33	46.7	45.7	47.2	47.2	0.87
35	36	45.9	44.8	46.3	46.6	0.96
37	38	48.4	49.2	47.7	48.3	0.75
39	32	44.2	43.9	45.1	43.6	0.79
42	34	43.4	42.3	44.5	43.4	1.10
44	35	44	43.2	45.2	43.6	1.06
46	40	42	41.9	43.2	40.9	1.15
48	40	40.7	41.3	40.5	40.3	0.53
53	35	38.4	38.1	39.5	37.6	0.98
55	34	38.1	37.3	38.9	38.1	0.80
58	37	37.8	36.4	38.9	38.1	1.28
60	37	38.4	37.8	39.2	38.2	0.72
62	38	39.5	38.1	39.9	40.5	1.25
65	35	36.7	35	36.8	38.3	1.65
67	34	36.1	34.3	37.2	36.8	1.57
69	35	36.7	35.2	37.4	37.5	1.30
72	38	38.5	38.4	39	38.1	0.46
74	36	36.7	36.2	37.5	36.4	0.70
79	35	35.8	36.2	35.2	36	0.53
81	37	36.7	37.1	36.4	36.6	0.36
83	35	35.8	35.1	36.4	35.9	0.66

E2.T4						
Days	**Mean daily temperature**	**Average**	**Reading # 1**	**Reading # 2**	**Reading # 3**	**Standard Deviation**
5	35	67.6	66.2	67.9	68.7	1.28
8	29	62.3	63.2	60.3	63.4	1.73
10	37	48.2	49	46.8	48.8	1.22
12	34	46.9	45.1	47.5	48.1	1.59
15	35	49.3	50.7	47.9	49.3	1.40
17	34	57.5	58.2	55.9	58.4	1.39
19	37	54	55.3	53.3	53.4	1.13
24	39	53.4	54.8	52.7	52.7	1.21
27	33	51.3	52.9	50.8	50.2	1.42
31	33	47.4	46.3	47.9	48	0.95
33	33	48	46.6	48.4	49	1.25
35	36	46.5	48.2	46	45.3	1.51
37	38	47.5	47.2	46.4	48.9	1.28
39	32	44.5	45.8	44.2	43.5	1.18
42	34	41.6	40.4	41.9	42.5	1.08
44	35	40.3	40	40.6	40.3	0.30
46	40	40	40.5	39.3	40.2	0.62
48	40	39.8	40	39.3	40.1	0.44
53	35	38	38.2	37.8	38	0.20
55	34	36.5	36	37.3	36.2	0.70
58	37	37.8	38.6	37.1	37.7	0.75
60	37	37	36.8	37.4	36.8	0.35
62	38	38.6	38	38.9	38.9	0.52
65	35	35.3	35.1	35.7	35.1	0.35
67	34	35.4	34.8	36	35.4	0.60
69	35	36.1	36	36.8	35.5	0.66
72	38	37.5	37.2	37.9	37.4	0.36
74	36	37.3	36.8	37.4	37.7	0.46
79	35	36.9	37	36.2	37.5	0.66
81	37	37.3	37.5	36.4	38	0.82
83	35	36.1	36	36.4	35.9	0.26

E2.T5						
Days	**Mean daily temperature**	**Average**	**Reading # 1**	**Reading # 2**	**Reading # 3**	**Standard Deviation**
5	35	68.4	69	67.4	68.8	0.87
8	29	64	63.2	65.3	63.5	1.14
10	37	49	48.3	49.9	48.8	0.82
12	34	52	50.8	53.2	52	1.20
15	35	52.7	54.3	51.6	52.2	1.42
17	34	61.4	61.6	62.9	59.7	1.61
19	37	53.2	52.5	54.7	52.4	1.30
24	39	47	48.8	46.4	45.8	1.59
27	33	45.2	44.6	45.8	45.2	0.60
31	33	42.5	40.8	42.5	44.2	1.70
33	33	43.4	41.8	43.8	44.6	1.44
35	36	48	47.2	48.9	47.9	0.85
37	38	48	47.5	49.2	47.3	1.04
39	32	39.9	38.2	40.6	40.9	1.48
42	34	39.7	38.2	40.6	40.3	1.31
44	35	39.9	41.3	39.5	38.9	1.25
46	40	40	38.9	40.7	40.4	0.96
48	40	40.6	39.6	40.3	41.9	1.18
53	35	39.5	38.9	39.7	39.9	0.53
55	34	38.3	38	39.2	37.7	0.79
58	37	39.2	38.9	39.4	39.3	0.26
60	37	38.9	37.5	39.4	39.8	1.23
62	38	38.5	38	38.9	38.6	0.46
65	35	37.4	36.8	37.9	37.5	0.56
67	34	36.5	35.8	36.8	36.9	0.61
69	35	37.1	36.5	37.4	37.4	0.52
72	38	39.8	40.4	39.5	39.5	0.52
74	36	37.4	36.5	38	37.7	0.79
79	35	36.8	35.6	36.8	38	1.20
81	37	37.8	37.3	38.5	37.6	0.62
83	35	36.3	35.8	36.3	36.8	0.50

