MANAGEMENT OF URBAN ORGANIC WASTE INTEGRATING COMPOSTING, CIRCULAR ECONOMY AND SOCIO-ECONOMICS

A Thesis Submitted
in Partial Fulfillment of the Requirements for the Degree of

DOCTOR OF PHLOSOPHY
by

MAJED IBRAHIM ISSA AL-SARI’
(Roll No. 2K20/PHDEN/505)

`

Under the supervision of
Prof. A. K. HARITASH
Delhi Technological University

DEPARTMENT OF ENVIRONMENTAL ENGINEERING

DELHI TECHNOLOGICAL UNIVERSITY
(Formerly Delhi College of Engineering)
Shahbad Daulatpur, Main Bawana Road, Delhi-110042, India

February, 2025

AKNOWLEDGEMENTS

I would like to express my deep gratitude and appreciation to my supervisor Professor A. K. Haritash, head of environmental engineering department, for his valuable guidance during my Ph.D. research work. I am thankful from the deep of my heart for all the encouragement, help, and support he generously extended to me.

Many thanks to Dr. S. D. Attri, Prof. Mukesh Khare, Dr. Rajeev Kumar Meshra, and Prof. Raju Sarkar for serving my SRC committee, efforts, and critical help which enabled me to complete my thesis on time.

My sincere thanks to all of the faculty and staff members of the Environmental Engineering Department at Delhi Technological University for their support during my entire research work.

I am thankful to my colleagues and friends for the shared experiences and moral support, which have helped me stay motivated and focused during the challenging times. I am especially thankful to my family for their endless patience and encouragement. Their belief in me has been my strength throughout this journey. To everyone who has contributed, directly or indirectly, to the successful completion of this thesis, I offer my heartfelt appreciation.

Majed Ibrahim Issa Al-Sari'

DELHI TECHNOLOGICAL UNIVERSITY
(Formerly Delhi College of Engineering)
Shahbad Daulatpur, Main Bawana Road, Delhi-42

CANDIDATE’S DECLARATION

I, Majed Ibrahim Issa Al-Sari’, hereby certify that the work which is being presented in the thesis entitled “**Management of Urban Organic Waste Integrating Composting, Circular Economy and Socio-economics**” in partial fulfillment of the requirements for the award of the Degree of Doctor of Philosophy, submitted in the Department of Environmental Engineering, Delhi Technological University is an authentic record of my own work carried out during the period from February 2021 to November 2024 under the supervision of Prof. A. K. Haritash, Department of Environmental Engineering, Delhi Technological University.

The matter presented in the thesis has not been submitted by me for the award of any other degree of this or any other institute.

Majed Ibrahim Issa Al-Sari’

DELHI TECHNOLOGICAL UNIVERSITY
(Formerly Delhi College of Engineering)
Shahbad Daulatpur, Main Bawana Road, Delhi-42

CERTIFICATE BY THE SUPERVISOR

Certified that **Majed Ibrahim Issa Al-Sari'** (2K20/PHDEN/505) has carried out the research work presented in this thesis entitled **"Management of Urban Organic Waste Integrating Composting, Circular Economy and Socio-economics"** for the award of **Doctor of Philosophy** from Department of Environmental Engineering, Delhi Technological University, Delhi, under my supervision. The thesis embodies results of original work, and studies are carried out by the student himself and the contents of the thesis do not form the basis for the award of any other degree to the candidate or to anybody else from this or any other University/Institution.

Dr. A. K. Haritash

Professor,
Department of Environmental Engineering
Delhi Technological University
Delhi, India

Date:

ABSTRACT

This research focused on management of organic waste considering composting, circular economy and socio-economics. The study area was southern West Bank/Palestine, mainly Hebron and Bethlehem governorates. The study utilized data from the literature, data collection via questionnaire, and experimental part.

The role of compost in the circular economy through the period extended from 2021 and up to 2035 was studied considering two scenarios: use of compost for agricultural purposes, and use as landfill cover materials. For agricultural purposes, and due to the strict restriction on access to high quality fertilizers by the Israeli Occupation, compost can be used as an alternative fertilizer where nutrients in compost can replace the existing chemical fertilizers available in Palestine such as humic acid (Iperen Humic 12+3 liquid) as source of carbon (C), Ammonium Sulphate (AS) source of nitrogen (N), Triple Super Phosphate (TSP) source of P, and Potassium Phosphate (SOP) source of Potassium (K). Replacement of chemical fertilizers can achieve financial benefit in addition to the environmental benefit through reduction of methane gas emissions and accordingly the saving as per the Clean Development Mechanism (CDM). Moreover, the tipping fees for waste landfilling are saved in addition to the landfill space.

The socio-economic factors were also studied to assess the attitude of the local authorities (LAs) towards composting of organic waste through data collection via structured questionnaire from all LAs in the study area through face-to-face interview, through email and over phone. The data so obtained analyzed using descriptive statistics, bivariate analysis, and binary logistic regression model (LRM).

The experimental part of the study focused on the design, test and evaluate two composting systems in two different climate regions, India and Palestine. A new composting forced-aerated device was designed and used in Palestine, and a steel mesh naturally-aerated composting bin was used in India. the operational parameters were monitored and controlled during the composting process, and physio-chemical and biological parameters were tested to evaluate the end quality of the produced composts.

The results of the research on the compost's role in the circular economy showed that the estimated revenue from compost use in agriculture is USD 194.8 million in 2021 and USD 369.8 million in 2035. The estimated saving from using compost as landfill cover is estimated USD 0.876 million annually, and USD 13.14 million during the 15 years' study period. The use for agricultural purposes is preferred over the use as landfill cover because the savings are larger. Implementation of the circular economy principles in municipal solid waste management through composting can reduce many waste management problems by closing the materials recycling loop, generating extra income, and adding net revenue to the national economy.

The results of the research on socio-economics showed that the LAs' attitude toward organic solid waste (SW) composting is low and can be considered as dissatisfactory since only 36.5% of the LAs are planning for composting compared to 63.5% who are not. The output of the LRM showed LAs' perception of compost contribution to SW reduction, availability of proper place, financial capacity, community awareness, and prevalent SWM bylaws are significant predictors of LAs' attitudes toward organic MSW composting.

The results of the research on design, test and evaluate two composting systems showed that both systems provide high efficiency in reducing the composting time (39-43 days in Palestine, and 31 days in India) although the aeration rate has no clear effect of the composting time. The physio-chemical analysis showed that most of the parameters comply with Palestinian Standards Institution (PSI) and Indian Fertilizer Control Order (FCO) except minor deviations. The volume reduction was 64.0,60.0, and 57.2 for experiments 1,2&3, respectively. Both systems also provided high fertility index (4.33, 4.73, & 4.8 for experiments 1,2&3, respectively), and high clean index (4.62, 5.00, & 4.69 for experiments 1,2&3, respectively). The biological parameters tests showed that all the experiments met PSI, but none of them met FCO, suggesting that the outer edges of the composting system didn't heat enough to inactivate pathogenic microbes, therefore, developing the system by adding turning option could overcome this shortcoming. It was concluded that forced-aeration system is suitable for Palestine, while natural aeration system is suitable for India.

CONTENTS

List of Tables

List of Figures

Acronyms

ADB	Asian Development Bank
ACCP	African Clean City Platform
ALPC	Al-Menya Landfill Private Company
ARIJ	Applied Research Institute – Jerusalem
AS	Ammonium Sulphate
CDM	Clean Development Mechanism
CPHEEO	Central Public Health and Environmental Engineering Organization
CI	Clean Index
DAP	Diammonium Phosphate
EC	Electric Conductivity
ECN	European Compost Network
EIA	Environmental Impact Assessment
EQA	Environmental Quality Authority
ERM	Environmental Resources Management
ESCWA	Environmental and Social Commission for Western Asia
EU	European Union
FAO	Food and Agriculture Organization
FCO	Fertilizer Control Order
FI	Fertility Index
GHG	Greenhouse Gases
GIZ	German International Cooperation
GPOBA	Global Partnership on Output Based Aid
HCCI	Hebron Chamber of Commerce and Industry
HDPE	High Density Polyethylene
HWE	House of Water and Environment
IFC	International Finance Corporation
IMG	International Management Group
IEE	Initial Environmental Evaluation
JICA	Japan International Cooperation Agency
JCSPDs	Joint Councils for Services, Planning and development
JSC-H&B	Joint Service Council for Solid Waste Management for Hebron and Bethlehem Governorates
JSCs-SWM	Joint Service Councils for Solid Waste Management
JSI	Jordan Standard Institution
LA	Local Authority
LAL	Local Authorities Law
LandGEM	Landfill Gas Emission Model
LGSIP	Local Governance and Service Improvement Program
LRM	Logistic Regression Model
KFW	German Development Bank
KSA	Kingdom of Saudi Arabia
MC	Moisture Content
MDLF	Municipal Development and Lending Fund
MoA	Ministry of Agriculture

MoH	Ministry of Health
MoLG	Ministry of Local Government
MSW	Municipal Solid Waste
MSWM	Municipal Solid Waste Management
MW	Medical Waste
MWM	Medical Waste Management
NGOs	Non-Governmental Organizations
NIS	New Israeli Shekel
NRDC	Natural Resource Defense Council
NSSWM	National Strategy for Solid Waste Management
OM	Organic Matter
O&M	Operation and Maintenance
PA	Palestinian Authority
PARK	Palestinian Agricultural Relief Committee
PCBS	Palestinian Central Bureau of Statistics
PEAP	Palestinian Environmental Assessment Policy
PEF	Palestinian Environmental Friend
PEL	Palestinian Environmental Law
PHL	Public Health Law
PPP	Public-Private Partnership
PMSP	Palestinian Municipalities Support Program
PSI	Palestinian Standards Institutions
RCV	Refuse Collection Vehicle
ROU	Recycled Organic Units
RRCAP	Regional Resource Center for Asia and the Pacific
RS	Royal Society
SOP	Potassium Sulphate
SPSS	Statistical Package for Social Sciences Software
SW	Solid Waste
SWM	Solid Waste Management
SWBSWMP	Southern West Bank Solid Waste Management Project
TSP	Triple Super phosphate
UNDP	United Nations Environmental Program
UNCTAD	United Nations Conference on Trade and Development
UN-HABITAT	United Nations Human Settlements Program
UK	United Kingdom
UNPF	United Nations Population Fund
UNRWA	United Nations Relief and Works Agency
USAID	United States Agency for International Development
USCC	United States Composting Council
USD	United States Dollar
USEPA	United States Environmental Protection Agency
USNAS	United States National Academy of Sciences
VCs	Village Councils
WERL	Woods End Research Laboratory
WRAP	Waste and Resources Action Programme

CHAPTER 1

INTRODUCTION

Solid waste management (SWM) is a global concern because the waste generation is increasing following the population growth and the management of this waste stream is still below the acceptable level for environmental protection. This problem is clearly evident in developing countries due to improper waste management systems, which mostly attributed to several factors including environmental, socio-economic, institutional, financial, political and technical capacity. This problem requires integrated SWM strategy taking into account technology and policy intervention to reduce its effect on the environment especially the greenhouse gas emissions (Ramachandra et al., 2018). Palestine is a developing country and faces several problems in solid waste management and many of them is attributed to the political conflict. Therefore, this research is focusing on the southern part of the West Bank of Palestine to provide solution for the problems to improve the SWM sector.

1.1 Municipal Solid Waste Management in Palestine

1.1.1 General Background:

Local authorities including municipalities, village councils, Joint Councils for Services, Planning and development (JCSPDs), and Joint Service Councils for Solid Waste Management (JSCs-SWM) are the main service providers in Palestine. The establishment of Joint Councils for Services, Planning and Development was to provide several services including the SWM service to a cluster of villages in the rural areas, while Joint Service Councils for SWM were established by the government to provide SWM service only for several cities, towns and villages. These were established on the governorate level. The boards of directors of these councils are consisted of mayors and heads of the village councils. Some of these councils are providing the collection service based on agreement with the local authority in the community, and others are only responsible for managing SW transfer stations (TSs) and the landfill site. So the waste collection service is provided by the local authority itself or by any of the Joint Service Councils mentioned above. However, Joint Service Councils for SWM that only manage the landfill site and the TSs are only responsible for long-hale transfer of the waste from the TSs to the landfill site, and managing the disposal of these waste inside the landfill.

The common waste collection system is consisted of street bins of different sizes including 1.2 cubic meter capacity, 4.0 cubic meters’ capacity which mostly placed in commercial areas, and 240-liters capacity which is mostly used on the household level. In many rural areas, the street bins are absent and therefore the residents used to put their waste beside the street curb in a plastic sack. The refuse collection vehicles are trucks with compactors but with different capacities including 4 tons, 8 tons, 12 tons and in some cases 16 tons. In few cases, where the streets are narrow, very small refuse open-top collection vehicles are used. Open-top refuse collection vehicles, but larger sizes, are also for the collection of the slaughterhouses wastes. In rural areas, a tractor with trailer is used for waste collection due to shortage of financial resources. The common collection mechanism is waste collection from the streets’ bins using the refuse collection vehicle. In urban areas where there are waste workers, the residents used to place their waste beside the street curb which then collected by the waste workers using carts and moved to the nearest street bin (Al-Khateeb, 2009). Sometimes, the waste workers used door to door waste collection. On the other hand, transfer of waste from the TSs to the landfill site is conducting using truck with trailer (Roll on – Roll off) which can transfer two containers per trip with a capacity of 40 cubic meters each.

Up to date, there is no SW segregation at the source in Palestine, and is still collected mixed (organic and inorganic) and is sent to the landfill as final destination for disposal. Some sorting pilots were implemented by some joint service councils for SWM, but some of these pilots failed due to several reasons including absent of legislations and governmental support, high cost, unavailable market for some sorted materials, and declining the prices of the sorted materials. Al-Khatib et al. (2020) reported that the low prices of the sorted materials are one of the main reasons that made the waste pickers dissatisfied with their job in waste scavenging.

The final destination of the SW stream is the landfill for final disposal. In Palestine, there are 3 sanitary engineered landfill sites in the West Bank and 2 in Gaza strip (Atallah, 2020). The 3 landfill sites in the West Bank are in north, south, and one in the Jordan River Valley. All of these were constructed in financial support from international donors. Another sanitary landfill was planned in the middle of the West Bank, but its construction was delayed due to opposition of the local residents as reported by Japan International Cooperation Agency - JICA (JICA, 2019a). Most of the random dumpsites were closed especially in the areas where sanitary engineered landfills were constructed.

1.1.2 Initiatives to Improve SWM in Palestine:

SWM sector in Palestine faced several difficulties and challenges during the last two decades. After the establishment of the Palestinian Authority (PA) after Oslo Accord in 1995 that was signed between the PA and the Israeli Occupation, the

PA started building and developing the official organizations including the local authorities to create change in the Palestinian community that was under the occupation since 1967 (West Bank and Gaza Strip). However, this period was short as by the year 2000, the second Palestinian Uprising (*Intifada*) was started due to the political situations and refusal of the Israeli occupation to adhere to the signed agreement. As a result, the Israeli occupation forced closure to all Palestinian areas (cities, towns, village and refugees camp) and sever restrictions on movement and trading. This action causes deterioration of the economic situation in Palestine. The World Bank reported that the huge challenges faced by Palestinian traders and business and created significant shrinkage in the market and increasing the costs are attributed to the closure forced on the West Bank (The World Bank, 2007).

SWM sector was like other sectors severely affected at all levels. The closures forced the local authorities to establish random dumpsites for SW disposal and away from the main roads in order to cope with these situations. Al-Khatib et al. (2007) reported that SW collection trucks rapidly deteriorated because the roadblocks forced it to move through difficult rough roads, and the military roadblock and curfews led to random dump sites within the borders of the residential communities. These random dumpsites pose significant environmental impacts to the atmosphere due gaseous emissions like carbon dioxide and dioxins as a result of wild fire, and to the groundwater due to leachate seepage, and affect the social and well-being of the communities due the obnoxious odors, flies and mosquitoes. The problems of SW disposal are attributed to the lack of engineered landfill sites and absent of programs for waste recycling (Talahmeh, 2005). In addition, the shortage in financial support and lack of technical capacity were the major challenges and constrained the efficiency of the Palestinian SWM system. Technical and financial challenges included absent of waste minimization principles, inadequate SW tariff and insufficient fee collection, limited human capacities and financial resources, the legal framework is incomplete, weakness of monitoring systems, and political conflict (Al-Khatib et al., 2010).

Beside the difficulties and challenges faced the SWM, the PA continued gradually to improve the situations. On the policy level, it issued the following laws, policies and strategies: (1) environmental law no.7 (1999); (2) environmental impact assessment policy in the year 2000; (3) public health law no. 20 (2004); (4) national strategy for solid waste management - NSSWM (2010 – 2014); (5) instructions and guidelines for closure and/or rehabilitation of random dumpsites (2011); (6) medical waste management bylaw in 2012; (7) environmental auditing procedures manual (2014); (8) environmental sector strategy (2010 – 2013); (9) the national development plan (2011 – 2013); (10) guidelines for environmental auditing on solid waste landfills (2016); (11) national strategy for solid waste management – NSSWM (2017 – 2022); (12) SWM bylaw in 2019. These are necessary to support the PA plan to improve the situations of SWM and regulate this important sector.

On the institutional level, the PA has established the joint service councils (JSCs) for solid waste management in order to enable the small size local authorities, such as village councils (VCs) and newly established municipality, providing better service to the communities, as small size local authorities haven't the enough capacity to provide SWM in a proper and sustainable manner. In addition, some JSCs were also established to operate the landfills and transfer stations to enable all local authorities, small and large sizes, disposal of municipal SW in complementary with the environmental protection rules. 15 JSCs have been established in the West Bank and 2 JSCs in Gaza Strip covering all the governorates as per the Ministry of Local Government (MoLG) records (MoLG, 2019; MoLG, 2018). All of these JSCs have been established the period that extended between 1998 and 2014 (MoLG, 2016). In addition, several capacity programs have been held for the local authorities and JSCs staff in the field of SWM such as "Project for Technical Assistance in Solid Waste Management in Palestine: A Technical Cooperation between Palestine and Japan (2015 – 2019)" which was financed by the Japan International Cooperation Agency (JICA) which also included public awareness on the community and schools levels, capacity building and training through Southern West Bank Solid Waste Management Project (SWBSWMP) which was financed by the World Bank (2009 – 2016), Gaza SWM project which was financed by the World Bank (The World Bank, 2009) which included capacity building and training, Palestinian municipalities support program (PMSP) which was supported by Italy government (GIZ, 2014), SWM project in Ramallah and Al-Bireh – middle West Bank (2012) which was supported by the German Development Bank - KfW (GIZ, 2014), north West Bank SWM project (2000 - 2007) which was supported by the World Bank, Gaza solid waste management project (2014 – 2021) which was also supported by the World Bank, and many other cooperation projects supported from international donors which included main components for training and capacity building in the field of SWM.

On the technical and implementation level, the SW sector has been prioritized due to the environmental and socio-economic implications. The PA sets the plans through which it can improve the status of SWM and coordinated with international donors in order to construct the required infrastructure and provide the proper SWM machinery. A part from the NSSWM (2010 – 2014), SW shall be disposed in sanitary engineered landfills (PA, 2010). It has been decided to build four regional sanitary engineered landfills in the West Bank, three of them to serve north, middle, and south of the West Bank, and one to serve Jericho area including the Jordan River valley. Three of them have been already constructed, while the one that is planned for the middle of the West Bank was not yet built to some constraints including political and social (MoLG, 2017). Another 2 sanitary engineered landfills were also built in the Gaza Strip to accommodate the SW stream there. All of these landfills were built in financial support from international agencies such as the World Bank and JICA within the framework of the above-mentioned projects, and in partial contribution from the United States Agency for International Development (USAID) in the SWBSWMP. In addition, 13 SW transfer stations have been built up to date covering all of the West Bank governorates (MoLG, 2017). These are constructed to serve remote areas that are located away from the landfills for the purpose of reducing the costs and time of SWM, thus increasing the level of cleanliness and improve environmental and health conditions.

Moreover, the PA in coordination with international donors has supported the local authorities and JSCs with SW collection vehicles and machinery to operate the SW transfer stations and landfills. SW collection vehicles are compacters included several capacities (4 tons, 8 tons, 12 toms, 16 tons) and grapple cranes to service the different communities, and long hale transport trucks (roll-on roll-off trucks with trailers). Machinery included track loaders, wheel loaders, backhoe loaders, waste compactors, and track excavators, which are necessary to waste uploading at the transfer stations, spreading, compaction and covering at the landfills. In some cases, waste recycling machines were provided such as the case of southern West Bank, where tires shredding and plastic and cardboard baling machines are supplied. Figure 1-1 shows sample of different trucks and machines supplied. Many international donors played a significant role in supporting the Palestinian SWM sector including, addition to the above-mentioned, European Union, governments of the Netherlands, Italy and Spain (PA, 2010).

Fig. 1-1: SW equipment and collection and transfer trucks

Source: Adapted from JSC-H&B brochure.

Within the initiatives and efforts to improve SWM, several random dumpsites have been closed. In the north of the West Bank, 85 random dumps were closed, while in the south 19 random dumps were closed as per the records of the Joint Service Council for Solid Waste Management for Hebron and Bethlehem Governorates – JSC-H&B (JSC-H&B, 2013) although the NSSWM (2010 – 2014) mentioned 147 random dumps (PA, 2010). The largest random dumpsite of 14.5 hectare in area was provided with a system for landfill gas collection and flaring as shown in the Figure 1-2.

An important initiative concerning the public-private partnership (PPP) in SWM was lunched in the southern West Bank under the project "Global Partnership on Output based Aid – GPOBA" between 2013 and 2017 in support from the World Bank and facilitated by the International Finance Corporation – IFC. The project aims to improve the SWM sector by encouraging the implementation of environmental and social safeguard measures, improve fee collection rate, and improve cost to billing ratio by upgrading the old tariff system to cover the cost. The project contributed to the fees of SWM on behalf of the local authorities based on its performance which was measured periodically on midterm bases against technical and financial performance indicators (JSC-H&B, 2013; IFC, 2012).

Fig. 1-2: Yatta dumpsite after closure and installation of gas collection system

Another initiative was lunched during the period extended between 2018 and 2021 under the program “Local Governance and Service Improvement Program – LGSIP” in southern West Bank and then extended to include the different governorates. The program was launched by the MoLG through the Municipal Development and Lending Fund (MDLF) and in financial support from the World Bank, KfW, and other donors. The program aimed to support small size local authorities by encouraging shared projects between these authorities. The project provided the local authorities by waste bins, waste collection trucks, heavy machinery to improve the roads conditions inside the villages to improve SW collection, machinery to operate SW transfer station, and infrastructure for offices and maintenance facilities to improve the quality of SW service provided (MDLF, 2018).

Initiatives also extended to include other waste stream such as medical waste (MW). The Palestinian Municipalities Support Program (PMSP) funded by Italy government supported the establishment of MW treatment facility in southern West Bank since 2012 (GIZ, 2014; JSC-H&B, 2012). The technology provided was microwave machine with capacity of 75kg/hour. Another program was launched in the Gaza Strip in 2017 supported by the JICA titled “Program for establishing a system of Health Care Waste Management in southern Gaza” (JICA, 2019b). This program included construction of MW treatment facility using Autoclave technology at the JSC south Gaza, developing MW management manual, training to the Ministry of Health, and maintenance of the incineration facility at Al-Shifa hospital in Gaza. In 2020, JICA in cooperation with the MoLG launched a new program to improve MWM in Palestine (West Bank and Gaza). The program included providing the JSCs with MW collection vehicles, maintenance of old treatment facilities, and providing new treatment machinery (JICA, 2021). Figure 1-3 shows one of the MW treatment facilities in Hebron city.

Other relatively small scale initiatives including pilot composting and recycling activities. Part of the program supported by JICA (2015 – 2019) included composting activities on the household level (JICA, 2019a). Other pilot waste sorting activities including large scale pilot composting such as that implemented by the JSC-H&B. A project on pilot composting was conducted at Al-Jalameh village in Jenin (north of the West Bank) using animal manure, farm waste and organic fraction of municipal SW (Bonoli, et al., 2019). Currently, there is a waste reduction project ongoing supported by JIAC which include pilot composting of municipal SW as central composting and implemented West Bank and Gaza Strip (JICA, 2021). The project included infrastructure and providing equipment for composting. There are other composting plants in Palestine which have been established by the non-governmental organizations (NGOs). For example, the Palestinian Agricultural Relief Committee (PARK) has established three composting plants in Jericho, Jenin (Di Maria et al., 2017) and Hebron for the benefit of farmers’ cooperatives. Both plants in

Jericho and Hebron were failed, due to high cost of operation and low participation of the local population, while the other in Jenin still working in summer only (CESVI, 2019). Another two composting plants were constructed by a Palestinian NGO called House of Water and Environment (HWE). These plants have been constructed in Jericho and Ramalla (Bytillu village) in 2017 for composting of agricultural waste and organic waste collected from hotels (CESVI, 2019). However, both plants stopped working in 2018. In Gaza Strip, there composting plants have been constructed. One of them is located in the north and belonging to Gaza and Beit Lahia municipalities, and the second one is in Rafah city and established by Palestinian Environmental Friend (PEF) NGO, which stopped working (CESVI, 2019). The PEF then obtained fund form the United Nations Development Program (UNDP) in 2011 in coordination with Rafah municipality and constructed the third sorting plant and conducted composting for the organic waste separated, but unfortunately it stopped working in 2017 due to marketing problems (CESVI, 2019). Figure 1-4 shows initiatives in SW recycling and composting.

Fig. 1-3: MW treatment plant in Hebron

1.2 Solid Waste Management in the Study Area

1.2.1 Overview

The study area is the south of the West Bank of Palestine which is consisted of two governorates, Hebron and Bethlehem. Those are the most densely populated areas in the West Bank There are 89 local authorities involved in SW management in both governorates in accordance with the Ministry of Local Government (MoLG) records (MoLG, 2021). These include municipalities, VCs, JCSPD, and Joint Service Councils for SWM. SWM in this area is almost similar to the other areas in Palestine. SWM in this area is located within the purview of the local authorities. SW primary and secondary collection is conducted by the local authority which collect the garbage bins using refuse collection vehicle and transfer the waste into the landfill or to the SW transfer station which is the nearer. In addition to the municipalities and village councils, there are 3 joint service councils for SW management in the area. One of them is serving Hebron Governorate and responsible for SW collection and transfer to the landfill or to the transfer station. This JSC is covering part of the governorate, while the other parts are served by the local authorities. The second one is serving Bethlehem governorate, and also is responsible for SW collection and transfer to the landfill as the distance to the landfill is relatively short and there is no transfer station there. This JSC is covering all Bethlehem governorates. The third JSC is serving both governorates and responsible for long-hale transfer of solid waste from the TSs and the landfill, and management of the landfill facility. This JSC is called The Joint Service Council for Solid Waste Management for Hebron and Bethlehem Governorates (JSC-H&B).

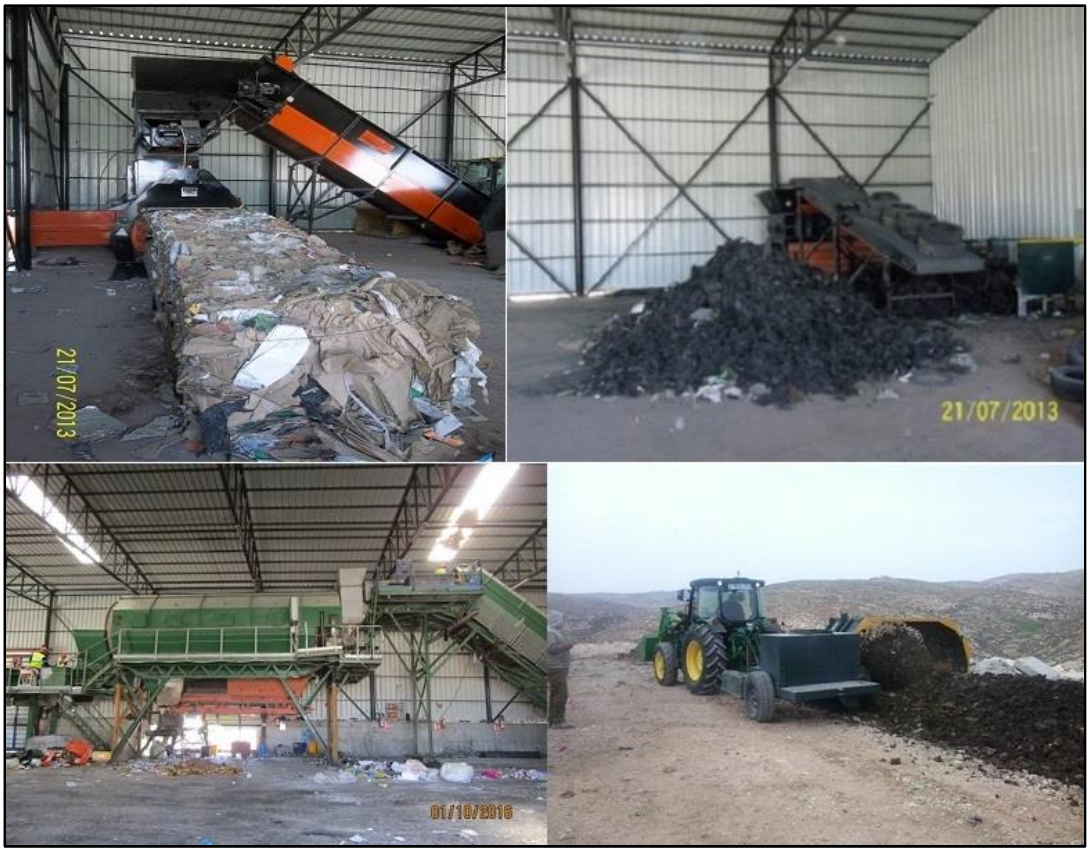


Fig. 1-4: Initiatives in recycling and composting

Currently, there are two SW transfer stations in the area under study. Both are located in the Hebron governorate to serve the communities that are located far away from the landfill. One is located to the west of Hebron city to serve the communities in the west part of the governorates and called West Hebron SW Transfer Station. The capacity of this station is 100 tons/day. The other is located south Hebron to the east of Yatta city to serve the communities in the south of the governorate, and called Yatta SW Transfer Station. The capacity of this station is 300tons/day. Both stations utilize the simple system of waste unloading from the refuse collection vehicle then uploaded by a wheel loader in $40m^3$ containers which is transferred using Roll on-Roll off truck with trailer.

A sanitary engineered landfill called Al-Menya landfill located to the south-east Bethlehem was constructed to serve both governorates, and located in easy accessible place by the local authorities in Hebron and Bethlehem governorates. The landfill was constructed and provided by environmental measures for the purpose of environmental protection. These measures include isolation of the bottom and underground sides with double liner system to prevent landfill leachate from immigration into the groundwater aquifer. The double liner system consisted of two layer: the bottom one is geo-synthetic clay liner ($4.5g/m^2$), and the upper one is high density polyethylene (HDPE) of thickness 1.5mm. The landfill is provided with weighing bridge and computer system to record all of the waste entering the landfill. In addition, the landfill site includes semi-mechanical sorting plant with capacity of 100 tons/day. It consisted of conveyor, trammel of opening size 10cm, manual sorting platform, and trammel of opening size 4.5cm. The 10cm opening trammel separates the large portion of organic fractions from waste, then the waste fractions larger than 10cm (mostly inorganic) moves to the manual sorting platform where the workers there separating three fractions: metals, plastics, and cardboard. Other waste from this belt is directed to the landfill. The waste fractions smaller than 10cm (mostly organic) moves to the 4.5cm opening trammel which separates objects larger than 4.5cm from the organic waste stream, which normally contain plastic and other pieces, and then directed to the landfill. The waste stream of smaller than 4.5cm is composted.

Since the operation of Al-Menya landfill 10 years ago, the JSC-H&B closed all old wild dumpsites in both Governorates. 18 random wild dumpsites (JSC-H&B, 2015) in both governorates were closed which resulted in improved environmental conditions. Random waste dumping is prohibited by law and all local authorities within the borders of the study area use the sanitary engineered landfill.

Moreover, medical waste management is also conducted by the local authorities in Palestine. In the study area, a medical waste treatment plant is operated by the JSC-H&B and located in the same site of the landfill. The facility is equipped with a microwave machine of capacity 75kg/hour, and medical waste incinerator of capacity 50kg/hour. The capacity of both machines is not enough to treat the medical waste quantities collected from the study area, therefore, medical waste collection is conducted partially focusing on public and private hospitals, health centers and part of the medical laboratories. Other MW from private clinics, dentals, and the rest of medical laboratories is still collected mixed with municipal waste. MW treated in the facility is disposed at the landfill with other municipal waste.

1.2.2 Organic Solid Waste Composting in the Study Area

Within the process of seeking adequate solutions for the relatively large amount of SW generated in Palestine, the JSC-H&B conducted pilot trials of composting the organic fraction which is the largest waste fraction. The first trial was conducted in the year 2012 in partnership with Rostock University - Germany, and Al-Jaar Engineering Establishment - Jordan. This pilot focused on using the fruits and vegetable waste generated from the Hebron fruits and vegetable market as it was collected separately and purity was ensured. In addition, other quantities of cow dung, poultry manure and sawdust was used. Also it included awareness workshops and brochures to promote for waste composting in order to reduce the waste quantities. The promotion focused on the member local authorities and agricultural societies and cooperative. The trial succeeded in producing good quality compost as shown in Table 1-1. (Al-Sari’, 2019).

Table 1-1: Compost quality in the study area

No.	Mixture No.	Results				
		pH	Ec (ds/m)	Total Nitrogen (%)	Phosphorus (P) (ppm)	C/N
1-	Mixture 1	9.48	8.69	1.09	243.82	10.0
2-	Mixture 2	9.51	9.36	1.23	197.61	12.0
3-	Mixture 3	8.74	6.12	1.17	165.80	9.0
4-	Mixture 4	10.03	10.72	1.25	255.39	10.0

Sources: Al-Sari’, 2019

The second trial was conducted in support from the Palestinian Municipal Support Program which is financed by the Italian Government through the Palestinian Ministry of Local Government (MoLG). This pilot is conducted based on the results obtained from the previous trial, but uses the organic fraction separated from municipal solid waste received at the landfill site. Furthermore, the support for the second trail included updating the manual for composting production on the household level (JSC-H&B, 2018). Figure 1-5 presents municipal SW pilot composting.

However, most of the previous attempts for compost production were failed. JICA supported a household compost program in West Bank, where part of the program implemented in the study area (Al-Walajah village / Bethlehem governorate). 90 household composter were distributed out of 150 were planned, and only 60 out of

90 were found in use during the monitoring of the program, which reflects relatively low interest of the household in composting (JICA, 2019a). The Applied Research Institute – Jerusalem (ARIJ) conducted a study conducted in the West Bank and found that the people didn't want to get involved in carrying out backyard composting (ARIJ, 2005). Another central composting facility was constructed in the study area (Dura city/Hebron) for compost processing after maturation and operated by Dura Cooperative society for Development of Irrigated and Protected Agriculture, and now out of service.

Fig. 1-5: Municipal SW pilot composting in the study area

Despite the above-mentioned initiatives and trials to improve SWM in Palestine, the waste recycling is still below 1% and only 33% of municipal SW is disposed in sanitary landfills (GIZ, 2014). Most of the composting trials were failed and the organic fraction is still disposed of in the landfills creating GHG emissions and contributing to the climate change. The waste management sector was found major emitting sector in Palestine with contribution of 23% of the total emissions in accordance with the United Nations Development Program – UNDP (UNDP, 2016). On the other hand, construction of landfills and expansion of the existed ones is facing huge restriction by the occupation. Moreover, the agricultural sector in Palestine is facing severe problems due to the restrictions on access to good quality fertilizers and control over water resources by the occupation. This is also associated with the climate change effect, which requires adaptation strategy to increase resilience and reduce the effect of these problems. On the policy level, waste recycling and composting is not obligatory policy in accordance with the SWM bylaw and mentioned as an elective option without any targets or limits.

Considering the problems of waste management, associated environmental issues, and the lack of political will, it become imperative to devise ways which can help reduce the extent of problem, minimize the environmental impacts, promote sustainability without much of economic burden. Utilizing the organic fraction of waste (≈46%) can significantly reduce the load over waste management system and its composting can lead to transformation of waste to wealth through a natural process. Municipal organic SW composting and mining of compost from existing/ closed landfills can help create more space for waste landfilling and reduce the problem of landfill construction or expansion. Since, compost has nutrient value, its use can be promoted in agriculture, thereby completing the nutrient cycling and reducing the economic burden in terms of impact of chemical synthetic fertilizers. Further, it can solve the problem of restricted access to good quality fertilizers and improve the water holding capacity thus reducing the climate change impacts on agriculture. However, success in SWM in general and composting in particular, depends on the key-stakeholders involved and their resources to build a clear plans specifying the responsibilities (Phong Le et al., 2018). Moreover, shortening the composting process can accelerate the treatment process and mitigate the shortage in land area required for composting (Liu et al. 2011). Therefore, this study aims to design and test composting system to shorten the composting process, evaluate the composting role in the circular economy, and assess the attitudes of the LAs' towards composting and identifying the factors that affect their attitudes.

This study has environmental and socio-economic significance. It can contribute to the achievement of the nationally determined contributions (NDCs) in Palestine. In addition, the study contributes to sustainable development goals (SDGs) achievement as presented in the Fig. 1-6.

1.3 Research Gaps

Although many studies have been conducted in composting in Palestine, the following gaps are identified:

(a) None of these studied the time/conditions of the composting process;

(b) Any new method to shorten the time required for composting under the conditions of the study area has not been studied;

(c) Recycling and economic benefits of municipal organic waste composting has been never studied before in Palestine and many other developing countries

(d) However, the attitude of local authorities, the key stakeholders in SWM, towards composting has never been studied before. Therefore, this study focuses on the assessment of the LAs toward MSW composting and the factors influencing their attitudes in southern West Bank of Palestine.

1.4 Research Objectives

The main goal of this research is to investigate the possibility of composting technique with shortened time, study the attitudes of the key stakeholders towards composting, and study the compost role in the circular economy. The aims of this research are:

(a) To test and compare natural and enhanced aeration for composting of organic waste to shorten composting time

(b) To monitor the physio-chemical and biological parameters (temperature, moisture content, pH, C/N and NH4+/NO3- ratio) and other quality parameters to evaluate the quality of compost according to the Indian and Palestinian Standards/guidelines

(c) To quantify the potential of organic waste recycling, chemical fertilizer replacement, opportunities for revenue generation etc. against normal landfilling of organic waste

(d) Assess the attitude of local authorities toward municipal solid waste composting, and the socio-economic and behavioral factors that could affect acceptance of composting in organic waste management, and suggesting an organic waste management framework.

1.5 Scope

This research dissertation titled “Management of Urban Organic Waste Integrating Composting, Circular Economy, and Socio-economics” is focusing on the southern part of the West Bank/Palestine, and consisted of five chapters. The summary description of these chapters is as follows:

Chapter one: introduction and provides an overview on SWM in Palestine, and organic waste management in the study area with emphasis on problems facing SWM, research gaps, research objectives, and scope.

Chapter two: presents the literature review.

Chapter three: describes the study area and presents the research materials and methods followed to achieve the research objectives.

Chapter four: provides the results of the research and discussion of these results.

Chapter five: presents the conclusion, environmental and social significance, and future scope.

The research dissertation document included also the references used and annexes that include supplementary information.

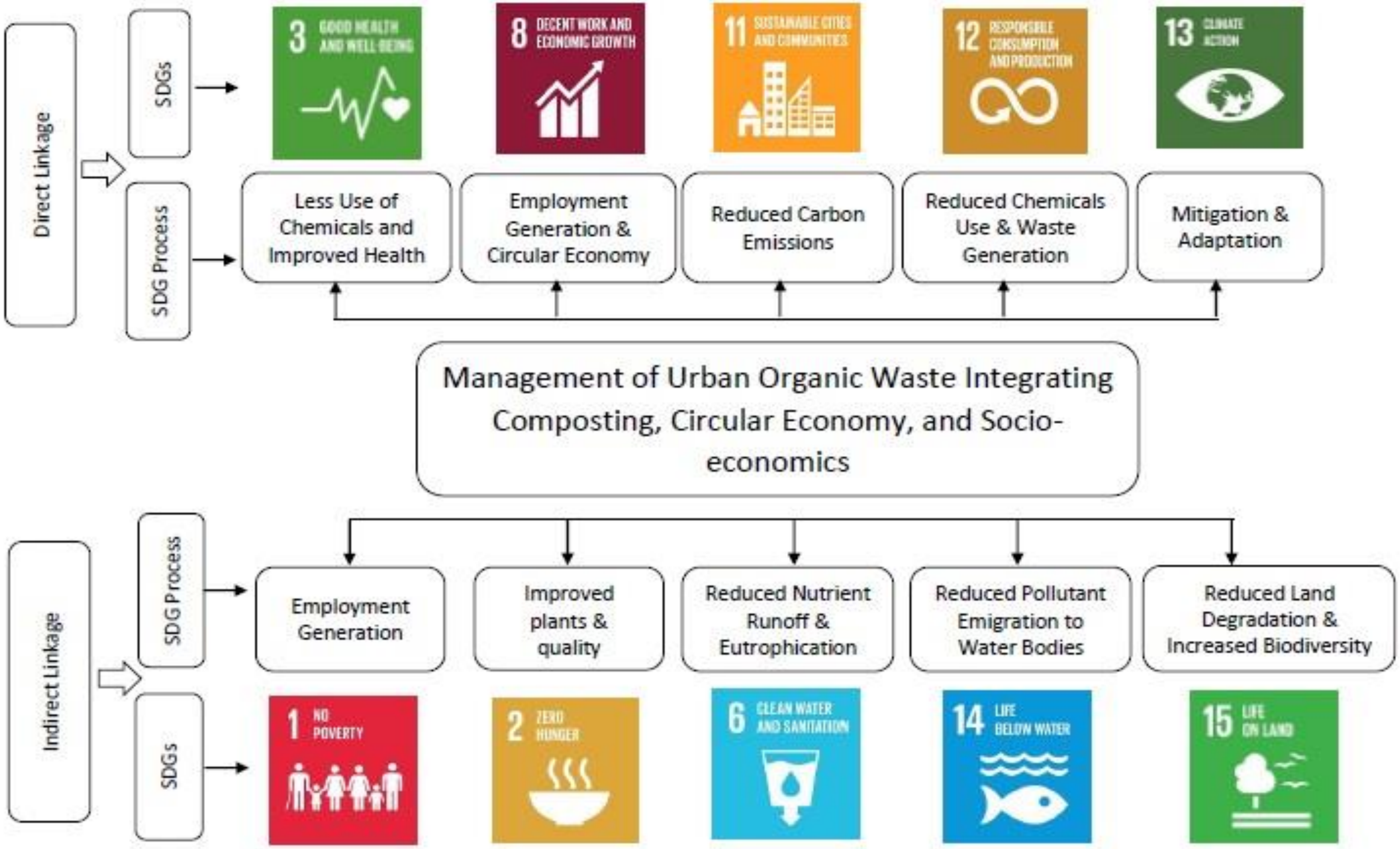


Fig. 1-6: Contribution of the study in achievement of SDGs

CHAPTER 2

LITERTURE REVIEW

2.1 Municipal Organic Solid Waste Management:

Organic SWM is a challenge worldwide, with large gap between developed and low income countries. Managing such waste stream in an environmental friendly and sustainable method should be one of the top priorities in the modern and developed society (Wilson, 2007). Municipal solid waste (SW) generated in developing countries usually contain higher organic SW fraction compared to high income countries (Kaza et al., 2018). Unfortunately, a lot of developing countries especially those of low income are still not implementing the best practices in SWM (Guerrero et al., 2013), while some European member state countries are still not employing the best practices (Koufodimos and Samaras, 2002; Papachristou et al., 2009), with large gap between both. Fernando and Zutshi (2023) comprehensively described the practices of municipal SWM in most developing countries as either inefficient, ineffective, or limited. However, the European Union upgraded the waste management legislations and polices to improve SWM in member states, and continuously updating these polices to ensure effectiveness and continuous improvements and focusing on reduce, reuse, recycling and recovery. The European Union (EU), for example, adopted policies and targets to recycle 65% of the waste generated by 2030 (Cecere and Corrocher, 2016). Frick et al. (1999; cited in Slater and Frederickson, 2001) reported large portion of organic waste generated in the European countries is composted. These include the Netherland (90%), Denmark (55%), Austria (50%), Germany (45%), Belgium (34%), Sweden (16%), Luxembourg (14%), Finland (10%), United Kingdom (6%), France (3%), and Italy (2%). In accordance with the European Compost Network (ECN), 47.5 million tons of food refuse was treated in 2019, 30.5 million tons of them composted, 12.4 million tons were anaerobic digested and 4.6 million tons were combined treated by anaerobic digestion and composting (ECN, 2021). In Europe, organic municipal SWM is in continuous development. The records of the Eurostat, as shown in Figure 2-1, showed that the waste landfilling has decreased from 61.1% in 1995 to 23.7% in 2019. In addition, the composting of organic waste has rised from 7.1% in 1995 to 17.4% in 2019 (Eurostat, 2021).