E2.T6						
Days	**Mean daily temperature**	**Average**	**Reading # 1**	**Reading # 2**	**Reading # 3**	**Standard Deviation**
5	35	68.5	69.3	67.5	68.7	0.92
8	29	65.6	64.8	66.3	65.7	0.75
10	37	52.7	51.3	53.5	53.3	1.22
12	34	58.6	57.4	59.3	59.1	1.04
15	35	55.2	54.3	55.9	55.4	0.82
17	34	58.6	57.3	59	59.5	1.15
19	37	47.8	47.2	48.7	47.5	0.79
24	39	45.7	44.5	46.4	46.2	1.04
27	33	44.4	43.2	45.1	44.9	1.04
31	33	48	47.3	48.6	48.1	0.66
33	33	47.6	46.3	48.6	47.9	1.18
35	36	49.5	49.3	50.7	48.5	1.11
37	38	50.8	49.3	51.4	51.7	1.31
39	32	41.6	40.3	42.3	42.2	1.13
42	34	40	39.4	40.6	40	0.60
44	35	37.6	36.2	38.4	38.2	1.22
46	40	40	40	39.3	40.7	0.70
48	40	40.6	39.2	41.2	41.4	1.22
53	35	37.4	36.5	37.5	38.2	0.85
55	34	36.3	35.7	36.5	36.7	0.53
58	37	38.7	37.2	38.8	40.1	1.45
60	37	39.1	38.5	39.5	39.3	0.53
62	38	39.5	38.2	40.5	39.8	1.18
65	35	37.6	36.5	38.5	37.8	1.01
67	34	36.3	35.6	37.4	35.9	0.96
69	35	37.2	36.2	38.6	36.8	1.25
72	38	38.6	37.4	39.4	39	1.06
74	36	37	36.2	37.6	37.2	0.72
79	35	36.8	35.6	37.5	37.3	1.04
81	37	37.6	36.5	38.4	37.9	0.98
83	35	36.4	35.4	37.4	36.4	1.00

E2.T7						
Days	**Mean daily temperature**	**Average**	**Reading # 1**	**Reading # 2**	**Reading # 3**	**Standard Deviation**
5	35	61	60.4	62.6	60	1.40
8	29	54	53.2	55.6	53.2	1.39
10	37	45	46.8	44.3	43.9	1.57
12	34	40.1	39.4	41.2	39.7	0.96
15	35	41.1	42.4	40.5	40.4	1.13
17	34	52	53.4	51.3	51.3	1.21
19	37	51.7	50.1	52.3	52.7	1.40
24	39	49.7	48.2	50.5	50.4	1.30
27	33	45	44.2	46.7	44.1	1.47
31	33	43	42.8	43.6	42.6	0.53
33	33	40.5	41.3	39.8	40.4	0.75
35	36	41.6	39.6	42.2	43	1.78
37	38	43.4	44.2	42.6	43.4	0.80
39	32	38	37.4	38.7	37.9	0.66
42	34	37.9	38.8	36.3	38.6	1.39
44	35	36.6	35.2	37.3	37.3	1.21
46	40	39.6	40.7	38.4	39.7	1.15
48	40	39.3	40.1	37.9	39.9	1.22
53	35	36.4	35.3	36.5	37.4	1.05
55	34	35.8	34.3	36.4	36.7	1.31
58	37	37.4	36.3	38.1	37.8	0.96
60	37	37.2	36.9	38.5	36.2	1.18
62	38	38.6	37.2	39.2	39.4	1.22
65	35	36.7	35.4	36.9	37.8	1.21
67	34	35.5	34	35.9	36.6	1.35
69	35	36.7	36	37.5	36.6	0.75
72	38	39.5	40	37.8	40.7	1.51
74	36	37.6	36.7	38.9	37.2	1.15
79	35	36.4	36	37.2	36	0.69
81	37	36.5	37.2	36.4	35.9	0.66
83	35	36.1	36	35.4	36.9	0.75

E2.T8						
Days	**Mean daily temperature**	**Average**	**Reading # 1**	**Reading # 2**	**Reading # 3**	**Standard Deviation**
5	35	63.8	64.5	62.8	64.1	0.89
8	29	61	62.3	60.5	60.2	1.14
10	37	58.6	59.8	58.1	57.9	1.04
12	34	54.4	53.2	55.9	54.1	1.37
15	35	50.4	51.6	49.7	49.9	1.04
17	34	62.6	63.6	61.8	62.4	0.92
19	37	54.4	53.8	55.6	53.8	1.04
24	39	50.8	50.3	51.8	50.3	0.87
27	33	48.5	47.4	49.2	48.9	0.96
31	33	47.7	46.3	48.5	48.3	1.22
33	33	41.2	40.2	42.3	41.1	1.05
35	36	44	43.6	44.5	43.9	0.46
37	38	46.4	45.6	47.5	46.1	0.98
39	32	41.4	42.3	40.7	41.2	0.82
42	34	37.8	38.9	37	37.5	0.98
44	35	37.4	36.5	38.5	37.2	1.01
46	40	40.5	39.8	40.7	41	0.62
48	40	41	40.2	41.4	41.4	0.69
53	35	36.4	37.5	36	35.7	0.96
55	34	35.2	36.3	35	34.3	1.01
58	37	36.9	37.1	36.4	37.2	0.44
60	37	36.2	36	37.5	35.1	1.21
62	38	36.8	37.9	36	36.5	0.98
65	35	36.4	35.4	36.5	37.3	0.95
67	34	35.7	34.8	36.4	35.9	0.82
69	35	36.8	35.5	37	37.9	1.21
72	38	37.5	38.1	37.3	37.1	0.53
74	36	37.2	36.8	37.5	37.3	0.36
79	35	36.3	35.3	36.4	37.2	0.95
81	37	36.9	37.2	36.4	37.1	0.44
83	35	36.2	35.4	36.8	36.4	0.72

E2.T9						
Days	**Mean daily temperature**	**Average**	**Reading # 1**	**Reading # 2**	**Reading # 3**	**Standard Deviation**
5	35	66.7	67.8	66	66.3	0.96
8	29	58	57.4	58.8	57.8	0.72
10	37	49.6	48.3	50.2	50.3	1.13
12	34	46.4	45.3	46.7	47.2	0.98
15	35	46.6	45.4	47.7	46.7	1.15
17	34	54.4	53.2	55.7	54.3	1.25
19	37	53.6	52.4	54.5	53.9	1.08
24	39	48.6	47.8	49.4	48.6	0.80
27	33	47.2	46.4	47.7	47.5	0.70
31	33	41	40.3	42.3	40.4	1.13
33	33	43.3	43	44.2	42.7	0.79
35	36	40.6	41.7	39.7	40.4	1.01
37	38	44	43.2	44.8	44	0.80
39	32	36.1	35.4	36.8	36.1	0.70
42	34	39.8	40.1	39.4	39.9	0.36
44	35	40.3	41.2	40.8	38.9	1.23
46	40	40.6	40.3	41.2	40.3	0.52
48	40	40.5	39.6	40.8	41.1	0.79
53	35	37.3	38.6	37	36.3	1.18
55	34	36.6	36.7	36	37.1	0.56
58	37	38.6	37.6	38.7	39.5	0.95
60	37	39.4	38.2	39.8	40.2	1.06
62	38	39.2	38.2	39.7	39.7	0.87
65	35	37.4	36.5	37.8	37.9	0.78
67	34	36.2	35.7	36.5	36.4	0.44
69	35	37.1	36.4	37.8	37.1	0.70
72	38	38.4	39.7	37.6	37.9	1.14
74	36	37.2	36.5	37.8	37.3	0.66
79	35	36.3	35.4	36.8	36.7	0.78
81	37	37.9	36.3	38.7	38.7	1.39
83	35	36.7	35.4	37.1	37.6	1.15