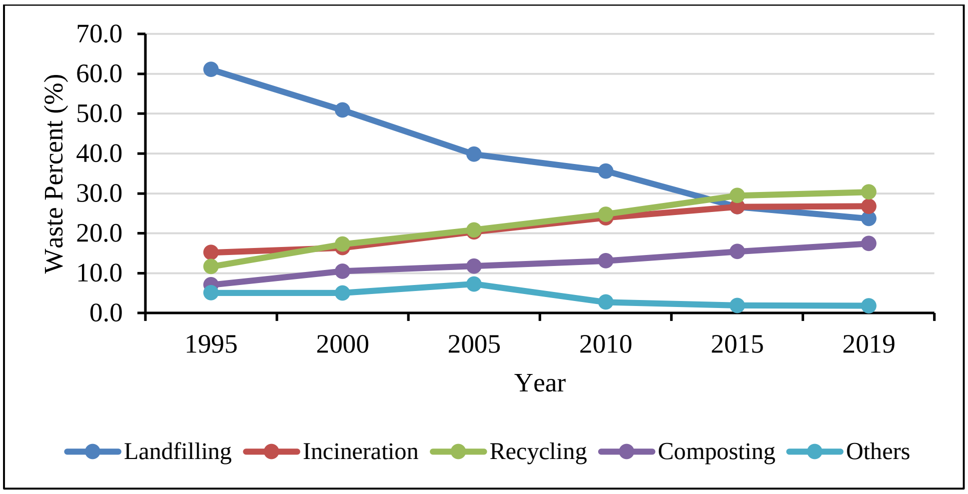


Fig. 2-1: Development of SWM in Europe during the period (1995 - 2019).

Source: adapted from the records on Eurostat, 2021.

In Latin America and Caribbean Region, around 50% of the total waste produced and collected in the region is organic waste, and generally is disposed of in landfills and dumpsites (UNEP, 2017). Open dumps are the mostly used method for waste disposal (Hettiarachchi, et al., 2018), so 85.2% of the population use uncontrolled open-air dumps in Belize, 69.8% in Guatemala, and 59.3 in Nicaragua (Espinoza et al., 2010). Formal waste sorting and recycling is limited to very small activities not exceeding 2% of the waste stream produced in the region (Grau et al., 2015), which also reported by United Nations Human Settlements Program – UN-HABITAT (UN-HABITAT, 2012). Nowadays, SWM is gaining attention in the Latin American as well as Caribbean Region, and there are some initiatives to improve the waste management. Examples of initiatives, in Brazil, the Resolution of the National Environment Council (CONAMA) No. 481/2017 on MSW composting sets the rules, methods, and procedures to assure environmental protection during the composting of organic waste, so article no. 9 in section II, clarified that municipal organic solid waste (MSW) for composting must be separated; in Argentina, a recycling center in Buenos Aires city was opened in 2015 as composting center for organic waste; in Chili, the municipality of Futaleufu has launched an organic waste collection scheme and succeeded to reduce the waste landfill by 43%; and in Columbia, the municipality of Cajica lunched separate organic waste collection program covering 30% of the waste generated (UNEP, 2017).

In southeast and East Asia region, some countries are of high level income countries like western countries such as Japan, and others of low to middle income countries. The common waste disposal method is varying between one country to another. For example, the open dumping represents 90%, 65%, 50%, and 85% for

India, Thailand, China, and Sri Lanka, respectively, while organic waste composting is still being practiced at small-scale in these countries (Visvanathan and Tränkler, 2003). In Nepal, the organic waste fraction reached 68% in and currently is dumped at open fields and on river banks creating environmental pollution and health hazards (Aryal and Adhikary, 2024). Food waste generation in the region for 14 countries is in the range of 15–73% in Japan and Myanmar respectively as reported by AIT-UNEP Regional Resource Center for Asia and the Pacific -RRCAP (RRC.AP, 2010). Composting of organic waste in selected countries in the region in 2001 was (2%) in Bangladesh; (10%) in India; (5%) in Nepal; and (5%) in Sri Lanka, while waste recycling and composting was (2%) in PRC in 2006; 45% in Hong Kong, China in 2007; and 19% in Japan in 2005 as reported by Asian Development Bank – ADB (ADB, 2011).

In the Arab region, municipal SWM is characterized by centralization at the national level, absence of effective cost recovery system, shortage of trained personnel, inequality of the service between rural and urban areas, and lack of a reliable database (Nassour et al., 2016). The common practice in SWM in the Arab states is collection mixed with other waste stream, recyclable materials are not separated, and disposal at dumpsites lacking the basic engineering and sanitary requirements, and around 50% of the waste is uncontrolled in many countries (Nassour et al., 2016). In accordance with the Environmental and Social Commission for Western Asia (ESCWA), round 1–3% only of total waste generated in the Arab region is recycled, while the other is dumped or landfilled (ESCWA, 2015). For example, in Egypt, few basic waste sorting and composting plants is existed but most of it has not proved reliable in practice; in Kingdom of Saudi Arabia, about 95% of the waste generated is being landfilled without any processing or treatment; in Lebanon, few sorting and composting plants are existed, but poorly planned and constructed; in Jordan and Tunisia, there is no plant for residual waste treatment; in the United Arab Emirates, about 95% of the waste generated is deposited at the landfills; in Kuwait, landfills are the main way for waste disposal (Nassour et al., 2016); and Morocco has failed to establish composting plants (ESCWA, 2015).

In Africa region, the largest portion of municipal SW is sent to landfills for disposal. Around 65% of municipal SW is disposed at open dumps at Nigeria thus causing surface and ground water pollution by leachate spills in the areas close to the dumpsites (Alao et al. 2024). Dumpsites were found the major contributor to potentially toxic element contamination of the surrounding soil in Nigeria (Olanipekun et al. 2024). Recycling of SW in Africa is in the range of 5% or less. For example, the volume of waste recycling is in Algeria 3%, Cameroon 5%, and Madagascar 3% (Yoshida, 2018). Organic waste management in the region, in general, is disposed of in landfills and dumpsites without any processing or composting. The first meeting of the African Clean City Platform (ACCP) that was held on April 2017 pointed out the existence of technological management problems concerning compost production from municipal solid waste. Other identified problems of SWM in the meeting included common open dumpsites, and sanitary landfills are not constructed (Yoshida, 2018). Other studies reported that composting is still carried out at pilot scale like the case in sub-Saharan Africa (Drechsel et al., 2004; Friedrich and Trois, 2013; Yeo et al., 2020).

2.2 Organic Solid Waste Composting

Composting is the process to convert organic matter into stabilized biomass through bio-chemical process so the organic matter is degraded by the microorganisms. It can be considered as an important and economic method for recycling of organic waste (Raza and Ahmed, 2016). Some researchers define the composting process as a biochemical and heterogeneous process, through which the organic matter is mineralization into CO_2, NH_3, H_2O and incomplete humification of materials, so that the final product stable with reduced pathogenic microorganism and toxicity (Wang et al., 2018). Diverting the organic fraction from solid waste stream can significantly reduce the waste quantity that is sent to the landfills and, accordingly, increase the lifespan of the landfill. Once diverted and composted, it became a valuable material that can generate environmental and economic value. Waqas et al. (2023) stated that composting of organic waste is a matter of interest from the perspective of sustainable waste management and agricultural benefit. Hassanshahi et al. (2018) reported that organic waste composting materials produced from the residential sector and that generated as residue of green spaces can significantly help in reducing the quantity of landfill waste and provide other environmental benefits. Al-Madbouh et al. (2019) highlighted that composting of organic waste fraction form MSW can significantly reduce the waste quantities especially in developing countries because the highest fraction among other waste fractions is organic waste. The composting process is illustrated in Figure 2-2.

Compost can play significant role in the circular economy. It is a key environmental and social factor in organic agriculture as it increases the productivity of the soil and improve the household income as well, and can support food security through improving soil quality and its moisture retention time (Bekchanov and Mirzabaev, 2018). The quality of compost is essential to enhance its marketing for agricultural purposes (Pergola et al., 2018). Benefits of compost in agriculture have been highlighted by many studies. So it can be used in bioremediation to reduce/remove pollution from polluted sites (Ventorino et al., 2019), control soil plant borne diseases (Pane et al., 2019), control of weeds (Coelho et al., 2019), and reduce the effects that are usually associated with the use of synthetic fertilizers as it improves the soil biodiversity (Pose-Juan et al, 2017). In addition, GHG emissions are normally released and deteriorate air quality as a result of improper solid waste management.

When landfilled, it is undergone anaerobic biodegradation and greenhouse gases are released accordingly, which can increase the climate change effects. Composting can reduce these greenhouse gases emissions, which is a mitigation measure to climate change impacts (Seo et al., 2004, Mohee et al, 2015). In Palestine, it has been found that the solid waste management sector is contributing to the climate change by 23% as per the study conducted by the United Nation Development Program -UNDP (UNDP, 2016). For agricultural purposes, compost can substitute the chemical fertilizers, which has been restricted from entrance to Palestine since the beginning of second *Intifada* in 2000 due to the conflict with the Israeli Occupation. The Ministry of Agriculture (MoA) in palestine, in order to sustain the agricultural sector, issued an investment call for agricultural societies and cooperatives and the private sector asking for investment in compost production in order to bridge the gap and make restitution of chemical fertilizers shortage in the market by compost (MoA, 2011). Moreover, previous studies showed positive attitude of Palestinian farmers to use compost in agriculture (Al-Sari' et al, 2018; Al-Madbouh et al, 2019).

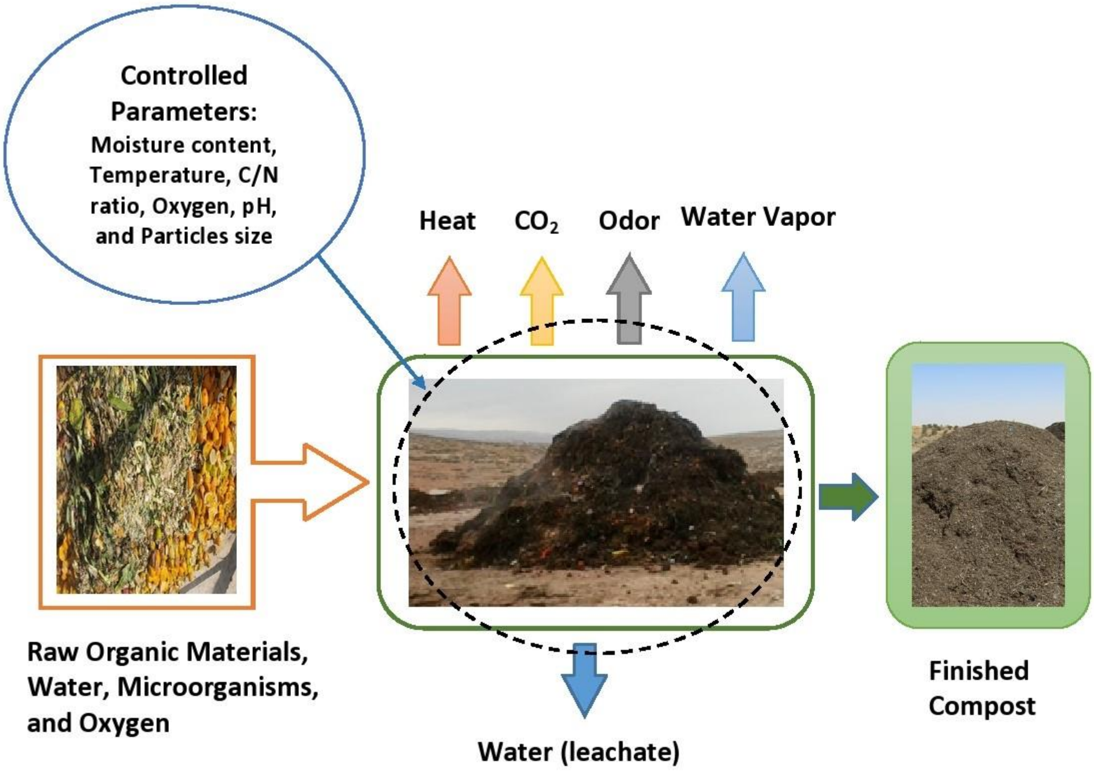


Fig. 2-2: Composting process

Besides the benefits of compost in the agricultural sector and climate change mitigation in Palestine, composting can significantly contribute to reduce the problem of SWM. Palestine as a developing country, the organic SW fraction is the largest one among other waste fraction of MSW similar to other developing countries (Al-Sari et al., 2018; Zhou et al., 2018; Wei et al., 2017; Colon et al. 2010), and, accordingly, composting can greatly reduce the volume and quantity of waste stream in the study area where the organic SW fraction is 46% of the total MSW generated. However, the availability of relatively rapid composting system can assist in coping with this large waste stream. Therefore, one of the purposes of this research is developing a new composting system which can accelerate the composting process.

2.3 Composting Methods

It is widely well-known that composting is process that allows biodegradation of the organic matter by micro-organisms and converts it into a stabilized biomass. Biodegradation of the organic matter can take place aerobically mediated by oxygen and bacteria and called aerobic decomposition and stabilization, or anaerobically mediated by anaerobic bacteria in the absence of oxygen and called anaerobic fermentation or digestion. In both process the micro-organisms utilize the organic materials and convert it into a more stabilized form. The difference between both is that in aerobic decomposition, much carbon is needed as an energy source for cell metabolism, where around two-third of carbon is respired as CO_2 and the one-third combined with the nitrogen to build a cell (Paul et al, 2019). In anaerobic fermentation, small portion of carbon is respired as CO_2, and none consumed carbon in the cell building is released as methane in reduced form (Howard, 1933). In addition, the stability of the organic matter produced via aerobic process is more than that produced by anaerobic process; therefore, it needs aerobic treatment after digestion (Van der Wurff et al., 2016). However, earthworms can consume the organic matter and produce a stabilized biomass called vermicomposting (Paul et al, 2019).

Composting can be carried out as small scale on the household level, and/or large scale as central composting. On the household level, several composting systems have been designed and in use worldwide. In central composting, full controlled and non-controlled composting systems are in practice. In the full-controlled systems, mechanical systems are normally used where the compost parameters are fully controlled, and the compost time is short. This type of systems is used when there is large quantity of waste is generated and there is a need to process such waste stream to overcome its impacts on the environment. Examples of such systems include in-vessel composting, container composting...etc. In non-controlled systems, the compost is carried out in an open yard under the atmospheric conditions, and the compost time in such systems is usually high. Examples of such systems are windrow composting, pile composting …etc. There are many different organic waste composting methods for municipal organic solid waste such as windrow composting method, aerated static pile method, and in-vessel composting techniques (Malakahmad et al., 2017). Selecting the appropriate composting method depends on several factors including capital and operational costs, space available for the composting process which depends on the availability of land, operational complexity and potential of social effects and nuisance problems (Malakahmad et al., 2017). Selected most common small and large scale composting systems can be summarized as follows:

2.3.1 Windrow composting:

One of the most common composting methods through which the waste can be placed in rows of approximate dimensions (2 – 3) meters height, (4 – 5) meters wide and (30 – 40) meters long as specified Food and Agriculture Organization – FAO (FAO, 2007). Dimensions can be changed based on the availability of space and raw materials. It can be carried out in open area but cover is required during rainy season. In order to allow oxygen penetration, turning is required once a week at least (FAO, 2007). The composting time, depend on the frequency of windrow or compost pile turning and type of the raw materials, could in the range of (5 – 10) weeks (FAO, 2007). Turning can be done manually or machine turning. Windrow composting is shown in Figure 2-3.

Fig. 2-3: Windrow composting

Source: Bio-cycle. Web reference accessed 13/10/2021

2.3.2 Pile composting

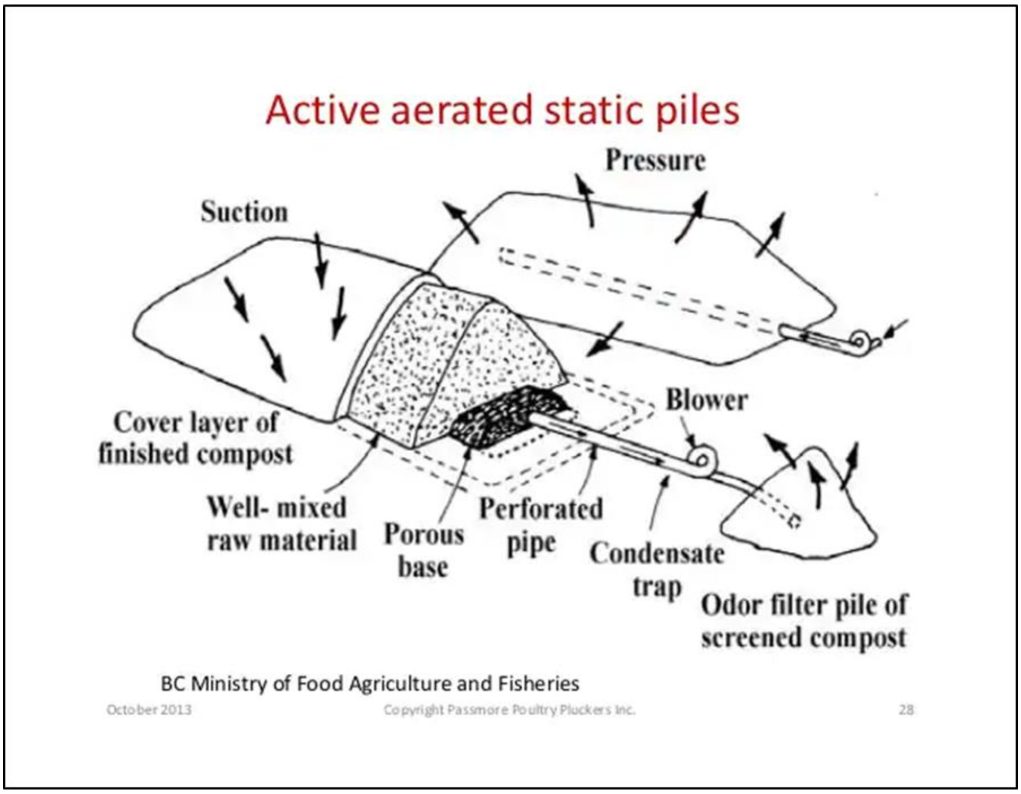
It is simple and effective way of composting. The raw materials are placed in piles which is turned on regular basis to ensure proper aeration. Alternative to turning, pile composting can be carried out as passive aerated static pile where the aeration is taking place through perforated pipes at the base of the pile as shown in Figure 2-4. Also it can be carried out as active aerated static pile where the aeration is taking place through forced aeration by air blowers through perforated pipes at the base as illustrated in Figure 2-5. Forced aeration could be by air suction (negative pressure) which forces the oxygen to enter the pile from the atmosphere, or could be through blowing air (positive pressure) into the system. Forced aeration could be continuously or based on time intervals or temperature sensors, and can achieve more control of the process. Time of composting in the case of forced aeration can be lowered and the process can be finished within (3 – 5) weeks (FAO, 2007). Central composting pilots in the study area were carried out using windrow and pile composting system – turning method.

Fig. 2-4: Passive aerated compost pile

Source: Washington State University. Web reference accessed 13/10/2021.

2.3.3 In-vessel Composting

This is a full controlled system used for handling large quantities of organics such as the organic fraction of MSW and can be situated indoor. This technology employs a controlled environment with optimal levels of oxygen, temperature and moisture content. This technology is available in different systems, such as compost containers, compost rotating drums, …etc. as reported by Waste and Resources Action Program-WRAP (WRAP, 2021). In-vessel composting systems can reduce odor emissions during the composting process. Also it is considered a power consuming technology compared to the open windrow system (Darrell et al., 1998). This system requires less space, and composting process can be accurately controlled by using this system compared to other composting systems (Cekmecelioglu et al., 2005). Moreover, the composting process needs shorter time when using such system (An C-J et al., 2012). Example of in-vessel composting is illustrated in Figure 2-6.



Active aerated static piles

BC Ministry of Food Agriculture and Fisheries

October 2013 Copyright Passmore Poultry Pluckers Inc. 28

Fig. 2-5: Active aerated static pile composting

Source: Slide share, https://www.slideshare.net/aberland/composting-poultry-offal-january-2014. Accessed on 13/10/2021

Fig. 2-6: In-vessel composting

Source: XACT-Systems. https://xactsystemscomposting.com/images/. Accessed on 13/10/2021

2.3.4 Vermicomposting

In this method, earthworms are used to divert organic matter into compost. Approximately all organic material types can be utilized by earthworms and it can degrade them accordingly. It is efficient in organic matter degradation as it can eat the same of its body weight (Ayilara et al., 2020). Only two stages can be distinguished in vermicomposting: (i) physical commination processing of organic material, ingestion, and biodegradation and this is called active stage, and (ii) further biodegradation of undigested waste fresh layers and this is called maturation stage (Van der Wurff, 2016). One problem could exist which is the survival of pathogens because the temperature doesn’t rise and remains in the *mesophilic* range.

2.3.5 Indian Bangalore Composting

This method has been developed in India, and compost raw materials and night soil can be placed in layers alternately inside a pit or a trench of one-meter depth, and finally (15 – 20) cm of cover material is placed on the pit or the trench and left for three months without turning or watering (Ayilara et al., 2020). Additional layers of organic materials and night soils will be added alternately during this period as the volume will be reduced and the surface will settle. The compost process will last within six to eight months in this method.

2.3.6 Sheet Composting

In this method, the organic refuse such as food waste, garden trimming, …etc. are spread on the soil surface in a layer, after that plowed or turned up and then left to biodegrade. No heap is formed in this method, therefore, it is cheap and straightforward (Ayilara et al., 2020).

2.3.7 Indore Composting

This method is also developed in India between 1924 and 1930, where different organic materials available on the farm are used including the animal dung. The materials are heaped in layers 15 cm thick near the farm at an elevated place to avoid rainwater flooding. When the heap reached of 1.5m height, it cut in the vertical direction into slices of (20 – 25) kg and placed on the floor of cattle barn for one night and then is taken to the compost pit and filled in layers within one week (Ayilara et al., 2020). One fourth of the pit is kept empty to allow turning, so it is turned only three times after 15 days, after 30 days and the last time after 60 days, and moisturizing is taking place only during turning (Paul et al., 2019). This is also a time consuming method where the compost process finished within (4 – 5) months (Paul et al., 2019).

2.3.8 Berkley Rapid Composting

The composting process runs fast in this method. The raw materials pieces shall be in the size of (0.5 – 1.5) inches in order to decompose rapidly (Ayilara et al., 2020). Composting is conducted as a batch using this method, so once the process is started no raw material is added to avoid lengthening of the composting process as any new added material needs s specific time to degrade, which extend the composting time (Misra, et al., 2003).

The above-mentioned composting methods are depicted in Figure 2-7.

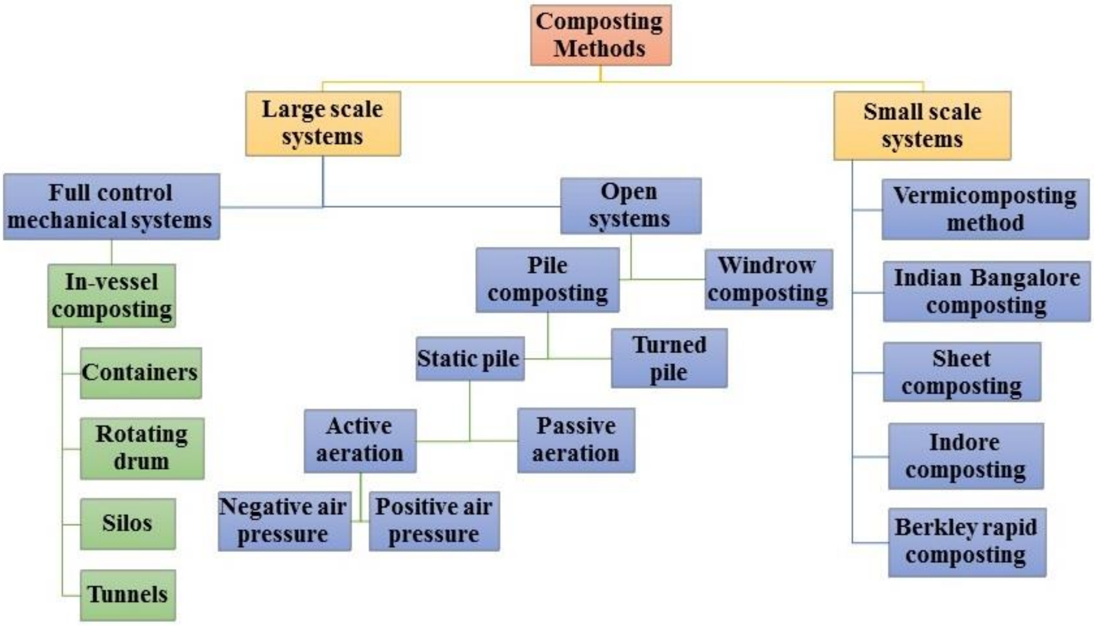


Fig. 2-7: Different composting methods

2.4 Composting Parameters

Compost quality as well as the time needed for composting depends on several parameters. Adjusting these parameters can optimize the time required for the composting process, and can improve the quality. These parameters can be summarized as follows:

2.4.1 C/N Ratio

Organic waste contains carbon and nitrogen. The carbon is utilized by the microorganisms as energy source cell building. Nitrogen also is important for protein production. Microorganisms used (25 – 30) unit of carbon mass for each 1 unit of nitrogen used for the production of the protein according Recycled Organic Units – ROU (ROU, 2007). Therefore, the compost mixture shall be prepared in accordance with this ratio in order to optimize the process of degradation. Huang et al. (2004) recommends (25 – 30) C: 1 N as optimum for active composting. In accordance with Kavitha and Sabramarian (2007), the C/N below 30:1 at the beginning of the composting process is optimum. Others reported that the most appropriate C/N ratio is in the range of 25-35 (Van der Wurff, 2016). When the C/N is higher than 35, this indicates limited source of nitrogen and accordingly slowing down of the composting process will happen and the time needed for composting will increase. On the contrary, when the C/N is below 25, this indicates high level of nitrogen and, accordingly, the composting process will go fast which will generate excess heat and nitrogen will be lost as ammonia. Excess heat can cause burning of the organic matter and generate ash. By the end of the process, the C/N for finished compost is about 15 (Van der Wurff, 2016; JSI, 2000), shall be less or equal 17 according to Woods End Research Laboratory – WERL (WERL, 2005), less or equal 25 (FAO, 2007), below 15 (Raza and Ahmad, 2016), and 20 (Kavitha and Sabramarian, 2007). Table 2-1 summarizes several initial ratios of C/N reported in the literature for different composting mixtures and purposes.

Table 2-1: Initial values of C/N from the literature

Study	Recommended Initial C/N	Notes
Huang et al., 2004	25-30:1	
Kavitha and Sabramarian, 2007	30:1	
Kumar et al., 2010	25-30:1	
Gao et al., 2010a	28:1	Provide better stability and maturity
Van der Wurff et al., 2016	25-35:1	
Vochozka et al., 2017	20-30:1	
Wu et al., 2017	25:1	For composting of pig manure, rice husk and maize straw
Macias-Corral et al., 2019	22:1	For pathogen elimination during composting of cow manure and straw
Ekinci et al., 2020	33-37:1	For 2-stages pomace of olive mill, straw and manure composting.
Yang et al., 2021	25:1	For composting of material containing cellulose, hemicellulose and lignin
El-mrini et al., 2022	22:1	For composting of olive pomace and turkey manure
Tippawan et al., 2022	33:1	For vermicompost
Azis et al., 2023	10:1 and 25:1	For kitchen waste using household electrical compost
Chiarelotto et al., 2023	25-35:1	For composting of sewage sludge and cotton waste
Tang et al., 2023	24:1	Optimal for compost maturity

2.4.2 Moisture content (MC)

It has been reported that the optimum microbial activity is taking place in the compost mixture when the MC is in the range between 50% and 60% (FAO, 2007, ROU, 2007). The optimum value of the MC in compost pile should range between 40% and 70% by weight in accordance with Luangwilai et al. (2011). MC is considered as an important parameter throughout the composting process due to its influence of the oxygen uptake, temperature, microorganisms, and air voids, in the compost mixture (Petric et al., 2012). In accordance with Van der Wurff (2016), the optimum value of the MC is located in the range of 45–55% during the *thermophylic* phase. Low MC level reduces the microbial activity, while the high water content can reduce the voids in the compost mixture as well as the oxygen quantity and accordingly oxygen deficit will take place and creates anaerobic process. MC of 30% is proposed to be the minimum (Van der Wurff, 2016), while below 30% the microbial activity in the compost mixture stops (ROU, 2007). Tang et al. (2023) found that MC of 65% is optimum for compost maturity. The MC is lost gradually during the composting process due to the action of the microorganisms, and this indicates high decomposition rate of the organic matter (Sudharsan and Kalamdhad, 2015). When testing the MC from a windrow or pile, the sample should be taken at a depth of 40–50 cm from the surface as the MC in the external layer 0–20cm from the surface is different from the inside layers (Van der Wurff, 2016).

2.4.3 pH

It is defined as the concentration of the hydrogen ions in the solution. In accordance with (Rynk et al., 1992), the sensitivity of the composting process to pH is law due to the wide variety of microorganisms existed in the compost raw materials. However, it becomes of great importance when composting organic materials with high nitrogen content such as manure. Optimum pH value in the compost is located in the rage of (5.5 – 9) as reported by (Pace et al., 1995; Van der Wurff, 2016), and in the range of (6 – 8) as reported by (Raza and Ahmad, 2016). At high values of pH (more than 8.5), the nitrogen starts converting into ammonia gas (FAO, 2007; Van der Wurff, 2016**)** and accordingly lost from the compost to the atmosphere causing nuisance odor and final compost product with low nutrient. At the initial stage of the composting process, the pH value falls down due to the generation of organic acids as a result of organic matter degradation, then it returns back to rise overtime as the organic acids are broken down. In the maturation phase, the pH value approaches neutrality value of 7 (Van der Wurff, 2016).

2.4.4 Temperature

Heat is generated during the composting process due to the biological decay of the organic materials, which increase the temperature of compost mixture. In pile composting, the volume of the compost pile plays an remarkable role in the temperature build up, so large size piles can generate high and quick temperatures, while small piles (1 – 2) m^3 size (ROU, 2007) may not heat up due to the heat loss to the atmosphere. Usually the heat loss occurs in the outer layers of the compost pile; while the interior layers are considered isolated by the outer layers and therefore the temperature build up there is different and especially at the center. Temperature can be affected by the MC, so the microorganisms' activity is reduced under low MC which causes reduction in the temperature. It has been reported that temperature is one of the major parameters during the monitoring the composting process (Xiu-lan et al., 2016; Raut et al., 2008; Onwosi et al., 2017). However, two temperature phases can be distinguished, *mesophilic* and *thermophilic*. Throughout the *mesophilic* stage, which is the initial stage and characterized by rapid increase of microbial activity of the *mesophilic* organisms, the temperature reaches 45ºC. As the temperature reaches 45ºC, *mesophilic bacteria* start die. The thermophilic phase starts at temperature of 40ºC (Van der Wurff, 2016) or at 45ºC (ROU, 2007) and could reach 70ºC (ROU, 2007; Van der Wurff, 2016), and this phase is characterized by high rate of decomposition due to dominant *thermophilic* organisms. This phase also is considered the disinfection (*pasteurization*) phase because pathogens, parasites and seeds are destroyed due to high temperature. To ensure proper disinfection of the compost end-product, the temperature during the composting process should 55°C and above as this temperature can eliminate pathogenic microbes and parasites (Ravindran and Sekaran, 2010). Thermophilic bacteria begin to die off at temperature 65–70ºC, and, accordingly, the rate of decomposition slows and the temperature starts decreasing indicating that the composting process is almost completed and this is considered as the curing phase. During the curing phase, the compost mixture could be re-invaded by beneficial microbes such as Fungi and Actinomycetes if it is placed in contact with the soil as such microbes are existed naturally in the soil. Fungi and Actinomycetes can degrade the more resistant materials such as *cellulose* and *lignin* (ROU, 2007). Temperature profiles and compost phases are shown in Figure 2-8.

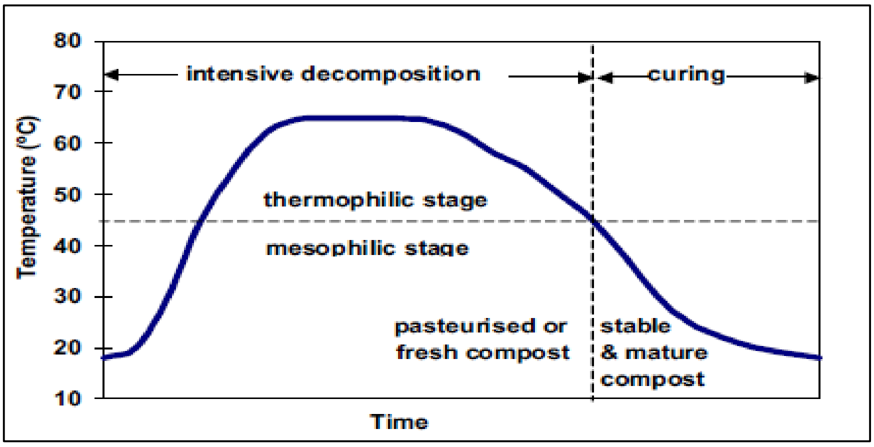


Fig. 2-8: Compost process phases and temperature profile

Source: *ROU, 2007*

2.4.5 Particle Size

A particles size is linking directly with the porosity, texture and structure of the compost materials. Particles with small sizes have more surface area and support the microbial activity and growth which leads to rapid decomposition. However, smaller particles can reduce the porosity in the compost mixture and oxygen circulation as well. Particle sizes in the range of 1/8–2 inches’ average diameter can obtain optimal composting conditions in accordance with Pace et al. (1995). Other studies reported a range of 10–50 mm particle sizes is adequate for gaseous exchange in the compost pile (FAO, 1987).

2.4.6 Oxygen

Composting is conducted in aerobic conditions. Microorganisms consume oxygen during the biodegradation process of the organic materials, and needs sufficient quantity of oxygen to ensure optimal composting process. In case of insufficient oxygen, aerobic microorganisms begin to die off, and the process starts turning anaerobic which activate the anaerobic microorganisms which results in production of some odorous volatile fatty acids and the compost became phytotoxic. Also oxygen deficit will cause incomplete nitrification and, accordingly, accumulation of the nitrite produced at the initial step, which is toxic to many organisms and plants. Therefore, sufficient oxygen is necessary to avoid incomplete nitrification. The adequate oxygen concentration in compost pile shall be 10–15% (FAO, 2007). Also it has been reported that the oxygen concentration of 10–14% results in optimum composting conditions (ROU, 2007). However, microorganisms can’t effectively function below oxygen concentration of 5% (ROU, 2007), and the process turns anaerobic below this oxygen concentration (5%) according to Dickson et al. (1991). Previous studies reported that large quantity of oxygen should be provided at the beginning of the process in order to initiate aerobic composting (Gao et al., 2010; Pace et al., 1995). A forced aeration composter system has been designed at an air difusing rate of 3–5 cubic feet/minute/ cubic yard of compost mix which is equal to 0.111–0.186 m^3 air /m^3 of compost mix (Coker and Gibson, 2013). Managed Organic Recycling Company is operating static composting system with air flow in the range of 750–1250 cubic feet/ hour/ ton of dry compostable materials, which is equal to 21.24–35.40 m^3 / hour/ ton of dry compostable material, which is also equal to operation of air blower for 3–5 minutes every 30 minutes (Coker and Gibson, 2013). In a batch composting process, an aeration rate of 0.095–0.236 liters’ /minute/ kg of dry matter and a peak of 1.79–2.27 liters/min/ kg dry solids is recommended by Haug (1993). Table 2-2 presents recommended several aeration rates from the literature.

Table 2-2: Recommended aeration rates from the literature

Study	Reported Aeration Rate	Notes
Wiley and Pierce, 1955	0.34 – 1.10 liter/min/kg OM	
Hong, et al., 1983	0.87–1.07 liter/min/kg OM	For manure, crop and forest residues composting
Pos, 1991	0.5 – 1.16 liter/min/kg OM	
Lau et al., 1992	0.04–0.08 liter/min/kg OM	For composting of swine manure
Haug, 1993	0.095 – 0.236 liter/minute/ kg DS of dry solids	
Haug, 1993	1.79–2.27 liter/min/kg DS (as optimum)	
Keener et al., 2001	0.3 – 0.9 liter air/min/kg OM	
Lu et al., 2001	0.43−0.86 liter/min/kg OM	For food waste composting
Vining, 2002	0.69 liter air/min/kg OM	
Li, et al., 2008	0.25 liter/min/kg OM	For dairy manure - rice husk composting
Gao et al., 2010b	0.5 liter/min/kg OM	For sawdust - poultry manure composting
Arslan et al., 2011	0.62 liter/min/kg VS	For vegetable and fruit refuse composting of
Sungsomboon et al., 2012	0.03 m^3 air/hour/kg	
Coker and Gibson, 2013	(3 – 5) cubic feet/minute/ cubic yard of compost mix, which is equivalent to (0.111 – 0.186) m^3 air /minute/ m^3 of compost mix.	
Coker and Gibson, 2013	(750 – 1250) cubic feet/ hour/ ton DCM	
Nada, 2015	0.44 L/min/kg DM	For compost of maize stalks and cow dung
Yuan et al., 2016	0.2 liter/kg DM/min	For sludge composting
Zhang eta al., 2016	0.2 liter/min/ kg DM	To control emissions of NH_3 and volatile sulfur compounds emissions
Qasim et al., 2019	0.3 liter/min/kg DM	For composting of sawdust and chicken manure
Wang et al., 2021	3.25 liter/min/kg DM	
Peng et al., 2023a	0.2-0.3 liter/min/kg DM	For composting of kitchen refuse
Tang et al. 2023	0.3l/kg DM/min	Optimal for compost maturity

Note: DM means dry matter, VS means volatile solids, OM means organic matter, DCM means dry compostable material.

2.5 Compost Quality and Standards

Standards of compost quality vary from one country to another depending on the situations. The legal framework for compost quality of finished compost in Palestine is the Standard specification for organic fertilizer (compost) No. PS/-2652 issued by the Palestinian Standards Institutions –PSI (PSI, 2012). The standard classified the compost into two types: type one is compost produced for gardening, and type two is for agricultural uses. Table 2-3 summarizes the physio-chemical end-quality parameters permissible limits by the PSI standards, and Table 2-4 summarizes the standard permissible limits of heavy metals as per the PSI standards.

Table 2-3: Standard limits for physical and chemical quality parameters for finished compost

Physical and Chemical Quality Parameters		
Quality Parameter	**For Gardening**	**For Agricultural Uses**
Particle size	20cm, larger size is allowed if it doesn't exceed the 10% of the compost weight	No limitation
Foreign particles (a)	Max size 5mm, up to 5%	Max size 10mm, up to 5%
Moisture Content (% of wet matter)	(25 – 40)%	(25 – 40)%
pH	5-8.5	5-8.5
Electric conductivity (Ec) ds/m (b)	As identified in the label	As identified in the label
Organic Matter (OM) (% of dry matter)	≥35	≥25
Total Nitrogen (% of dry matter)	As per the notice of producer ±25%	As per the notice of producer ±25%
Carbon-Nitrogen ratio (C/N)	As per the notice of producer	As per the notice of producer
Degree of maturation	As per the notice of producer, but not less than 4	As per the notice of producer, but not less than 2
Potassium (% of dry matter)	As per the notice of producer ±25%	As per the notice of producer ±25%
Potassium (K)	As per the notice of producer ±25%	As per the notice of producer ±25%
Borax (mg/kg)	≤200	≤200
Sodium (Na)	As per the notice of producer	As per the notice of producer

(a)foreign particles are particles from plastics, glass, metals, ceramic or stones which can't pass through a sieve opening 5mm.

(b)*Ec≤4 for compost application at 5 cm below the soil surface, and limitless for application at 20 cm deep from the soil surface.*

Source: PSI, 2012, standard No. PS/-2652

Table 2-4: Finished compost standard limits for heavy metals quality parameters

Heavy Metals Quality Parameters for Both Uses		
Quality parameter	**Max limit**	**Units**
Lead (Pb)	300	mg/kg
Chrome (Cr)	400	
Nickle (Ni)	90	
Cadmium (Cd)	20	
Zinc (Zn)	2500	

Source: PSI, 2012, standard No. PS/-2652

Quality standards of finished compost in other surrounding countries such as Jordan that is the nearest country to Palestine and with almost the same conditions are summarized as follows: MC ≤12%, pH ≤ 7.5, total nitrogen ≥ 1.5%, C/N ≤ 1:15, OM ≥ 60%, and EC ≤ 15 dS/cm according to the Jordanian Standards Institution –JSI (JSI, 2000). The Jordanian standard can be used in Palestine due to the similarity in the conditions. However, since the quality standards are differing from country to another; selected quality parameters and standard limits or expert recommended limits are shown in Table 2-5. Heavy metals international limits are presented in Table 2-6.

Table 2-5: Selected compost quality parameters international standards/expert recommended limits

Quality parameter	**Limits**	**Reference**	**Notes**
Organic matter	(30 – 70)%	United States Composting Council (USCC, 2001)	US composting council
Nitrate (NO_3-N)	(20 – 150) ppm	Qadomi (2014)	Expert recommended
C/N ratio	≤17	Woods End Research Laboratory (WERL, 2005)	Expert recommended
PO_4-P	(800 – 2500) mg/l	Woods End Research Laboratory (WERL, 2000)	USA standards
Potassium (K)	(500 – 2000) mg/l	Woods End Research Laboratory (WERL, 2000)	USA standards
Chloride (Cl)	<1000 mg/l	The Waste and Resources Action Programme- WRAP (WRAP, 2002)	German standards, type 2 compost
Sodium (Na)	<500 mg/l	The Waste and Resources Action Programme- WRAP (WRAP, 2002)	German standards, type 2 compost

Table 2-6: Heavy metals quality parameter international limits

Quality parameter	**Italy (mg/kg)**	**Spain (mg/kg)**	**European Range Union (mg/kg)**	**USA (mg/kg)**
Lead (Pb)	140	1200	70 - 1000	300
Copper (Cu)	300	1750	70 - 600	1500
Zinc (Zn)	500	4000	210 - 4000	2800
Chrome (Cr)	100	750	70 - 200	1200
Nickle (Ni)	50	400	20 - 200	420
Cadmium (Cd)	1.5	40	0.7 - 10	39
Hg	1.5	25	0.7 - 10	17

Source: Woods End Research Laboratory, 2000

2.6 Compost and Climate Change

Solid waste management represents a challenge worldwide and specially in developing countries where the organic fraction is the highest component of the waste stream. The majority of the organic waste stream is sent to the landfills for final disposal. At the landfill, the waste undergoes decomposition as a result of anaerobic conditions and release GHG and mainly methane (CH_4), carbon dioxide (CO_2), and substantial amount of nitrous oxides (N_2O) as reported by Jia et al. (2014). Bogner et al. (1996) reported that 50–60% of the landfill gas is methane and the remaining is carbon dioxide. The global warming potential of methane and nitrous oxide is 25 and 300 times greater than carbon dioxide, respectively, as reported by Natural Resource Defense Council – NRDC (NRDC, 2021). Relatively large portion of GHG is attributed to the decay of organic waste at the disposal sites and landfills. Methane levels have significantly risen due to human activities such as filling landfills as reported by the United States National Academy of Sciences (USNAS) and the Royal Society – RS (USNAS and RS, 2020). Globally, the estimation of methane gas emissions from landfill sites was in the range of 500–800MtCO_2-equ/year as reported by the other studies (Monni et al., 2006; Bogner and Matthews, 2003). Therefore, GHG emitted from landfills is considered major contributor to the climate change.

In Palestine, SWM sector is contributing to the climate change by 23% of the total emissions (UNDP, 2016), which is considered one of the main contributing sectors. This is due to the fact that almost all of the SW collected by the LAs is sent to the dumpsites and landfills and absence of methane gas active collection and recovery systems from the landfills in Palestine. Composting is one of the tools that can significantly reduce the carbon emissions released from the landfills if the organic fraction is diverted from the SW stream and composted. In accordance with Jalalipour et al. (2024), home composting can reduce about 9% CO_2-eq per year if 10% of municipal SW is composted in Shiraz/Iran. Bogner et al. (2007) reported variety of technologies to reduce GHG emissions from waste including composting of selected waste fractions, and he highlighted that composting can be sustainable at reasonable cost in developing countries. A study conducted by the World Bank stated that composting is preferable SWM option in countries of low-income due to the high organic fraction (Kaza et al., 2016). Kutos et al. (2023) found that compost amendments played important role in carbon sequestration as it improved belowground carbon content by 50%.

2.7 Legislative Framework

SWM in Palestine is regulated by several laws. These are including:

2.7.1. Local Authorities Law (LAL) No. 1 for the year 1997

The law defines the responsibilities of the LAs in article (15) which include: planning of roads including construction, sidewalks, lighting, gardening, maintenance, and monitoring; planning for the building and issuance of building permits; domestic water service providing including specifying the specifications, prices, connection fees and prevent water pollution; provide the community with the electricity and specify the its prices and connection fees; construction of sewage systems, public toilets and monitoring of these facilities; regulation of public markets; regulating industries through locating specific places for each type and monitoring that of significant public health effects; cleanliness and waste collection and disposal; monitoring of public health through taking all necessary measures to protect public health and prevent spread of pandemic, monitoring of food, fighting of mosquitoes and flies and rodents, construction of slaughterhouses, and construction of health centers and hospitals; regulating public facilities and shops such as restaurants, coffee shops, playgrounds, and entertainment facilities; construction and regulation of public gardens; take the necessary measure to prevent flooding, fire outbreaks, natural disasters and relief; construction and monitoring of cultural and social facilities such as museums, libraries, and sport facilities; construction and regulation of parking; regulation and monitoring of mobile traders and vendors’ stalls; inspection and monitoring of weighting equipment in public markets; monitoring of billboards; demolition of risky buildings; prevent begging and construction of shelters for the needy people; construction of cemeteries; hotels monitoring; regulation of animals markets; regulation of dogs acquisition and prevent the risk of wild dogs; preparation of annual budgets; managing the assets and financial resources; other necessary jobs but subjected to the approval of the minister of the local government such as establishing of JSCs.

The relevant responsibilities of the local authorities to SWM in accordance to article (15) are waste management within their own jurisdiction to ensure cleanliness. The responsibility includes waste collection, transfer, disposal, management of landfill facilities, and to take any precautionary action to protect the public health and prevent future pollution or epidemic outbreaks. The law opens the door in front of the local authorities to establish the JSCs in coordination with the ministry and define the responsibilities of the JSCs in conducting the joint services. However, the law doesn't provide any details options SWM such as reduce, reuse and recycle (LAL, 1997).

2.7.2. Palestinian Environmental Law (PEL) No. 7 (1999)

The law is consisted of 82 articles regulating the different environmental parameters. The objective of the law in defined in in article (2) which include: environmental and public health protection, introduction of environmental and social safeguards to be part in development plans and activities, enhance sustainability principles in the development of vital resources, protection of natural reserves and biodiversity, and ensure public awareness of environmental problems. Relevant articles to SWM set the general framework for SWM in Palestine. Article (1) defines solid waste and hazardous waste; article (7) and (9) defines the responsibilities of the Environmental Quality Authority (EQA) in setting up the national strategic plan and specifications of the disposal sites; article (8) asks the competent authorities to encourage the 3Rs principle (reduce, reuse and recycle); article (10) asks all parties to take the required precautions to store and safe transfer construction and demolition waste to avoid any environmental pollution; articles (11), (12) and (13) regulate hazardous wastes. In accordance with article (11), the ministry will issue a list of hazardous substances and hazardous waste. Article (12) prevents any manufacturing, storage, distribution or disposal of hazardous materials and waste unless otherwise in compliance with the environmental regulations. Article (13) forbids importing any hazardous waste to the country, and forbid passing any hazardous waste through the country unless otherwise a special permit is issued by the ministry. Article (23) prevent dumping or incineration of garbage and waste except in the places provided for this purpose; articles (74) and (76) are in the meaning of the "polluter pays" principle where the violator of the law shall pay the compensation for the damage he caused. (PEL, 1999).

2.7.3. Palestinian Environmental Assessment Policy (PEAP)

The policy issued in the year 2000 to ensure that the environmental and social safeguards are taken into account in development activities to ensure sustainable development. The policy aims to protect the communities and individuals and the environment through preventing irreversible damages to the environment, protection of water resources, biodiversity, air quality, cultural heritage and valuable resources, aquatic environment, and natural resources during any development activity. In accordance with the policy, the development activity or project should be subjected to environmental assessment: initial environmental evaluation (IEE), or environment impact assessment. IEE is usually conducted for projects where significant environmental impacts are uncertain. The EIA is usually conducted for projects that are likely have significant environmental impacts. EIA could be conducted after conducting the IEE if it has been discovered that the proposed activity will have potential significant impact on the environment. The policy listed the projects that require full EIA study, which included large scale projects such as waste disposal sites, because such projects have significant environmental and social impacts during construction, operation, and aftercare.

In accordance with the policy, the environmental approval is perquisite for the initiation of the project. The project owner, after obtaining the preliminary approval from the planning-related agency, shall apply to the Environmental Quality Authority (EQA) to obtain the environmental approval. The application will undergo screening to decide whether the project needs IEE or EIA, or none is required. The whole process from the application up to notification the applicant about the result of screening shall be finalized within 14 days. The screening is conducted based on specific criteria that considers natural resources, community displacement, biodiversity and natural reserves, cultural heritage, environmental and social impacts of the proposed project …etc. The environmental approval could include the required measures to mitigate significant environmental impacts that the project proponent shall take to comply with the environmental regulations and relevant standards, and monitoring and reporting required. The policy required environmental auditing for the existing projects of facilities. The auditing report shows the level of compliance with the mitigation measures, and could result in suspension of the permission of the facility until corrective action is taken to comply with the mitigation plan, or agreement on conditions to be applied with clear implementation plan. According to the policy, SWM projects shall undergone full environmental impact assessment study due to its high negative impact on the environment (PEAP, 2000).

2.7.4. Public Health Law (PHL) No. 20 (2004)

The law is consisted of 13 chapters: definitions and general principles, mother and child, combating diseases, food safety, occupational health, health and education, loathsome sites, health institutions, medical and auxiliary professions, medications and drugs, buried of dead, monitoring and inspection, and penalties and concluding provisions. The law defines the role of the Ministry of Health (MoH) in SWM in chapter one and chapter seven. Chapter one, article (2), item 12, the ministry is responsible for issuing a license for SWM facilities. Chapter seven defines the roles of individuals and the ministry to avoid loathsome sites. Chapter seven, article 40, asks individuals to keep all elements of the environment and not to create hazard or harm, and to remove any hazard or harm each creates as he is the responsible for that. Article (41) said that the specialized person in the ministry shall send a note to the person who created hazard asking him to remove it within a certain period, and the ministry in cooperation with all competent bodies will work to remove the health hazard. Article (42), the ministry in coordination with the other relevant parties shall determine the appropriate transfer, suitable storage, treatment or disposal methods of hazardous items (PHL, 2004).

2.7.5. Medical Waste Management (MWM) Bylaw (2012)

The law is consisting of 71 articles which define the medical waste and its types, and the responsibility of each stakeholder. The law defines the major and minor sources of MW; responsibilities of the medical institution; protection of the workers in MWM; asks every organization or institution to set a MWM manual in compliance with the bylaw and the responsibility of the institution manager; it defines the hazardous and non-hazardous portion of the MW and lists the characteristics of the hazardous waste fraction; sets the procedures for MW separation and the container or sack color for each fraction; sets the specifications of MW storage places, and the procedures for storage and transfer; defines the specifications of MW collection vehicles; defines the specifications of the MW treatment plants and construction places and define permission procedures; methods of MW treatment; final disposal after treatment. In addition, the law defines the responsibilities of inspection and monitoring agency, and it defines the role of the MoH, the EQA and the local authorities to exchange information between the stakeholders and prepare emergency plans (MWM Bylaw, 2012).

2.7.6. Solid Waste Management (SWM) Bylaw (2019)

This bylaw is consisted of 38 articles which sets the regulation and responsibilities in SWM in Palestine. It specifies and defines the following: the scope of the bylaw application; the competent authorities; the waste and bins ownership; the responsibility of the waste producer; occupational and public health and safety; commitment of the service provider during waste collection and transfer, construction and operation of solid waste TSs; waste treatment and disposal; specifications and conditions of the landfill; commitments of the landfill operator during construction and operation; waste prohibited from entering the landfill; landfill closure and conditions; closure of random dumpsites; waste incineration and conditions; special waste management; licensing of SWM facilities; duties of the Ministry of Health (MoH) in SWM; hazardous waste; waste reuse, recycling and composting; delegation of the private sector in SWM; SW records and records keeping; inspection and monitoring and facilitation for monitoring agencies; prohibition of mixing household waste with hazardous waste; import and export of waste; and penalties..

The bylaw encourages compost production from SW stream. Article no. (3) of the bylaw sets the responsibilities, and among these responsibilities item (7) which is encouraging the reuse and recycling of the SW as much as possible through production of compost from municipal organic waste and use it for agriculture purposes in compliance with the health and environmental requirements. Waste reduction, reuse, recycling and composting is mentioned in article no. (27), item (a) asks the component authorities to take all necessary measures to reduce the waste stream as much as possible through reuse, recycling and recovery; and item (b) asks to comply with the technical specifications of the compost (SWM Bylaw, 2019).

2.8 Attitude Towards SW Composting

Apart from the technical inputs, the social and behavioral aspects-people’s perception and participation, positive attitude and acceptance are important parameters towards development of new composting system that aims to solve the problem of organic waste to achieve sustainable MSWM. Therefore, studying the attitudes of solid waste service providers toward organic SW composting is very important and can contribute to solve many challenges in waste management. In Palestine, the LAs including municipalities; village councils; joint councils for services, planning and development (JCSPD); and joint service councils for solid waste management are the service providers of MSW management service. The stakeholders play a major role in MSW management and can apply the waste management principles, reduce, reuse and recycle (3R’s) if they have the resources and positive attitudes. Also they can play a remarkable role in country strategy and translate this strategy into action in reality.

The National Strategy for Solid Waste Management in Palestine - NSSWM (2017 – 2022) sets eight strategic objectives to achieve its vision in solid waste management, and focused on organizational, technical and financial issues. Under objective no. three “efficient and environmentally-safe SW service”, policy no. (6) “Encourage methods and policies that lead to waste reduction, reuse, and recycling before final disposal at the landfills” (NSSWM, 2017), encourages organizations and the private sector investment in waste recycling and reuse to reduce the quantities that are currently sent for landfilling. One of the recycling options mentioned under this strategic objective is composting of organic SW materials to be used as compost or as cover material in the sanitary landfills. From strategic point of view, the local authorities are the key players who can create real change through direct investing or attracts investors this sector. Attitude of these authorities toward SW recycling through composting is very important and can indicate their future direction and steps toward composting and acceptance of new composting system. Therefore, this research included assessment the local authorities’ attitude towards SW composting in the study area. In addition, it aims to identify the influencing factors on the LAs’ attitude toward SW composting.

Local authorities are major players in the effective management of waste. It has been reported that the success in SWM depends, to a large extent, on the stakeholders involved and their resources that enable them to set adequate plans with clear responsibilities (Klundert and Anschütz, 2001; Phong Le et al., 2018). Joseph (2006) has discussed and defined the role of the different stakeholders including municipalities in sustainable SWM. Phong Le et al. (2018) has investigated the stakeholders' perspectives in using the organic municipal SW for agricultural purposes.

2.8.1 Factors Affecting Local Authorities Attitude towards SW Composting:

As composting is considered recycling of organic SW and one of the options in SWM, factors affecting local authorities toward composting could be the same as that affects their attitudes toward other recycling programs. Previous researches on challenges and constraints faced by the WM organization highlighted financial, technical, awareness and institutional constraints. McAllister (2015) studied the influencing factors on SWM in the developing world, and classified the factors into culture and education, infrastructure and technology, policy and institutional and integrated SWM system. Since municipalities in the developing countries are providing SWM service, they are responsible for providing the needed infrastructure for waste collection, transportation, treatment and final disposal, and oftentimes fail to manage the waste due many constraints including technical, social, and institutional (McAllister, 2015). Nitivattananon and Suttibak (2008) assessed the factors that affect the performance of SW recycling programs including composting and they classified the factors into general factors such as awareness, technical, financial, and institutional. Lalitha and Fernando (2019) assessed the factors that affect SWM in Sri Lanka, which included citizens' participations, adequacy of resources, peoples' training in waste management and awareness, staff training and awareness, market availability for compost and other recyclables, awareness of SWM laws and policies, innovative solutions for SWM such as developing methods for SWM, staff members motivation, the contribution provided by businesses and the society, staff remuneration, and successful execution of the SWM program. Phong Le et al. (2018) reported that the stakeholders influence various SWM system elements including composting through environmental compliance, financial and institutional capacities, social acceptance and legal aspects. Raza and Ahmad (2016) reported that lack of political, legal, and regulatory environment can derail composting efforts. He also reported that the outcome priorities of the LA should be taken into account in the earlier stage of policy-related dialogue to be appropriately reflected in the policy setting. Based on the review of the literature and the situation of the local authorities in the study area, the following factors are identified to be included in the study:

(a) Community awareness and participation:

Community participation in waste recycling program is very important and especially if the local authority plans to apply the role of waste separation at the source, which is a key element in successful of any waste recycling program as it reduces the time, efforts and cost. Shukor et al. (2011) reported that the citizens are responsible because they are users and their minimum input and participation is required especially in separation of recyclable items or organic materials from the other waste. Community participation can contribute to the successful of SWM programs, and according to Rathi (2006) is a crucial factor in the successful implementation of SWM. However, community awareness regarding organic waste separation and composting is essential and can facilitate their participation in waste segregation at the source. A comparative study conducted in Delhi/India and Jakarta/Indonesia to investigate the attitude of the community towards waste separation and composting and identified several factors affect the community participation in sorting and composting (Widyatmika and Bolia, 2023). Alimoradiyan et al. (2024) found that training on municipal SW reduction, dissemination of information in the media, and availability of environmental cadre are significant factors affecting the community participation in MSW composting. Mangundu et al. (2013) raised the importance of community awareness and promotion regarding the use of compost through road show, radio and TV programs, which should be associated with awareness and education on policies and implication regarding violation of by-law. A study conducted in Greece to assess public participation in SWM and awareness of the new SWM plan and showed that the residents lack the knowledge of the new SWM schemes, and concluded that the participation of citizens should urgently be enhanced through informative campaigns (Chachami-Chalioti et al., 2024).

(b) Availability of adequate resources:

Availability of adequate resources is essential to implement any SWM program. Resources include financial, technological, land and infrastructure, which are necessary for the local authorities to initiate and sustain the WM system. Malwana (2008) reported that many local government units do not pay enough attention to the infrastructure of SW and waste collection and disposal resources due to the shortage in financial resources and limited budget allocated to them by the central government and inadequate allocated resources. Previous studies highlighted the importance of adequate resources in the successfulness of the WM. Henry et al. (2006) highlighted that lack of SW collection vehicles, poor infrastructure, and lack of financial resources with local government units reduced the successfulness level in SWM projects′ implementation. Atienza (2011) reported that the lack of financial resources to purchase and employ modern technologies in SWM has more effect on developing countries than developed ones. A study conducted in *Sri Lanka* showed that limited area of land available was a major obstacle facing the local government units in conducting their recycling and composting programs (Lalitha and Fernando, 2019). The study also found that the majority of the LAs who participated composting activities have failed because they lack the required essential facilities and latest technology (Lalitha and Fernando, 2019). The main financial resources contributing to

SWM at the local authorities' level is that the fees collected from the community on monthly or annually basis. The rate of fee collection is an indicator about the financial status of the local authority and could affect its attitude toward initiating a composting facility as well as accepting new composting method. Another important financial indicator is the cost to billing ratio which indicate if the tariff is adequate in covering the cost of the SWM service, and also could affect the local authority toward alternative methods in SWM.

(c) Employees' awareness and training:

The awareness of the local authority staff and the training they received on compost production could encourage the local authority to initiate a composting program. In addition, it can accelerate the rate of organic SW processing and improve the end-quality of the produced compost. Training of the local authorities' staff shall include training on the collection, recycling and composting of SW (Lalitha and Fernando, 2019).

(d) Marketing:

Composting of organic municipal SW is generating a final product – compost, and this compost should have proper marketing to achieve the purpose of reducing the quantity of the waste stream that is sent to the landfill, and cover the cost of compost production. Marketing availability of compost produced from municipal SW can generate income and considered a financial resource that contributes to SWM. Bandara (2008) reported that the reason behind the failure of large composting is not only operational failure, but also the lack of marketing which discourage production of compost on large scale. Moreover, the quality of the compost is a cornerstone in marketing, and can encourage users to buy the produced compost and improve marketing as well. Pergola et al. (2018) reported that the quality of compost is very important from marketing point of view because good quality compost is preferable by farmers for agricultural purposes. Therefore, marketing of the produced compost can significantly affect the local authority attitude toward municipal SW composting.

(e) Support from government:

Support from the government could be financial, technical or political. Direct financial contribution from the government to solid SWM or through tax deduction or other incentives on compost produced from the organic fraction of municipal SW can significantly solve many waste management problems and can encourage local authorities to look for composting of the organic SW. in addition, this will promote the public-private partnership in SWM. Technical contribution from the government can take several forms such as establishing regional composting plants, providing the local authorities with bins for waste sorting, providing the local authorities the required machines and collection vehicles …etc. political support is through issuing and/or enforcing the policies and regulations of SWM, which can support the local authorities to seek alternative solutions in WM such as composting. support from the political leadership is considered as one of the mandatory element to achieve radical SWM system (Gustavson, 2008). Another important intervention and support from the government is directing the international donors to support the local authorities in the field of SWM including the recycling and composting programs.

(f) National policy and laws related to organic waste composting:

Policies and roles can support local authorities to develop WM practices and move to better environmental friendly systems in SWM. Waste separation at the source at the policy level as well as waste reduction through waste composting can ensure cooperation of both the community and the service provider to establish composting programs. Previous studies highlighted the importance of well-established SWM polices for successful implementation (Mangundu et al., 2013; Taylor, 2000).

(g) Innovation on solid waste management:

One of the challenges in SW composting using turned windrow or pile composting is the long time needed for processing until maturation and use, which require a large area of land to operate effective composting program. Therefore, developing new rapid composting system with acceptable operation cost for local authorities, which can reduce the area and time needed, is considered a novel method and attractive and could change the attitude of these local authorities toward composting.

Factors affecting some stakeholders' attitude toward SWM in Palestine were studied. Al-Khateeb et al., (2017) studied the influencing factors on the sustainability of SWM system in Ramallah and Jericho cities /Palestinian. Al-Sari' et al. (2018) studied the farmers' attitude toward compost use in agriculture and factors affecting their attitudes in the Hebron area (part of the study area). Al-Madbouh et al. (2019) studied the perception of farmers and their willingness to engage in compost production and use for agriculture purposes in Wadi al-Far'a agricultural area in north of the west Bank/Palestine. The study also assessed the socio-economic and agricultural factors that affect the farmers' attitude towards compost use. However, local authorities, the key stakeholders in SWM, attitude toward composting have never been studied before. Therefore, this study will focus on the assessment of the local authorities toward municipal SW composting in southern West Bank of Palestine.

2.9 The Role of Compost in the Circular Economy

The linear economic model of production and consumption through which the goods are manufactured, used and finally discarded as waste is the dominant global economy. This model of “make-use-dispose” is considered as challenging because it can generate waste, degrade the environment, cause price hike due to volatile resources and supply disruption, and cause supply risks for countries that depend on imports. However, the circular economy is an alternative option and can substitute the linear economy, which can solve these challenges and promote the environmental practices by returning the discarded products into the production cycle. Bentil et al. (2024) studied SWM in higher educational institution from economic perspectives and found that the circular economy approach is more sustainable than linear economy approach. Up to date, only 7.2% of all materials input in the economy are coming from circular sources (World Economic Forum, 2024). The linear economy is the dominant consumption model in the developing world, while the developed high-income countries are applying the principles of the circular economy in policy and action. For example, the European Union (EU) issued an action plan and circular economy monitoring framework to implement the principles of the circular economy in waste management sector (Mayer et al., 2019). In accordance with the plan, 65% of the municipal waste shall be recycled as target (EU, 2020) and food waste per capita shall be reduced on the retailer consumer level to half by 2030 (Flanagan et al., 2018). The principles of circularity in economy include: capital preservation through use of renewable resources; optimization of resource yields through material circulation in technical and biological cycles; enhance effectiveness of system through proper design to reduce the effect of externalities on systems (food, shelters ...etc.) and manage external effects (air, water ...ect.) (Ellen Macarthur Foundation, 2015).

The purpose of the circular economy is to use the products as longer as possible by reusing and repairing them to minimize waste generation and more utilization of secondary raw materials in the production cycle (Cossu and Williams, 2015). Composting fits perfectly with the principles of the circular economy as it enables the efficient treatment and utilization of organic refuse for different uses and closing of the environmental loop (Pajura, 2024). Composting of municipal organic waste is an application of use of secondary materials in the production cycle instead of depositing at landfills. Following the model of the circular economy, previous studies highlighted the recycling of organic waste materials into various products. For example, the seeds and skin of grape can be recycled and through composting and to produce bio compost as reported by Sehnem et al. (2020) and organic fraction of municipal waste generated by households and other establishments including food waste can also be transferred into compost according to Slorach et al. (2020). The compost is rich in carbon, which in the soil, can resist soil erosion, improve soil water retention, improve soil fertility, and increase biodiversity due to the enumeration enrichment of bacteria, fungi, insects and worms (Razza et al., 2018), which can appropriately restore the health conditions of the agricultural soil and support the growth of the plant, and at the end increase the community resilience capacity to cope with the climate change effects such as severe droughts.

Compost can support the food chain as well as food security by returning nutrients into the soil and enhance its productivity and crop yield (Ellen MacArthur Foundation, 2015; Razza et al., 2018). In accordance with the European Compost Network (ECN), bio-waste through compost can contribute to the main objectives of the circular economy via closing the biological cycles of materials, and reducing organic SW disposal at landfills thus reducing the linear economy; rich in carbon and nutrients thus contributing to improving the fertility of the soil and its C-sequestration; producing environmental friendly bio-based fertilizers suitable for replacement of synthetic fossil fuel-based fertilizers (ECN, 2016). Fig. 2-9 illustrates the biological cycle in the circular economy.

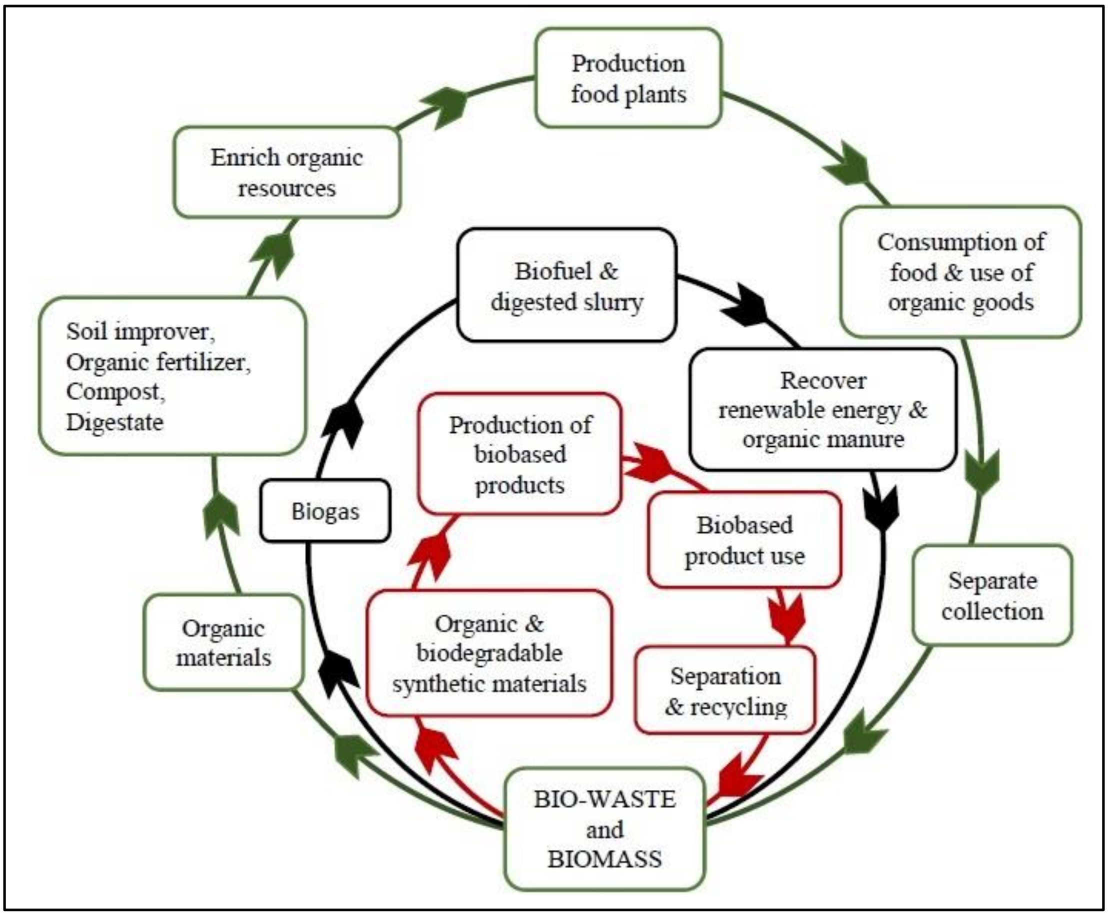


Fig. 2-9. Biological cycle of organic waste and the concept of circular economy

(Source: Adapted from Ellen MacArthur Foundation, 2015)

Furthermore, the circular economy can contribute to environmental protection and sustainable development through reducing demand on virgin materials, less environmental impacts from extraction and processing of materials, lower energy consumption during the manufacturing process of products from recyclables compared to goods produced from virgin materials, and less waste sent to the landfills which means less landfill gas emissions and less economic costs and other environmental and health risks (Pisuttu et al., 2024). The circular economy principles can contribute to climate change mitigation through carbon reduction not only from industry, construction sector, and energy use, but also from waste disposal through conversion of waste into circulating materials such as metals, plastics, glass, paper, and utilizing kitchen waste for compost production (Yang et al. 2023). Moreover, there is clear connection between circular economy, food waste management, and sustainable development goals (SDGs) especially SDG 2 and SDG 12, zero hunger and responsible consumption and production, respectively (Prokic et al., 2022).

2.9.1 Compost and Urban Mining

Urban mining is a component of circular economy as the valuable materials are isolated/ extracted and separated from the waste, recycled and returned to the material cycle. The raw primary material used in the industrial processing is the material resource that remains unprocessed such the wood which is used in the pulping industry, while the secondary raw material is that which has already been processed and used and has become discard; such material can be used again to produce new goods. For example, paper and cardboard waste can be recycled to produce recycled one. Large cities are considered as a source of large quantities of waste due to the large number of population and intensive consumption pattern as well. Such cities are considered as a warehouse of secondary raw materials. Urban mining is defined as the processing and recycling of the waste materials by transferring it into a resource for new products particularly in cities and urban areas. Utilization of the virgin materials (the raw primary materials) in the industry is expensive and considered as energy consuming process which in turn imposes environmental stress. However, as the population is increasing continuously, the demand on different products is increasing as well, and the utilization of virgin materials is increasing proportionately. Some resources of materials become scarce, and the use of such resources is considered unsustainable. On the other hand, disposal of discarded products and waste materials results in accumulation of waste at landfills and dumpsites, which is considered as a loss of valuable alternative resource, and above all, these landfills and disposals sites become a matter of concern from environmental and social point of view due to the release of pollutants. Therefore, recycling and recovery of such waste material and returning it to the material cycle through urban mining has great benefit to the communities and the environment, thus supporting the circular economy. Urban mining is, therefore, the process of extraction of used and discarded materials of urban metabolism from the waste, recovery of these discarded materials through recycling and reused it as resource for the production of new items. (Rau, 2019). It is an effective way for resource recovery such as landfill mining to extract the valuable recycled materials (Park et al. 2017). Some previous studies defined urban mining as, indirectly, the activity of recovery of elements from buildings, energy, compounds, and other recyclable elements from urban waste generated (Baccini & Brunner, 2012; Arora et al., 2017). The terminology of urban mining was used for exploitation and extraction of secondary materials from landfills in the beginning, but nowadays it is widely used to include any sort of material recycling (Cossu and Williams, 2015). Composting is a treatment process of recycling through which the organic refuse is recycled and transformed into organic fertilizer. Based on the above-mentioned, and using the terminology of urban mining that include any sort of material recycling, extraction of organic waste towards its composting can be considered as a compost of urban mining. The composting process can be used to recover nutrient from the waste material (Girotto et al., 2015), which can be used in agriculture to replace chemical fertilizers. This can achieve environmental and social benefits through reduction in emissions and nuisance, and reducing the energy and virgin raw materials used to produce chemical fertilizers simultaneously.

On the other hand, landfill mining which is a type of urban mining can result in extraction of the decomposed organic matter from the landfill to be used as compost. Zaulfikar et al. (2020a) reported that long term buried solid waste in landfills can be extracted and used for agricultural purposes as compost to support plants or alternatively, can also be reused as landfill cover materials as biocover. In developing countries, the largest fraction of solid waste is generated from the household, and it includes peelings from fruit and vegetables, food remnants and leaves (Bobeck, 2010). This large waste stream is deposited in landfills for a long time and undergoes decay by the biological action thus transformed into stable biomass, which can be extracted through landfill mining and used as compost for agriculture, landscaping, and bioremediation. Ye et al. (2024) reported that soil from aged municipal solid waste landfills has proved effectiveness in providing the plants with large amount of organic matter and nutrients. Landfill mining compost is rich in broad variety of microorganisms such as methnotrophs, which can biologically convert methane into Carbone dioxide when applying this compost on the active landfill as biocover materials. (USEPA, 2002; Barlaz et al., 2004; Albanna et al., 2007).

2.9.2 Waste Generation and Characteristics in the Study Area

Few years ago, many studies were conducted to estimate the generation rate and composition of SW in Palestine, in general, as well as the study area in particular. These include:

- Environmental Resources Management – ERM (2000);
- International Management Group – IMG (2010);
- Tamimi and Gebra (2012); and
- International Finance Corporation – IFC (2012).

Excluding the result of the study that was conducted by the ERM (2000) as it was very old, and considering the composite of the other studies including the latest study which was conducted by the IFC, the composition of the waste is shown in Table 2-7.

Table 2-7: SW composition in the study area

MSW Fraction	**Percentage (%)**
Paper (includes cardboard)	10.9
Plastic containers	18.3
Textile	6.1
Organics	46.0
Metal (ferrous and non-ferrous)	1.8
Glass	2.3
Miscellaneous (including diapers, shoes and inert)	14.6

Source: (IFC, 2012)

The IFC study conducted in (2012) showed that SW generation per capita was 0.69kg in the Hebron governorate, and 0.79kg in Bethlehem governorate (IFC, 212). The updated data from the records of the weighing bridge at Al-Menya landfill showed that the daily average waste received at the landfill is around 1,200.0 tons; 925 tons of them are collected from the study area, 155 tons from east and southeast Jerusalem area, and 120 tons from the Israeli occupation settlements that are located in southern West Bank, which enter the landfill under force. The large portion of this waste stream which is about 925.0 tons is collected from the study area (JSC-H&B, 2020). The monthly as well as annual waste delivered from the study area to Al-Menya landfill since opening the landfill in March 2014 up to end of year 2020 is shown in Figure 2-10.

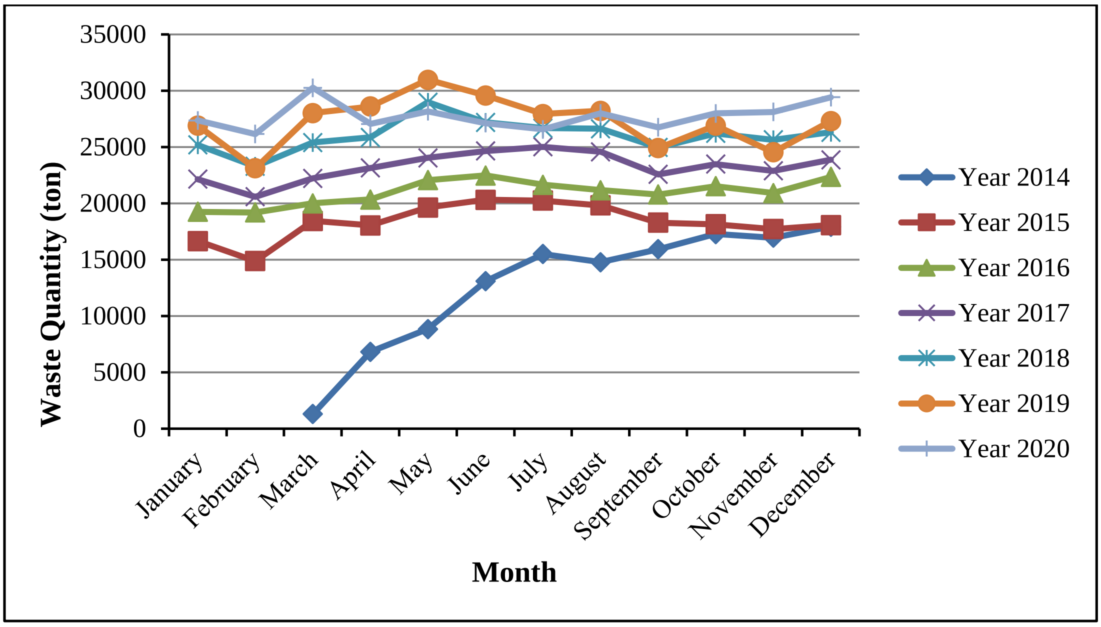


Fig. 2-10: Monthly quantities of SW waste received at Al-Menya Landfill site since opening the site in 2014 up to year 2020
(Source: adapted from the JSC-H&B records, 2020)

2.9.3 Potential for Compost Production through Landfill Mining

The organic fraction which contains food refuse, fruits and vegetable waste, agricultural residues such as leaves and tree trimming residues, etc. is the highest waste fraction in solid waste stream containing 46% of the total waste and collected from the study area. All of the waste is being sent to the landfill, buried there for a long time, and decomposed under anaerobic conditions. In addition, 18 random dumpsites have already been closed upon request of the competent authority after the construction of the regional engineered landfill. The largest one was in use since the mid of eighties and has been closed in 2016. Although some of these sites were subjected to burning during the operation, but still large amount of organic waste can be extracted and used as compost for landscaping, and sanitary landfill cover if the quality parameters lie within the limits for agricultural use especially with respect to the heavy metals. Mining of these dumpsites can repair and recover the land conditions, overcome the environmental problems related to leachate seepage into the aquifer and landfill gas emissions. All of the random dumps in the study area have been abandoned and closed before 2012 (i.e. more than 12 years ago), while the larger one has been closed in 2016 (i.e. 8 years ago). This elapsed period of time makes the mining of these dumps favorable for the purpose of compost extraction. Zaulfikar et al. (2020b) studied a landfill mining in Indonesia based on the garbage heap age and he found that best percentage of compost can be attained after garbage heap reaches optimum age of 8-9 years.

Furthermore, the regional landfill currently in operation in the study area, which contains more than 3.5 million tons of SW, is facing constraints for expantion. These constraints represented by unavailability of land since the land around the landfill is privately owned and owners are asking for high prices to sell their land. Other political constraint is obtaining the permission for expansion from the Israeli occupation as the site is located in area classified “C” according to Oslo Accord between the Palestinian Authority and Israel, which is under the full control of the Israeli occupation, and obtaining construction permission is very difficult. Under the given constraints, landfill mining is one of the options to extend the service life of the landfills (Zaulfikar et al., 2020a).

On the policy level, there are no guidelines regarding urban and landfill mining of SW in Palestine in general. Although there is severe limitation of land for landfills and expansion of the existing ones due to the political reasons, and opposition of the local communities to construct landfills near them, there is no obligatory policy or legislative framework for waste reuse and recycling as well, and landfill mining has never been mentioned.

2.9.4 Use of Compost and Chemical Fertilizers in Agriculture

The benefits of compost for agricultural purposes are widely reported in the literature. It can be used for soil bioremediation to treat the contaminated soil (Ventorino et al., 2019), reduces plant diseases as it controls soil-borne diseases (Pane et al., 2019), controls weed and enhances plant growth (Coelho et al., 2019), improve the agricultural soil biodiversity (Pose-Juan et al, 2017), improve soil fertility and water holding capacity (Bekchanov and Mirzabaev, 2018), and substitute chemical fertilizers (Rajaie and Tavakoly 2016; Azim et al. 2017; Oliveira et al. 2017). In accordance with Olson et al. (2024), who conducted study on Cannabis Sativa waste conversion into organic fertilizers, composting of digested biomass can promote plant growth and suppress soilborne disease. Compost, in general, can reduce heavy metals-related toxicity through reducing its mobility and bioavailability while vermicomposting, in particular, can reduce heavy metals concentration (Ejileugha et al., 2024). Moreover, compost has proven better performance as soil amendment in terms of moisture retention compared to synthetic water-retaining amendment such as hydrogel (Zgallai et al., 2024). Due to intensive use of inorganic fertilizers in agriculture, which contribute to considerable amount GHG emissions, the replacement of synthetic inorganic fertilizers with organic one is urgently needed for environmental considerations (Peng et al. 2023b).

Palestinian farmers' acceptance of use of compost in agriculture has been assessed at different locations. All the studies showed positive willingness of farmers and attitude towards engagement in compost production and use. Al-Madbouh et al. (2019) found that 84% of the farmers in Wadi Al-Far'ah Watershed have the willingness to produce and use compost for agricultural purposes. Al-Sari' et al. (2018) found that 91.2% of the farmers in Hebron district have positive attitude towards use of compost in agriculture. In addition, 57.2% of the Palestinian agricultural holding are using organic fertilizers or animal manure compared 42.7% that are using the chemical fertilizers (HydroplanIngenieur-GesellschaftmbH, 2013). However, utilization of animal manure in agriculture reduces the dependence of farmers of chemical fertilizers and leads to economic outcome (Yılmaz et al., 2024).

The compost market demand in Palestine is 76,575 tons/year (IFC, 2012). The demand of compost in Palestine is increasing due to the shortage of chemical fertilizers in the market because of the Israeli occupation restrictions. The Israeli occupation has restricted imports of many of dual use goods such as fertilizers and chemicals (The World Bank, 2019). The United Nations Conference on Trade and Development (UNCTAD) reported that the restrictions include fertilizers like ammonium nitrate (NH_4NO_3), potassium nitrate (KNO_3), urea (CH_4N_2O), urea nitrate ($CH_4N_2ONO_3$), fertilizers containing nitrogen, phosphorus and potassium (at percentages of 27-10-17 and 20-20-20) and any other fertilizer containing any ammonium nitrate, potassium nitrate or urea (UNCTAD, 2015; World Bank, 2019).

This has forced the Palestinian farmers to use alternative fertilizers with lower nutrient concentration which is inappropriate and sometimes ineffective. The use of such low nutrient concentration fertilizers heavily burdened the farmers and incurred high costs due to the relatively large quantity of fertilizers they use to compensate the low concentration, which in turn increase the soil salinity and deterioration of the agricultural productivity. It has been reported that the agricultural productivity declined in the range of 20 -33% due to the use of N, P, K chemical fertilizers type 13-13-13 rating instead of 20-20-20 rating, and the farmers bore extra costs of $29 million/year as well (UNCTAD, 2015). Under the current conditions of such severe restricted access to good quality chemical fertilizers, compost is the best alternative which can remediate the soil after the intensive use of inappropriate chemical fertilizers in relatively large quantities.

2.9.5 Use of Compost as Landfill Cover

Another important use of compost is replacing filling materials as landfill cover. This use is also widely reported in the literature (Huber-Humer, 2011; Sadasivam and Reddy, 2014; Chetri et al., 2019). Applying compost as cover materials over the waste at the landfills is considered as an environmental benefit which can mitigate, to a large extent, the spread of odors, flies, mosquitoes and reduce the release of methane. Methanotrophs in compost can oxidize methane gas and convert it into Carbone dioxide, water and biomass under aerobic conditions (Albanna et al., 2007; Barlaz et al., 2004; Boeckx and Cleemput, 1996; Croft and Emberton, 1989; Kightley et al., 1995; Park et al., 2002; USEPA, 2002; Whalen et al., 1990). The option of compost application on the landfill as biocover materials instead of soil could be viable to enhance methane oxidation and GHG emission reduction from the landfills as well (Tanthachoon et al., 2007). In addition, it can achieve financial benefit through reducing the preparation and transportation of filling materials to cover the landfill. Hermawansyah et al (2018) has conducted a study on compost extracted from landfill mining and reported that the compost quality parameters exceed the quality limits of fertilizers, and accordingly the extracted compost is suitable only for alternative landfill cover.