%OM changes of Experiment # 2

		Average	Reading # 1	Reading # 2	Reading # 3	Standard Deviation
E2.T1	Initial	61.2	60.4	62.1	61.1	0.85
	After 30 days	55.3	54.5	56.7	54.7	1.22
	After 60 days	37.5	36.5	38.2	37.8	0.89
E2. T2	Initial	66.21	65.6	67.4	65.63	1.03
	After 30 days	56.41	55.7	57.2	56.33	0.75
	After 60 days	38.76	37.6	39.4	39.28	1.01
E2. T3	Initial	62.14	61.7	63.4	61.32	1.11
	After 30 days	54.11	53.7	55.2	53.43	0.95
	After 60 days	35.16	34.5	35.9	35.08	0.70
E2.T4	Initial	63.22	62.8	64.3	62.56	0.94
	After 30 days	60.3	59.4	61.2	60.3	0.90
	After 60 days	36.63	35.9	37.2	36.79	0.66
E2.T5	Initial	68.11	67.7	68.8	67.83	0.60
	After 30 days	58.3	57.2	58.2	59.5	1.15
	After 90 days	38.2	37.1	39.3	38.2	1.10
E2.T6	Initial	65.33	64.8	66.2	64.99	0.76
	After 30 days	51.2	50.3	51.9	51.4	0.82
	After 60 days	35.24	34.1	36.2	35.42	1.06
E2.T7	Initial	63.11	62.9	63.7	62.73	0.52
	After 30 days	52.4	51.9	52.8	52.5	0.46
	After 90 days	44.16	43.6	45.8	43.08	1.44
E2.T8	Initial	67.2	66.5	68.2	66.9	0.89
	After 30 days	58.31	57.8	58.9	58.23	0.55
	After 60 days	42.68	41.3	43.3	43.44	1.20
E2.T9	Initial	60.11	60.2	61.6	58.53	1.54
	After 30 days	51.3	52.4	50.4	51.1	1.01
	After 60 days	36.57	36.2	37.4	36.11	0.72

One-way ANOVA

%OM					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	238.158	8	29.770	29.401	.000
Within Groups	18.226	18	1.013		
Total	256.384	26			

The ANOVA results indicate that the p-value is less than the significance level; therefore, the null hypothesis is rejected, and it can be concluded that there is a significant difference between the means. This indicates that each additive has a different effect on the compost pile in terms of organic matter.

%OC changes of Experiment # 2

		Average	**Reading # 1**	**Reading # 2**	**Reading # 3**	**Standard Deviation**
E2.T1	Initial	35.50	35.03	36.02	35.44	0.50
	After 30 days	32.07	31.61	32.89	31.73	0.71
	After 60 days	21.75	21.17	22.16	21.92	0.52
E2. T2	Initial	38.40	38.05	39.09	38.07	0.60
	After 30 days	32.72	32.31	33.18	32.67	0.44
	After 60 days	22.48	21.81	22.85	22.78	0.58
E2. T3	Initial	36.04	35.79	36.77	35.57	0.64
	After 30 days	31.38	31.15	32.02	30.99	0.55
	After 60 days	20.39	20.01	20.82	20.35	0.41
E2.T4	Initial	36.67	36.42	37.29	36.29	0.55
	After 30 days	34.97	34.45	35.50	34.97	0.52
	After 60 days	21.25	20.82	21.58	21.34	0.39
E2.T5	Initial	39.50	39.27	39.90	39.34	0.35
	After 30 days	33.81	33.18	33.76	34.51	0.67
	After 60 days	22.16	21.52	22.79	22.16	0.64
E2.T6	Initial	37.89	37.58	38.40	37.70	0.44
	After 30 days	29.70	29.17	30.10	29.81	0.47

	After 60 days	20.44	19.78	21.00	20.54	0.62
E2.T7	Initial	36.60	36.48	36.95	36.38	0.30
	After 30 days	30.39	30.10	30.62	30.45	0.27
	After 60 days	25.61	25.29	26.56	24.99	0.84
E2.T8	Initial	38.98	38.57	39.56	38.80	0.52
	After 30 days	33.82	33.52	34.16	33.77	0.32
	After 60 days	24.75	23.95	25.11	25.20	0.69
E2.T9	Initial	34.86	34.92	35.73	33.95	0.89
	After 30 days	29.75	30.39	29.23	29.64	0.59
	After 60 days	21.21	21.00	21.69	20.94	0.42