In the study area, the residues of excavations from the landfill construction are recycled and used as daily and intermediate cover. Currently, the excavated residue is over, and the agencies are applying daily cover from fill material imported from outside the landfill area. The cost of each ton of cover material is NIS 13 (USD 4.0/ton) (JSC-H&B, 2021). Therefore, diversion of organic waste from the SW stream and using it as cover materials after composting is a viable and sustainable option and supports the circular economy.

CHAPTER 3

MATERIALS AND METHODS

To achieve the research objectives, a strict methodology was developed and followed. The following sections provide detailed information about the study area and research methodology.

3.1 The study Area

3.1.1 Location

The study area is located at the southern part of the West Bank, and consisted of two governorates according the governmental managerial system. These governorates are Hebron governorate and Bethlehem governorates as illustrated in Figure 3-1. The total area of the study area in accordance with the Applied Research Institute Jerusalem (ARIJ) is about 1,675.0 km^2; Hebron governorate is about 1,067.0 km^2(ARIJ, 2009a) while a Bethlehem governorate is about 608 km^2 (ARIJ, 2009b).

3.1.2 Demographic Features

Southern West Bank is considered the largest densely populated area in West Bank. In accordance with the Palestinian Central Bureau of Statistics (PCBS), the total population in the study area, Hebron and Bethlehem governorates, is about 922,064 (PCBS, 2018), which is around one third of the total population of the West Bank, and around one fifth of the total population in Palestine (West Bank and Gaza strip). Hebron governorate is larger than Bethlehem, so the total population of Hebron governorate is about 707,017 which is about (76.7%) of the total population in the study area compared to 215,047 living in Bethlehem governorates which is about (23.3%) of the total population in the study area.

3.1.3 Local Government Structure

Cities, towns and villages in the study area, like other Palestinian communities, are run by local authorities. There are 89 local authorities (municipalities and village councils), 53 of them are in the Hebron Governorate and 36 are in Bethlehem governorate as per the MoLG records (MoLG, 2021). The LAs are responsible for the planning and development and are service providers to the communities. The MoLG is the regulator of the local government sector in Palestine, so it issues the regulations and strategies in cooperation with the local authorities and other government ministries and agencies. Services provided by the local authorities included electricity, water and solid waste. These services are provided directly by the local authorities, or through an official body established in cooperation between these local authority and government such as the electricity companies and the joint councils for services, planning and development (JCSDs), and the joint service councils for solid waste management (JSCs).

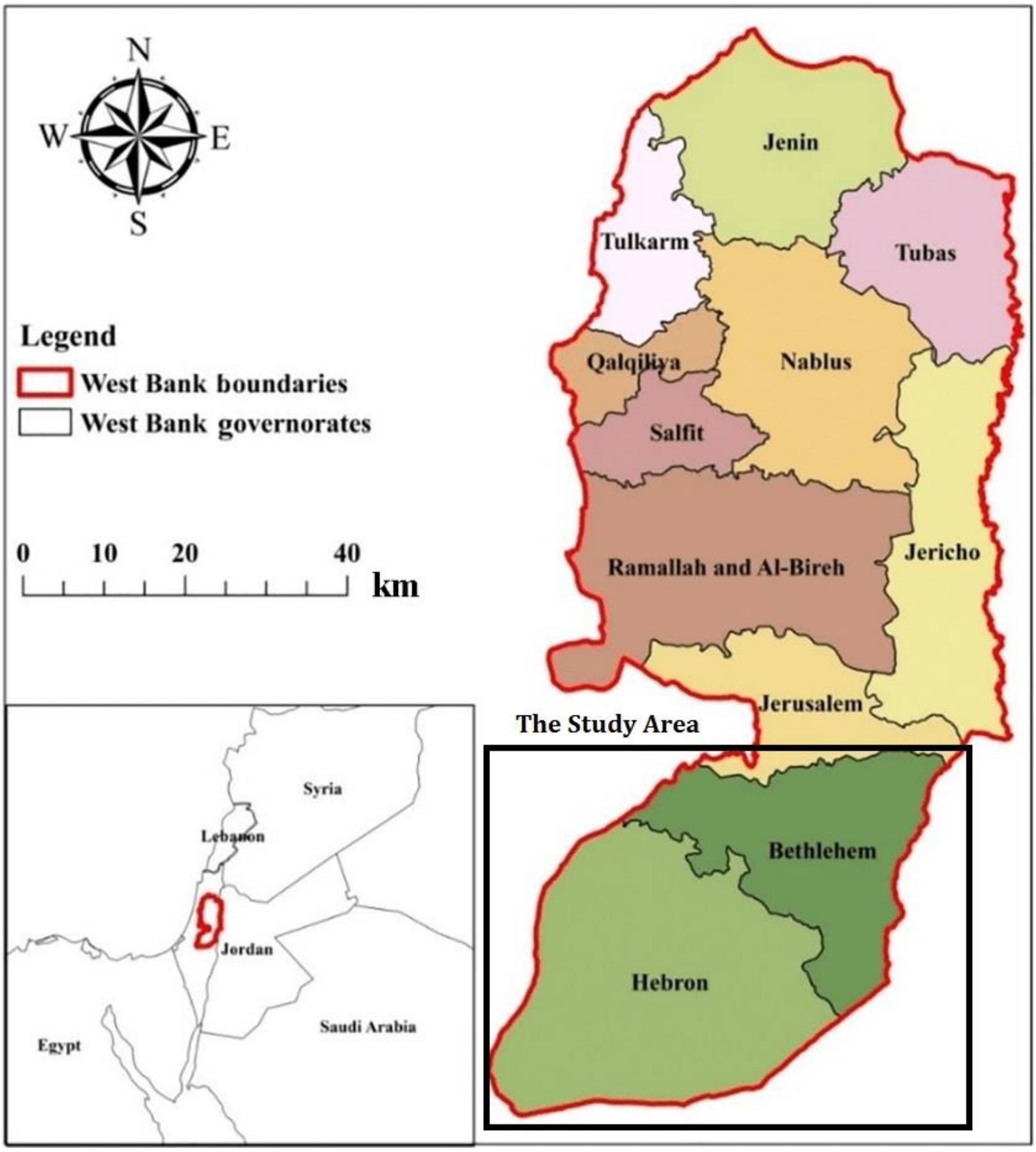


Fig. 3-1: West Bank map showing the study area

Source: Shadeed et al., 2019.

For SWM, there are 3 JSCs-SWM, and 2 JCSPD, all are providing SWM service in the study area. JCSPD were established in the rural areas where several villages cooperated to establish these councils for the purpose of optimizing the services provided. Two of these councils are in the Hebron area while the other 4 are in Bethlehem area. Served villages are members in these councils and represented by the head of the VC, and the board of directors are elected by the members. The joint service councils for SW management were established on the governorate level to handle the SWM service, but still these councils are not taking over the service in all of the governorates because contracting the service is optional, and therefore there is still a lot of local authorities are providing the SWM service. There are three councils for SW in the study area, one in Bethlehem area and one in the Hebron area, while the third one is serving both governorates through the operating of the regional landfill site and the SW transfer stations. This joint service council is called Joint Service Council for Solid Waste Management for Hebron and Bethlehem Governorates (JSC-H&B). All local authorities in each governorate have membership in the governorate council and the board of directors is elected by the members. However, all local authorities in both governorates are members in the JSC-H&B, the chairman is the mayor of Hebron (the biggest municipality), and the rest members of the board of directors are elected by the members' local authorities.

The refugee camps in the study area are run by the United Nations Relief and Works Agency (UNRWA)[1] for Palestinian refugees in the Near East. UNRWA is providing the SWM in all refugees' camps in the study area which are 5 camps, 3 of them are located in Bethlehem area while the remaining 2 are located in the Hebron area.

The structure of relationships between the local authorities and fee collection and payments is shown in Figure 3-2. LAs are responsible for SWM inside its border of jurisdiction, fees collection from households and payment for the SWM to the agency responsible for SWM which are normally the JSCs and JCSPDs who paid to the JSC-H&B (the responsible agency for the operation of the landfill and the transfer stations). Many of the local authorities who are carrying out the waste collection are paying fees to the JSC-H&B directly.

3.1.4 Classifications of the Local Authorities

The MoLG classifies the local authorities and mainly the municipalities into four groups from "A" to "D". This classification system is based on local government minister decision no. 20/4/1998. In accordance with the decision, large municipalities that are considered as central of governorates are classified as group "A", municipalities that were established before the Palestinian Authority rolled over the West Bank and Gaza and that were established after with a population inside the boarders of jurisdiction of theses municipalities are more than 15,000 are classified as group "B", municipalities of population more than 5,000 and less than 15,000 are classified as group "C", and municipalities of population less than 5,000 are classifies

---

[1] Established in accordance with the United Nations General Assembly Resolution 302 (IV) of 8 December 1949 to carry out direct relief and works programs for Palestinian refugees after the 1948 war between Arabs and Israel.

as group “D” (MoLG, 2005). The classification system doesn’t provide any other information about the purpose of the classification, and the link between the responsibilities and the classification. However, small local authorities are called Village Councils (VCs) and established in small villages to provide the services in these small villages.

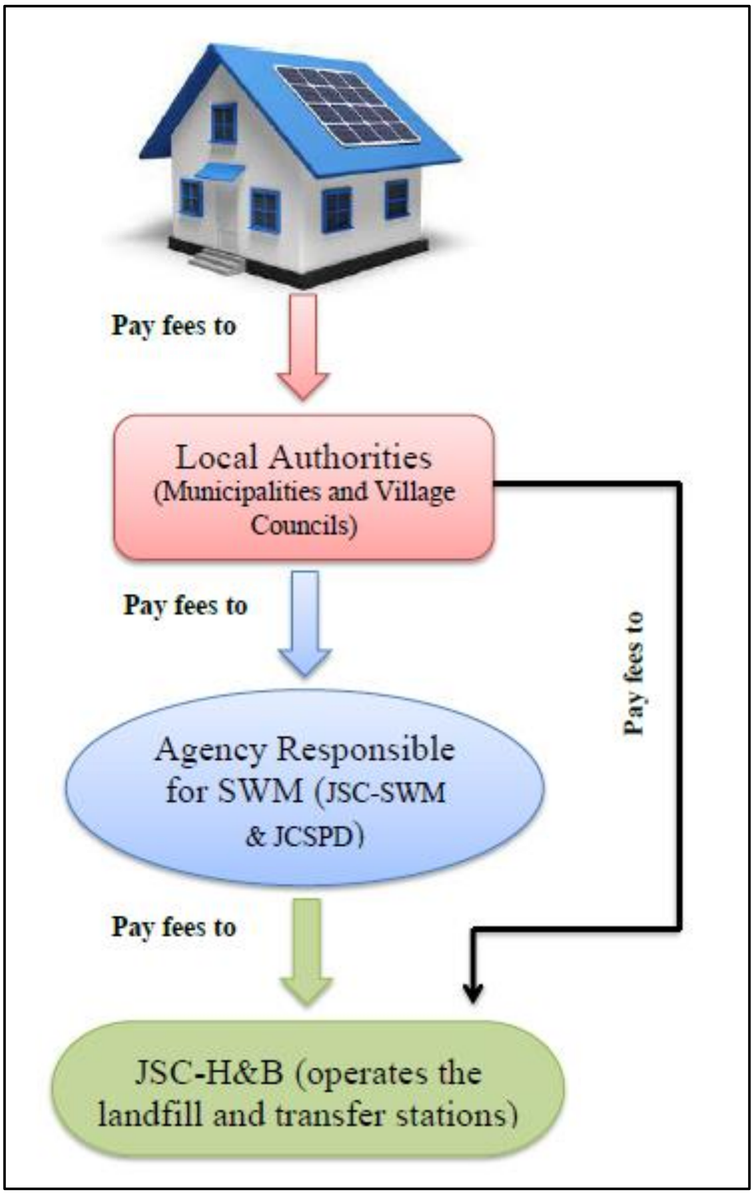


Fig. 3-2: Current structure of relationships in SWM in the study area

After reviewing the local authorities list provided by the MoLG, it has been found that only two municipalities classified “A”, Hebron and Bethlehem municipalities; 17 municipalities are classified “B”, 15 of them in the Hebron governorate and 2 in Bethlehem governorate; 16 municipalities are classified “C”, 7 of them in Hebron governorate and 9 in Bethlehem governorate; none of the municipalities are classified “D”; and 54 VCs, 30 of them are in the Hebron governorate and 24 in Bethlehem governorate (MoLG, 2021).

3.1.5 Socio-economic Conditions and Relationship with SWM

There is no detailed updated data concerning the socio-economic conditions in each governorate in Palestine, but the available data from the PCBS showed that 11% of the families in Hebron governorate and 12.5% in Bethlehem governorate receives assistance even in cash or in kind (PCBS, 2019). This could indicate the level of poverty in the study area and the lifestyle as well, which also affect the SW generation. In addition, political situation plays an important role in the socio-economic situations in Palestine. Political stability of the situations promotes the trading, industry and tourism. It has been reported that instability of political conditions negatively affects tourist flows to the region of conflict (Sonmez, 1998; Sonmez and Graefe, 1998; Neumayer, 2004). Aisen and Veig (2011) Found that the growth rate of the per capita gross domestic (GDP) is severely affected by political instability.

Beside the political instability in Palestine as it is still under the occupation by Israel, there is several industries spread across the study area. Stone cutting industry is famous in Palestine and especially in southern West Bank, so the stone cutting facilities are spread across both governorates, Hebron and Bethlehem (Palestinian Federation of Industries, 2009). Hebron is considered as commercial center in the governorate and an important industrial city. The famous industry in Hebron is the tanning and leather industry, shoemaking industry, pottery industry, food industry, and glass (ceramic) industry according to Hebron Chamber of Commerce and Industry – HCCI (HCCI, 2021). The existence of such industries in Hebron can promote the economy and social well-being. However, the industry can significantly contribute to waste generation and even hazardous waste. For example, the stone-cutting industry can generate large amount of construction waste, and the tanning industry can generate considerable amount of hazardous waste.

On the other hand, Bethlehem is considered as a tourist city as it accommodates the *Nativity Church*, the most holy place for Christians in Palestine. The city attracts tourists from different countries worldwide. Although the number of tourists in Bethlehem fluctuated depending on the political situations and conflict, Al-Rimmawi and Butcher (2015) have noticed increase in the number of tourists since 2009. Tourism can significantly affect the quantity of municipal solid waste generation.

However, agriculture is a main and important sectors in Palestine which contribute by 22% of the GDP, and providing employment to 155 of the population

(Butterfield et al., 2000). The common agricultural activities in the study area are livestock (sheep, goats, cows …etc.), fruits, vegetables, olive, and seasonal crops (ARIJ, 2009a; ARIJ, 2010, HCCI, 2021). Most of the plant agricultural activities are rain-fed agriculture due to the shortage of water in Palestine in general and in the study area in particular, so southern West Bank is facing water crisis even for domestic purposes, and accordingly irrigated agriculture sector is very small in the study area. SW generated from the agricultural sector has limited impact on municipal SWM as the waste is managed by farmers except that generated from the trees pruning from the green areas, and fruit and vegetables waste that generated from the markets which is included in the organic fraction of municipal SW.

3.1.6 Climatic Conditions

The description of the climatic conditions is very important because it can affect the composting process. However, this research included conducting composting experiments in two different climates to predict the influence of the climatic conditions on the composting time and process as well. Two of the composting experiments were conducted in the study area in Palestine, and one experiment in Delhi/India. The climatic conditions in both areas are described below.

3.1.7 Climate of the Study Area/Palestine

The climate in south West Bank/Palestine is described by ‘Mediterranean’, which is rainy in winter rain and dry in summer, with mean temperature of 22°C in summer and 7°C in Winter (USAID, 2017).

3.1.8 Climate of Delhi/India

The climate of Delhi/India overlaps between monsoon-influenced humid subtropical and semi-arid with average temperature of 38°C and 14°C in summer and Winter, respectively (Wikipedia, 2022). The monsoon season, which extends between July to August, is described by hot, high to very high humidity, and heavy precipitation (Wikipedia, 2022).

3.2 Research Methodology

3.2.1 Design, Test and Evaluate of Two Composting Systems

3.2.1.1 Composting System

The composting device used in India was a steel-mesh bin with approximate volume of 0.2m^3, which receives aeration from naturally from the atmosphere through the steel-mesh openings as presented in Fig. 3-3. The system developed and fabricated in Palestine is a forced aeration as shown in Fig. 3-4. The net volume of this composting device is 0.94m^3. Both systems were in complementary with the sizes reported in the literature. Several sizes of bioreactors used were reported in previous studies. For example, Ahn et al. (2007) used a bioreactor of 900 liters in volume for composting poultry manure. Alkoaik (2019) has conducted a study on tomato plants residues and chicken manure composting using two bioreactors, one rotating and anther static, each volume was 0.2m^3, which can handle 50kg of wet weight. Santos et al. (2014) has used a bioreactor of five liters in volume. Te Ma (2020) used a fermentation bioreactor of volume 30 liters to study loss of nitrogen during the composting of sewage sludge and the effect of processing conditions. Hwang et al. (2020) used a compost box of volume 0.15m^3. Misra et al. (2003) recommends a minimum dimension (0.9*0.9*0.9 = 0.729m3) of compost pile to prevent heat loss during the composting process. The device used in this experiment consists of two cylinders, one is small installed inside a larger. The diameters of the small and large cylinders are 20 and 10cm, respectively, while the height is 130cm and 125cm, respectively. The space between both cylinders was filled with waste; the bottom was provided by a pipe and valve for leachate drain, while the upper was provided by movable steel cover for easy remove during taking measurement of the temperature, gases and moisture content. The internal (small) cylinder was perforated in the vertical walls to allow for oxygen penetration into the waste body, and the top was blind. The external cylinder was provided by a door of dimensions 1-meter height and 0.6-meter-wide to facilitate sampling and emptying the device when the process come to end.

Fig. 3-3: Natural aeration system

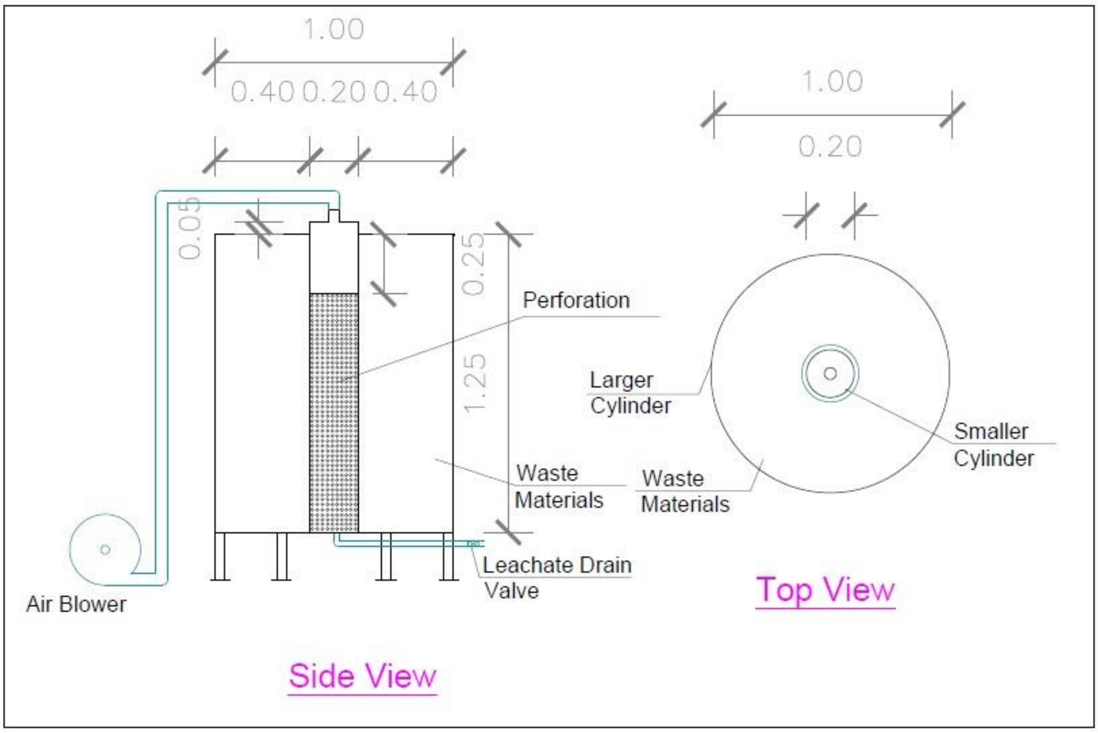


Fig. 3-4: Cross-section of the composting device (forced aeration)

An air pump type RENOVA of capacity $55m^3$/hour and made by MEDAN Company/Israel complying with the European standard EN 60034-1 was used for compost aeration, which was connected to the top of the small cylinder. The pump was provided by an electricity panel containing electricity meter type GREEN complying with the European standards EN 62053-21, timer with 40 schedules of operation, and switch-on switch-off device to allow automatic intermittent operation during the composting process. The complete fabricated system, control panel, and the pump is presented in Fig. 3-5.

Fig. 3-5: Composting device complete (forced aeration)

The composting raw material were prepared and filled in the space between the two cylinders, forming a composting round layer in the vertical direction around the small perforated cylinder. The perforation of the small cylinder allowed the air to penetrate into composting layer through the inside surface. Municipal organic waste obtained from the central fruit and vegetables market of the Hebron city. Before loading the device, the waste was shredded to reduce the size using mechanical shredder and mixed with sawdust to adjust the C/N ratio, and the water content of (40 – 60) % and then filled in the device, which was installed at 15 cm above the ground that enable installation of the leachate draining pipe and valve at the bottom of the device. The leachate drain valve opened and closed on daily basis to drain the leachate that was accumulated at the bottom. The system was placed under a shed to prevent direct exposure to the sunlight.

3.2.1.2 Experiments Setting

Three static composting experiments were conducted: first experiment in Palestine, second experiment at Delhi Technological University/ India, and the third experiment in Palestine, respectively. The first and third experiments (replicates) were conducted using the designed composting device, while the second experiment was conducted using steel-mesh compost bin. Santos et al. (2014) has conducted four compost mixtures in a study on carbon conservation strategy for management of pig slurry by composting. Te Ma (2020) has conducted 4 composting trials to measure the Nitrogen loss and the influence of processing conditions. One compost mixture was used in a study conducted in Saudi Arabia to compare the efficiency of two bioreactors using tomato plants residues and chicken manure as raw material for composting (Alkoaik, 2019). Mengistu et al. (2017) conducted a composting experiment to compare the efficiency of four composting methods and he used three mixtures (replicates) for each composting method.

Two different air flow rates, 0.12m^3/min (7.1m^3/hour) and 0.24m^3/min (14.1m^3/hour) (7.5 and 15m^3/hour/m^3 compost) were used to identify the effect of the air flow rate on the duration of the composting process in the first and third experiments, respectively. These air flow rates were determined based on the literature. As per the previous studies, a forced aeration composting system has been designed at an air flow rate of (3 – 5) cubic feet/minute/ cubic yard of compost mix which is equal to (0.111 – 0.186) m^3 air /minute/ m^3 of compost mix (Coker and Gibson, 2013), which is also equivalent to (6.66 – 11.16) m^3 air/hour/m^3 of compost. Managed Organic Recycling Company is operating static composting system with air flow in the range of (750 – 1250) cubic feet/ hour/ ton of dry compostable materials which is equal to (21.24 – 35.40) m^3 / hour/ ton of dry compostable material, which is also equal to operation of air blower for (3 – 5) minutes every 30 minutes (Coker and Gibson, 2013). An aeration rate of 0.095 – 0.236 liter/minute/ kg of dry matter (5.7 – 14.16

m^3/hour/ton of dry solids) and peak of 1.79–2.27 liters/min/kg dry solids (107.4 – 136.2 m^3 of air/hour/ton of dry solids) in a batch process is recommended by Haug (1993) for best efficiency. Hwang et al. (2020) used an aeration rate of 1-1.5 liter/minute/0.15m^3 compost, which is equivalent to 0.4-0.6m^3/hour/m^3 compost. The composting experiments were conducted in the sequence presented in Fig. 3-6.

Fig. 3-6: Experimental process

3.2.1.3 Parameters' Measurement

During the operation, temperature, MC and gases emissions were recorded. The temperature was recorded on daily basis using a thermometer with long probe (20cm) which can penetrate the external layer and obtain accurate measurement. The moisture content was measured every one to three days in the lab. The moisture content testing samples representing different parts of the composting column were collected from three different places and at different levels to monitor the MC throughout the process. The samples were being kept in closed plastic sack at the time of sampling and sent directly to the lab. while the gases emissions were recorded daily using special gas analyzer type Geotech GA5000 made by Geotechnical Instruments (UK) Ltd., which comply with the relevant European standards. Other biological, physical, chemical, and heavy metals parameters which include (Fecal coliform, pH, Ec, C/N, NH_4, NO_3, Organic matter, total organic carbon, total Nitrogen, Na, K, Ca, Mg, P, Zn, Ni, Pb, Cr, and Cd) were measured in the labs owned by Hebron and Birzeit Universities / Palestine.

The fertility index (FI) was calculated for the end product of the three compost experiments considering the quality parameters N, P, K, C/N and TOC. These parameters were assigned a score value from 1-5 according to its importance for agriculture, 1 representing the lowest and 5 representing the highest importance in accordance with Saha et al. (2010) and Oviedo-Ocaña et al. (2022). The scoring criteria is presented in Table 3-1.

Table 3-1: Fertility index scoring criteria

Parameter	**Score (Si)**					**Weights (Wi)**
	5	**4**	**3**	**2**	**1**	
TOC (%)	>20.0	15.1–20.0	12.1–15.0	9.1–12.0	<9.1	5
Total Nitrogen (%)	>1.25	1.01–1.25	0.81–1.00	0.51–0.80	<0.51	3
Total Phosphorus (%)	>0.60	0.41–0.60	0.21–0.40	0.11–0.20	<0.11	3
Total Potassium (%)	>1.00	0.76–1.00	0.51–0.75	0.26–0.50	<0.26	1
Carbon/Nitrogen	<10.1	10.1–15	15.1–20	20.1–25	>25	3

The FI is calculated according to the equation (3-1)

$$FI = \frac{\sum_{n}^{i=1} S_i * W_i}{\sum_{n}^{i=1} W_i} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (3\text{-}1)$$

Where *Si* is the score given to the parameter based on its value as indicated above, and *Wi* is the weight given to each parameter from 1 to 5.

The clean index (CI) was also calculated following the same methodology of Saha et al. (2010) but excluding cupper (Cu) parameter from the calculation, where the heavy metals parameters were assigned a score value from 1-5 according to its content of heavy metals, 1 representing the highest content and 5 representing the lowest content as presented in Table 3-2.

Table 3-2: Clean index scoring criteria

Heavy Metal Parameter (mg/kg)	**Score (Sj)**						**Weights (Wi)**
	5	**4**	**3**	**2**	**1**	**0**	
Lead (Pb)	<51	51-100	101-150	151-250	251-400	>400	1
Chrome (Cr)	<51	51-100	101-150	151-250	251-350	>350	5
Nickle (Ni)	<21	21-40	41-80	81-120	121-160	>160	3
Cadmium (Cd)	<0.3	0.3-0.6	0.7-1.0	1.1-2.0	2.1-4.0	>4.0	1
Zinc (Zn)	<151	151-300	301-500	501-700	701-900	>900	3

The CI is calculated according to the equation (3-2).

$$CI = \frac{\sum_{n}^{j=1} s_j * W_j}{\sum_{n}^{j=1} W_j} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3-2)}$$

3.2.2 The Role of Compost in the Circular Economy

This part of the study was conducted in the southern West Bank/Palestine, mainly Hebron and Bethlehem governorates. The main goal of this part is to assess the potential of organic fraction of municipal SW composting and its role in the circular economy considering two scenarios: (1) use of compost for agricultural purposes and (2) use of compost as landfill cover material as presented in Fig. 3-7. For scenario (1), the study determines the environmental and economic benefits of diverting the organic form of the waste stream, and composting and selling the compost product for agricultural purposes. The proposed model for waste management in the study area including diversion of the organic fraction for recycling as an indicator for the circular economy as presented in Fig. 3-7. The saving will be revenues generated from the compost selling, saving the dumping fees that is normally paid for waste dumping at the landfill, saving from the methane emissions reduction, and saving from reduction of use of chemical fertilizers.

In Palestine, the landfill fee is USD 9.5/ton (NIS 30) which is usually paid by local authority to the JSC-H&B for waste dumping. Methane emission reduction is paid through the Carbon Credit – Clean Development Mechanism (CDM) and equals to USD 23.2/ton CO_{2eq} as per Ali et al. (2020) although the CDM is not functioning in Palestine at the present. The global warming potential of methane gas is 25 times carbon dioxide over 100 years' calculation. The solid waste management sector in Palestine is contributing by 23% of the total emissions as identified by a study conducted by the UNDP (UNDP, 2016). The amount of the methane gas emission saving that is supposed to be emitted from the waste diverted from waste stream is calculated using the landfill gas emission model (LandGEM) version 3.03 designed by the United States Environmental Protection Agency (USEPA, 2020). However, compost produced from organic waste is replacing the synthetic fertilizers; therefore, the saving is the revenues generated from selling the compost and the saving from the replacement of the synthetic fertilizers.

The selling price of the compost as provided by a study conducted by the IFC on municipal organic waste composting in Palestine is USD 33/ton (NIS 100/ton) (IFC, 2012) considering the quality of the compost produced from municipal SW central sorting plant is less than that produced from organic municipal waste separated at the source, and the producer wants to promote the product at lower prices in order to encourage the users. The saving in chemical fertilizers is estimated based on the nutrients which include carbon (C), Nitrogen (N), Potassium (K), and Phosphorus (P), which are available in chemical fertilizers and supplied to the plants. The commercial source of these nutrient available in the form of Iperen Humic 12+3 liquid for C, Ammonium Sulphate for N, Triple Super phosphate (TSP) for P, and potassium sulphate (SOP) for K. The nutrient content in compost as reported by Shah et al. (2017) and Rashid and Shahzad (2021) is 21.02 for C, 0.935% for N, 0.32% for K and 0.235% for P. The nutrients will replace that available in the synthetic fertilizers when using the compost in agriculture. The nutrient content in the synthetic fertilizers and its prices are: Iperen Humic 12+3 liquid contains 7.3% C (Van Iperen International, 2021) with a price of USD 3,750.0/ton (NIS 12,000.0/ton), Ammonium Sulphate (AS) 21% N (Eurosolids Nederland, 2020a) with a price of USD 1,250.0/ton (NIS 4,000.0/ton), TSP contains 46% P (TAS, 2021) in the form of P_2O_5 with a price of USD 1,406.0/ton (NIS 4,500.0/ton), and SOP contains 50% K (Eurosolids Netherland, 2020b) with a price of USD 1,500.0/ton (NIS 4,800.0/ton). The prices of the fertilizers are provided by Sharabati Brothers Trading and Agricultural Company (SBTAC, 2021).

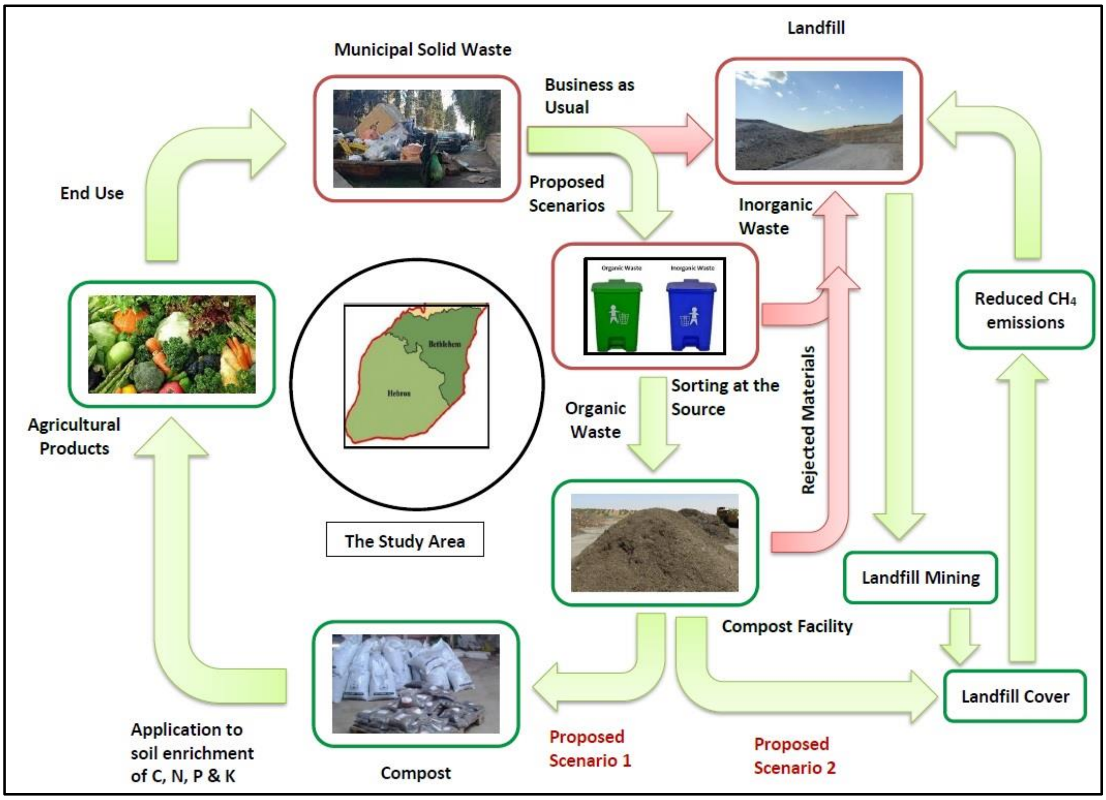


Fig. 3-7. Proposed municipal organic SW management model for the study area.

The saving in the landfill volume is also considered. The construction cost of the existing landfill was USD 6.987 million for 4 cells of capacity 2.65 million m^3, which means that each 1cubic meter capacity costs USD 2.64 (JSC-H&B, 2011). The on-site practices showed that the waste density in place after compaction reached 0.93

as reported by Al-Menya Landfill Private Company (ALPC, 2016) as the waste is compacted using steel roller type BOMAG 36 ton in weight. Using the density in place, the space cost of 1 ton of organic waste is USD 2.84 (NIS 9.0/ton). The waste collection cost is excluded from the calculations because the composting facility is on the same site as the landfill, and in normal operation, the waste is collected and transferred to the site, so there is no difference in the waste collection cost between both scenarios, landfilling and composting.

The saving is calculated based on the following:

$Rn = Rg - OM$ ……………………………………………………………. (3-3)

$Rg = D + Cc + C + F + Ls$ ………………………………………….… (3-4)

Where Rn is the net revenue; Rg is the gross revenue; OM is the cost of operation and maintenance of the composting plant; D is the dumping fee saving; Cc is the carbon credit value; C is the compost selling; F is the fertilizer savings; and Ls is the landfill space saving.

The trend is taken through the coming 15 years starting from 2021 to 2035. To calculate the waste generation projection, the history of waste delivered to the landfill site and the population growth are used. The landfill site was opened for the first time, after construction, on March 25th, 2014. At that time, some of the local authorities were using open random dumps, and therefore, the waste quantities generated by these authorities were not delivered to the landfill. Before the year 2014, there was no regular and clear data about waste generation because most of the local authorities were using their own random dumps as mentioned. By closing the random dumps, the waste delivered to the landfill gradually increased. However, the population increase has caused increase in the waste quantities generated. The population is projected using year 2017 (PCBS, 2018) as the base for projection, because it is the actual number of population as identified by the PCBS, and a growth rate of 2.8% is used as identified by the United Nations Population Fund – UNPF in Palestine (UNPF, 2021). The relationship between the population and the annual waste generation during the period extended between 2015 and 2020 is drawn and interpreted. The data interpretation showed that the logarithmic function is accurately predicting the waste quantity generation with $R^2 = 0.96$ as shown in Figure 3-8. The regression model data is shown in Table 3-3. The waste quantities generated during the year 2014 was excluding from the data interpretation because the waste generated by some local authorities was missing due to the use of random dumps. The annual waste quantity can be estimated using the following equation:

$Waste\ Quantity = 850{,}744.61\ ln(x) - 11{,}409{,}{,}010.59$ ……………. (3-5)

where x is the number of population.

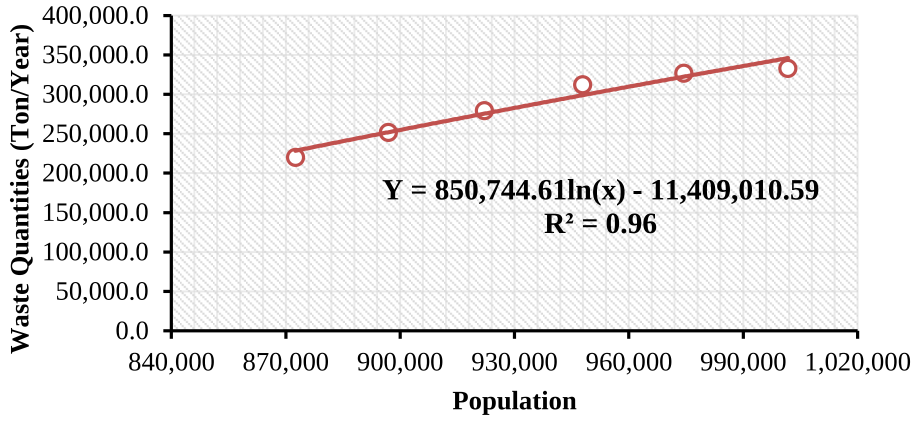


Fig. 3-8: Interpretation of waste quantity increase

Table 3-3: Regression data

Regression Statistics		*ANOVA*			
			df	*F*	*Significance F*
Multiple R	0.98				
R Square	0.96	Regression	1	85.87	0.00075
Adjusted R Square	0.94	Residual	4		
Standard Error	10606.07	Total	5		
Observations	6				

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-11409010.59	1262221.18	-9.04	0.00083
Ln(X)	850744.61	91809.53	9.27	0.00075

Residual Output

Observation	*Predicted Y*	*Residuals*	*Error*
1	228443.93	-8236.88	-0.036
2	251937.38	-279.63	-0.001
3	275430.84	3698.40	0.013
4	298924.29	13362.76	0.045
5	322417.75	4482.20	0.014
6	345911.20	-13026.85	-0.038

The organic compostable fraction is calculated based on the constituent of the organic fraction from the total waste stream based on the waste characterization which is 46%. Compost from landfill mining is not considered in this study due to safety concerns related to heavy metals content. It has been assumed that only 70% of the organic waste fraction is compostable (IFC, 2012) as a conservative figure taking into account that the waste separation at the source could be insufficient, which results in some rejected materials. The waste projection is shown in Fig. 3-9.

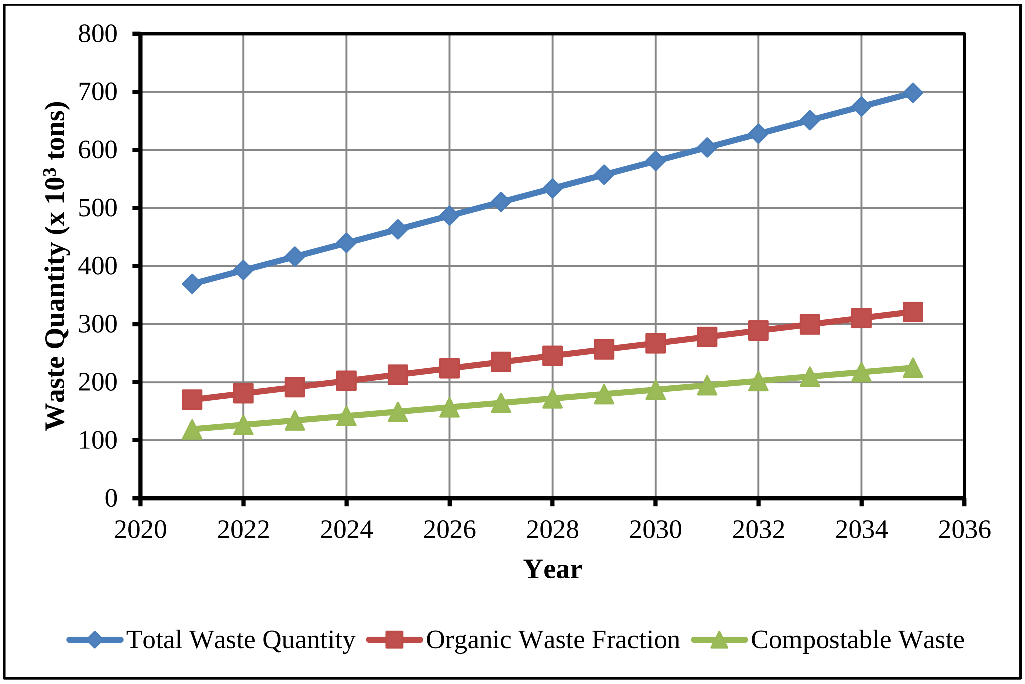


Fig.3-9. Projection of municipal SW production in the study area from 2021 to 2035

For compost yield, it has been assumed that 25% of organic waste is retrievable with water content of 40% (Shah et al., 2017; Rashid and Shahzad, 2021).

For scenario (2), the study considers the quantity and cost of soil that is used as cover material for the regional landfill in the study area. The quantity of soil used on daily basis to cover the waste is 600 tons and the cost is about USD 4.0 (NIS 13.0)/ ton as per the records of the JSC-H&B).

3.2.3 Attitude Towards Organic Solid Waste Composting

3.2.3.1 Survey Design and Data Collection

This part of the research was conducted in southern West Bank/Palestine, mainly Hebron and Bethlehem governorates. The study aims to evaluate the local authorities’ (LAs) attitudes toward organic SWM. Perception of the LAs toward organic SWM was evaluated through data collection via survey questionnaire. The questionnaire was designed to include information about the solid waste service provider, solid waste generated, knowledge and awareness of composting, and challenges being faced by the service provider in composting the organic fraction of the solid waste. The questionnaire was peer reviewed by two Professors of environmental engineering from India and Palestine. The peer review was conducted prior to data collection in order to ensure adequacy of the questionnaire for the purpose of study. A copy of the questionnaire is attached in Annex 1.

The target group for collecting the responses was the local authorities in southern West Bank/Palestine, which include municipalities, VCs, JCSPDs and JSCs-SWM, who are providing the SWM service. The list of the LAs was obtained from the MoLG (MoLG, 2021). In accordance with the list, there are 89 municipalities and VCs, 3 JSCs-SWM, and 6 JCSPDs but only 3 of them are providing SWM service. The JCSPDs that are not providing SWM service are excluded from the study. In addition, it has been found that 9 of the remote communities are not served, and the VCs in these communities are not providing the SWM service. Such VCs were excluded for the data collection via questionnaire, but general information about current practices of organic waste management was obtained. A total of 85 LAs were included in the data collection using the questionnaire. Because the research population is limited, all of the population is considered as a sample, and the data is collected from all.

The questionnaires were filled through direct interviews where possible, via email and over phone. The interviewees were the key staff members such as the heads of SWM division or the managers of the LAs. For few instances, the finance managers participated partially in the survey to answer the questions related to the waste quantities and cost as directed by the LA officials.