%TN changes of Experiment # 2

		Average	**Reading # 1**	**Reading # 2**	**Reading # 3**	**Standard Deviation**
E2.T1	Initial	0.95	0.93	0.98	0.94	0.026
	After 30 days	1.11	1.02	1.18	1.13	0.082
	After 60 days	1.22	1.24	1.19	1.23	0.026
E2. T2	Initial	1.13	1.02	1.29	1.08	0.142
	After 30 days	1.32	1.23	1.41	1.32	0.090
	After 60 days	1.55	1.51	1.69	1.45	0.125
E2. T3	Initial	0.87	0.81	0.96	0.84	0.079
	After 30 days	1	1.03	0.92	1.05	0.070
	After 60 days	1.09	1.14	1.03	1.1	0.056
E2.T4	Initial	0.98	0.92	1.15	0.87	0.149
	After 30 days	1.12	1.04	1.17	1.15	0.070
	After 60 days	1.29	1.22	1.36	1.29	0.070
E2.T5	Initial	1.11	1.02	1.17	1.14	0.079
	After 30 days	1.16	1.04	1.23	1.21	0.104
	After 60 days	1.21	1.13	1.28	1.22	0.075
E2.T6	Initial	0.91	0.98	0.84	0.91	0.070

	After 30 days	1.25	1.23	1.34	1.18	0.082
	After 60 days	1.35	1.24	1.39	1.42	0.096
E2.T7	Initial	1.1	1.03	1.18	1.09	0.075
	After 30 days	1.17	1.26	1.05	1.2	0.108
	After 60 days	1.22	1.19	1.28	1.19	0.052
E2.T8	Initial	1.21	1.13	1.28	1.22	0.075
	After 30 days	1.31	1.23	1.37	1.33	0.072
	After 60 days	1.42	1.37	1.46	1.43	0.046
E2.T9	Initial	0.85	0.82	0.97	0.76	0.108
	After 30 days	1	0.93	1.04	1.03	0.061
	After 60 days	1.01	0.92	1.16	0.95	0.131

One Way ANOVA

%TN

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.647	8	.081	11.898	.000
Within Groups	.122	18	.007		
Total	.770	26			

The ANOVA results indicate that the p-value is less than the significance level; therefore, the null hypothesis is rejected, and it can be concluded that there is a significant difference between the means. This indicates that each additive has a different effect on the compost pile in terms of TN.

%NH_4^+ changes of Experiment # 2

		Average	**Reading # 1**	**Reading # 2**	**Reading # 3**	**Standard Deviation**
E2.T1	Initial	310	311	308	311	1.73
	After 30 days	150	151	149	150	1.00
	After 60 days	38	37	41	36	2.65
E2. T2	Initial	425	427	424	424	1.73
	After 30 days	335	334	336	335	1.00
	After 60 days	29	27	31	29	2.00
E2. T3	Initial	159	161	159	157	2.00

	After 30 days	110	112	110	108	2.00
	After 60 days	38	37	39	38	1.00
E2.T4	Initial	480	481	478	481	1.73
	After 30 days	390	391	390	389	1.00
	After 60 days	29	28	31	28	1.73
E2.T5	Initial	129	121	118	148	16.52
	After 30 days	91	91	90	92	1.00
	After 60 days	28	26	29	29	1.73
E2.T6	Initial	295	295	294	296	1.00
	After 30 days	211	213	210	210	1.73
	After 60 days	38	38	40	36	2.00
E2.T7	Initial	190	191	189	190	1.00
	After 30 days	95	94	97	94	1.73
	After 60 days	30	29	32	29	1.73
E2.T8	Initial	432	432	433	431	1.00
	After 30 days	155	154	157	154	1.73
	After 60 days	39	38	39	40	1.00
E2.T9	Initial	240	242	240	238	2.00
	After 30 days	190	190	191	189	1.00
	After 60 days	38	37	39	38	1.00

%NO_3^- changes of Experiment # 2

		Average	**Reading # 1**	**Reading # 2**	**Reading # 3**	**Standard Deviation**
E2.T1	Initial	20	19	21	20	1.00
	After 30 days	26	25	28	25	1.73
	After 60 days	98	97	101	96	2.65
E2. T2	Initial	13	12	13	14	1.00
	After 30 days	118	119	116	119	1.73

	After 60 days	130	128	131	131	1.73
E2. T3	Initial	9	11	8	8	1.73
	After 30 days	35	34	36	35	1.00
	After 60 days	315	313	315	317	2.00
E2.T4	Initial	15	13	16	16	1.73
	After 30 days	75	74	75	76	1.00
	After 60 days	86	85	87	86	1.00
E2.T5	Initial	22	23	20	23	1.73
	After 30 days	65	63	65	67	2.00
	After 60 days	130	132	128	130	2.00
E2.T6	Initial	26	25	26	27	1.00
	After 30 days	166	164	166	168	2.00
	After 60 days	462	461	463	462	1.00
E2.T7	Initial	10	9	12	9	1.73
	After 30 days	55	53	56	56	1.73
	After 60 days	77	78	75	78	1.73
E2.T8	Initial	25	25	26	24	1.00
	After 30 days	140	142	141	137	2.65
	After 60 days	152	152	154	150	2.00
E2.T9	Initial	13	12	13	14	1.00
	After 30 days	55	54	57	54	1.73
	After 60 days	224	223	224	225	1.00

%TP changes of Experiment # 2

		Average	**Reading # 1**	**Reading # 2**	**Reading # 3**	**Standard Deviation**
E2.T1	Initial	0.75	0.67	0.84	0.74	0.085
	After 30 days	0.87	0.74	0.96	0.91	0.115
	After 90 days	0.92	0.85	0.98	0.93	0.066
E2. T2	Initial	0.73	0.62	0.79	0.78	0.095

	After 30 days	0.81	0.76	0.87	0.8	0.056
	After 60 days	0.88	0.73	0.94	0.97	0.131
E2. T3	Initial	0.78	0.63	0.85	0.86	0.130
	After 30 days	0.91	0.83	0.96	0.94	0.070
	After 60 days	1.09	1.13	0.96	1.18	0.115
E2.T4	Initial	0.82	0.75	0.93	0.78	0.096
	After 30 days	0.91	0.83	0.98	0.92	0.075
	After 60 days	0.98	1.09	0.86	0.99	0.115
E2.T5	Initial	0.9	0.82	0.97	0.91	0.075
	After 30 days	1.13	1.18	1.03	1.18	0.087
	After 60 days	1.15	1.18	1.04	1.23	0.098
E2.T6	Initial	0.82	0.76	0.94	0.76	0.104
	After 30 days	0.94	0.83	1.04	0.95	0.105
	After 60 days	1.12	1.05	1.18	1.13	0.066
E2.T7	Initial	0.63	0.54	0.72	0.63	0.090
	After 30 days	0.75	0.63	0.84	0.78	0.108
	After 60 days	0.81	0.76	0.93	0.74	0.104
E2.T8	Initial	0.85	0.76	0.92	0.87	0.082
	After 30 days	0.91	0.82	0.98	0.93	0.082
	After 60 days	1.08	0.94	1.14	1.16	0.122
E2.T9	Initial	0.72	0.63	0.85	0.68	0.115
	After 30 days	0.84	0.75	0.92	0.85	0.085
	After 90 days	0.91	0.81	0.97	0.95	0.087

One-way ANOVA

%TP					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.349	8	.044	4.122	.006
Within Groups	.191	18	.011		
Total	.540	26			

The ANOVA results indicate that the p-value is less than the significance level; therefore, the null hypothesis is rejected, and it can be concluded that there is a significant difference between the means. This indicates that each additive has a different effect on the compost pile in terms of TP.

%TK changes of Experiment # 2

		Average	**Reading # 1**	**Reading # 2**	**Reading # 3**	**Standard Deviation**
E2.T1	Initial	0.45	0.32	0.48	0.55	0.118
	After 30 days	0.8	0.73	0.87	0.8	0.070
	After 60 days	0.98	0.86	1.03	1.05	0.104
E2. T2	Initial	0.51	0.43	0.58	0.52	0.075
	After 30 days	0.85	0.72	0.97	0.86	0.125
	After 60 days	0.91	0.85	0.98	0.9	0.066
E2. T3	Initial	1.07	0.97	1.12	1.12	0.087
	After 30 days	1.18	1.03	1.23	1.28	0.132
	After 60 days	1.3	1.22	1.38	1.3	0.080
E2.T4	Initial	0.51	0.45	0.59	0.49	0.072
	After 30 days	0.65	0.57	0.73	0.65	0.080
	After 60 days	1.14	1.03	1.18	1.21	0.096
E2.T5	Initial	0.63	0.56	0.68	0.65	0.062
	After 30 days	0.87	0.73	0.94	0.94	0.121
	After 60 days	1.13	1.17	1.02	1.2	0.096
E2.T6	Initial	1.12	1.03	1.16	1.17	0.078
	After 60 days	1.23	1.28	1.13	1.28	0.087