3.2.3.2 Data Analysis

After the completion of the data collection, the questionnaires were coded, data entry, and then data was analysis using statistical package for social sciences software (SPSS) version 23. In addition, Microsoft excel 2010 was also used in the data analysis. Beside the descriptive statistics used, bivariate analysis is used to assess the relationship between the dependent variable (LAs' attitude toward composting) and the independent variables which represent the factors of potential effect and could shape the LAs' attitude. Since the bivariate analysis doesn't provide the direction of the relationship, a logistic regression model (LRM) is developed to assess the factors that affect the LAs attitude towards composting of municipal organic waste. The model is used to predict the significance of the relationship between the independent variables, from one side, and dependent variable, from the other side, the direction of the relationship as repeated in previous studies (Ali et al. 2012; Al-Khateeb et al. 2017; Al-Madbouh et al., 2019; Al-Sari' et al. 2012; Begum et al. 2006; Begum et al. 2009; Ittiravivongs, 2012). The dependent variable is the LAs' planning to compost organic SW fraction, while the independent explanatory variables are presented in Table 3-4. The independent variables were selected carefully after conducting bivariate analysis to ensure significant relationship with the dependent variable from one side, and to avoid multicolinearity between explanatory independent variables above 0.7. As the bivariate analysis assess the relationship of each influencing factors with the dependent variable independently, and the LRM assess the relationship of the influencing factor with the effect of others factors, factors identified less effect in the LRM were excluded, and other factors introduced even those identified non-significant by the bivariate analysis in order to adjust the model.

The LRM used is presented in equations (3-6) - (3-9) as follows:

$$Log\frac{P_i}{1-P_i} = Z_i = \beta_0 + \beta_i X_i + e \qquad \text{(3-6)}$$

Where *Pi* is the LA's attitude toward organic waste composting. *Pi* = 1 if the LA attitude toward organic waste composting is positive; and Pi = 0 if not; *Xi* is the explanatory variable; *βo* is a constant term; *βi* is a coefficient of the explanatory variable; *e* is the error, and *1, 2 ..., n* represents the number of the explanatory variables in the model.

The model uses the maximum likelihood function presented in equation (3-7) according to Begum et al. (2009).

$$L(\frac{\beta}{y}) = \prod_{i=1}^{N} \frac{n_i!}{y_i!(n_i - y_i)!} P_i^{y_i} (1-P_i)^{(n_i - y_i)} \qquad \text{(3-7)}$$

The Wald statistical test presented in equation (3-8) is used to measure the coefficient's significance (Begum et al. 2009).

$$W_i = (\frac{\beta_i}{S.E_{\beta_i}})^2 \qquad \text{(3-8)}$$

where $i = 1, 2 \ldots, n$ and *S.E* is the standard error.

The model goodness of fit is measured by log-likelihood function, which is defined in equation (3-9) (Al-Sari et al., 2012; Begum et al., 2009).

$$Log - likelihood = \sum_{i=1}^{n} [Y_i \ln(\hat{Y}_i) + (1-Y_i)\ln(1-\hat{Y}_i)] \qquad \text{(3-9)}$$

As the model uses the observations to predict the expectations, Y_i value represents the observations and $\hat{Y}_i$ value represents the expectations, which is a probability function and approximately chi-square distribution and can be quoted as 2log-likelihood. Omnibus test is used to assess the suitability of the model and goodness of fit if all coefficients equal zero in the model. Cox and Snell R^2 and Nagelkerke Ř^2 are statistical tests show how the explanatory variable explain the dependant variable through the variation proportion of the dependent variable. Because the maximum values of Cox and Snell R^2 tests cannot reach 1, Nagelkerke Ř^2 statistical test, which can obtain values in the range of 0-1 is used and is preferable according to Bewick et al. (2005).

Table 3-4 Summary of the independent variables in the LRM

Variable	**Description of the Variable**	**Definition of the Variable**	**Abbreviation in the Model**
X_1	Monthly SW quantity generated (tons)	1 = ≤ 20; 2 = 21 – 50; 3 = 51 – 100; 4 = 101 – 200; 5 = 201 – 400; 6 = 401 – 600; 7 = > 600	Mon. SW generated Qt.
X_2	Household SW tariff (NIS)	1 = 10 - 20; 2 = 21 - 30; 3 = (2 – 3)/capita	HH SW tariff
X_3	Fee collection rate (%)	1 = ≤ 20; 2 = 20 - 40; 3 = 41 – 50; 3 = 41 – 60; 4 = 61 – 80; 5 = 81 – 100	Fee collection rate
X_4	Perception of compost contribution to SW reduction	1 = Yes; 2 = Don’t know; 3 = NO	Per. of compost reduce SW
X_5	Having appropriate area of land to be used for composting	1 = Yes; 2 = NO	Place availability
X_6	Having financial capacity to conduct composting	1 = Yes; 2 = Yes, but limited capacity; 3 = NO	Financial capacity
X_7	Staff attended training on compost production	1 = Yes; 2 = No	Staff training
X_8	Staff having previous experience in compost production	1 = Yes; 2 = No	Staff prev. experience
X_9	Conducted community awareness on organic waste composting	1 = Yes; 2 = NO	Community awareness
X_{10}	Potential community participation in compost through organic SW sorting at the source	1 = Yes; 2 = Yes, but partially; 3 = NO	Pot. Comm. participation
X_{11}	Familiarity with SWM bylaw	1 = Yes; 2 = NO	Familiarity with SWM bylaw

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Design, Test and Evaluate of Two Composting Systems

4.1.1 Process Performance Monitoring & Composting Time

The composition of the raw materials of the three experiments was (vegetables and fruit waste and sawdust) for experiment 1, (fruit and vegetables waste, caw dung, and trees leaves) for experiment 2, and (fruit and vegetables waste, sawdust, sheep and goat fresh manure, and poultry manure) for experiment 3.

(a) Temperature

The temperature profile for the three experiments was recorded as presented in Figures 4-1 to 4-3. The process behavior of three experiments is presented in Table 4-1. The data showed that the max temperature reached 54.3-72.6°C which is the preferred one to ensure sanitization of the final product. Experiment 2 recorded the highest temperature because it contains cow dung which is rich in microorganisms associated with high weather temperature as presented in Fig. 4-2. The duration of the mesophilic phase recorded three days for experiment 1 and two days for experiments 2&3. This agrees with Oviedo-Ocaña et al. (2022) who founds that the time to start thermophilic phase was two days. The thermophilic duration, which started at 45°C (Soobhany, 2018), extended for 16-20 days as presented in Table 4-1. Experiment 2 showed the lowest thermophilic phase (16 days) which can be attributed to the high weather temperature in India, and high biodegradation rate. The lower max temperature and longer duration of the thermophilic phase was recorded for experiment 1 which attributed to the lower weather temperature in Palestine and lower microorganisms content because this experiment contained fruits and vegetable waste and didn’t contain any animal manure. Therefore, the biodegradation rate was expected lower than other experiments. The max temperature and duration for experiment 3 was recorded in between the other experiments because of the weather temperature as presented in Fig. 4-3 and the composition of this experiment that contains animal and poultry manure that was rich in microorganisms’ contents which could accelerate the biodegradation rate. The addition of manure improves the efficiency of the composting process according to Zhou et al. (2019).

The duration of the max temperature is an indicator of pasteurization of the final compost product. The sufficient temperature to eliminate pathogens and parasites should be above 55°C (Ravindran & Sekaran, 2010). Experiment 1 achieved 54.3°C and lasts for one day only and therefore, failed to achieve min disinfection temperature. Achieving the ideal disinfection temperature is difficult if fruit and vegetables waste composted at small-scale system (Smith & Jasim, 2009). However, experiments 2 and 3 achieved this min temperature and lasted for 8 and 5 days, respectively. Álvarez-Alonso et al. (2024) conducted six pile composting experiments on organic refuse obtained from municipal SW mixed with urban pruning and donkey's manure and found that the max temperature was in the range of 72-76°C and temperature above 55°C for more than 15 consecutive days.

Declining the temperature after the thermophilic phase is an indication of approaching the process end. The composting process completed when the compost temperature reaches the ambient temperature. The results showed that the shortest composting time recorded for experiment 2, which recorded 31 days only, while there was no real difference between experiments 2 and 3 as shown in Table 4-1. The difference in weather temperature is the main cause of this variation, while the composition of the compost raw material seam of lower effect on this variation in the compost time between experiment 1&3 conducted in Palestine. Experiment 3 took more time because it contains sheep and goad refuse which contains high organic matter and cellules material. Variation in ambient temperature can significantly affect the self-heating of the compost pile as reported by Luangwilai et al. (2012).

Table 4-1 The process performance behavior of the three experiments

Experiment No.	**Duration of the mesophilic phase (days)**	**Max Temp. (°C)**	**Time to reach max temp.**	**Duration of the Thermophilic phase (days)**	**Time to cool to ambient temp. ±3 (days)**
1	3	54.3	16	20	39
2	2	72.6	3	16	31
3	2	56.7	2	17	43

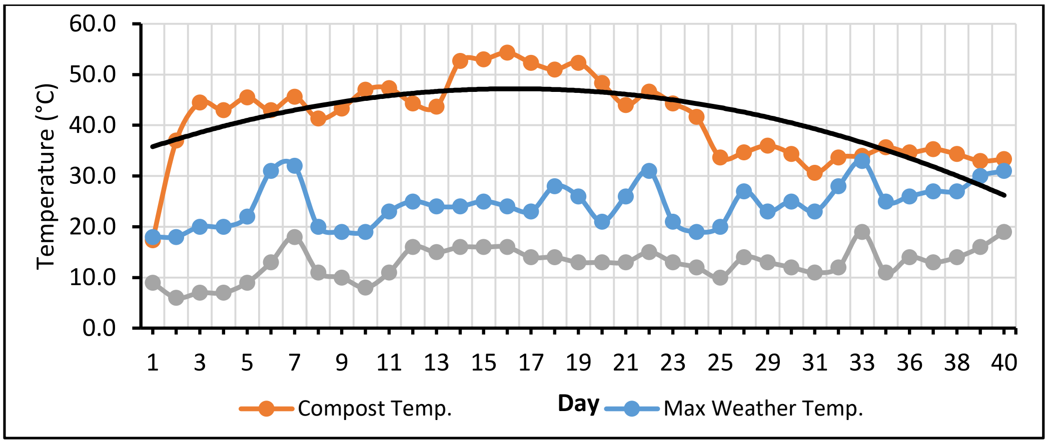


Fig. 4-1 Temperature profile for experiment 1

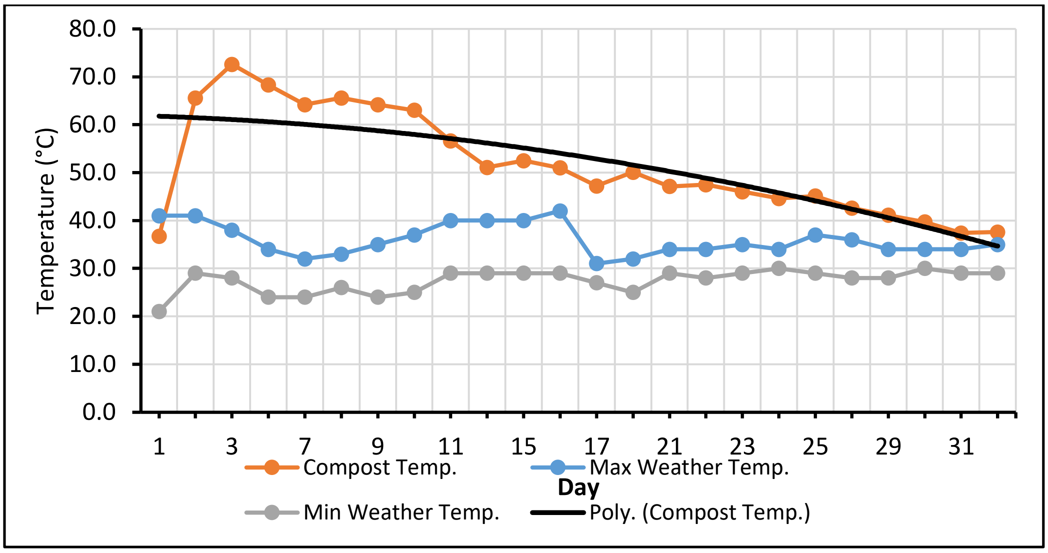


Fig. 4-2 Temperature profile for experiment 2

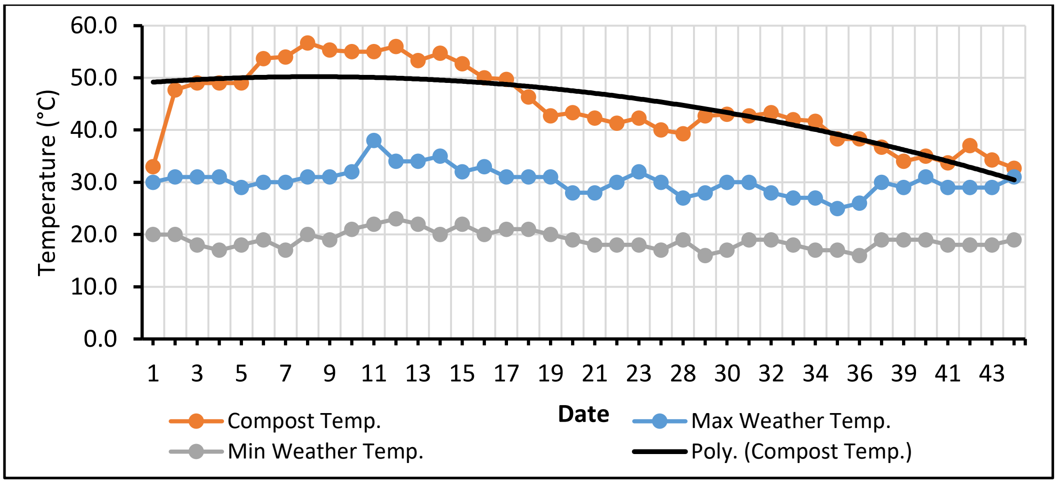


Fig. 4-3 Temperature profile for experiment 3

(b) Moisture Content

Moisture content (MC) in the range of 40-70% is essential to ensure proper performance of the microorganisms (Luangwilai et al., 2011). Tang et al. (2023) found that MC in the range of 60-65% is optimal for compost maturity and gaseous emission reduction during the composting process. The monitoring data showed that of the MC was within the preferable range as most of the values were in the range of 60-70% as presented in Figures 4-4 to 4-6.

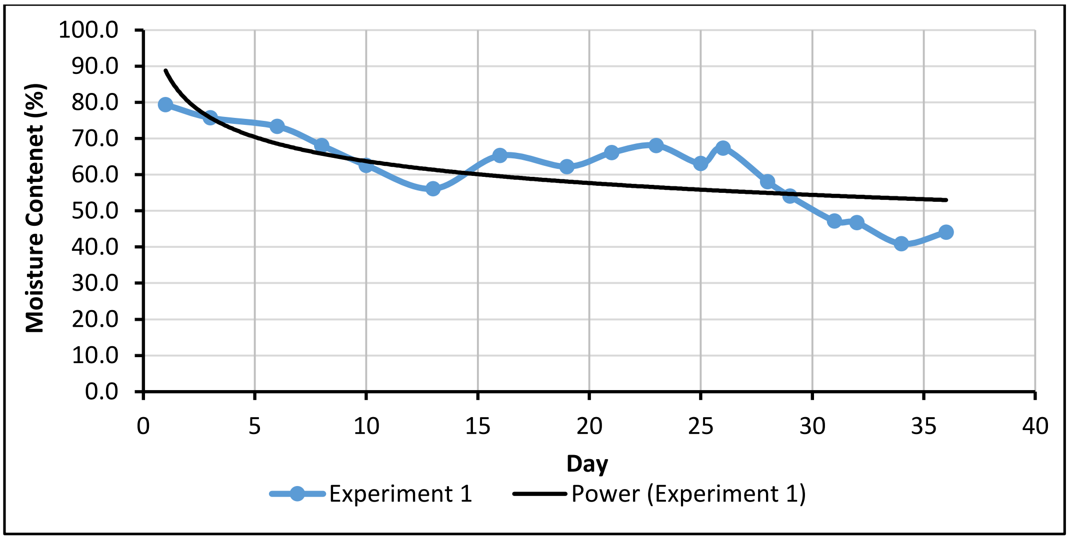


Fig. 4-4 Moisture content profile for experiment 1

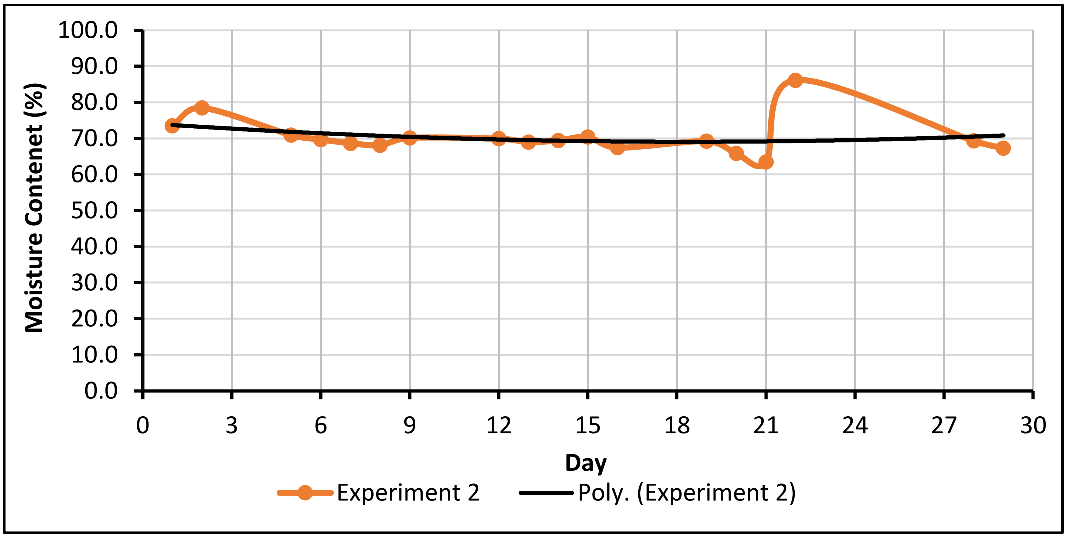


Fig. 4-5 Moisture content for experiment 2

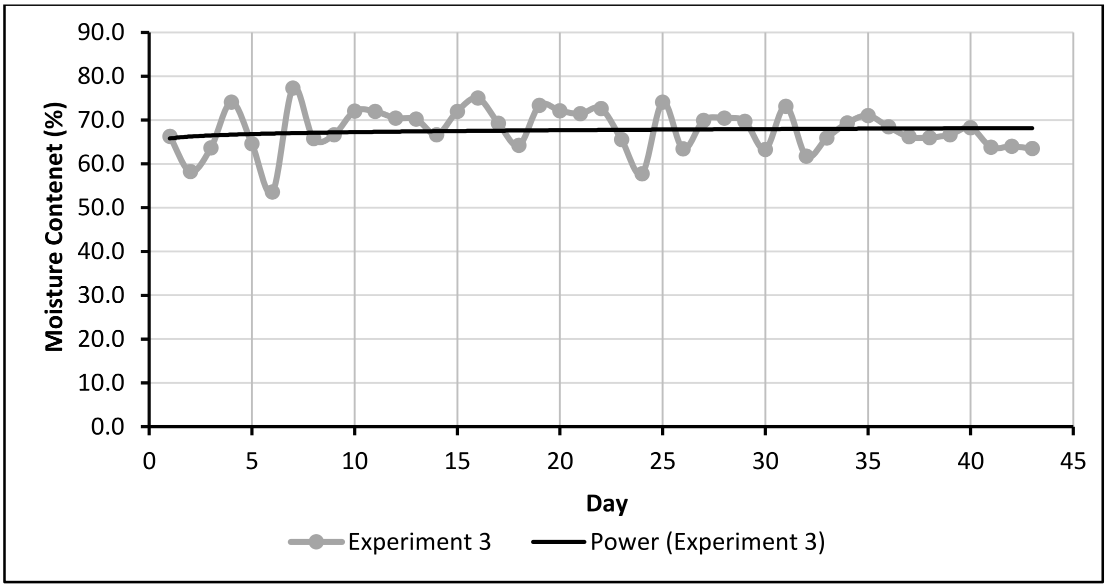


Fig. 4-6 Moisture content for experiment 3

(c) Aeration Rate

Two different forced aeration rates of 7.1m^3/h and 14.1m^3/h (7.5 and 15m^3/h/m^3 compost) were used experiment 1&3, respectively, while natural aeration was utilized for experiment 2. Intermittent forced-aeration was used (air blower operation for 4.6 minute/36 minute for experiment 1, and 15.4 minutes/h for experiment 3) because intermittent aeration has proven more efficient to achieve higher peak temperature and lower moisture loss than continuous aeration (Then et al., 2021), reduce heat loss (Shimizu, 2018), and reduce greenhouse gas emissions (Jiang et al., 2015). The forced aeration rates didn't show significant effect on the composting process as the process duration from the start and up to cooling to the ambient temperature ±3°C was 39 days for experiment 1 and 43 days for experiment 3. However, the natural aeration in experiment 2 associated with warm weather temperature was efficient to complete the composting process within 31 days. This indicates that natural aeration is efficient for composting under tropical climate like India. Vilela et al. (2022) conducted enhanced aeration static composting of organic refuse obtained from slaughterhouse in Brazil (under climatic conditions of characterized by dry winter and hot-humid summer climate) and found that forced aeration didn't affect the decomposition process. Along the composting process, the oxygen concentration was monitored to ensure adequacy of the aeration rate. The results revealed that the oxygen concentration was in the range of 6.1-14.5% for experiment 1 and 5.7-13.4% for experiment 3 as presented in Fig. 4-7 and Fig.4-8.

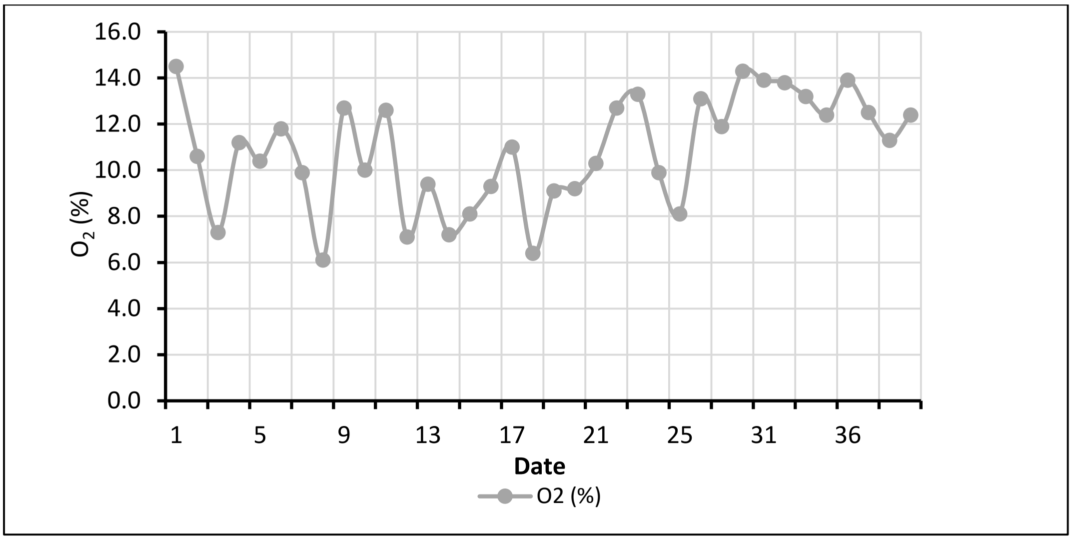


Fig. 4-7 Oxygen concentration during the composting process for experiment 1

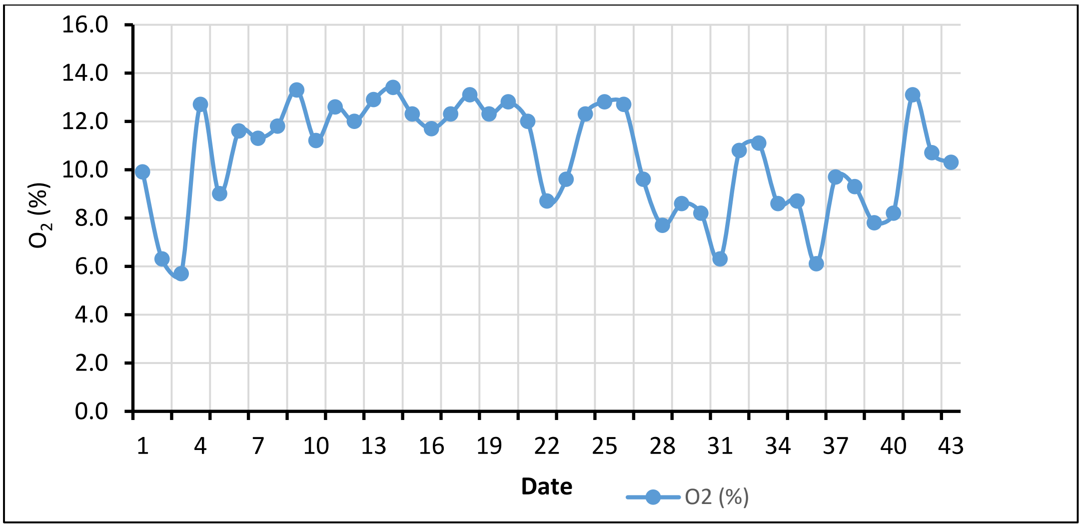


Fig. 4-8 Oxygen concentration for experiment 3 during the composting process

(d) Volume Reduction

The volume reduction of the compost mixtures during the experiments was recorded as presented in Figures 4-9 to 4-11. The relationship between the cumulative percentage volume reduction and the elapsed time showed logarithmic function with R^2 value of 82.5, 95.9 and 95.0% for experiments 1,2&3, respectively. The total volume reduction achieved at the end of the experiments was 64% for experiment 1, 60% for experiment 2, and 57.2% for experiment 3. Augustin & Rahman (2022) reported that composting can reduce 50-65% of the original volume. Breitenbeck & Schellinger (2013) reported 40.7% average volume reduction in windrow composting system. Costa eta al. (2016) reported volume reduction in the range of 53.5-67.8% for different covered and outdoor compost systems. A 60% volume reduction was reported by Baron et al. (2019).

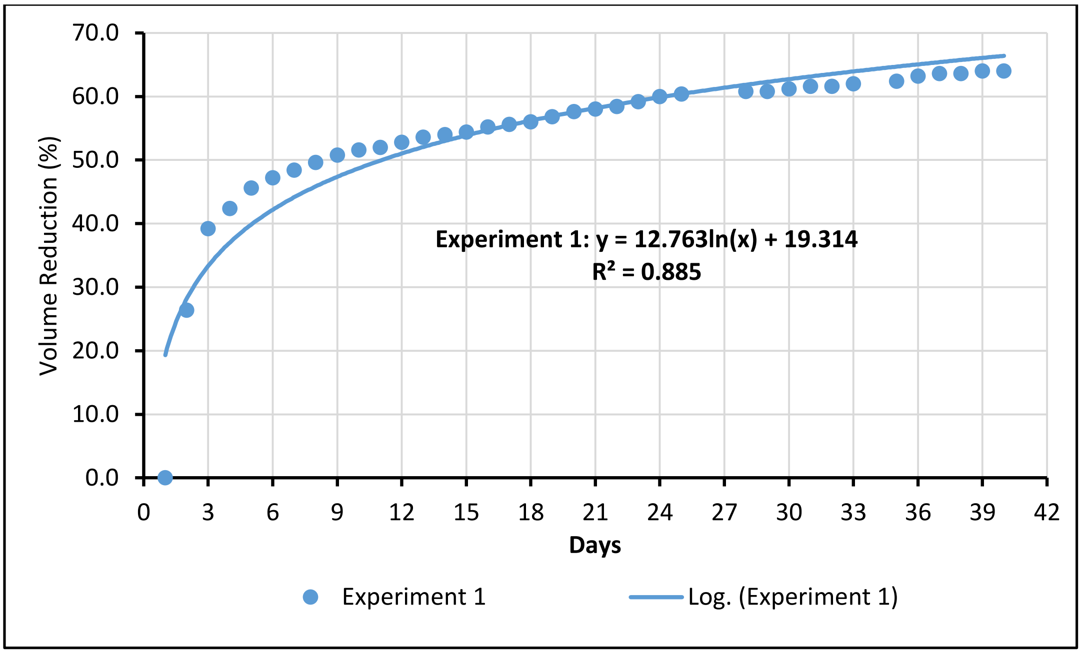


Fig. 4-9 Volume reduction for experiment 1

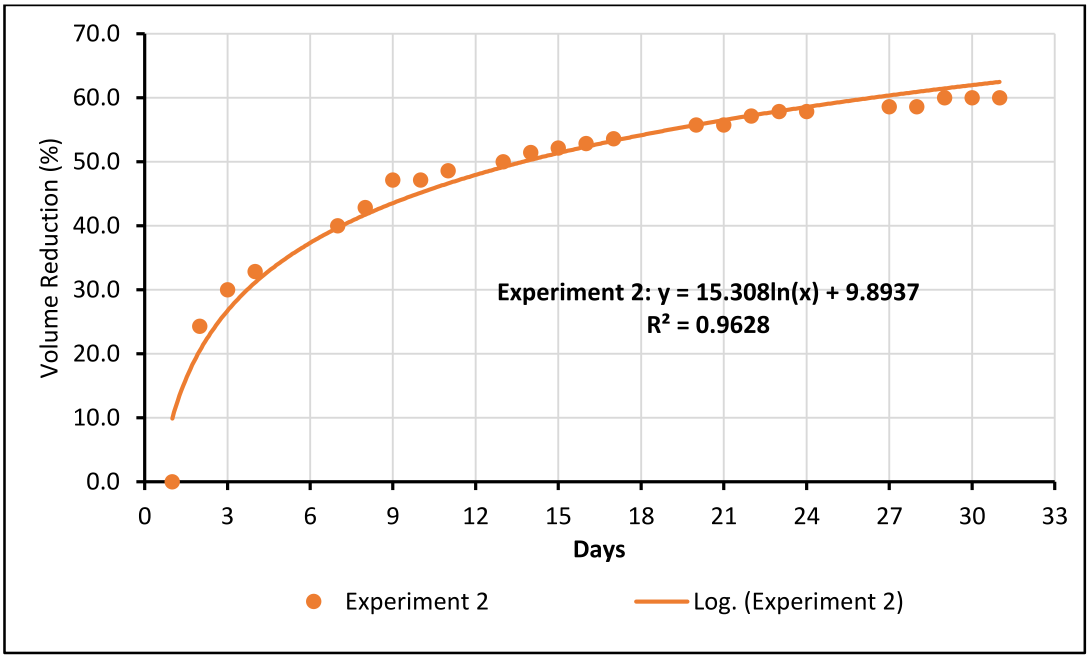


Fig. 4-10 Volume reduction for experiment 2

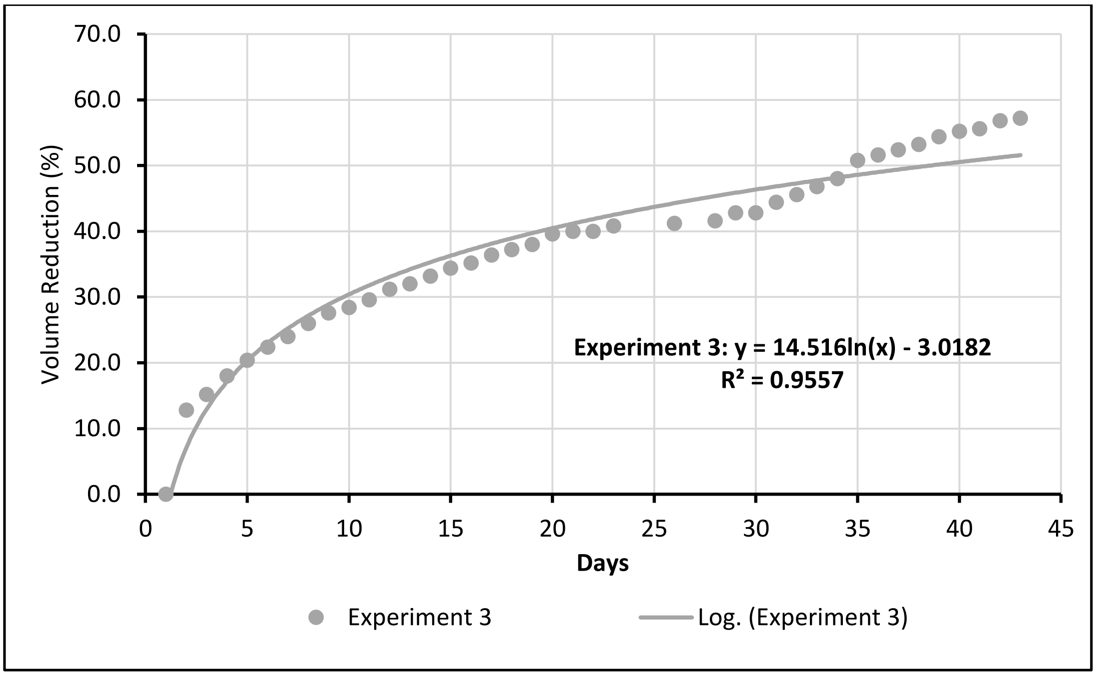


Fig. 4-11 Volume reduction for experiment 3

(e) Gaseous Emissions

Gaseous emissions including Methane (CH_4), Carbon Dioxide (CO_2), and Hydrogen Sulfide (H_2S), were monitored throughout the composting process of experiment 1&3 as presented in Figures 4-12 and 4-13. The purpose was to ensure adequacy of the aeration and minimize greenhouse gas (GHG) emissions. Composting process can generate GHG but in lower amount, and therefore less impact on climate change (Sayara & Sánchez, 2021). Previous studies reported that GHG emissions during the composting process such as CH_4 is inevitable, but can be mitigated by proper composting process management (Jiang et al., 2015). In addition, the composting process can release large quantities of CO_2 (Shimizu, 2018), even in a well-aerated process (Clemens and Cuhls, 2003). The composting process can also release H_2S as a result of biodegradation of organic matter containing sulfur compounds. Previous study reported that H_2S emission is one of the parameters that allow the assessment of the decomposition of the compost mixture (Czekała et al., 2022). GHG emissions occurred during the composting process are attributed to inadequate aerobic conditions (Dhamodharan et al., 2019). It has been reported that the sort of organic wastes, the size of the compost pile, and the aeration are factors affecting the GHG emissions throughout the composting process (Wang et al., 2024). The composting method used as well as feedstock materials and the adjustment of the C/N ratio at the start of the process play a crucial role in the variation of CH4 and CO2 amount release during the composting process (Ba et al., 2020). The use of sawdust or straw in composting found to reduce CH4 emissions by 66.3% (Ba et al., 2020).

The results showed that the emissions of these gases were in the range of 2.4-5.2% CH_4, 0.1-13.2% CO_2, and 0-4ppm H_2S for experiment 1, and 2-4% CH_4, 0.5-8.1 CO_2, and 0-5ppm H_2S for experiment 3. Czekała et al. (2022) conducted a study to measure gaseous emissions during a forced-aeration composting process and found that the H_2S concentration was in the rage of 0-57ppm, the CO_2 concentration in the range of 1-18%, and no CH_4 was detected. Dume et al. (2021) conducted a study on composting of sewage sludge mixed with straw pellets and concluded that the total CH_4 emissions was 0.34-1.69% and CO_2 released was 2.3-8.65. previous research on lab scale forced-aerated co-composting of sewage sludge, leaves, rice straw with different ratio of mixing showed H_2S release in the range of 45-63ppm (Sun et al., 2022). The highest values of CO_2 and H_2S release occurred during the thermophilic phase due to the high decomposition rate, which is in agreement with some previous studies (Sun et al., 2022; Yasmin et al., 2022; Dume et al., 2021). Both CO_2 and H_2S tend to decrease with the progress of the composting process, while the there was no much change in CH_4 emissions.

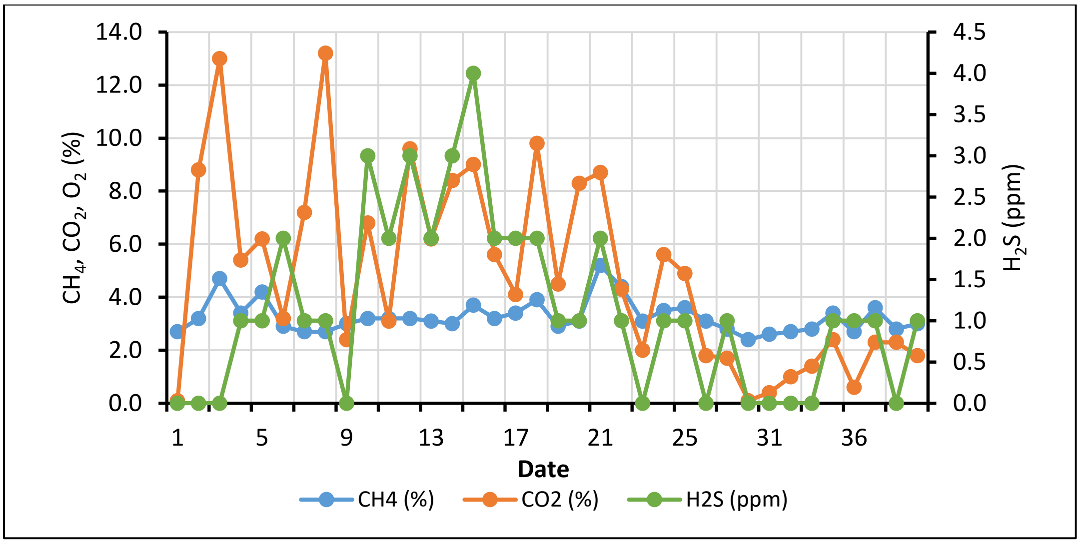


Fig. 4-12 Gaseous emissions during experiment 1

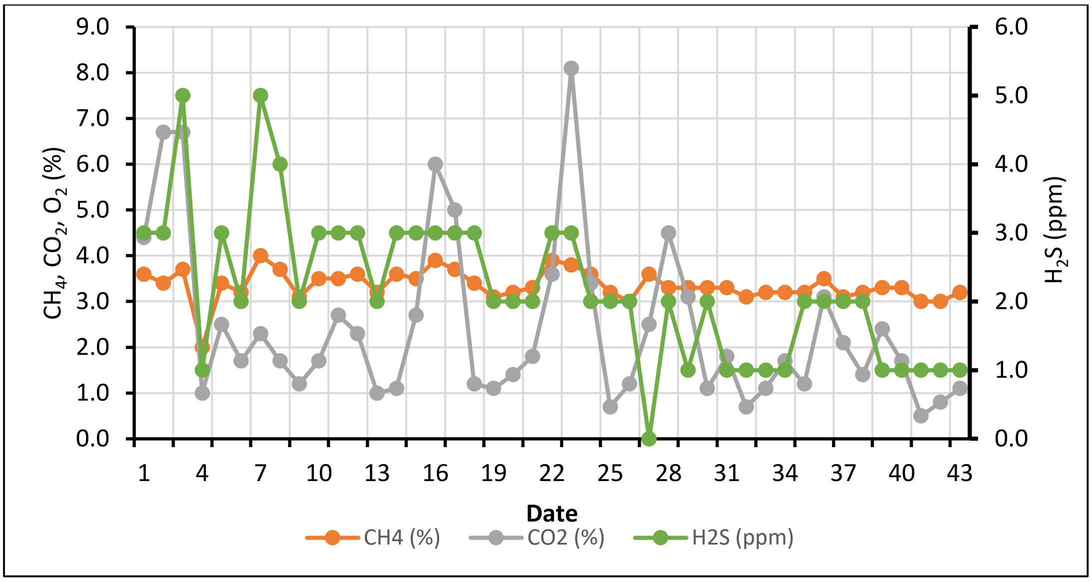


Fig. 4-13 Gaseous emissions during experiment 3

(f) Composting Time

The composting time can be defined as the total time from the starting date of the composting process up to the end date when the compost temperature declines to the ambient temperature ±3°C. The results showed that the composting time in the three experiments was 39, 31, and 43 days respectively. The shortest time was recorded for experiment 2 (India experiment), which can be attributed to the climate conditions in Delhi that is classified by hot and high humidity during the period of the experiment (June – July). The max temperature during the experiment time was in the range of 31-42°C and the min was in the range of 21-30°C. The time of composting for the other two experiments (Palestine experiments) was 39 for experiment 1 and 43 for experiment 3, with no much difference although there was a difference in the forced aeration rates used. The max weather temperature during both experiments was in the range of 18-33°C for experiment 1 and 25-38°C for experiment 3, while the min temperature was in the range of 6-19°C and 16-23°C, respectively. Previous studies reported different composting time in the range of 20-110 days using different composting systems (Lalremruati & Devi, 2021). Bhave and Joshi (2017) conducted vegetable and cooked food waste composting within 40 days. Varma et al. (2017) reported a 20 days composting time for composting cattle manure, saw dust and dry leaves using a rotary composting drum. A composting experiment of pig manure mixed with corn stalks in aerated cylinder was observed to complete with 37 days (Guo et al., 2012). Yin et al. (2024) summarized the factors that influence rapid composting and plaid important role in speeding up the composting process and affect the composting duration as well, which include, raw materials, reactors, temperature, and microorganisms.

4.1.2 Compost End-Quality Monitoring

(a) Physio-chemical Parameters

pH: it recorded 7.98, 8.19, and 8.28 for experiments 1,2 &3, respectively, which meet the Palestinian standards (PSI) and do not meet Indian standards as per the Fertilizer Control Order (FCO). Almost similar values were reported by Al-Sari' et al. (2018) who conducted a study on the compost quality available in the Palestinian market and reported pH values in the range of 6.56-8.88 for several compost samples. Al-Sari (2019) also reported pH values in the range of 8.74-10.03 for four compost experiments conducted in Palestine. Silva et al. (2024) conducted three pile composting experiments on agroforestry waste, agroforestry waste amended by sewage sludge, and agroforestry waste but without pile management and found that the pH values 7.92, 7.97, 5.78, respectively. The pH value from six pile composting experiments is reported in the range of 8.1-8.7 (Álvarez-Alonso et al. (2024). Other studies reported final pH values in the range of 6.6-7.3 (El-mrini et al., 2022).

Electric Conductivity (EC): EC is a measure of the ability of the compost to conduct the electric current based on the concentration of the soluble salts in the compost and an indication of the salinity level. High level of salt in compost reduces the agricultural productivity because the root cannot extract a sufficient quantity of water from the soil amended by compost with high salt concentration (Rashwan, et al., 2021). However, compost with high level of salts is rich in nutrient and beneficial to the plants if added in low rate (Sullivan et al., 2018) depending on the soil characteristics. The EC values recorded 5.04, 9.76, and 1.8ds/m for experiments 1,2&3, respectively. Both Indian and Palestinian standards require EC values equal or less than 4ds/m for normal application. However, in accordance with the PSI, compost with EC values greater than 4ds/m can be applied at depth ≥ 20cm from the soil surface with specific quantities per area of land depending on the sensitivity of the crop to salinity. From the results, only experiment 3 meets the PSI and FCO for normal application. An assessment of compost quality in the Palestinian market founded the EC values in the range of 2.4-15.8ds/m for several tested samples (Al-Sari et al., 2018). Álvarez-Alonso et al. (2024) reported Ec values in the range of 3.2-7.4 dS/m.

Organic matter (OM): test results showed that the OM content was 38.47, 58.01, and 67.0% for experiments 1,2&3, respectively. The PSI specifies a limit of ≥35% for gardening and ≥25% for agricultural purposes, while there is no limit specified by FCO, therefore, the results of the three experiments meet PSI. Al-Sari et al. (2018) reported an OM range of 5.74-56.40% in several matured compost samples obtained from different sources in Palestine. OM valued for six composting piles were found in the range of 38.6-51.8% (Álvarez-Alonso et al., 2024).

Maturity and Stability (C/N, NH_4-N/NO_3): the final values of C/N and NH_4-N/NO_3 are indicators for compost maturation and stability. The recommended C/N ratio for best performance of composting process is within values of 25–30 (Huang et al., 2004), and could be 20-35 as reported by Lu et al. (2022). This value declines with the process progress to reach less than 20 to indicate compost maturation (Keng et al., 2020; Mahapatra, et al., 2022) with indication of good maturity if it declines around 12 (Bernai, et al., 1998). Sánchez-Monedero (2002) reported that the decline of the C/N value throughout the composting process is an indication of the compost stability. Similarly, nitrification activity during the composting process reduces NH_4 concentration and increase NO_3 concentration (Samal et al., 2018). Therefore, the ratio of NH_4/NO_3 is considered an indication measure for compost maturity which tends to decrease after the theomorphic phase (Mahapatra et al., 2022). The results of the experiments showed that the C/N ratio declined from 23 at the beginning of the process to13 at the end for experiment 1 and from 28 to 12 for experiment 3, while the final value for experiment 2 was 10, which indicate that the compost produced by the three experiments was stable and mature. These results comply with the FCO standards, while the PSI doesn't specify limit for C/N ratio. The results also showed that the ratio of NH_4/NO_3 was 0.639, 0.105 & 0.017 for experiments 1,2&3. Mahapatra et al. (2022) highlighted that the lower the ratio of NH_4/NO_3 indicates the maturity of the compost. Bazrafshan et al. (2016) monitored a composting process and observed the decrease of NH_4/NO_3 ratio. Li et al. (2020) reported final NH_4/NO_3 values of 1.1, 0.4 and 0.2 for livestock manure digestion.

Macronutrients (Ca, Mg, Na, N, P, K): Calcium (Ca), Magnesium (Mg), and Sodium (Na) are essential for the plants as microorganisms utilize it and stimulate assimilation of the macronutrients by the plants (Hargreaves, et al. 2008). All of these parameters are limitless because they are not specified by either PSI nor FCO. The results showed that Ca recorded 15.94, 2.29, and 5.16%; Mg recorded 0.5, 1.17, and 0.95%; Na recorded 0.027, 0.019, and 0.44% for experiments 1,2&3. Phosphorous (P) is necessary macronutrient for plant growth, essential for photosynthetic, support survival of plants in sever winter conditions, and plays an essential role in cell division (Zewdie & Reta, 2021). The experiments' results showed that the P value recorded 0.43, 0.68, and 2.17% for experiments 1,2&3, respectively. The results of the three experiments comply with the PSI, while experiments 2&3 only comply with FCO. Potassium (K) is a macronutrient essential for water uptake and transport of nutrients under adverse conditions (Jiang et al.,2018). The K results of the three experiments were 0.088, 0.103, and 3.37% for experiments 1,2&3, respectively. Only experiment 3 comply with FCO, while this parameter is not specified by the PSI.

(b) Biological Parameters

A broad variety of microorganisms are engaged in the biodegradation of the organic materials throughout the composting process (Wei et al., 2018). Pathogens are inactivated during the thermophilic phase due to elevated temperature. Previous studies reported that dominant temperature above 50°C for the duration of 7 days is capable to destroy pathogens (Shen et al., 2019). Others reported a range of temperature values of 55-60°C for at least 3 days is sufficient to inactivate most of pathogens (Deportes et al., 1995). Coliform organisms and especially fecal coliforms are a measure of fecal contamination. Final compost shall meet fecal coliform standard specification before use to avoid health risks. The results showed that the fecal coliforms content of the final compost were 28800, 1550, and 20 cfu/g for experiments 1,2&3 respectively. The highest fecal coliform content was noticed in experiment 1 because the max temperature recorded in the range of 52.3-54.3°C and lasts for 6 days only, and the temperature at the edges could be lower because of static composting. For experiment 2, the fecal coliform content is much lower that experiment 1 because the max temperature lasts for 12 days above 50°C and 7 days above 60°C which should be enough eliminate all pathogens. However, the nature of static composting which leave the edges cooler than inside could be the main reason for pathogen survival. The side-walls of the compost device are the main contributor to the heat loss and temperature drop as well. In a laboratory-scale study, Alkoaik et al. (2018) used a reactor insulated walls by 25 mm-thick glass wool blanket and reported that the reactor side-walls contribute by 28% of the total heat loss along the composting process. Other study reported 30-90% of the total heat generated from the composting process can be lost through the bioreactor side-walls depending on the effectiveness of the insulation (Ghaly et al., 2006). The lowest fecal coliform content was observed for experiment 3, which was also much lower than experiment 2, can be ascribed to the fact that the weather temperature during the composting process, which could rise the temperature of the compost device. In addition, the aeration rate was higher than that of experiment 1 which could be efficient to reach the edges and increased the temperature. None of the experiments comply with FCO, but met the PSI, where experiments 1&2 comply with the PSI type 2 and experiment 3 with type 1 compost, as presented in Table 4-2. Previous studies reported existence of pathogenic microbes in finished compost (Epelde et al., 2018). Álvarez-Alonso et al. (2024) reported Total coliform in the range of <3-2400 for six composting experiments consisted of organic refuse obtained from municipal solid SW and mixed with urban pruning and donkey’s manure.

(c) Heavy Metals

Heavy metals group included in this study are Lead (Pb), Chrome (Cr), Nickle (Ni), Cadmium (Cd), and Zinc (Zn). Although these metals play significant role in the life of organisms and biosphere functioning, it is very toxic if its concentration exceeds the max permissible limits (Antonenko et al., 2022). Compost is an interesting solution to reduce the effect of heavy metals in agricultural soil (Medy´nska-Juraszek et al., 2020) because it binds with it forming complex compounds and reduce its availability for absorption by crops and plants (Antonenko et al., 2022). Nevertheless, compost with high heavy metals concentration can lead to heavy metals accumulation in the plants and threaten the human health (Liu et al., 2019). The risk of heavy metals if existed in compost is its bioaccumulation when it is used as a fertilizer and entering the food chain through plants uptake thus affecting the food quality and causing adverse health risks to the consumers (Mohee & Soobhany, 2014, Papafilippaki, et al., 2015). It can be uptake and accumulated in the plants even when exist at low concentration in the soil (Jolly et al., 2013). The portion of heavy metals content in compost varies and depend on the quality of raw materials input (Amlinger et al., 2004; Swati & Hait, 2017), aerial deposition of heavy metals especially in winter season (Cercasov and Wulfmeyer, 2008), and treatment process such as sieving the product before delivery which control impurities (Paradelo et al., 2011). Therefore, the heavy metal content of compost is very important, which should comply with the standard specifications before application to the soil to avoid adverse health effects.

Test results for the three experiments showed that all heavy metals parameters comply with the PSI and FCO as presented in Table 4-2. The results showed that Zn>Ni>Pb>Cr>Cd for experiments 1&2, while for experiment 3 Ni>Cr>Pb>Cd>Zn. The range values of the recorded results for all experiments were Pb (2.2-10.14), Cr (9.27-12.71), Ni (18.86-23.9), Cd (0.5-1.0), and Zn (0.38-79.51) mg/kg. Bożym (2017) conducted a study on heavy metals content in home composting of vegetable, fruit, leaves, and branches waste and found that the range values of Cd (0.2-0.7), Pb (17.3-28.5), Zn (144-388), Cr (7.8-25.6), and Ni (12.8-34.5) mg/kg. An assessment of compost quality in the Palestinian market reported a range values of Pb (30.25-48.75), Cr (46.75-81.5), Ni (14.08-24.78), Cd (13.75-23.0), and Zn (288.25-390.25) mg/kg (Al-Sari et al., 2018). Previous studies in India reported heavy metals content in compost in the range values of Zn (82-946), Cd (trace-8.4), Pb (11-647), Ni (8.6-190), and Cr (14-401) mg/kg (Saha et al., 2010). A study was conducted on six pile composting experiments using organic waste obtained from municipal solid waste and mixed with urban pruning and donkey's manure, found that the heavy metals portion content of final compost was in the range of Zn (48.1-109.3), Cr (22.1-54.5), Cd (0.35-0.41), Pb (6.6-20.8), and Ni (4.4-18.3) mg/kg (Álvarez-Alonso et al., 2024)

The results of all quality parameters are presented in Table 4-2 and more photos showing the different stages of the experimental process are depicted in Annex-2.

Table 4-2 Physio-chemical parameters test results for the three experiments

No.	Parameter	Test Results				PSI Limits $^{(a)}$	Indian Standard Limits (FCO)$^{(b)}$
		Unit	**Experiment 1 (Palestine)**	**Experiment 2 (India)**	**Experiment 3 (Palestine)**		
1-	pH	-	7.98	8.19	8.28	5-8.5	6.5-7.5
2-	Electric conductivity (EC)	ds/m	5.04	9.76	1.80	≤4$^{(c)}$	≤4
3-	C/N	-	13:1	10:1	12:1	-	≤20
4-	Organic matter (OM)	(%)	38.47	58.01	67.0	≥35 for gardening, and ≥25 for agriculture	-
5-	Sodium (Na)	%	0.027	0.019	0.44	-	-
6-	Potassium (K)	%	0.088	0.103	3.37	-	≥1
7-	Calcium (Ca)	%	15.94	2.29	5.16	-	-
8-	Magnesium (M)g	%	0.50	1.17	0.95	-	-
9-	Nitrate (NO_3^-)	%	0.18	1.157	0.878	-	-
10-	Ammonium (NH_4-N)	%	0.115	0.121	0.015	-	-
11-	Total Nitrogen (N_T)	%	1.67	3.48	3.29	-	≥0.5
12-	Phosphorus (P)	%	0.43	0.68	2.17	≤200	≥0.5
13-	Lead (Pb)	mg/kg	7.05	10.14	2.20	300	100
14-	Chrome (Cr)		12.71	9.27	11.70	400	50
15-	Nickle (Ni)		22.05	18.86	23.90	90	50
16-	Cadmium (Cd)		1.0	Not detected	0.50	20	5
17-	Zinc (Zn)		41.57	79.51	0.38	2500	1000
18-	Total Organic Carbon (TOC)	%	32.30	33.65	39.40	-	≥16
19-	Fecal Coliform	cfu/g	28800	1550	20	1000 (type 1), $2*10^6$ (type 2)	Nil
20-	Initial C/N	-	23:1	-	28:1	-	-

21-	NH4/NO$_3$	-	0.639	0.105	0.017	-	-

(a) *PSI: Palestinian Standards Institution, Organic Fertilizer (Compost), standard no. PS/2652-2012.*

(b) *FCO: The Fertilizer Control Order 1985, updated 2021. Source: Mandal et al. (2014).*

(c) *This limit is for compost application at 5cm deep from the soil surface, and limitless for application at 20 cm deep from the soil surface.*

(d) Fertility and Clean Indices

Fertilization index (FI) indicate the agricultural value of the compost end product as it supplies the plant by the required nutrients. The clean index (CI) is a measure to regulate the use of compost based on heavy metals content. Both FI and CI are used to grade the compost and its marketability.

The calculated FI was 4.33, 4.73 and 4.8 for experiments 1,2&3, respectively, as presented in Fig 4-14. Although the three experiments showed high fertilization index, compost produced from experiment 3 has the higher fertilization index, followed by experiment 2, and experiment 1 showed the lowest fertilization index. This could be attributed to the type of the feed stock materials (experiment 1 doesn't include manure, experiment 2 includes cow dung, and experiment 3 includes sheep, goat and poultry fresh manure) beside fruits and vegetable waste and sawdust for experiment 1&3, and leaves for experiment 2. FI could be correlated with the quality of the input materials (Tibihika et al., 2021), and could be affected by stability and maturity stage of the compost (Mukai & Oyanagi, 2021). In accordance with Saha et al. (2010) classification, compost produced from the three experiments classifies as Grade "A" (FI>3.5). Saha et al. (2010) calculated a fertilization index for different compost samples produced from source-separated, partially separated, and mixed municipal waste, and found that the FI in the range from 1.8-4.2, where compost produced from source-separated municipal waste showed the highest FI (4.2). Previous research in Uganda conducted on compost sample obtained from 12 composting plants reported FI in the range of 2.1-2.9 (Kabasiita et al., 2022).

The calculated CI was 4.62, 5.00, and 4.69 for experiments 1,2&3, respectively, as depicted in Fig. 4-14. The compost produced by the three experiments is classified as grade "A" (CI>4) in accordance with the classification system set by Saha et al. (2010). Findings of other research showed that the CI was ranging from 0.5-5 (Saha et al., 2010), and in the range of 3.8-4.9 (Kabasiita et al., 2022).

(e) Energy Consumption

Forced-aeration systems require energy input for air blowers, and therefore are considered power consuming systems. Forced-aeration system is used in experiment 1&3 to accelerate the composting process. The system is connected electricity meter type GREEN complying with the European standards EN 62053-21 to measure the measure the electricity consumed during the composting process. The data showed that electricity consumption was 16.0KWh for experiment 1, and 32.2KWh for experiment 3. Considering the industrial electricity tariff of USD 0.20 (NIS 0.7137), the cost of 0.94m^3 of compost equals to USD 3.2 of fresh waste in experiment 1, and USD 6.44 for experiment 3, which is equal to USD 3.4/m^3 and USD 6.85/m^3 for experiments 1&3, respectively. However, there is no much data reported for energy consumption in aerated compost systems, and the few available data is relatively old. For example, Eades et al. (2010) conducted a research on in-vessel rotating drum and estimated the electricity consumption by the air handling system at 167KWh/ton of waste. Levis and Barlaz (2013) reported electricity consumption for aeration and rotation of 30.2KWh/ton of waste for in-vessel composting system.

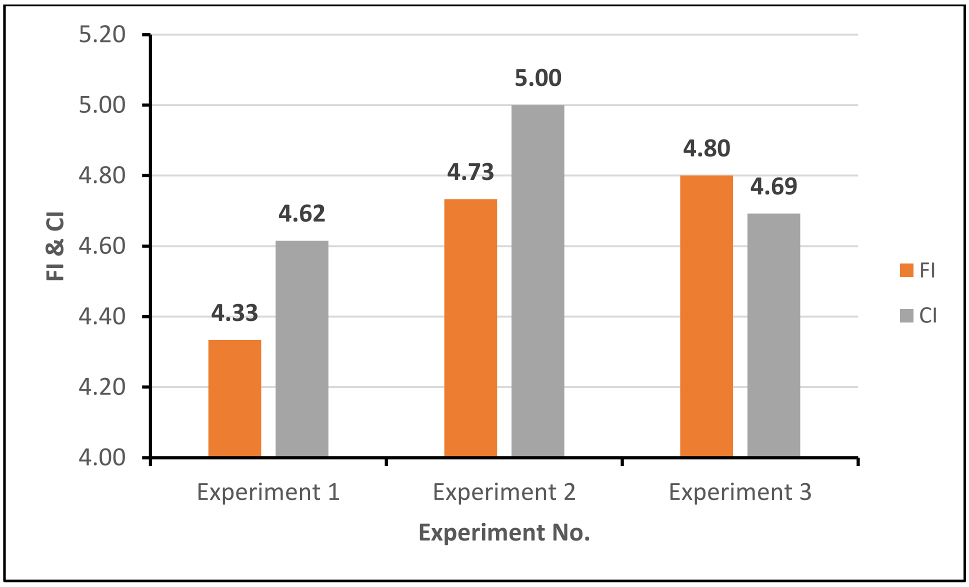


Fig. 4-14: Fertility and clean indices

4.2 The Role of Compost in the Circular Economy

Based on the objectives of the present study, the results have been classified into two scenarios - use of compost in agriculture, and use of compost as landfill cover, as given below.

4.2.1 Scenario 1: Use of Compost in Agriculture

a) Compost Production and Selling Revenues

The organic waste generation is about 118,948.29 tons in 2021 and will reach 224,856.78 tons in 2035. It has been assumed that the organic waste generated will yield 25% compost, so the compost production is in the range of 29,737 - 56,214 tons for 2021 to 2035. The operation and maintenance (O&M) cost of the compost facility is assumed to be 60% of the compost selling considering the low prices of compost. Other researchers assumed the O&M cost to be 30% of the returns from compost selling prices for operating and maintaining a compost facility only (Rashid and Shahzad, 2021). However, the revenues generated from compost selling are in the range of USD 392,529 - 742,027 from 2021 to 2035. Table 4-3 presents the revenues in each year.

Table 4-3: Compost production and revenues during the period 2021-2035

Year	**Waste Quantity (ton)**	**Compost (ton)**	**Selling Value (USD)**	**O&M Cost (USD)**	**Revenue (USD)**
2021	118,948	29,737	981,323	588,794	392,529
2022	126,513	31,628	1,043,734	626,240	417,494
2023	134,078	33,520	1,106,144	663,687	442,457
2024	141,643	35,411	1,168,555	701,133	467,422
2025	149,208	37,302	1,230,965	738,579	492,386
2026	156,773	39,193	1,293,375	776,025	517,350
2027	164,338	41,084	1,355,786	813,471	542,314
2028	171,903	42,976	1,418,196	850,918	567,278
2029	179,467	44,867	1,480,606	888,364	592,243
2030	187,032	46,758	1,543,017	925,810	617,207
2031	194,597	48,649	1,605,427	963,256	642,171
2032	202,162	50,541	1,667,837	1,000,702	667,135
2033	209,727	52,432	1,730,248	1,038,149	692,099
2034	217,292	54,323	1,792,658	1,075,595	717,063
2035	224,857	56,214	1,855,069	1,113,041	742,027

(OM cost is assumed 60% of the returns from compost selling)

b) Potential Replacement of Chemical Fertilizers and Monetary Saving

Compost can be used for agricultural purposes, and once it is produced and used, it enters the cycle of circular economy. The available chemical fertilizers in Palestine and mostly used in agriculture are Ammonium Sulphate (AS), Triple Super Phosphate (TSP), and Potassium Phosphate (SOP). Due to the restricted access to high quality chemical fertilizers by the Occupation, the Ministry of Agriculture (MoA) encourages the production of compost to alleviate the problem and compensate for the shortage of high quality fertilizers in Palestine (MoA, 2011). The results of calculations showed that 17,842 tons of compost can replace 794 tons of AS, 91 tons of TSP, and 29 tons of SOP in 2021, and 33,729 tons of compost can replace 1,502 tons of AS, 172 tons of TSP, and 54 tons of SOP in 2035 as shown in Fig. 4-15 and Table 4-4.

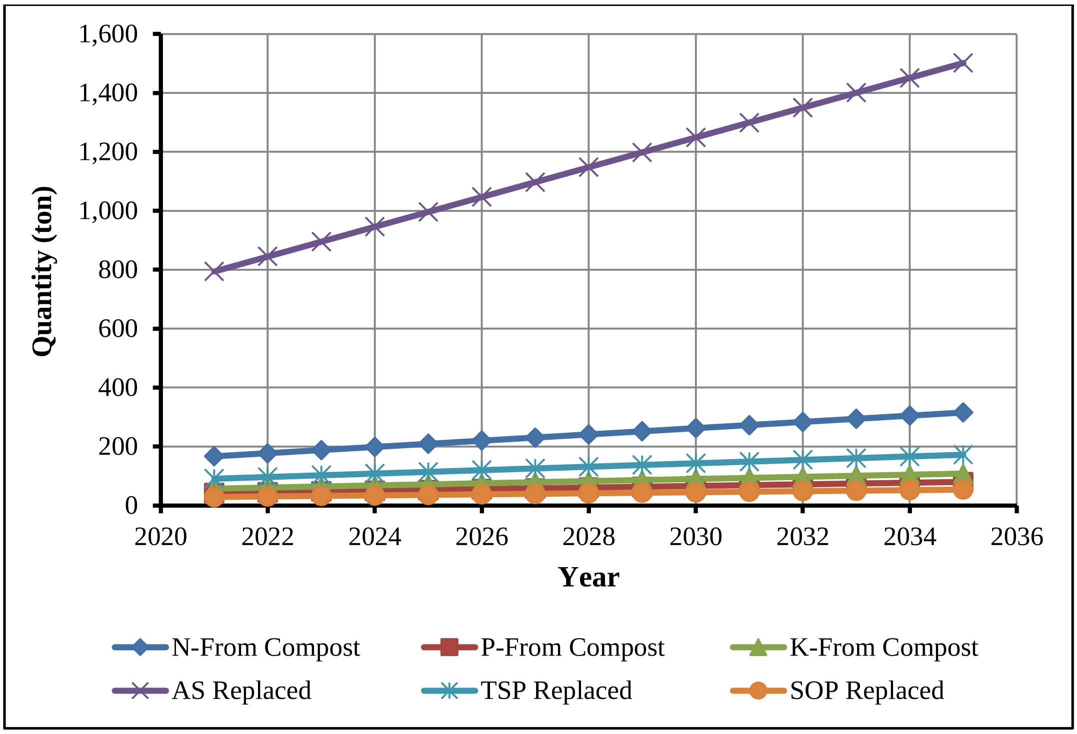


Fig. 4-15. Replacement of Ammonium Sulphate (AS), Triple Super Phosphate (TSP) and Potassium Phosphate (SOP) by compost

Table 4-4: Replacement of AS, TSP and SOP by compost

Year	**Compost (ton)**	**Compost DM (ton)**	**N, P, K in Compost (ton)**			**AS, TSP, SOP Replaced (ton)**		
			N	**P**	**K**	**AS**	**TSP**	**SOP**
2021	29,737	17,842	167	42	57	794	91	29
2022	31,628	18,977	177	45	61	845	97	30
2023	33,520	20,112	188	47	64	895	103	32
2024	35,411	21,246	199	50	68	946	109	34
2025	37,302	22,381	209	53	72	996	114	36
2026	39,193	23,516	220	55	75	1,047	120	38
2027	41,084	24,651	230	58	79	1,098	126	39
2028	42,976	25,785	241	61	83	1,148	132	41
2029	44,867	26,920	252	63	86	1,199	138	43
2030	46,758	28,055	262	66	90	1,249	143	45
2031	48,649	29,190	273	69	93	1,300	149	47
2032	50,541	30,324	284	71	97	1,350	155	49
2033	52,432	31,459	294	74	101	1,401	161	50
2034	54,323	32,594	305	77	104	1,451	167	52
2035	56,214	33,729	315	79	108	1,502	172	54

(DM: dry matter; compost contains 40% moisture content, 21.02% carbon, 0.935% N, 0.235% P, and 0.32% K. Alternative source of carbon such as humic acid used is "Iperen Humic 12+3 liquid" contains 7.3% carbon; Ammonium Phosphate contains 21% N; TSP contains 46% P, and SOP contains 50% K).

Rashid and Shahzad (2021) conducted a study on compost economic benefits in the Kingdom of Saudi Arabia (KSA) using commercial fertilizers in the KSA and found that 0.23 Mt of compost produced from organic food waste of Makkah city is enough to replace 2.8, 0.7, and 0.9 kt of Urea, diammonium phosphate (DAP), and sulphate of potash. In addition, compost is rich in carbon (C) and is considered as supplementary source of C to the soil which can improve the organic content of the soil, improve the structure of the agricultural soil, and extend moisture retention time in the soil. This study showed that the same above-mentioned quantity of compost that replaced AS, TSP and SOP can provide the soil with 3,750 tons of C which in turn can replace 51,376 tons of alternative fertilizers of humic acid (commercially used is Iperen Humic 12+3 liquid which contains 7.3% C) in 2021. The replacement increases with time as the compost quantity increases based on the waste generation. The projection of replacement showed that 33,729 tons of compost can enrich the soil with 7,090 tons of C which can replace 97,120 tons of "Iperen Humic 12+3 liquid" in 2035 as presented in Table 4-5. Rashid and Shahzad (2021) found that 28.9kt and 50.4kt of C from compost quantity 0.23Mt and 0.40Mt can replace 119.4kt and 208.8kt of humic acid in 2015 and 2030 respectively.

Table 4-5: Compost soil enrichment with C and replacement of alternative fertilizers

Year	Compost (ton)	Compost DM (ton)	C-Enrichment (tons)	Alternative Source (tons)
2021	29,737	17,842	3,750	51,376
2022	31,628	18,977	3,989	54,643
2023	33,520	20,112	4,228	57,911
2024	35,411	21,246	4,466	61,178
2025	37,302	22,381	4,705	64,446
2026	39,193	23,516	4,943	67,713
2027	41,084	24,651	5,182	70,980
2028	42,976	25,785	5,420	74,248
2029	44,867	26,920	5,659	77,515
2030	46,758	28,055	5,897	80,783
2031	48,649	29,190	6,136	84,050
2032	50,541	30,324	6,374	87,317
2033	52,432	31,459	6,613	90,585
2034	54,323	32,594	6,851	93,852
2035	56,214	33,729	7,090	97,120

Notes: Compost contains 40% moisture and 21.02% carbon, alternative source of carbon such as humic acid used is "Iperen Humic 12+3 liquid" which contains 7.3% carbon; Ammonium Phosphate contains 21% N; TSP contains 46% P, and SOP contains 50% K.

Moreover, compost build up organic matter which confers long-term nutrient release (approximate for six years) according to Allievi et al. (1993), which is challenging to estimate. Taking this long term effect of compost on the soil, the value-added replacement of chemical fertilizers by compost would be greater along the subsequent years (Jaza Folefack, 2009).

The monetary value of the saving from replacement of the chemical fertilizers is depicted in Fig. 4-16. The estimated results show that the saving generated is USD 993,005.80, USD 128,157.73, and USD 42,821.38 from AS, TSP, and SOP, respectively in 2021. The saving rises as the quantity of compost increase with time based on the population growth and reached USD 1,877,152.60 from AS USD 242,266.07 from TSP, and USD 80,948.44 from SOP in 2035. In addition, the estimated saving from replacing "Iperen Humic 12+3 liquid", the source of C, is USD 192.7 million in 2021 and USD 364.2 million in 2035. The total estimation of C, N, P, and K replacement saving of "Iperen Humic 12+3 liquid", AS, TSP and SOP by compost is USD 193.8 million and USD 366.4 million in 2021 and 2035, respectively.

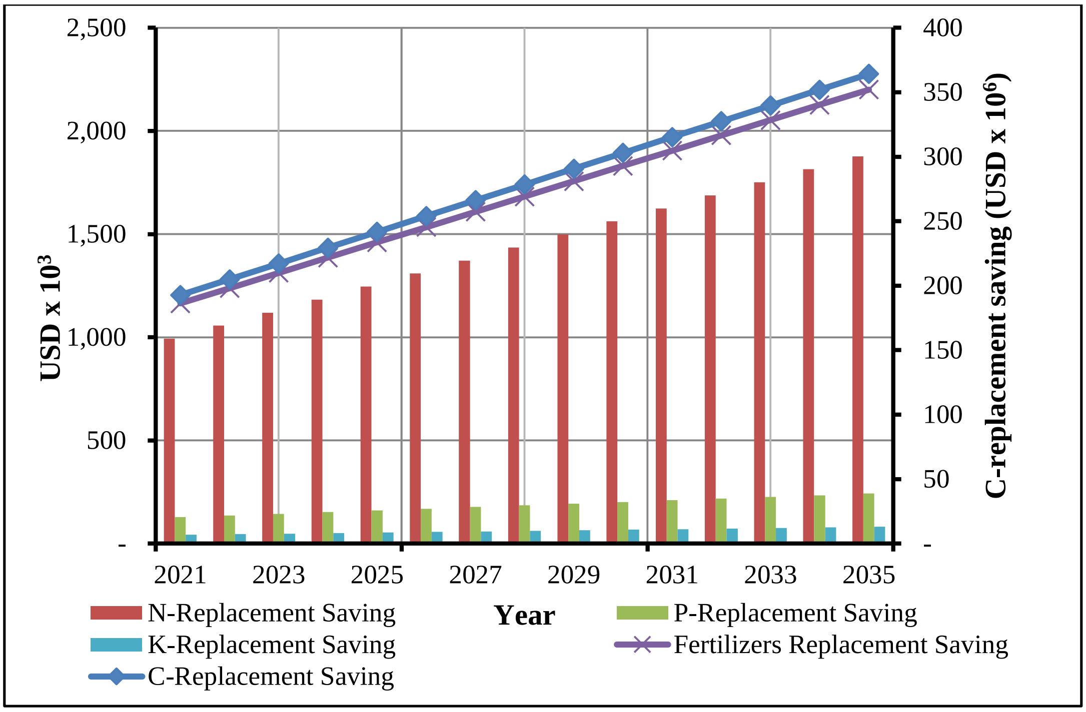


Fig.4-16. Saving from replacement of chemical fertilizers by compost in Palestine

Notes: AS price USD 1,250.0/ton; TSP price is USD 1,406.0/ton; SOP price is USD 1,500.0/ton; and "Iperen Humic 12+3 liquid" source of C price is USD 3,750.0/ton (Source: SBTAC, 2021)

c) Reduction in Methane Emission and Monetary Saving

Reduction in methane emission is considered as environmental indicator of the circular economy. The organic waste that is sent to the landfill in the business as usual scenario can degrade under anaerobic conditions in the landfill releasing methane gas. In the proposed scenario, it will be composted and methane emissions will be prevented. The calculated results show that the methane emissions reduction is 165 tons, which is equal to 4,122 tons CO_2 reduction in 2022 while the LandGEM doesn't provide estimates in the first year (2021) and provides estimates next year from the start. By the year 2035, the methane emission reduction will reach 2,493 tons that is equivalent to 62,324 of CO_2 which is prevented from release to the atmosphere, thereby reducing the potential global warming and mitigating the climate change. In a similar study, Rashid and Shahzad (2021) found that composting of food waste can reduce CO_2eq emissions by 1.09Mt and 1.9Mt in 2015 and 2030 respectively. The monetary value of this reduction according to the CDM is presented in Table 4-6.

Table 4-6: Saving from CDM and dumping fees

Year	**CH_4 (ton)**	**GWP CO_2 eq (tons)**	**Saving from CDM (USD)**	**Dumping Fees (USD)**	**Total Saving (USD)**
2021	0	0	0	282,502	282,502
2022	165	4,122	95,640	300,469	396,109
2023	332	8,306	192,699	318,435	511,134
2024	502	12,548	291,106	336,402	627,508
2025	674	16,845	390,796	354,369	745,165
2026	848	21,194	491,708	372,335	864,043
2027	1,024	25,594	593,780	390,302	984,082
2028	1,202	30,041	696,956	408,269	1,105,225
2029	1,381	34,534	801,183	426,235	1,227,418
2030	1,563	39,069	906,410	444,202	1,350,612
2031	1,746	43,646	1,012,587	462,168	1,474,755
2032	1,931	48,262	1,119,668	480,135	1,599,803
2033	2,117	52,914	1,227,609	498,102	1,725,711
2034	2,304	57,602	1,336,369	516,068	1,852,437
2035	2,493	62,324	1,445,907	534,035	1,979,942

Notes: GWP of CH_4 = 25 CO_2; CO_2 saving price = USD 23.2/ton; Dumping fees = USD 9.5/ton

d) Saving from Dumping Fees

The tipping fee of municipal waste at the regional landfill is USD 9.5/ton (NIS 30/ton). As the organic waste will be diverted from the waste stream, this fees will not be paid and is considered as saving. The calculations presented in Table 4-6 showed that the saving in 2021 from the dumping fees is USD 282,502. However, this saving will reach USD 534,035 in 2035. Similar to the present study, Rashid and Shahzad (2021) reported that composting of food waste can achieve saving in the tipping fees of 524.25 and 914.19 million Saudi Riyal in 2015 and 2030 respectively.

e) Environmental Saving

Saving achieved from the tipping fees (dumping fees) and from the reduction of methane emissions according to the CDM is considered as *environmental saving,* and also is one of the indicators that best reflect the role of composting organic waste in the circular economy. The calculations presented in Table 5-6 show that the environmental saving (total saving) is USD 282,502.19 and USD 1,979,941.67 in 2021 and 2035, respectively.

f) Landfill Space Saving

Diverting the organic fraction from the municipal solid waste stream and its composting is an alternative environmental option to waste landfilling. Accordingly, the space of the landfill saved from organic waste diversion can be used for disposal of other waste stream and, accordingly, increase the landfill lifespan and reduce the costs required for expanding the landfill or construction of new landfill. As these costs are drawn from the budget, then saving the landfill space can reduce expenditure and support the treasury as well, which is considered as an indicator of the circular economy.

The landfill space construction cost USD 2.65/m^3 (JSC-H&B, 2011), which equals to USD 2.84/tons of waste considering the density of the waste after compaction at the landfill 0.93 (ALPC, 2016). The calculation results of the landfill space saving are USD 337,813 in 2021 and USD 638,593 in 2035 as presented in Fig. 5-17.

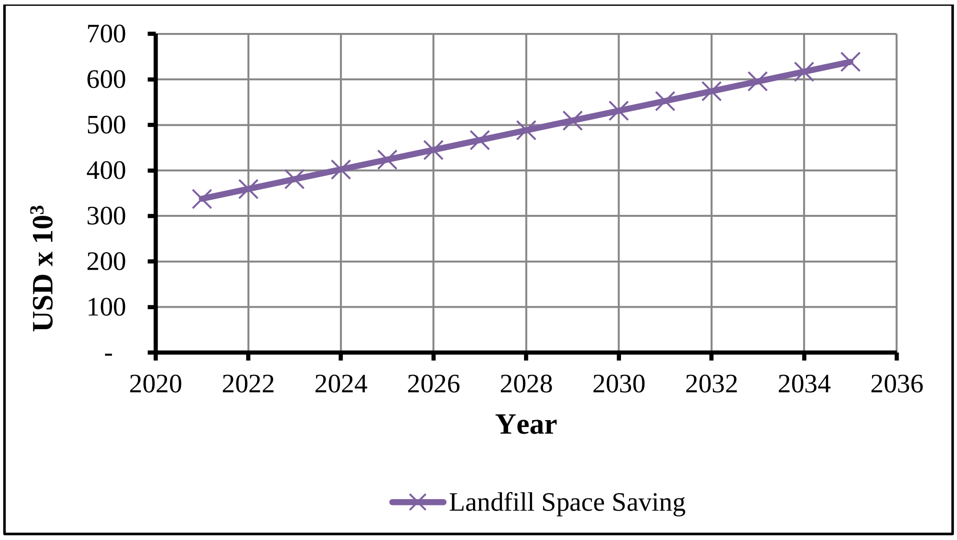


Fig.4-17. Saving with respect to reduced space requirement for landfilling

g) Net Revenues

The net revenue generation from municipal organic waste composting and replacement of chemical fertilizers by compost is calculated by adding the revenues generated from using the compost, the environmental saving through reduction of methane gas, saving the tipping fees to the landfill, and the saving achieved from fertilizer replacement as presented in Fig. 4-18. It has been estimated that sustainable composting system can add net revenue of USD 194.8 million to the national economy in 2021 and USD 369.8 million in 2035. Saving from replacement of chemical fertilizers is relatively high because the prices of chemical fertilizers in Palestine are very high compared to other countries where there is free access to fertilizers and the governments support the agricultural sector with fertilizers of viable prices. For example, the price of alternative (C) source in Saudi Arabia is 562.5 SAR/ton (Rashid and Shahzad, 2021) which is equal to USD 150/ton as per the exchange rate of USD = 3.75 SAR (Exchange Rates, 2022), whereas the price in Palestine is USD 3,750.0/ton. The restrictions on imports of chemical fertilizers imposed by the Israeli occupation are the main reason for the high prices because this restriction creates shortage of fertilizers in the market, which in turn result in the prices to rise.

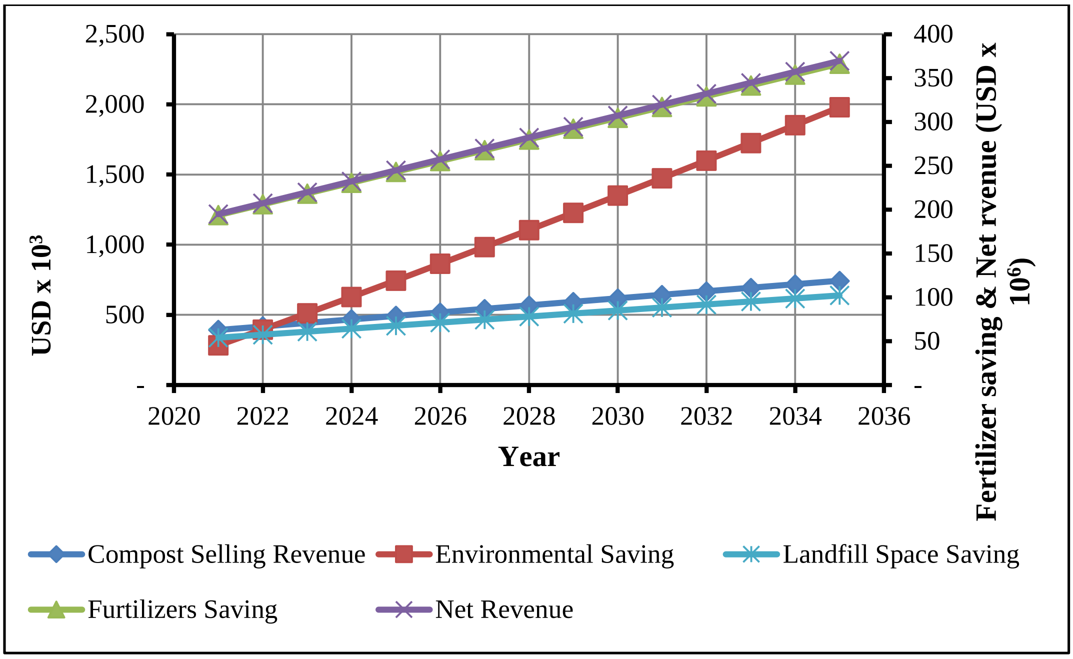


Fig.4-18. Net revenues generated from compost selling, environmental saving, fertilizer replacement saving and landfill space saving

Note: Fertilizers saving = saving from (AS + TSP + SOP + Iperen Humic 12+3 liquid" source of C), which has a value closer to the net revenue because the environmental saving and compost selling is relatively small, therefore the lines of net revenue and the fertilizers saving are almost attached on the Fig.

4.2.2 Scenario 2: Use of Compost as Landfill Cover

Beside the agricultural uses of compost, it can also use as daily and intermediate landfill cover, thus saving the cost of the filling materials that used on daily basis in the business as usual scenario. Landfill daily cover is essential because it prevents spread of flies, mosquitoes and insects, and reduces odor emission. At the regional landfill in the study area, about 600 tons of filling materials consisted of crushed stone, marl, sand and clay is used to cover the daily cell and working face. The price of the cover materials is USD 4.0 (NIS 13.0) per ton of cover material (JSC-H&B, 2021). Accordingly, the cost of this quantity is USD 2,400.0/day. The landfill is open for 12 hours per day and all days of the year. The annual estimated cost of the cover materials is USD 876,000.0 and USD 13.14 million during the 15 years starting from 2021 and up to 2035. These amounts can be saved if the compost is used as an alternative cover. Saving this amount is supporting the circular economy concept principles as the waste is recycled and returns to the material cycle and achieves financial profits.

4.3 Attitude Towards Organic Solid Waste Composting

4.3.1 Description of the LAs

It has been found that 56.5% of the LAs (48 LAs) are located in the Hebron governorate and 43.5% (37 LAs) are located in Bethlehem governorates. The largest portion is the VCs which represent 51.8% (44 VCs), followed by the municipalities which represents 42.4% (36 municipality), and then the joint services councils (JSCs) including the JSC-SWM and JCSPD which represent 5.9% (5 JSC-SWM and JCSPD) of the total LAs in the study area. Although the number of VCs is larger than the municipalities and the JSCs, the number of population served by the municipalities and the JSCs is larger than that served by the VCs as it depicted in Fig. 4-19. However, 2.4% of the municipalities (2 municipalities) are classified "A", 20.0% (17 municipality) are classified "B", and 22.4% (19 municipality) are classified "C", while there are no official classifications of VCs, JSCs-SWM and JCSPDs which represents 55.3% (47 JSC-SWM & JCSPD) of the total LAs. The MoLG classifies the local authorities (municipalities only) into four groups, group "A", group "B", group "C" and group "D". This classification system is based on local government minister decision no. 20/4/1998. In accordance with the decision, large municipalities that are considered as central of governorates are classified as group "A", municipalities that were established before the Palestinian Authority rolled over the West Bank and Gaza and with a population more than 15,000 are classified as group "B", municipalities of population more than 5,000 and less than 15,000 are classified as group "C", and municipalities of population less than 5,000 are classifies as group "D" (MoLG, 2005). The classification system doesn't provide any other information about the purpose of the classification, and the link between responsibilities and classification.

LAs are the service providers for street sweeping, waste collection, and disposal. The LAs in cooperation with the MoLG have established the JSCs-SWM and JCSPDs to optimize the SW collection and disposal. The JCSPDs were established in the rural areas where several villages cooperated to establish these councils for the purpose of optimizing the services provided, while the JSCs-SWM were established on the governorate level to handle the SW collection, transfer and disposal services. But, the councils are not fully functioning in all of the governorates because contracting the service is optional, and therefore there are still a number of local authorities providing the SWM service. However, it has been found that 21.2% of the LAs (18 LAs) are fully providing the SW collection service, 15.3% of them are providing the collection service in part (13 LAs), and 63.5% are not providing the collection service (54 LAs). LAs providing the SW collection service in part don't have enough refuse collection vehicles to handle all the waste stream, therefore, it contracts part of the service to the JSC-SWM. However, LAs not providing the collection service are normally small-sized and mostly VCs which don't have the capacity to carry out the collection service. Therefore, these LAs contract the SW collection service to the JCSPD or to the JSC-SWM or to nearby municipality. Figure 2 presents the service provider for the LAs which are partial or not providing the waste collection service. It has been found that the JSC-SWM for Bethlehem governorate is providing the service for 42.4% of the LAs, JCSPD for Dura rural areas (Hebron governorate) is providing the service to 22.7%, the JSC-SWM for Hebron governorate is providing the service for (10.6%) and the remaining is conducted by the JCSPD for Yatta rural areas, nearby municipality, and shared between the LA and the JSC-SWM in the area.

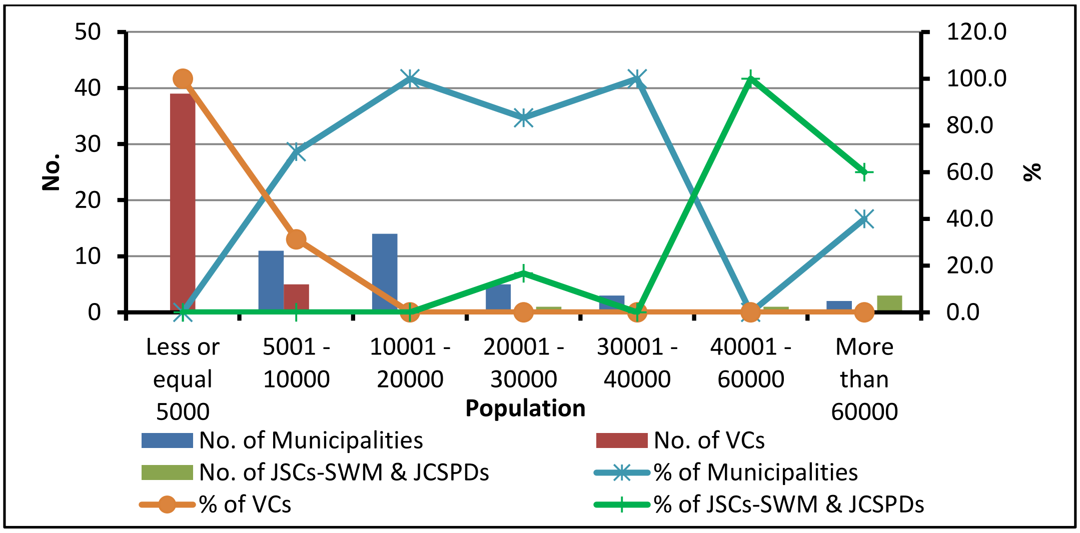


Fig. 4-19 Number of the LAs against the population served by waste management system in the study area

The LAs excluded from data collection via the questionnaire are 9 small-sized VCs. These are located in remote areas, no waste collection service, and the residents have livestock breeding as a main source of income. The current and common organic SWM practice being followed is to use the food waste as animal feed. Di Maria et al. (2018) have also suggested the promotion of animal feeding recycling activities in the absence of adequate funding programs for organic MSW in the West Bank of Palestine. Animal feed is one of the food waste management option according to a study conducted by the German International Cooperation – GIZ as well (GIZ, 2020).