	After 60 days	1.6	1.57	1.69	1.54	0.079
E2.T7	Initial	0.63	0.54	0.68	0.67	0.078
	After 30 days	0.7	0.63	0.77	0.7	0.070
	After 60 days	0.82	0.73	0.86	0.87	0.078
E2.T8	Initial	0.49	0.33	0.57	0.57	0.139
	After 30 days	0.72	0.62	0.84	0.7	0.111
	After 60 days	0.79	0.67	0.85	0.85	0.104
E2.T9	Initial	0.71	0.61	0.74	0.78	0.089
	After 30 days	0.82	0.73	0.88	0.85	0.079
	After 60 days	0.94	0.83	1.02	0.97	0.098

One-way ANOVA

%TK					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1.601	8	.200	24.643	.000
Within Groups	.146	18	.008		
Total	1.747	26			

The ANOVA results indicate that the p-value is less than the significance level; therefore, the null hypothesis is rejected, and it can be concluded that there is a significant difference between the means. This indicates that each additive has a different effect on the compost pile in terms of TK.

Moisture Content changes of Experiment # 2

		Average	**Reading # 1**	**Reading # 2**	**Reading # 3**	**Standard Deviation**
E2.T1	Initial	65	64	64	67	1.73
	After 30 days	63	63	62	64	1.00
	After 60 days	32	31	33	32	1.00
E2. T2	Initial	65	64	62	69	3.61
	After 30 days	62	62	61	63	1.00
	After 60 days	33	31	34	34	1.73
E2. T3	Initial	65	63	65	67	2.00

	After 30 days	60	59	62	59	1.73
	After 60 days	32	32	33	31	1.00
E2.T4	Initial	65	65	63	67	2.00
	After 30 days	61	58	61	64	3.00
	After 60 days	35	34	33	38	2.65
E2.T5	Initial	63	61	64	64	1.73
	After 30 days	66	64	68	66	2.00
	After 60 days	35	32	35	38	3.00
E2.T6	Initial	67	66	69	66	1.73
	After 30 days	63	61	64	64	1.73
	After 60 days	38	39	36	39	1.73
E2.T7	Initial	60	58	60	62	2.00
	After 30 days	67	66	67	68	1.00
	After 60 days	33	31	32	36	2.65
E2.T8	Initial	65	64	66	65	1.00
	After 30 days	60	58	57	65	4.36
	After 60 days	30	28	31	31	1.73
E2.T9	Initial	66	67	65	66	1.00
	After 30 days	59	58	60	59	1.00
	After 60 days	34	32	35	35	1.73

Bulk Density changes of Experiment # 2

		Average	**Reading # 1**	**Reading # 2**	**Reading # 3**	**Standard Deviation**
E2.T1	Initial	285	287	288	280	4.36
	After 30 days	340	342	341	337	2.65
	After 60 days	445	445	443	447	2.00
E2. T2	Initial	320	321	320	319	1.00
	After 30 days	450	451	452	447	2.65

	After 60 days	533	532	531	536	2.65
E2. T3	Initial	300	302	298	300	2.00
	After 30 days	340	342	340	338	2.00
	After 60 days	470	468	471	471	1.73
E2.T4	Initial	210	208	211	211	1.73
	After 30 days	330	332	331	327	2.65
	After 60 days	420	421	418	421	1.73
E2.T5	Initial	290	288	291	291	1.73
	After 30 days	417	412	416	422	5.03
	After 60 days	436	435	437	436	1.00
E2.T6	Initial	280	281	278	281	1.73
	After 30 days	350	352	351	347	2.65
	After 60 days	480	481	478	481	1.73
E2.T7	Initial	210	209	212	209	1.73
	After 30 days	280	278	282	280	2.00
	After 60 days	394	392	398	392	3.46
E2.T8	Initial	220	220	222	218	2.00
	After 30 days	380	378	383	379	2.65
	After 60 days	452	451	452	453	1.00
E2.T9	Initial	270	272	275	263	6.24
	After 30 days	330	329	331	330	1.00
	After 60 days	466	465	467	466	1.00

One-Way ANOVA

Bulk Density

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	47412.667	8	5926.583	1523.979	.000
Within Groups	70.000	18	3.889		
Total	47482.667	26			

The ANOVA results indicate that the p-value is less than the significance level; therefore, the null hypothesis is rejected, and it can be concluded that there is a significant difference between the means. This indicates that each additive has a different effect on the compost pile in terms of bulk density.