4.3.2 Cost-related Issues of Municipal SWM

SW collection and disposal cost differs from one LA to another depending waste quantity generated, the number of refuse collection vehicles, and the number of workers. This is dependent on the population and the size of the LA as well. This section highlights the cost of SW collection and disposal and the elements that could influence the costs. The results reveal that the monthly waste collection cost is less than or equal to NIS 10,000.0 for 43.8% of the LAs which are of small size (i.e the VCs). The monthly waste collection cost is between NIS 10,000.0 and 300,000.0 for majority of the LAs (51.4%), while the cost exceeds NIS 300,000.0 for few LAs (5.0%) as presented in Table 4-7. However, the monthly disposal cost for the majority (59.3%) of the LAs is less or equal NIS 5,000.0, while the disposal cost is between NIS 5,000.0 and NIS 30,000.0 for 30.8% of the LAs. Few LAs (9.9%) exceed the cost of NIS 30,000.0 as disposal cost. As the organic waste fraction is the highest, the highest portion of the SW collection and disposal costs is attributed to the organic waste fraction. However, following other options in organic waste management such as composting could, to the large extent, reduce these costs by 40%.

Table 4-7 Monthly cost of SW collection and disposal against number of LAs in the study area

Monthly cost of SW collection (NIS)	**No. (%)**	**Monthly cost of SW disposal (NIS)**	**No. (%)**
Less or equal 10,000.0	35 (43.8)	Less or equal 5,000.0	48 (59.3)
10,001 - 30,000.0	17 (21.3)	5,001.0 - 10,000.0	10 (12.3)
30,001 - 80,000.0	14 (17.5)	10,001.0 - 20,000.0	10 (12.3)
80,001 - 150,000.0	7 (8.8)	20,001.0 - 30,000.0	5 (6.2)
150,001.0 - 300,000.0	3 (3.8)	More than 30,000.0	8 (9.9)
More than 300,000.0	4 (5.0)	**Total**	**81 (100.0)**
Total	**80 (100.0)**		

Selected factors of potential influence on SWM are shown in Table 4-8. The results showed that 18.5% of the LAs are generating 20 tons or less of SW monthly, while 14.8% of them are generating more than 600 tons on monthly basis. The majority of LAs (66.7%) are generating 50 – 600 tons of SW per month. For the refuse collection vehicles (RCVs), 67.5% of the LAs don’t own RCVs because they contracted the service to the JCSPD, JSC-SWM or nearby municipality. Around one fourth of the LAs have one to four RCVs, and few of them (7.2%) have five or more RCVs. However, more than one third of the LAs don’t have SW workers because of small size, such LAs are not conducting street sweeping in rural areas with low density of population. LAs that have more than 20 SW workers represent 12.0% part of the total LAs in the study area, while 52.9% of them have a number of SW workers in the range of 1 – 20.

Tariff is an important element in SWM which can ensure the cost recovery and support the sustainability of the SWM system. The fee collection rate is another important parameter and one of the sustainability pillars in SWM. Community willingness to pay the fees to improve SWM system is also a sustainability element (Al-Khateeb et al., 2017). The results showed two types of tariff-per household and per capita. Majority of the LAs (89.6%) are using household-based tariff. 64.9% of them are using tariff of NIS 10 – 20/household, and 24.7% are using tariff of NIS 21 – 30/household. However, only 10.4% of the LAs are using per capita-based tariff of NIS 2 – 3/capita. The fees collection showed that 9.9% of the LAs have collection less than or equal to 20%, and 30.9% of them have collection in the range of 81 – 100%, and rest of the LAs (60%) in the study area have collection in the range of 21 – 80%. In general, the fee collection is relatively low, which can in turn affect the performance of the LAs and attitudes toward developing an effective SWM system.

Table 4-8 Factors of potential effect on SWM at the LAs

Monthly Waste Generation (tons)	**No. (%)**	**RCV**	**No. (%)**	**SW Workers**	**No. (%)**
Less or equal 20	15 (18.5)	None	56 (67.5)	None	29 (34.9)
21 - 50	17 (21.0)	One	7 (8.4)	1 - 5	27 (32.5)
51 - 100	5 (6.2)	Two	7 (8.4)	6 - 10	10 (12.0)
101 - 200	14 (17.3)	Three	6 (7.2)	11 - 20	7 (8.4)
201 - 400	13 (16.0)	Four	1 (1.2)	More than 20	10 (12.0)
401 - 600	5 (6.2)	Five or more	6 (7.2)	**Total**	**83 (100)**
More than 600	12 (14.8)	**Total**	**83 (100)**		
Total	**81 (100)**				

Tariff System	**No. (%)**	**Fee Collection (%)**	**No. (%)**
NIS 10 – 20/household	50 (64.9)	Less or equal 20	8 (9.9)
NIS 21 – 30/household	19 (24.7)	21 – 40	15 (18.5)
NIS 2 - 3/capita	8 (10.4)	41 – 60	21 (25.9)
		61 – 80	12 (14.8)
		81 – 100	25 (30.9)
		Total	**81 (100)**

4.3.3 Challenges in Organic SW Composting

Composting of the organic municipal SW fraction can attract LAs because it can reduce the transport and disposal costs, and can prolong the life of the landfills (Folz, 1991; Muttamara et al., 1994). However, LAs could face constraints and challenges, including technical, financial, social, and legal, which can affect their decision in selecting the appropriate option. Several challenges were selected in this study as presented in Fig. 4-20 and the LAs opinion was assessed against these challenges. The results revealed that all the LAs lack proper equipment and machinery to conduct composting; 94.3% of the LAs reported shortage of RCVs to collect SW; 90.6% of them suffer from lack of financial resources; 86.8% of them lack knowledge and experience in composting, and the SW tariff system was built on the cost of SW collection and disposal only, and any other associated costs with composting (cost for separate bins) were not considered; 75.5% of the LAs consider that SW sorting at the source is difficult to apply due to the lack of awareness; 73.6% of them consider a legal challenge as the compost is not forced by law; 71.7% provided that there is no incentives from the government for composting of organic waste; and 67.9% of them suffer from non-availability of proper place to carryout composting. However, other challenges listed in Fig. 2 are of less importance in accordance with the LAs as less than 50.0% of the LAs highlighted them as challenges. Typical constraints and challenges being faced by developing countries which affect the development of effective SWM system include lack of financial, human and infrastructure resources (Zhu et al., 2008).

4.3.4 Attitudes toward Municipal Organic SW Composting

Attitude of LAs towards applying SW separation at the source and composting of organic municipal SW are almost similar and low. The results revealed that only 36.9% of the LAs (31 LAs) are planning to apply separation at the source compared to 63.1% of them (53 LAs) which are not, and only 36.5% of them (31 LAs) are planning to compost the organic fraction of municipal SW compared to 63.5% (54 LAs) which are not planning for that.

4.3.5 Factors Affecting LAs' Attitude toward Municipal Organic SW Composting

A. Findings of the Bivariate Analysis

The bivariate analysis is used to identify the relationship between two variables only, and test the degree of influence (significant or insignificant) of each affecting factor independently. Findings of the bivariate analysis are presented in Tables 4-9 to 4-11. The analysis of results of these factors as described follow.

(a) Financial Factors

A number of factors were chosen to investigate its influence in shaping the LAs' attitude toward composting of organic waste as presented in Table 4-9. Only one factor showed significant relationship with the LAs' attitude, which is "having financial capacity to conduct composting" (with *P-value = 0.012*). Financial capacity is one of the key elements in initiation and successful implementation of any project. It has been found that 50.0% of the LAs have financial capacity to conduct composting but are not planning compared to 41.7% and 75.5% of them which have limited capacity, and haven’t financial capacity, respectively, and are not planning for composting.

Other financial factors are of less importance because it is not significant in shaping the LAs’ attitude toward composting. The debts on the LA is not of significant effect (*P-value = 0.459*), where 66.1% of the LAs having debts are not planning for composting compared to 57.1% of them which have no debts. The monthly cost of SW disposal factor (*P-value = 0.056*) hasn’t provided specific relationship with the planning for composting. It showed that majority of the LAs which pay in the range of NIS 5,000.0 - NIS 30,000.0/month for waste disposal are also not planning to for composting. Household tariff factor (*P-value = 0.110*) showed that 84.2% of the LAs which have a tariff system in the range of NIS 21 – 30/household/month are not planning for composting. Similarly, 60.0% and 50.0% of which have tariff system in the range of NIS 10 – 20 and NIS 2 – 3/capita/month, respectively, have no plan for composting. The fee collection rate is one of the most important element in SWM because it enables the LA to cover the costs associated with waste collection, transport and disposal, and the financial capacity of the LA increase with the increase of the fee collection rate. User charges and fees are the most appropriate revenue source for the LAs which can be amenable to cover the cost of services (UN-HABITAT, 2015). The fee collection rate factor (*P-value = 0.18*) didn’t provide clear relationship with the planning for composting. About 62.5% of the LAs which have a collection rate of ≤20% haven’t planned for composting, 40.0% of the LAs which have fee collection rate in the range of 21 – 40% are not planning for composting, and similarly, 57.1% of them which have fee collection rate in the rage of 61 – 60% and are also not planning for composting. Finally, the factor of receiving financial support from the government to develop waste reduction through composting (*P-value = 0.565*) showed that 50.0% of the LAs which “sometimes” received financial support from the government are not planning for composting compared to 64.2% of them which haven’t received any financial support from the government. Al-Khatib et al. (2010) reported that support from the government budget is limited, which limit the opportunities for development of SWM system.

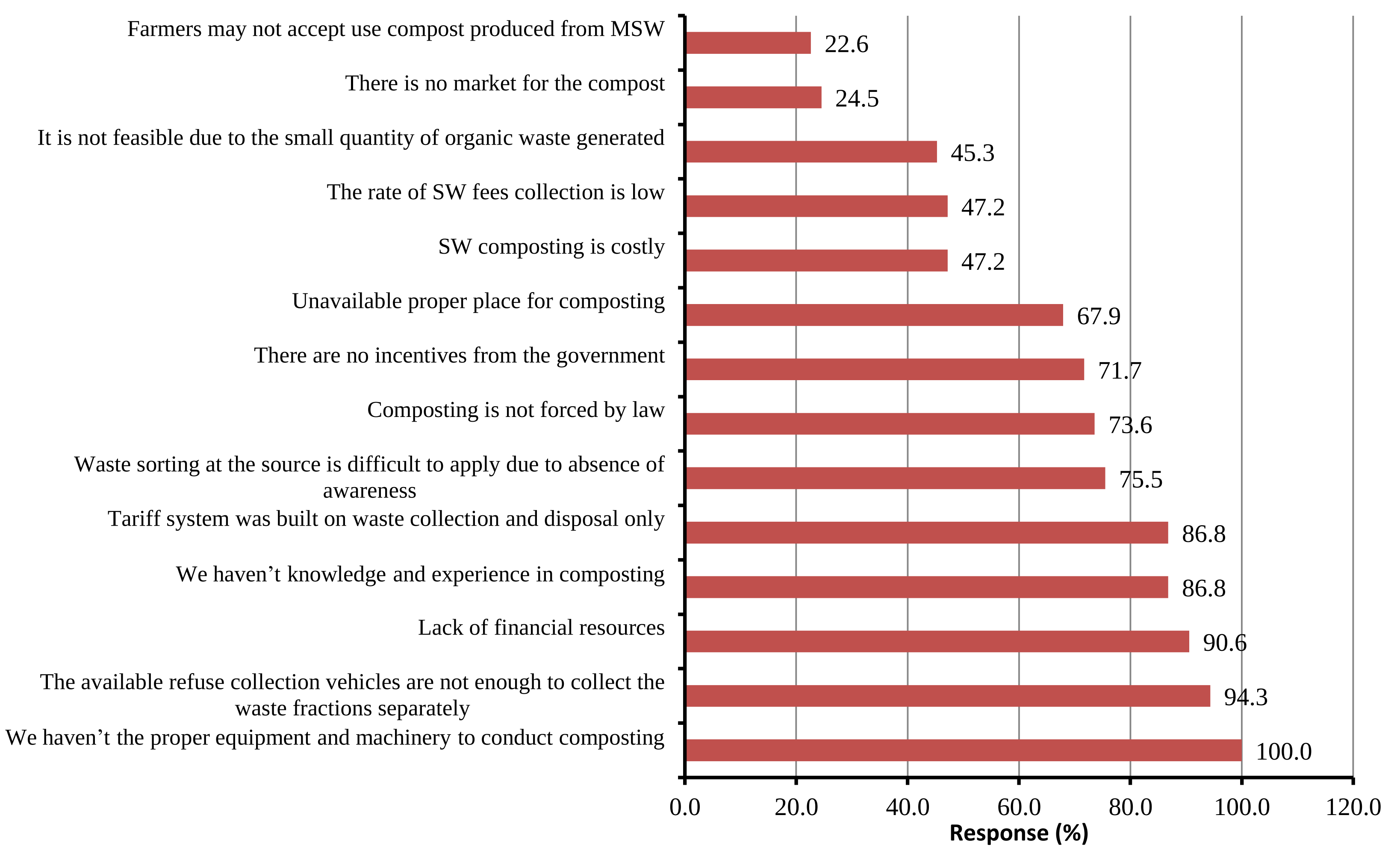


Fig. 4-20 Challenges faced by LAs in organic municipal SW management and composting

(b) Environmental Factors

Perception of the “impact on the environment” could be one of the driving forces behind positive attitude toward organic SW composting. Two variables were set to measure the effect of the environmental factors on the LAs’ attitude toward SW composting as presented in Table 4-9. The data analysis revealed that none of the factors is significant in shaping the LAs’ attitude. About 61.3% of the LAs which perceive that compost can contribute in reduction of the environmental pollution (*P-value = 0.117*) haven’t planned for composting compared to 100.0% of the LAs which lack this perception. In addition, 61.1% of the LAs which have the perception of compost contribution to SW reduction (*P-value = 0.197*) haven’t planned for composting against 71.4% and 100.0% of the LAs which don’t know and haven’t perceived this, respectively, have also not planned for organic SW composting. As reported by Aini et al. (2002), the attitude of SW recycling, including organic SW recycling through composting was found positively affected by the level of knowledge of environmental conservation and environmental awareness.

Table 4-9 Economic and environmental factors and their role in determining attitude of LAs towards composting of organic SW in the study area

Variable Description	Planning to compost organic fraction of MSW		Significance (P-Value)
	Yes No. (%)	NO No. (%)	
Financial factors			
Debts on the local authority			0.459
Yes	21 (33.9)	41 (66.1)	
NO	9 (42.9)	12 (57.1)	
Monthly cost of SW disposal (NIS)			0.056
≤ 5,000.0	20 (41.7)	28 (58.3)	
5,001.0 – 10,000.0	4 (40.0)	6 (60.0)	
10,001 – 20,000.0	0 (0.0)	10 (100.0)	
20,001 – 30,000.0	1 (20.0)	4 (80.0)	
> 30,000.0	5 (62.5)	3 (37.5)	
Household tariff (NIS)			0.110
10 – 20/ household/month	20 (40.0)	30 (60.0)	
21 – 30/ household/month	3 (15.8)	16 (84.2)	
2 – 3/ capita/month	4 (50.0)	4 (50.0)	
Fee collection rate			0.180
≤ 20%	3 (37.5)	5 (62.5)	
21 – 40%	9 (60.0)	6 (40.0)	
41 – 60%	9 (42.9)	12 (57.1)	
61 – 80%	3 (25.0)	9 (75.0)	

81 – 100%	6 (24.0)	19 (76.0)	
Having financial capacity to conduct composting			
Yes	4 (50.0)	4 (50.0)	0.012*
Yes, but limited capacity	14 (58.3)	10 (41.7)	
NO	13 (24.5)	40 (75.5)	
Receiving financial support from the government to develop SWM such as waste reduction through composting			
Yes	0 (0.0)	0 (0.0)	0.565
Sometimes	2 (50.0)	2 (50.0)	
NO	29 (35.8)	52 (64.2)	
Environmental Factors			
Perception of compost contribution to reduce environmental pollution			0.117
Yes	31 (38.8)	49 (61.3)	
NO	0 (0.0)	4 (100.0)	
Perception of compost contribution to reduce SW generation			0.197
Yes	28 (38.9)	44 (61.1)	
Don’t know	2 (28.6)	5 (71.4)	
NO	0 (0.0)	5 (100.0)	

*Significant at P≤0.05

(c) Resources (Technical and Technological)

The data analysis showed that 5 out of 7 factors are found significant in shaping the attitude of LAs towards composting of the MSW as presented in Table 4-10. All of the LAs which have proper machinery to conduct composting (*P-value = 0.007*) are planning for waste composting compared to 66.7% of them which don’t have proper machinery and haven’t planned for composting. In addition, 100.0% of the LAs which have enough RCVs to collect SW fractions separately (*P-value = 0.006*) are planning for composting compared to 67.5% of them with limited number of RCVs not planning for composting. Lalitha and Fernando (2019) reported that most of the LAs lack sufficient number of waste collection vehicles and the available vehicles are old and broken. The factor of “having appropriate area of land to be used for composting” such as construction of composting plant (*P-value = 0.001*) showed that 42.9% of the LAs that owned appropriate land area have no plan for composting compared to 78.0% of them which have no appropriate area of land. Limitation of land was found to be a major issue being faced by the LAs for composting (Lalitha and

Fernando, 2019). Moreover, 42.3% of the LAs that are familiar with composting system (*P-value = 0.007*) are not planning for compost of organic waste compared to 72.9% of them which are not familiar with composting systems. Further, 40.0% of the LAs which have staff members with previous experience in compost production (*P-value = 0.037*) are not planning for composting of the SW compared to 68.6% which lack previous experience. Staff experience, in general, affects the LAs' performance. Tembo et al. (2020) reported that inadequate qualification of manpower affects the LAs' service delivery.

On the other hand, 2 out of the 7 factors are not significant in determining the LAs' attitude toward organic SW composting. The factor of having enough financial resources to employ modern technology in SW composting (*P-value = 0.714*) showed that 57.1% of the LAs which have financial resources are not planning for composting compared to 64.1% with no financial resources for this purpose. Although the availability of financial resources to employ modern technology in composting was found insignificant, the absence of proper technology to apply was found the main factor behind the failure of LAs composting programs (Lalitha and Fernando, 2019). The monthly SW quantity generated (*P-value = 0.633*) didn't show specific relationship with the attitude toward composting. For example, 60.0%, 64.7%, 60.0% of the LAs which produce monthly quantity of SW of ≤20 tons, 21 – 50 tons, and 51 – 100 tons, respectively, are not planning for composting. So the size of the SW quantity produced didn't provide any specific relation regarding planning for composting or organic waste.

Table 4-10 Role of resources, technical and technological factors towards shaping the LAs' attitudes towards organic SW composting

Factor Description	Planning to compost organic fraction of MSW		Significance (P-Value)
	Yes No. (%)	NO No. (%)	
Having proper machinery to conduct composting			0.007**
Yes	4 (100.0)	0 (0.0)	
NO	27 (33.3)	54 (66.7)	
Having enough RCV to collect SW fractions separately			
Yes	4 (100.0)	0 (0.0)	0.006**
NO	26 (32.5)	54 (67.5)	
Having appropriate area of land to use it for composting			0.001**
Yes	20 (57.1)	15 (42.9)	

NO	11 (22.0)	39 (78.0)	
Having enough financial resources to employ modern technology in SW composting			0.714
Yes	3 (42.9)	4 (57.1)	
NO	28 (35.9)	50 (64.1)	
Familiarity with composting systems			0.007**
Yes	15 (57.7)	11 (42.3)	
NO	16 (27.1)	43 (72.9)	
Staff having previous experience in compost production			0.037*
Yes	9 (60.0)	6 (40.0)	
NO	22 (31)	48 (68.6)	
Monthly SW quantity generated (tons)			0.633
≤ 20	6 (40.0)	9 (60.0)	
21 - 50	6 (35.3)	11 (64.7)	
51 - 100	2 (40.0)	3 (60.0)	
101 - 200	6 (42.9)	8 (57.1)	
201 - 400	4 (30.8)	9 (69.2)	
401 - 600	0 (0.0)	5 (100.0)	
> 600	6 (50.0)	6 (50.0)	

*Significant at P≤0.05, **significant at P≤0.01

(d) Innovation

Developing novel methods are essential to appropriately improve the efficiency of SWM (Lalitha and Fernando (2019). Development of new rapid composting system, which can optimize the compost parameters and reduce the time span required for composting is a novel system and can attract the interest of the organizations and companies working for compost production. The LAs were asked whether they can accept the use a new rapid composting system if developed, and the result showed significant relationship (*P-value = 0.036*) with LAs attitude toward composting as presented in Table 4-11, about 60.3% of the LAs that accept the use of the new developed composting system haven't planned for composting compared to 100.0% of them which declined to use it.

(e) Marketing

Marketing of compost is essential as the revenues from sale can ensure cost recovery and support the sustainability of the composting program as well. Lalitha and Fernando (2019) reported that most of the LAs engaged in composting programs have failed, and key reason of failure is the marketing. The influence of marketing on the LAs' attitude toward composting is measured and found insignificant in shaping the LAs' attitude (*P-value = 0.294*) as presented in Table 4-11. The results revealed that 58.6% of the LAs which believe in good marketing for the compost produced from municipal SW in Palestine are not planning for composting. Marketing of compost depends on the quality as well as the willingness and acceptance of the farmers. The Palestinian farmers' attitudes and acceptance toward use of compost in agriculture was found positive as per the findings of Al-Sari et al. (2018) and Al-Madbouh et al. (2019).

(f) Institutional

Staff training, familiarity with the laws and policies, and understanding the responsibilities are all considered as institutional factors. Three institutional factors were set to test its impact on the LAs' attitude toward SW composting as presented in Table 4-11. The results showed "staff training in compost production" and "SW composting as the responsibility of the LA" have significant relationship with the planning for organic SW composting. The analysis showed that 35.7% of the LAs which have staff members trained on compost production from organic materials lack plan for composting. However, 51.0% of the LAs believe that SW composting is within the LA responsibilities.

"Familiarity with SWM bylaw" factor was found of insignificant effect on the LAs' attitude with *P-value = 0.818* as presented in Table 4-11. The analysis of the data pointed out that 62.2% of the LAs which are familiar with the SWM bylaw are not planning to compost the organic fraction of MSW since the law doesn't enforce it over the LAs.

(g) Social

The social acceptance of any program is one of the important sustainability pillars beside the environment and economy. Community awareness about composting, community participation in the composting program through waste segregation at the source, and farmers' willingness for the use of compost produced from MSW in agriculture, are all social factors and could affect the LAs' attitude toward composting of MSW. The effect of these factors is investigated as shown in Table 4-11, and the results revealed that none on these factors is significant in determining the LA attitude toward composting. The results revealed that 55.6% of the LAs which have conducted community awareness on organic waste composting haven't planned to compost organic fraction of MSW compared to that which didn't. In addition, 55.6% of the LAs which believe in citizens' participation through sorting of organic waste at the source if the LA decided to start composting program are planning for composting. Moreover, 61.1% of the LAs which believe in farmers' acceptance to use the compost produced from MSW in agriculture haven't planned for composting. Milea (2009) reported that attitude can be influenced by broad of reasons such as lack of participation of the public in waste management, and lack of awareness and education about efficient WM techniques.

Table 4-11 Role of innovation, marketing, institutional and social factor in shaping the attitude of LAs' towards organic SW composting

Factor Description	Planning to compost organic fraction of MSW		Significance (P-Value)
	Yes No. (%)	NO No. (%)	
Innovation factor			
Acceptance of new rapid composting system			0.036*
Yes	31 (39.7)	47 (60.3)	
NO	0 (0.0)	7 (100.0)	
Marketing factor			
Believe in good market for compost produced from municipal SW in Palestine			0.294
Yes	24 (41.4)	34 (58.6)	
Don’t know	6 (30.0)	14 (70.0)	
NO	1 (14.3)	6 (85.7)	
Institutional Factors			
Staff training in compost production			0.018*
Yes	9 (64.3)	5 (35.7)	
NO	22 (31.0)	49 (69.0)	
Familiarity with SWM bylaw			0.818
Yes	14 (37.8)	23 (62.2)	
NO	17 (35.4)	31 (64.6)	
Believe that SW composting is within the LA responsibility			0.005**
Yes	24 (49.0)	25 (51.0)	
NO	7 (19.4)	29 (80.6)	
Social factors			
Having conducting community awareness on organic waste composting			0.250
Yes	12 (44.4)	15 (55.6)	
NO	18 (31.6)	39 (68.4)	
Believe in participation of the residence through sorting of organic waste at the source if the LA decided to start composting program			0.157

Yes	16 (44.4)	20 (55.6)	
Yes, but partially	14 (31.8)	30 (68.2)	
NO	0 (0.0)	4 (100.0)	
Believe in farmers' acceptance to use compost produced from municipal SW in agriculture			0.615
Yes	28 (38.9)	44 (61.1)	
Don't know	2 (22.2)	7 (77.8)	
NO	1 (33.3)	2 (66.7)	

*Significant at P≤0.05; **significant at P≤0.01

B. Findings of the LRM

To evaluate the LAs' attitudes toward composting of municipal organic SW, many factors were chosen. The selection of these variable took into consideration the results of the bivariate analysis, so all factors that had muticolinearity were excluded. The independent variable that better explain the LAs' attitudes included in the model are: monthly SW generated quantity by the LA, SW tariff on the household level, the rate of SW fee collection, LA's perception of compost contribution to SW reduction, availability of proper place (area of land) to be used for compost production, financial capacity of the LA to conduct composting, staff attended training on compost production, previous experience in compost production, awareness about compost production from organic SW, potential community participation in SW sorting, and LA's familiarity with the SWM bylaw. The LAs' attitude is estimated based on the LRM equation 5 as per the following:

$$\mathit{Logit}\ (\mathit{LA's\ attitude}) = -\,12.719 + 0.370X_1 + 0.151X_2 + 0.429X_3 + 2.044X_4 + 2.001X_5 + 2.235X_6 + 0.930X_7 + 1.704X_8 - 1.886X_9 + 1.494X_{10} - 2.697X_{11} \ldots\ldots\ldots\ldots\ldots\ldots \ (4\text{-}1)$$

The LRM results as shown in Table 4-12 revealed that 5 out of 11 factors are significantly influencing the LAs' attitudes toward composting. The data fits the model as presented in Table 4-13. The significant outcomes drawn from the study showed that the attitude of LAs towards composting was negative for those which didn't perceive that composting of municipal organic SW fraction can contribute to reduce SW generation. LAs that lack proper place to conduct composting showed negative attitude toward organic SW composting. This finding is in agreement with Lalitha and Fernando (2019) who found that limited area land available was major obstacle in front waste composting and recycling in Sri Lanka, and most of the LAs participated in composting activities have failed due to lack of facilities. The attitude towards organic waste composting is negative for LAs which don't have enough financial resources to cover the cost of organic waste composting. Lack of financial resources is considered a challenge by 90.4% of the LAs. Financial resources are crucial for the LAs performance, and lack of financial resources can not only affect the attitude toward SW composting but also can negatively affect the entire services. Choi (2021) found that financial soundness is significant for the LAs performance, and he reported that the higher the LA revenues the higher the performance level, and LAs with sufficient financial resources are more advantageous for superior performance. Zeidan et al. (2020) pointed out that budget deficit due to lack of financing is the primary obstacle which hinder the execution of strategic plans and the improvements of local government units and municipalities. In addition, the outcomes showed that LAs that have already conducted awareness in the community about compost production showed negative attitude toward organic waste composting. LAs which conducted awareness in the community regarding composting of organic waste could have concluded that awareness without practice is not enough to change the community attitude or the awareness campaigns conducted were not enough. Awareness and knowledge of composting has been identified a crucial factor for community cooperation and participation in composting programs (Karkanias et al., 2016; Loan et al., 2019). Moreover, the outcomes draw that LAs familiar with the SWM bylaw showed negative attitude toward compost production from municipal organic SW. This could be attributed to the fact that composting of organic waste is not compulsory by law. SWM bylaw has been issued in 2019, which encourages compost production from municipal organic SW fraction in articles no. 3 and no. 27. Item 7 under article no. 3, encourages the reuse and recycling of the SW as much as possible through compost production and use it in agriculture, and this use shall be in compliance with the environmental protection and health requirements. In addition, article no. 27 asks the authorities to take all necessary measures to reduce the waste stream as much as possible through reuse, recycling and recovery (SWM bylaw, 2019). LAs which are familiar with SWM bylaw are aware that composting of municipal organic waste fraction lies within their responsibilities, but the bylaw doesn't provide target limits as mandatory to reach, and accordingly showed negative attitude toward composting.

Other factors are of less importance because these had insignificant influence. The results of this study pointed out that, first, the larger the waste quantity generated the lower is the attitude toward composting. The reason could be that the LA is suffering from lack of resources such as availability of enough area of land to conduct composting. Second, the higher the SW tariff group the lower the attitude toward SW composting. Some LAs are using the revenues to cover other services, which means that even the tariff is high, the revenue are not used to develop the SWM system. However, some LAs have a high tariff system, but the rate of fee collection is low which means that the LA lacks the capacity to conduct composting. Other reasons could be attributed to the fact that the revenues, in some LAs, are not being able to cover the cost of the service. The World Bank (2017) also reported that intergovernmental fiscal architecture in Palestine is characterized by local revenues assignments that are insufficient to cover the operational expenditure needs of local government units. Third, the higher the collection rate the lower the LA’s attitude, which could be attributed to the fact that LAs are using the revenues to cover other services, or the tariff, is not being able to cover the expenditures. Fourth, LAs with staff members who attended training on compost production showed positive attitude toward organic waste composting. Fifth, the LAs with staff members having previous experience in compost production showed positive attitude toward composting, and sixth, the higher the LA’s expectation of community participation the higher the positive attitude toward MSW composting.

Table 4-12 Output of the LRM of the LAs' attitude toward composting of organic municipal SW

Var.	**Abbreviation**	**Estimated Coefficients (β)**	**Standard Error (S.E)**	**Wald Statistics**	**Degree of Freedom (df)**	**Significance (P-value)**
X_1	Mon. SW generated Qt.	0.370	0.243	2.324	1	0.127
X_2	HH SW tariff	0.151	0.543	0.078	1	0.780
X_3	Fee collection rate	0.429	0.304	1.991	1	0.158
X_4	Per. of compost reduce SW	2.044	1.042	3.846	1	0.050*
X_5	Place availability	2.001	0.821	5.948	1	0.015*
X_6	Financial capacity	2.235	0.767	8.484	1	0.004**
X_7	Staff training	0.930	0.985	0.890	1	0.345
X_8	Staff prev. experience	1.704	1.096	2.416	1	0.120
X_9	Community awareness	-1.886	0.925	4.161	1	0.041*
X_{10}	Pot. Comm. participation	1.494	0.807	3.429	1	0.064
X_{11}	Familiarity with SWM bylaw	-2.697	1.110	5.898	1	0.015*
Constant		-12.719	4.069	9.770	1	0.002

**significant at P≤0.01; *significant at P≤0.05

Table 4-13 LRM summary and results of goodness of fit

Test	**Results**		
Model summary	-2 Log likelihood	Cox & Snell R^2	Nagelkerke R^2
	53.313	0.413	0.573
Omnibus tests of model coefficients	Chi-square	df	Sig.
	38.345	11	0.000

4.3.6 Organic Waste Management Framework

Understanding the root causes of problems and deficiencies as well as modern techniques in SWM can contribute to develop efficient new system. The review of the literature assisted in identifying the main reasons behind the failure of SWM globally and the results of this study identified that at the national level. The aim of this section is to develop complete organic waste management framework following the system approach.

It has been identified that SWM system can be affected by many factors which can be grouped into technical and technological, socio-economic, institutional and environmental factors. Developing an organic waste management system shall be in line with of sustainability pillars: environmental protection, social acceptance, and economic viability. The waste management options hierarchy are reduce, reuse, recycle, recover and landfilling is the least preferable option as shown in Figure 4-21 will be used in developing organic waste management framework in southern West Bank of Palestine.

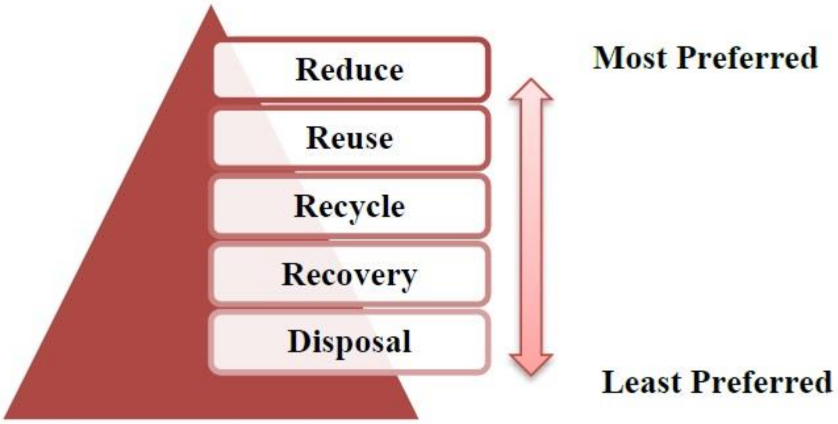


Fig. 4-21: Waste Management Hierarchy

Waste reduction at the source is very important and the most preferred because it reduces the waste collection, handling, transfer, treatment and final disposal. In addition, it reduces the environmental impacts as a result of leachate, greenhouse gas emissions and odors. In order to achieve this option, community awareness and promotion is essential to increase understanding and solidify knowledge about environmental and economic benefits achieved by following this principle. A research study in the United Kingdom (UK) pointed out that every dollar spent for the prevention of food waste and reduction as well achieve average returns of USD 14 for businesses in the form of financial benefit as reported by Champions 12.3 (Champions 12.3, 2017).

Waste reuse is the second preferred option because it also reduces the financial and environmental costs. Reuse will reduce the waste generation and the collection cost as well, transportation and final disposal. In addition, environmental impacts and nuisance will be reducing as well.

Recycling of waste is the third preferred option, where the waste is considered as a resource which can be processed to produce another beneficial material which can achieve environmental and economic benefit. Organic waste can be composted and transferred into organic fertilizers and used in organic farming and agricultural activities. It is considered as soil amendment and can enhance the productivity, reduce plant diseases and an alternative to synthetic fertilizers. Composting is considered a recovery process for organic material according to Central Public Health and Environmental Engineering Organization- CPHEEO (CPHEEO, 2016). This option can be applied at the source (at the household level) and this case can reduce SW collection cost, handling, treatment and disposal. However, it can be conducted at the central level and, in addition to the environmental benefit; it can reduce the cost of waste disposal. Considering the situation in the study area, household composting is not viable because the large number of population is living in urban areas of high density, and the required space for home composting is unavailable. In addition, the previous initiatives and trials for conducting compost on the household level were not enough succeed to build on. Therefore, central composting is the preferred option for organic waste management.

The fourth option in waste management is recovery through waste to energy option. This option is followed where the waste recycling is not possible. It requires high technology and investment cost, therefore, it is the fourth option but preferred over waste disposal. This option is not recommended for waste stream of high organic fraction such that in the study area.

Based on the above-mentioned and in order to develop sound framework for organic waste management, support from the legislation and policies, cooperation between stakeholders, community involvement and awareness, institutional development, and introduction of technology are required to ensure comprehensive framework for organic waste management. The following are representing the main components of comprehensive and integrated organic waste management.

Institutional arraignments, development and capacity building: institutional development requires support from the legislative framework and policies. Current legislations and policies in Palestine are focusing on waste collection transfer and safe disposal. The provision of waste sorting and composting is still in general form without any mandatory targets. Therefore, upgrading the legislative framework is perquisite to establish any waste framework, because this will force the community as well as the local authority to adhere to the law. In addition, any introduced waste management system requires capacity building of the human resources to ensure effectiveness in waste collection, sorting, composting, use of machinery, and records keeping. Composting of organic waste requires knowledge in biological process, how the compost process is developed with time and the necessary steps required from the operators to keep on process progressing well.

In addition, cooperation of the stakeholders and responsible organizations is essential to regulate and add more control to the waste management framework. In organic waste management, the stakeholders are presented in Table 4-14.

Table 4-14: Stakeholders in SWM in Palestine

Stakeholder	**Responsibility**
Local authorities	These are the key stakeholders as it is responsible for waste collection, transfer, sorting, recycling and composting, and disposal. Their role is organic waste management is force sorting at the source, construction and operation of sorting and composting plants, and community promotion and awareness regarding organic waste management to encourage community participation.
MoLG	Regulator of the local government sector. It sets the rules, regulations and policies. It can issue the instructions and define the targets in organic waste management.
MoH	Monitoring the health situations of the SWM facilities to ensure safeguard of the public health, occupational health and safety of the workers, and issuing the required approvals for licensing SWM facilities.
MoA	Monitoring the quality of the compost to be used for agricultural purposes. It can regulate the market of compost and encourage the use of the compost produced from organic waste in agricultural activities. It can promote organic farming.
EQA	EQA is the responsible for issuing the environmental approval for the composting plants. Its role is conducting screening of the project and decides if the project is subjected to ESIA, IEE or doesn’t need any further environmental study. In case the project is a subject for ESIA, it issues the terms of reference for the study. Also, it reviews ESIA report to assure the report complies with the terms of reference. Furthermore, it conducts inspection and monitoring visits to the project site during the operation phase to assure the environmental law and policy is respected.
PSI	Issuing the technical specifications of the compost, monitoring the quality, and issuing the obligatory technical standards.
NGOs working in the agricultural	As these organizations are working directly with the farmers, they can encourage the use of compost in agriculture, and can

sector and farmers cooperatives	assist in removing barriers toward using compost produced from organic municipal waste in agriculture.
Farmers	Farmers are the key users of the compost product. Their role is very important because it promotes the marketing the produced compost and consumes it in the agricultural activities.
The community	Community is the waste producers and their role can contribute to the first option of the SWM hierarchy “Reduce”. In addition, they can contribute to organic waste management and compost quality through separation at the source. Moreover, accepting the construction of SWM facilities near the community is very important as the many communities resist the construction of such facilities near them. A study conducted in part of the study area (Hebron district) to assess the community concerns and attitudes toward the construction of SWM facilities showed significant concerns about water pollution (Al-Khatib et al., 2014). Therefore, community involvement, participation, and awareness is essential and can contribute to overcome many problems and successful of integrated SWM system.
The private sector	The private sector can provide investment in organic waste management through construction and operation of composting plants in partnership with the local authorities. The private sector can operate waste management facilities more efficiently.

Social aspects: organic waste management requires community involvement and participation because innovation and engineering solutions are not enough. People are the waste producers; therefore, socio-economic and cultural issues are of great importance to tackle in waste management sector. Acceptance of the introduced system for organic management by the community, affordability and willingness to pay for the service are essential issues to be considered. Zurburgg et al. (2014) highlighted that social endorsement of any proposed project by the residents is a cornerstone in project planning and this requires community interest and participation to ensure successful implementation of the project. However, job creation is a social aspect and beneficial to the community could be one of the tools to ensure community participation and acceptance. In the study area, the composting plant is suggested to be constructed at the landfill site to be away from the local residence. Organic waste sorting shall be conducted at the source in order to produce high quality compost, which in turn can be accepted by farmers and other regulating authorities.

Economic feasibility: the selected option for organic waste management shall be in line with the capacity of the managing authority which in turn affects the community as it is directly connect to the tariff system. For sustainability, the system should be cost effective (Zurbrügg et al., 2014, Cellini and Kee, 2010; Ravi and Vishnudas; 2017). Affordability of the system to all of the society slides can, to a large extent, contribute to sustainability. For the study area, pile composting and windrow composting are the best feasible option for organic waste treatment from economical point of view.

Technical aspect: the selected technology for organic waste management shall take into account the local conditions. Assessment of the technology shall include investment and operation costs, level of complexity and availability of local maintenance, availability of space, skills needed, and environmental compliance. Technology evaluation shall be based on integration (within ecosystems); investment cost per unit product; simplicity; adaptability, and the required resource inputs (Baetz and Korol, 1995).

Environmental aspect: one of the main purposes of developing organic waste management is environment protection and safeguard the public health. The system framework shall assure compliance with the environmental rules regarding emissions and released pollutants and safeguard policies. For environmental sustainability, health risk assessment is required to investigate potential threats to humans (Yang et al., 2012).

The suggested organic waste management framework using following approach concept is illustrated in Figure 4-22.

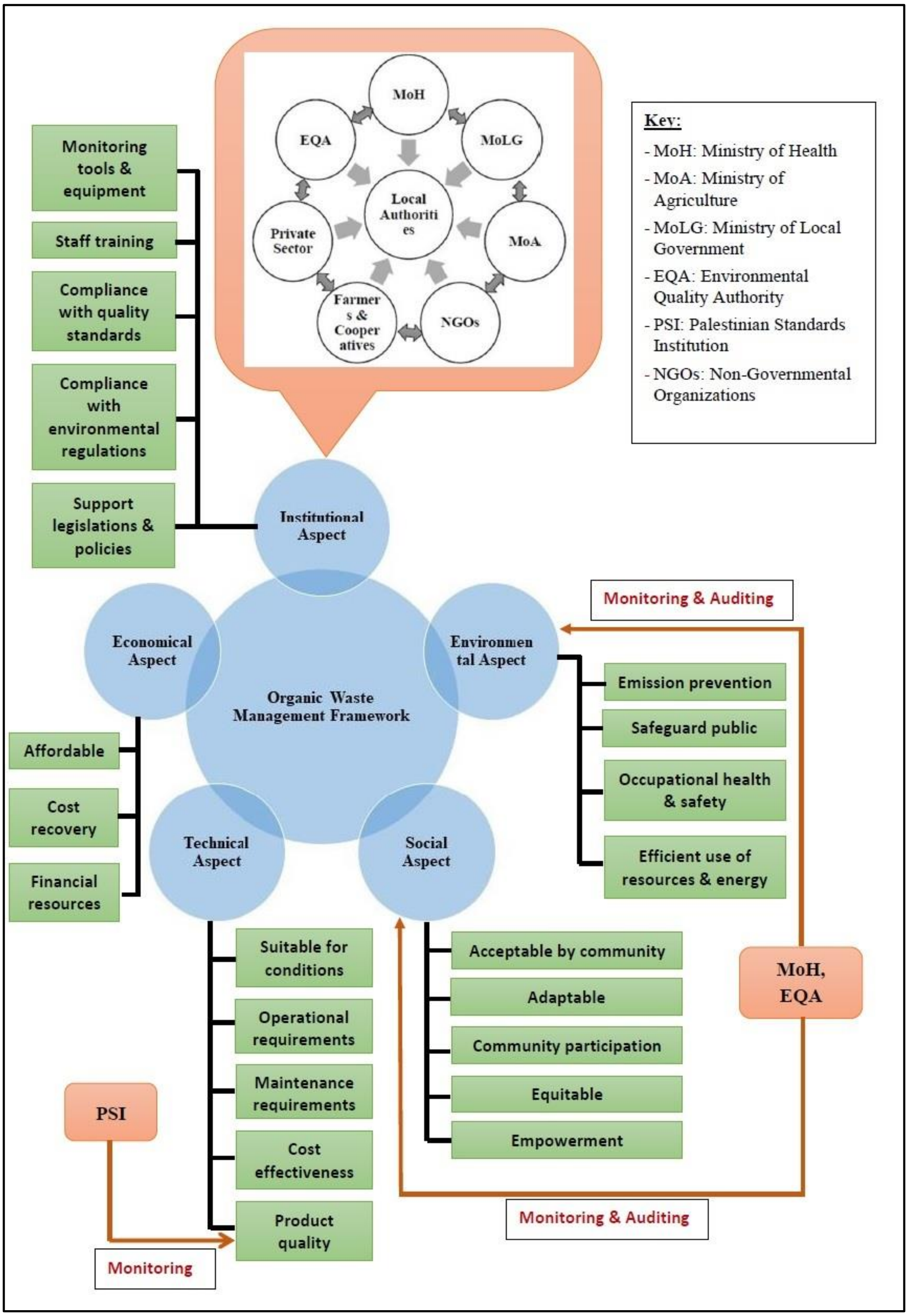


Fig. 4-22: Organic waste management framework

CHAPTER 5

CONCLUSION AND FUTURE SCOPE

5.1 Conclusion

This research focused on management of organic municipal solid waste taking into consideration three main components. These include development of composting systems that can accelerate and optimize the composting process to cope with the increasing solid waste generation in Palestine and India, study of the contribution of the compost in the circular economy in Palestine, mainly Hebron and Bethlehem governorates, and study the socio-economic factors of influence on the attitudes of the LAs (key-stakeholders in SW management in Palestine) towards organic solid waste composting in Hebron and Bethlehem governorates/Palestine. These three main components can guide policy-makers to appropriately set SWM policy or upgrade the current SWM policies.