EC changes of Experiment # 2

		Average	Reading # 1	Reading # 2	Reading # 3	Standard Deviation
E2.T1	Initial	2.2	2.19	2.24	2.17	0.036
	After 30 days	2.55	2.46	2.53	2.66	0.101
	After 60 days	2.89	3.01	2.93	2.73	0.144
E2. T2	Initial	1.8	1.77	1.83	1.8	0.030
	After 30 days	2.14	2.15	2.12	2.15	0.017
	After 60 days	2.12	2.02	2.16	2.18	0.087
E2. T3	Initial	2.02	1.98	2.15	1.93	0.115
	After 30 days	2.09	2.04	2.13	2.1	0.046
	After 60 days	2.13	2.14	2.09	2.16	0.036
E2.T4	Initial	2.11	2.07	2.11	2.15	0.040
	After 30 days	2.85	2.83	2.88	2.84	0.026
	After 60 days	3.01	2.98	3.05	3	0.036
E2.T5	Initial	2.14	2.07	2.19	2.16	0.062
	After 30 days	2.22	2.14	2.27	2.25	0.070
	After 60 days	2.28	2.23	2.31	2.3	0.044
E2.T6	Initial	2.11	2.11	2.1	2.12	0.010
	After 30 days	2.15	2.16	2.14	2.15	0.010
	After 60 days	2.2	2.19	2.24	2.17	0.036
E2.T7	Initial	2.68	2.56	2.71	2.77	0.108
	After 30 days	2.72	2.68	2.74	2.74	0.035
	After 60 days	2.81	2.76	2.82	2.85	0.046
E2.T8	Initial	1.19	1.23	1.26	1.08	0.096
	After 30 days	1.7	1.72	1.66	1.72	0.035

	After 60 days	2.01	1.97	2.02	2.04	0.036
E2.T9	Initial	1.98	2.03	2.01	1.9	0.070
	After 30 days	2.03	1.99	2.06	2.04	0.036
	After 60 days	2.07	2.06	2.08	2.07	0.010

pH changes of Experiment # 2

		Average	Reading # 1	Reading # 2	Reading # 3	Standard Deviation
E2.T1	Initial	7.77	7.75	7.82	7.74	0.044
	After 30 days	7.95	7.91	7.98	7.96	0.036
	After 60 days	7.74	7.71	7.76	7.75	0.026
E2. T2	Initial	8.15	8.04	8.19	8.22	0.096
	After 30 days	7.91	7.92	7.86	7.95	0.046
	After 60 days	8.29	8.19	8.34	8.34	0.087
E2. T3	Initial	8.1	8.03	8.19	8.08	0.082
	After 30 days	8.31	8.27	8.36	8.3	0.046
	After 60 days	8.5	8.42	8.59	8.49	0.085
E2.T4	Initial	7.91	7.87	7.96	7.9	0.046
	After 30 days	8.11	8.04	8.17	8.12	0.066
	After 60 days	8.49	8.36	8.53	8.58	0.115
E2.T5	Initial	8.06	7.89	8.14	8.15	0.147
	After 30 days	8.21	8.21	8.17	8.25	0.040
	After 60 days	8.49	8.36	8.49	8.62	0.130
E2.T6	Initial	7.95	7.91	7.99	7.95	0.040
	After 30 days	8.11	8.02	8.15	8.16	0.078
	After 60 days	8.43	8.42	8.43	8.44	0.010
E2.T7	Initial	7.88	7.84	7.93	7.87	0.046
	After 30 days	8.31	8.31	8.29	8.33	0.020
	After 60 days	8.28	8.28	8.25	8.31	0.030
E2.T8	Initial	7.6	7.62	7.58	7.6	0.020

	After 30 days	8.29	8.31	8.25	8.31	0.035
	After 60 days	8.12	8.11	8.16	8.09	0.036
E2.T9	Initial	7.65	7.62	7.67	7.66	0.026
	After 30 days	8.4	8.41	8.37	8.42	0.026
	After 60 days	8.69	8.67	8.73	8.67	0.035