Technological development is essential in organic waste management to cope with the growing SW stream and to achieve sustainable solutions. The development of proper composting system focused on two static composting systems to find appropriate system for Palestine and India which faces problems in SWM, political and technical, respectively. However, the development of an appropriate composting system for each country that can accelerate and optimize the process can, to the large extent, contribute to solve solid waste-related problems through accelerating processing of organic SW in environmental friendly way. The climate conditions in both countries, India and Palestine, were taken in account for optimization of the composting process and select the appropriate system for each country. Accordingly, a new forced-aeration system was designed and tested in Palestine, and natural aeration system was selected and tested in India (DTU Campus/ Delhi). The process was monitored during the composting process through measurement and controlling the operational parameters. The end-quality parameters were tested for produced compost after maturation. Both systems showed high efficiency in reducing the time of composting (39-43 days in Palestine, and 31 days in India) compared to conventional windrow composting system. In addition, both provided high efficiency in reduction of SW volume (57.2-64%). Although the compost produced showed high fertility and clean indices, there was small deviations from the standard specifications' thresholds.

The product end-quality monitoring showed that most of the parameters met the standard specifications (PSI and FCO), except few of them were exceeded the max permissible limits or didn't reach the min limits, but in line with that reported in the literature. These deviations can be overcome through co-composting of municipal organic SW and agricultural waste and adjusting the initial mixture as the type of the feedstock plays a crucial role in the compost end-quality. The biological parameters didn't comply the FCO, but met the PSI. The detection of pathogens was attributed to the nature of the static composting and susceptibility of the external edges to the weather temperature which prevent heating to reach the required temperature to ensure elimination of pathogenic microbes. Although pathogens were detected in several composting trials worldwide, the proposed systems can be developed by adding the option of turning through rotation to bring the edges inside, which can ensure the destroy of pathogens. The overall conclusion of this experiment was that forced-aeration system is suitable for Palestine, while the natural aeration system is more suitable for Indian conditions.

Urban mining of municipal compost plays a great role in the circular economy. Municipal SW in Palestine has potential for recycling of the organic fraction and returns it to the material cycle as a resource for production as part of the circular economy. Composting of this waste fraction can return it to the material cycle through using the produced compost for several purposes. This research focused on the compost benefits from two uses: the environmental and economic benefits of compost use for agricultural purposes and as cover materials in the landfill in Palestine (Hebron and Bethlehem governorates) through the period extended from 2021 to 2035. For agricultural purposes, the nutrient exist in the compost can replace that exist in the chemical fertilizers such as AS, TSP, SOP and humic acid such as “Iperen Humic 12+3 liquid” the source of C. In addition, the organics diverted from waste stream can reduce the methane emissions and achieve financial saving in accordance with the CDM. Also, the tipping fees for waste disposal at the landfill can be saved. Moreover, it can achieve saving in the landfill space and reduce the cost required to expand the landfill or construct new landfill. The estimated net revenue for this use of compost is USD 194.8 million in 2021 and USD 369.8 million in 2035 which support the national economy and is type of the circular economy. However, using the compost as landfill cover can achieve financial saving through reduction in the use the soil as cover materials, which is estimated annually at USD 0.876 million and USD 13.14 million throughout the study period. The results of this study can pave the way toward the implementation of the circular economy in SWM in Palestine.

Given the restrictions on land for landfill construction and expansion, and restricted access to chemical fertilizers by the Israeli occupation in Palestine, composting of organic municipal waste can contribute to solve the current technical and financial problems of waste management and agricultural sector. For waste management, it can reduce the demand on landfill space required for waste landfilling, thus, reducing the demand on construction of new landfills or extension of the existing ones. For the agricultural sector, farmers will have access to compost to replace the low quality chemical fertilizers currently in use. In addition, it can reduce the demand on water for agriculture as compost can improve the properties of the agricultural soil and water holding capacity and increase moisture retention time in the soil as well, knowing that water shortage is one of the severe problems being faced in the agricultural sector in Palestine due to the severe restrictions imposed by the Israeli occupation on water resources. Therefore, compost can contribute to solve the problems related to fertilizers and water thereby supporting the food security in the country which depends largely on external funding and suffers from political instability due to the Israeli-Palestinian conflict. However, agencies responsible for SWM can use the revenues as subsidies to cover part of the cost associated with SWM which in turn can improve the service. The environmental benefits are invaluable which are beneficial to the human, the climate, the soil, air quality and health, the water, and the society as well. It can support the sustainability pillars as well as contribute to achieve the sustainability development goals in Palestine at large.

Socio-economic factors can, to a large extent, affect the SWM. Attitude of LAs towards MSW composting is of great importance and can assist in the design of proper composting program. The research also focused on the factors that than affect the LAs attitude towards composting of organic municipal SW. Several factors from the literature were considered and assessed using bivariate analysis and LRM. The bivariate analysis, which assess the influence of each single factor alone, concluded that nine factors were significantly affected the attitude of the LAs towards composting. These include financial capacity of the LA, availability of proper machinery to conduct composting, availability of enough number of waste collection vehicles to enable collection of solid waste fractions separately, availability of place wide enough such as piece of land to accommodate composting activities, knowledge of composting systems, previous experience of the staff in compost production, ability to the LA to accept the available rapid composting system, training of staff on composting, and perception of the LA that composting of municipal SW is within its responsibility. The LRM, which assess the influence of the factors together in one model, concluded that the LAs' attitude towards organic MSW composting was significantly affected by the five factors including LAs' perception of compost contribution to SW reduction, availability of proper place to be used for composting activities, familiarity with SWM bylaw, conducting community awareness, and financial capacity of the LAs.

5.2 Environmental and Socio-Economic Significance

The study has significant environmental, economic and social effects on the sustainability. This significant effect can be summarized as follows:

5.2.1 Environmental Significance

The study provided solution to the municipal organic SWM, which achieve the following benefits:

- Waste: awareness of the communities on waste management principles will reduce SW generation and organic waste composting will reduce waste accumulation;
- Air quality: GHG emissions will be reduced thus contributing to climate change mitigation. In addition, it reduces the emissions of offensive odors usually released by organic waste dumping or landfilling;
- Biodiversity: compost produced from organic SW will improve the soil biodiversity. In addition, replacing chemical fertilizers by compost will reduce the use of pesticides and thus contribute to the protection of biodiversity;
- Water resources protection: waste processing through composting will reduce the possibility of leachate leakage to reach surface and groundwater thus reducing contamination and contributing to water resources protection. Further, use of compost in agriculture increases the soil moisture retention, and reduces demand on water for irrigation;
- Soil erosion: compost produced from municipal organic waste can improve the soil properties and reduce the possibility of water erosion;
- Natural resources: using compost as landfill cover reduces the use of soil as landfill cover which contribute to the protection of natural resources;
- Power consumption: use of compost for agricultural purposes reduces dependence on chemical fertilizers, which will reduce the power consumption during the manufacturing process of these synthetic fertilizers which is considered climate change mitigation;
- Bioremediation: compost can bio-remediate and cleans up the contaminated soil thus eliminate the environmental pollution;

5.2.2 Economic Significance

The economic benefits of the study are summarized as follows:

- Circular economy: composting is a method of organic refuse recycling and returning back the waste material into the material cycle, enhances the circular economy, and reduces the linear economy;
- Enhance national production and reduce dependence on imported items, which increases the productivity of the community;
- Increase revenues: replacement of chemical fertilizers reduces expenditures on imported goods and increases revenues;

- Sustainable agriculture: compost can increase minerals in the agricultural soil and ensure continuous improving the agricultural productivity. Also it reduces soil-borne plant diseases and reduces demand and expenditure on pesticides thus reducing the cost of agricultural production;
- Employment generation: waste recycling creates job opportunities, reduce unemployment rate, and improve the financial situation for the individuals and the community as well;
- Reduces the cost of trash disposal through reducing the cost of landfill daily cover when using compost as landfill cover instead of soil;

5.2.3 Social Significance

- Health: composting of organic waste improves the quality of life of individuals and communities. It prevents waste accumulation (waste accumulation is attractive to wild animals and diseases transmitters), which reduces diseases transmission and improves social welfare of the community;
- Food security: use of compost in agriculture can improve the properties and quality of the agricultural soil and, accordingly, improve the plants' quality and agricultural products as well thus supporting the food security;
- Community resilience: increase the adaptation capacity of the community and farmers to resist climate change effects. Compost increases the moisture retention time in the soil and reduces the demand on irrigation water, which is an adaptation measure to climate change;
- Reduced nuisance related to offensive odors released from organic waste biodegradation. The fast processing of organic waste through composting will reduce waste accumulation and thus reduces potential spread of mosquitos, flies and rodents;
- Education: awareness regarding SW management options and composting as a proper waste management option among others increases the knowledge and understanding of the waste impacts and increases the community participation in waste management such as reduce waste generation and separation at the source to facilitate composting of organic waste.

5.3 Future Scope

Based on the research findings, the following are recommended:

1- Support to the LAs from the government is necessary to overcome the challenges faced by LAs in Palestine and inhibit their capacity to compost organic SW fraction. This is a corner stone towards upgrading or setting a new SWM policy and implementing any composting program;

2- It is highly recommended that, prior to force any policy or initiate for MSW composting program, the LAs shall be provided institutional capacity building, financial, and technical requirements in order to support the sustainability of the program. Awareness of the SWM bylaw, staff training on compost production and community awareness are all essential perquisites for social and institutional capacity building activities. LAs also shall be equipped with the proper machinery and RCVs to enable composting of MSW. SWM bylaw shall be upgraded to include targets in order to ensure LAs adherence through composting of the organic waste to meet the specified targets. This shall be associated with monitoring program by the regulating Ministry to ensure compliance. Finally, financial support is mandatory through direct contribution or through attracting investors in the organic MSW composting;

3- Upgrading SWM policies in Palestine is necessary to force composting as a popular organic SWM option because this will solve waste management problems, agricultural problems related to fertilizers, and assist the government to achieve carbon reduction targets in accordance with the nationally determined contributions (NDCs). Moreover, it can contribute to achieve SDGs at the regional and international levels;

4- Compost can replace chemical fertilizers and contribute to overcome the huge challenges and constraints that are currently facing agricultural in Palestine. However, additional studies are recommended on replacement of chemical fertilizers by compost to be in accordance with plan in order to avoid sudden drop in agricultural productivity. This should take into account the crop type, current agricultural productivity, and gradual replacement of chemical fertilizers by compost taking into account the current situations concerning the restrictions on import of chemical fertilizers in Palestine;

5- As the new static composting system developed and tested within the framework of this research can’t completely eliminate pathogens, it is recommended to provide the system with overturning mechanism which can bring outer sides of the compost mixture into insides where the temperature is higher and enough to kill all pathogens;

6- Natural-aerated composting system is highly recommended for India based on the results obtained due to the weather conditions because this can solve the problems of organic waste at lower prices compared to other power consuming systems;

7- Forced-aerated composting systems is recommended for Palestine due to the weather conditions and other related issues such as restrictions on land use and availability of places for composting. Natural-aerated systems require large area due to relatively long time of composting process because of the weather conditions, while forced-aerated system can shorten the duration of the composting and reduction in the area required as well.

REFERENCES

ADB (Asian Development Bank), (2011). Toward sustainable municipal organic waste management in South Asia: A guidebook for policy makers and practitioners. Mandaluyong City, Philippines. ISBN 978-92-9092-412-8.

Ahn, H.K., Richard, TL., Choi, H., L. (2007). Mass and thermal balance during composting of a poultry manure—Wood shavings mixture at different aeration rates. *Process Biochemistry*, 42, 215–223.

Aini M.S, Razi A.F, Lau S.M, Hashim, A.H. (2002). Practices, attitudes and motives for domestic waste recycling. *International Journal of Sustainable Development and World Ecology*, 9(3), 232.

Aisen, A., Veiga, F.J. (2011). How Does Political Instability Affect Economic Growth? IMF Working Paper, International Monetary Fund.

Olanipekun, O.O., Olanipekun, O.S., Idowu G.A., Aiyesanmi, A.F. (2024). Impacts of solid waste management site on some toxic elements contamination of the surrounding soil in Akure, Nigeria. *Science of The Total Environment*, 928, 172450. https://doi.org/10.1016/j.scitotenv.2024.172450.

Alao, J.O., Ayejoto, D.A., Fahad, A., Mohammed, M.A.A., Saqr, A.M., Joy, A.O. (2024). Environmental Burden of Waste Generation and Management in Nigeria. In: Souabi, S., Anouzla, A. (eds) Technical Landfills and Waste Management. Springer Water. Springer, Cham. https://doi.org/10.1007/978-3-031-55665-4_2.

Albanna, M., Fernandes, L., Mostafa, W. (2007). Methane oxidation in landfill cover soil; the combined effects of moisture content, nutrient addition, and cover thickness. *Journal of Environmental Engineering and Science*, 6 (2), 191-201.

Ali, A.M., Nawaz, A.M., Al-Turaif, H.A., Shahzad, K. (2020). The economic and environmental analysis of energy production from slaughterhouse waste in Saudi Arabia. *Environment, Development and Sustainability*, 1–18. (https://doi.org/10.1007/s10668-020-00770-6.

Ali H., Ali, N., Ahmad A.R., Ibrahim, M., Ahmad, S., Yaacob, S. (2012). Solid Waste management and the willingness to pay for improved services towards achieving sustainable living. *Advances in Natural and Applied Sciences*, 6(1), 52-60, 2012.

Alimoradiyan, H., Hajinezhad, A., Hossein Yousefi, H., Giampietro, M. (2024). Fostering Community Participation in Sustainable Municipal Solid Waste

Management at Multiple Scales in Tehran, Iran. Results in Engineering, 102174. https://doi.org/10.1016/j.rineng.2024.102174.

Alkoaik, F.N. (2019). Integrating aeration and rotation processes to accelerate composting of agricultural residues. *Plos One*, 14(7), e0220343. https://doi.org/10.1371/journal.pone.0220343.

Alkoaik, F.N., Abdel-Ghany, A.M., Rashwan, M.A., Fulleros, R.B., Ibrahim, M.N. (2018). Energy Analysis of a Rotary Drum Bioreactor for Composting Tomato Plant Residues. *Energies*, 11, 449; doi:10.3390/en11020449.

Al-Khatib, I.A., Arafat, H.A., Basheer, T., Shawahneh, H., Salahat, A., Eid, J., Ali, W. (2007). Trends and problems of solid waste management in developing countries: A case study in seven Palestinian districts. *Waste Management*, 27, 1910–1919.

Al-Khatib, I.A., Monou, M., Abu Zahra, A.F., Shaheen, H.Q., Kassinos, D. (2010). Solid waste characterization, quantification and management practices in developing countries. A case study: Nablus district – Palestine. *Journal of Environmental Management*, 91(5), 1131-1138.

Al-Khatib, I.A., Ajlouny, H., Al-Sari', M.I. (2014). Residents' concerns and attitudes toward solid waste management facilities in Palestine: A case study of Hebron district. *Waste Management and Research*, 32(3), 228–236.

Al-Khateeb, A.J. (2009). Municipal Solid Waste Management in Jericho and Ramallah Cities in the West Bank, Palestine. Master thesis, Birzeit University.

Al-Khateeb, A.J., Al-Sari, M.I., Al-Khatib, I.A., Anayah, F. (2017). Factors affecting the sustainability of solid waste management system – the case of Palestine". *Environmental Monitoring and Assessment*, 189(2), 93.

Al-Khatib, I.A., Al-Sari', M.I., Kontogianni, S. (2020). Scavengers' contribution in solid waste management sector in Gaza Strip, Palestine. *Environmental Monitoring and Assessment*, 192:354.

Allievi, L., Marchesini, A., Salardi, C., Piano, V., Ferrari, A. (1993). Plant quality and soil residual fertility six years after a compost treatment. *Bioresource Technology*, 43 (1), 85–89. https://doi.org/10.1016/0960-8524(93)90088-S.

Al-Madbouh, S., Al-Khatib, I.A., Salahat, J.I., Jararaa, B.Y.A., Ribbe, L. (2019). Socioeconomic, agricultural, and individual factors influencing farmers' perceptions and willingness of compost production and use: an evidence from Wadi al-Far'a Watershed-Palestine. *Environmental Monitoring and Assessment*, 191:209.

ALPC (Al-Menya Landfill Private Company) (2016). Landfill survey report, survey no. 6. Bethlehem, Palestine.

Al-Rimmawi, H., Butcher, S. (2015). Trends of tourism in Bethlehem, Palestine: 1994-2015. TOURISM, 63 (3), 317 – 335

Al-Sari', M.I. (2019). Pile composting efficiency in organic waste management. The second international conference on civil engineering (ICCE), November 25th and 26th, 2019. Bethlehem, West Bank – Palestine.

Al-Sari', M.I., Sarhan, M.A.A., Al-Khatib, I.A. (2018). Assessment of compost quality and usage for agricultural use: a case study of Hebron, Palestine. *Environmental Monitoring and Assessment*, 190: 223.doi: 10.1007/s10661-018-6610-x.

Al-Sari', M.I., Al-Khatib, I., Avraamides, M., Fatta-Kassinos, D. (2012). A study on the attitudes and behavioural influence of construction waste management in occupied Palestinian territory. *Waste Management and Research*, 30(2), 122 - 136.

Álvarez-Alonso, C., Pérez-Murcia, M.D., Sánchez-Méndez, S., Martínez-Sabater, E., Irigoyen, I., López, M., Nogués, I., Paredes, C., Orden, L., García-Rández, A., Bustamante, M.A. (2024). Municipal Solid Waste Management in a Decentralized Composting Scenario: Assessment of the Process Reproducibility and Quality of the Obtained Composts. *Agronomy*, 14, 54. https://doi.org/10.3390/agronomy14010054.

Amlinger, F., Pollack, M., Favoino, E. (2004). Heavy metals and organic compounds from wastes used as organic fertilizers. Directorate-General for the Environment of the European Commission. http://ec.europa.eu/environment/waste/compost/pdf/hm_finalreport.pdf (17.07.13).

An C-J, Huang, G-H, Yao, Y., Sun, W., An, K. (2012). Performance of in-vessel composting of food waste in the presence of coal ash and uric acid. *Journal of Hazardous Materials*, 203–204,38–45.

Antonenko, D.A., Nikiforenko, Y.Y., Melnik, O.A., Yurin, D.A., Danilova, A.A. (2022). Organomineral compost and its effects for the content of heavy metals in the top layer leached chernozem. IOP Conference Series: *Earth and Environmental Science*, 1010 012028, doi:10.1088/1755-1315/1010/1/012028.

ARIJ (Applied Research Institute – Jerusalem), (2005). Analysis of Waste Management Policies in Palestine: Domestic Solid Waste and Wastewater. Palestine.

ARIJ (Applied Research Institute – Jerusalem), (2009a). Locality profile and needs assessment in the Hebron governorate.

ARIJ (Applied Research Institute – Jerusalem), (2009b). The geopolitical status in Bethlehem governorate.

ARIJ (Applied Research Institute – Jerusalem), (2010). Bethlehem city profile.

Arora, R., Paterok, K., Banerjee, A., Saluja, M.S. (2017). Potential and relevance of urban mining in the context of sustainable cities. IIMB Management Review, 29, 210–224. https://doi.org/10.1016/j.iimb.2017.06.001.

Aryal, M., Adhikary, S. (2024). Solid waste management practices and challenges in Besisahar municipality, Nepal. *PLoS ONE*, 19(3): e0292758. https://doi.org/10.1371/journal.pone.0292758.

Arslan, E., Ünlü, A., Topal, M. (2011). Determination of the Effect of Aeration Rate on Composting of Vegetable–Fruit Wastes. *CLEAN Soil Air Water*, 39(11): 1014-1021. https://doi.org/10.1002/clen.201000537.

Atallah, N., (2020). Palestine: Solid waste management under occupation. https://ps.boell.org/en/2020/10/07/palestine-solid-waste-management-under-occupation. Accessed 28/9/2021.

Atienza, V. (2011). Review of the Waste Management system in the Philippines: Initiatives to promote waste segregation and recycling through good governance K. a. In: Economic Integration and Recycling in Asia: An Interim Report. Institute if Developing Economics, Chosakenkyu Hokokusho, pp. 65–97.

Augustin, C., Rahman, S. (2022). Composting animal manure: A guide to the process and management of animal manure compost. North Dakota State University, Fargo, North Dakota.

Ayilara, M.S., Olanrewaju, O.S., Babalola, O.O., Odeyemi, O. (2020). Waste Management through Composting: Challenges and Potentials, Review. *Sustainability*, 12, 4456; doi:10.3390/su12114456.

Azim, K., Komenane, S., Soudi, B. (2017). Agro-environmental assessment of composting plants in southern western of Morocco (Souss-Massa region).

International Journal of Recycling of Organic Waste in Agriculture, 6, 107–115.

Azis, F.A., Choo, M., Suhaimi, H., Abas, P.E. (2023). The Effect of Initial Carbon to Nitrogen Ratio on Kitchen Waste Composting Maturity. *Sustainability*, 15(7), 6191, https://doi.org/10.3390/su15076191.

Ba, S., Qu, Q., Zhang, K., Groot, J.C.J. (2020). Meta-analysis of greenhouse gas and ammonia emissions from dairy manure com-posting. *Biosystems Engineering*, 193, 126–137.

Baccini, P., Brunner, P. (2012). Metabolism of the Antroposphere: Analysis, Evaluation, Design, second edition. Cambridge, MA: The MIT Press, ISBN 9780262016650. https://doi.org/10.7551/mitpress/8720.001.0001.

Baetz, B. W., Korol, R. M. (1995). Evaluating technical alternatives on basis of sustainability. *Journal of Professional Issues in Engineering Education and Practice*, 121, 102-107.

Bandara, N. (2008). Municipal Solid Waste Management – The Sri Lankan Case. Conference on Development in Forestry and Environment in Sri Lanka. The University of Sri Jayewardenepura.

Barlaz, M.A., Green, R.B., Chanton, J.P., Goldsmith, C.D., Hater, G.R. (2004). Evaluation of a Biologically Active Cover for Mitigation of Landfill Gas Emissions. *Environmental Science and Technology*, 38(18), 4891-4899. https://doi.org/10.1021/es049605b.

Baron, V., Supriatna, J., Marechal, C., Sadasiban, R., Bonneau, X. (2019). Waste reduction and nutrient recovery during the co-composting of empty fruit bunches and palm oil mill effluent. *Menara Perkebunan*, 87(2), 77-86. DOI: http://dx.doi.org/10.22302/iribb.jur.mp.v87i2.338.

Bazrafshan, E., Zarei, A., Mostafapour, F.K., Poormollae, N., Mahmoodi, S., Zazouli, M.A. (2016). Maturity and Stability Evaluation of Composted Municipal Solid Wastes. *Health Scope*, 5(1), e33202, doi: 10.17795/jhealthscope-33202.

Begum, R.A., Siwar, C., Pereira, J.J., Jaafar, A. (2006). A Logistic regression analysis of the contractor's awareness regarding waste management. *Journal of Applied Sciences*, 6(9), 1904-1908.

Begum, R.A., Siwar, C., Pereira, J.J., Jaafar, A. (2009). Attitudes and behavioural factors in waste management in the construction industry of Malaysia. *Resources, Conservation and Recycling*, 53, 321-328.

Bekchanov, M., Mirzabaev, A. (2018). Circular economy of composting in Sri Lanka: Opportunities and challenges for reducing waste related pollution and improving soil health. *Journal of Cleaner Production*, 202 (20), 1107-1119.

Bentil, J., Braimah, S. & Obeng, A.F. (2024). Solid Waste Management in Higher Educational Institution: An Investigation Using the SWOT Analysis and the Circular Economy Principle Perspective. *Circular Economy and Sustainability*. https://doi.org/10.1007/s43615-024-00349-7.

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

Bewick, V., Cheek, L., Ball, J. (2005). Statistics review 14: logistic regression. *Crit Care*, 9(1), 112–118.

Bhave, P.P., Joshi, Y.S. (2017). Accelerated in-vessel composting for household waste. *Journal of the Institution of Engineers (India)*, 98, 367-376.

Bio-cycle, https://www.biocycle.net/county-yard-trimmings-facility-achieves-ems-certification/. Accessed on 13/10/2021.

Bobeck, M. (2010). Organic Household Waste in Developing Countries: An overview of environmental and health consequences, and appropriate decentralized technologies and strategies for sustainable management. Department of engineering and sustainable development, Mid Sweden University.

Boeckx, P., Cleemput, O.V. (1996). Methane oxidation in a neutral landfill cover soil: influence of moisture content, temperature and nitrogen-turnover. *Journal of Environmental Quality*, 25, 178–183. https://doi.org/10.2134/jeq1996.00472425002500010023x.

Boeckx, P., Cleemput, O.V., Villaralvo, I. (1996). Methane emission from a landfill and the methane oxidising capacity of its covering soil. *Soil Biology and Biochemistry*, 28 (10–11), 1397–1405.

Bogner, J., Ahmed, M.A., Diaz, C., Faaij, A., Gao, Q., Hashimoto, S., Mareckova, K., Pipatti, R., Zhang, T. (2007). Waste Management, In Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Bogner, J., Matthews, E. (2003). Global methane emissions from landfills: New methodology and annual estimates 1980-1996. *Global Biogeochemical Cycles,* 17, 34-1 to 34-18.

Bogner, J., Sweeney, R., Coleman, D., Huitric, R., Ririe, G., T. (1996). Using isotopic and molecular data to model landfill gas processes, *Waste Management and Research*, 14, 367–376.

Bonoli, A., Zanni, S., Awere, E. (2019). Organic waste composting and sustainability in low-income communities in Palestine: lessons from a pilot project in the village of Al Jalameh, Jenin. *International Journal of Recycling of Organic Waste in Agriculture*, 8,253–262.

Bożym, M. (2017). Heavy metal content in compost and earthworms from home composters. *Environmental Protection and Natural Resources*, 28, 4(74): 1-4. DOI 10.1515 /oszn-2017-0022.

Breitenbeck, G.A., Schellinger, D. (2013). Calculating the Reduction in Material Mass and Volume during Composting. *Compost Science & Utilization*, 12:4, 365-371, http://dx.doi.org/10.1080/1065657X.2004.10702206.

Butterfield, D., Isaac, J., Kubursi, A., Spencer, S. (2000). Impacts of Water and Export Market Restrictions on Palestinian Agriculture.

Cecere, G., Corrocher, N. (2016). Stringency of regulation and innovation in waste management: An empirical analysis on EU countries. *Industry and Innovation*, 23: 625–646.

Cekmecelioglu, D., Demirci, A., Graves, R.E, Davitt, N.H. (2005). Applicability of optimized in-vessel food waste composting for windrow systems. *Biosystems Engineering*, 91,479–486.

Cercasov, V., Wulfmeyer, V. (2008). Trends in airborne particulates in Stuttgart, Germany: 1972–2005. *Environmental Pollution*, 152, 304–313.

Clemens, J., Cuhls, C. (2003). Greenhouse gas emissions from mechanical and biological waste treatment of municipal waste. *Environmental Technology,* 24,745–754

CESVI (2019). Solid waste management in the Palestinian territory, West Bank including East Jerusalem & Gaza Strip. Overview report.

Cellini, S., R., Kee, J. E. (2010). Cost-Effectiveness and Cost-Benefit Analysis. In J. S. Wholey, H. P. Hatry, & K. E. Newcomer (eds.), San Francisco Hand book of practical program evaluation (3rd Ed.), 493-530.

Chachami-Chalioti, SE., Emmanouil, C., Latinopoulos, D., Kungolos, A. (2024). Circular Economy Aspects of the New National Solid Waste Management Plan and Citizens' Engagement in Northern Greece. *Circular Economy and Sustainability*. https://doi.org/10.1007/s43615-024-00374-6.

Champions 12.3 (2017). The business case for reducing food loss and waste. https://champs123blog.files.wordpress.com/2017/03/report_-business-case-for-reducing-food-loss-and-waste.pdf. Accessed on 29/10/2021.

Chetri, J.K., Rai, R.K., Reddy, K.R. (2019). Effect of temperature on CO_2 sequestration by BOF slag in landfill cover. International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE). *American Conference on Soil Mechanics and Geotechnical Engineering (XVI PCSMGE)*, 2502-2509. http://doi:10.3233/STAL190320.

Chiarelotto, M., de Melo, D.C., dos Santos, M.V.A. (2023). Does the initial C/N ratio interfere with the performance of sewage sludge composting and cotton waste? *Environmental Technology*, https://doi.org/10.1080/09593330.2023.2180672.

Choi, N. (2021). Analyzing local government capacity and performance: *Implications for sustainable development. Sustainability*, 13: 3862. https://doi.org/10.3390/su13073862.

Coelho, L., Osório, J., Beltrão, J., Reis, M. (2019). Organic compost effects on Stevia rebaudiana weed control and on soil properties in the Mediterranean region. *Rev. Ciênc. Agrár.*, 42, 109–121.

Coker, C., Gibson, T. (2013). Design consideration in aerated static pile composting. *BioCycle*, 54, 5, pg. 21.

Colon, J., Martinez-Blanco, J., Gabarrell, X., Artola, A., Sلnchez, A., Rieradevall, J., Font, X. (2010). Environmental assessment of home composting. *Resources, Conservation and Recycling*, 54,893–904.

Cossu, R., Williams, I.D. (2015). Urban mining: Concepts, terminology, challenges. *Waste Management*, 45, 1-3. https://doi.org/10.1016/j.wasman.2015.09.040.

Costa, M.S.S.D, Carneiro, L.J., Costa, L.A.D.M, Pereira, D.C., Lorin, H.E.F. (2016). Composting time reduction of agro-industrial wastes. *Journal of the Brazilian Association of Agricultural Engineering*, 36(6), 1206-1217.

CPHEEO (Central Public Health and Environmental Engineering Organization), (2016). Solid waste management manual part II: the manual. Ministry of urban development, India.

Croft, B., Emberton, R. (1989). Landfill Gas and the Oxidation of Methane in Soil, The Technical Aspects of Controlled Waste Management, Department of Environment, Wastes Technical Division, Research Report No. CWM 049/89.

Czekała, W., Janczak, D., Pochwatka, P., Nowak, M., Dach, J. (2022). Gases Emissions during Composting Process of Agri-Food Industry Waste. *Applied Sciences*, 12, 9245. https://doi.org/10.3390/app12189245.

Darrell, W., Donahue, Jonathan, A., Chalmers, & Jennifer, A., Storey (1998). Evaluation of In-vessel Composting of University Postconsumer Food Wastes. *Compost Science & Utilization*, 6(2), 75-81, DOI: 10.1080/1065657X.1998.10701922.

Deportes, I., Benoit-Guyod, J.L., Zmirou, D. (1995). Hazard to man and the environment posed by the use of urban waste compost: a review. *Science of The Total Environment*, 172, 197-222.

Dhamodharan, K., Varma, V.S., Veluchamy, C., Pugazhendhi, A., Rajendran, K. (2019). Emission of volatile organic compounds from composting: A review on assessment, treatment and perspectives. *Science of the Total Environment*, 695, 133725.

Dickson, N., Richard, T., Kozlowski, R. (1991). Composting to reduce the waste stream. A guide to small-scale food and yard waste composting. Northeast Regional Agricultural Engineering Service, Cornell University, NY 14853: 607-255-7654.

Di Maria, F., Lovat, E., Caniato, M. (2017). Comparing Waste Management In Developed And Developing Countries: The Case Study Of The Umbria Region (Italy) And Of West Bank (Palestine). Proceedings Sardinia 2017 / Sixteenth International Waste Management and Landfill Symposium/ 2 - 6 October 2017. S. Margherita di Pula, Cagliari, Italy / CISA Publisher, Italy.

Drechsel, P., Cofie, O., Fink, M., Danso, G., Zakari, F., Vasquez, R. (2004). Closing the Rural-Urban Nutrient Cycle. Options for Municipal Waste Composting in Ghana. Final Scientific Report Submitted to IDRC (project 100376); IWMI: Ghana, Africa.

Dume, B., Hanc, A., Svehla, P., Míchal, P., Chane, A.D., Nigussie, A. (2021). Carbon Dioxide and Methane Emissions during the Composting and Vermicomposting of Sewage Sludge under the Effect of Different Proportions of Straw Pellets. *Atmosphere*, 12, 1380. https://doi.org/10.3390/atmos12111380.

Eades, P., Banks, C., Heaven, S., Walker, M. (2011). Mass and energy balance for a rotating-drum composting plant. *Waste and Resource Management*, 164(WR3), 151-159. https://doi.org/10.1680/warm.2011.164.3.151.

ECN (European Compost Network) (2021). https://www.compostnetwork.info/policy/biowaste-in-europe/treatment-bio-waste-europe/. Accessed on 27/10/2021.

ECN (European Compost Network) (2016). Bio-waste: the valuable organic resource in a circular economy. Fact sheet. https://www.compostnetwork.info/ecns-factsheet-organic-resource/. Accessed on 20/11/2021.

Ejileugha, C., Onyegbule, U.O., Osuoha, J.O. (2024). Use of Additives in Composting Promotes Passivation and Reduction in Bioavailability of Heavy Metals (HMs) in Compost. *Reviews of Environmental Contamination and Toxicology*, 262:2. https://doi.org/10.1007/s44169-023-00055-9.

Ekinci, K., Tosun, I., Kumbul, B.S., Şevik, F., Sülük, K., Bıtrak, N.B. (2020). Effect of initial C/N ratio on composting of two-phase olive mill pomace, dairy manure, and straw, *Environmental Progress and Sustainable Energy*, 40(2), e13517, https://doi.org/10.1002/ep.13517.

Ellen Macarthur Foundation (2015). Toward a circular economy: business rationale for an accepted transition. https://emf.thirdlight.com/link/ip2fh05h21it-6nvypm/@/preview/1?o. accessed on 20/11/2021.

El-mrini, S., Aboutayeb, R., Zouhri1, A. (2022). Effect of initial C/N ratio and turning frequency on quality of final compost of turkey manure and olive pomace. *Journal of Engineering and Applied Science*, 69:37, https://doi.org/10.1186/s44147-022-00092-6.

Epelde, L., Jauregi, L., Urra, J., Ibarretxe, L., Romo, J., Goikoetxea, I., Garbisu, C. (2018). Characterization of composted organic amendments for agricultural use. *Frontiers in Sustainable Food Systems*, 2, 44.

ERM (Environmental Resources Management) (2000). West Bank and Gaza Solid Waste and Environmental Management Project (SWEMP) Solid Waste Management Study, Vol. 5, Supplementary Environmental Analysis of the Hebron/Yatta landfill site.

EU (European Commission) (2020). Communication from the commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. a New Circular Economy Action Plan for a Cleaner and More Competitive Europe, Communication No.

98; European Commission: Brussels, Belgium. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2020%3A98%3AFIN. Accessed on 7/1/2022.

Eurosolids Nederland (2020a). Ammonium Sulphate Horticultural Grade data sheet. The Netherland. https://www.eurosolids.com/products/ammonium-sulphate/. Accessed on 20/11/2021.

Eurosolids Netherland (2020b). The Netherland. https://www.eurosolids.com/products/potassium-sulphate-sop/. Accessed on 20/11/2021.

ESCWA (Environmental and Social Commission for Western Asia) (2015). Review of innovative and appropriate technologies for waste management in Morocco and the Arab region. Report, E/ESCWA/SDPD/2015.

Espinoza, P., Arce, E., Daza, D., Faure, M., Terraza, H. (2010). Regional Evaluation of Municipal Solid Waste Management in Latin America and the Caribbean: 2010 Report; PAHO: Washington, DC, USA; AIDIS: São Paulo, Brasil; IDB: Washington, DC, USA.

Eurostat (2021). Municipal waste statistics. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Municipal_waste_statistics. Accessed on 27/10/2021.

Exchange rates (2022). Live Saudi Riyal to Dollar Exchange Rate (SAR/USD) Today. https://www.exchangerates.org.uk/Saudi-Riyal-to-Dollars-currency-conversion-page.html. Accessed on 7/1/2022.

FAO (Food and Agriculture Organization) (2007). Waste management opportunities for rural communities: Composting as an effective waste management strategy for farm households and others.

FAO (Food and Agriculture Organization) (1987). Soil management: compost production and use in tropical and subtropical environments. by H. W. Dalzell, A. J. Biddlestone, K. R. Gray & K. Thurairajan. FAO Soil Bulletin No. 56. Rome.

Fernando, S.J., Zutshi, A. (2023). Municipal solid waste management in developing economies: A way forward. *Cleaner Waste Systems*, 5, 100103. https://doi.org/10.1016/j.clwas.2023.100103.

Flanagan, K., Clowes, A., Lipinski, B., Goodwin, L., Swannell, R. (2018). SDG Target 12.3 on food loss and waste: 2018 progress report. An annual update on behalf of Champions 12.3. https://champions123.org/sites/default/files/2020-09/champions-12-3-2018-progress-report.pdf. Accessed on 7/1/2022.

Folz, D.H. (1991). Recycling program design, management, and participation: a national survey of municipal experience. *Public Administration Review*, 51(3), 222–31.

Frick, K., Bidlingmaier, W., Muller, W. (1999). Low cost pre-treatment of waste landfill emissions-does mechanically biologically treated waste facilitate the operation of low environmental impact landfills. In: Bidlingmaier W, de Bertoldi M, Diaz L, Papaddimitriou FK, editors. Organic recovery and biological treatment. Berlin: Rhombos, 857–67 (ISBN 2-930894-20-3).

Friedrich, E., Trois, C. (2013). GHG emission factors developed for the recycling and composting of municipal waste in South African municipalities. *Waste Management*, 33, 2520–2531.

Gao, M., Liang, F., Yu, A., Li, B., Yang, L. (2010a). Evaluation of stability and maturity during forced-aeration composting of chicken manure and sawdust at different C/N ratios. *Chemosphere*, 78(5),614-619.

Gao, M., Li B., Yu, A., Liang, F., Yang, L., Sun, Y. (2010b). The effect of aeration rate on forced-aeration composting of chicken manure and sawdust, *Bioresource Technology*, 101(6):1899–903, https://doi:10.1016/j.biortech.2009.10.027.

Ghaly, A.E., Alkoaik, F., Snow, A. (2006). Thermal balance of in-vessel composting of tomato plant residues. *Canadian Biosystems Engineering*, 48, 6.1–6.11.

Girotto, F., Alibardi, L., Cossu, R. (2015). Food waste generation and industrial uses: A review. *Waste Management*, 45, 32-45. https://doi.org/10.1016/j.wasman.2015.06.008.

GIZ (German International Cooperation) (2014). Country report on the solid waste management in Occupied Palestinian territories. The Regional Solid Waste Exchange of Information and Expertise network in Mashreq and Maghreb countries (SWEEPNET).

Grau, J., Terraza, H., Velosa, R., Milena, D., Rihm, A., Sturzenegger, G. (2015). Solid Waste Management in Latin America and the Caribbean; Inter-American Development Bank: Washington, DC, USA.

Guerrero, L.A., Maas, G., Hogland, W. (2013). Solid waste management challenges for cities in developing countries. *Waste Management*, 33, 220–232.

Guo, R., Li, G., Jiang, T., Schuchardt, F., Chen, T., Zhao, Y. Shen, Y. (2012). Effect of aeration rate, C/N ratio and moisture content on the stability and maturity of compost. *Bioresource Technology*, 112, 171-178. https://doi.org.10.1016/j.biotech.2012.02.099.

Gustavson, A. (2008). Minor Field Study: Implementation of SWM Kancheepuram, Tamil Nadu State of India. Master of Science Thesis INDEK 2008:86.

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

HCCI (Hebron Chamber of Commerce and Industry) (2021). http://www.hebroncci.org/en/index.php?option=com_content&view=article&id=1649&Itemid=194. Accessed on 19/10/2021.

Huber-Humer, M., Tintner, J., Böhm, K., Lechner, P. (2011). Scrutinizing compost properties and their impact on methane oxidation efficiency. *Waste Management*, 31, 871-883. https://doi.org/10.1016/j.wasman.2010.09.023.

Hassanshahi, N., Karimi-Jashni, A., Talebbeydokhti, N. (2018). The Role of Home Composting in Waste Management Cost Reduction. *International Journal of Environmental and Ecological Engineering*, 12(8), 529-533.

Haug, R.T. (1993). The practical handbook of compost engineering Boca Raton, FL: Lewis Publishers.

Henry, R.K., Yongsheng, Z., Jun, D. (2006). Municipal solid waste management challenges in developing countries – Kenyan case study. *Waste Management*, 26(01), 92–100.

Hermawansyah, Y., Hadinata, F., Dewi, R., Hanafiah (2018). A study of compost use as an alternative daily cover in Sukawinatan Landfill Palembang. *International Journal of GEOMATE*, 15(51), 47-52. http://doi.10.21660/2018.51.50249.

Hettiarachchi, H., Ryu, S., Caucci, S., Silva, R. (2018). Municipal Solid Waste Management in Latin America and the Caribbean: Issues and Potential Solutions from the Governance Perspective. *Recycling*, 3, 19.

Howard, A. (1933). The waste products of agriculture: Their utilization as humus. *Journal of Royal Society of Arts*, (82) 4229, 84 – 121.

Huang, G.F., Wong, J.W.C., Wu, Q.T., Nagar, B.B. (2004). Effect of C/N on composting of pig manure with sawdust. *Waste Manage*, 24, 805-813.

Hwang, H.Y., Kim, S.H., Kim, M.S., Park, S.J., Lee, C.H. (2020). Co-composting of chicken manure with organic wastes: characterization of gases emissions and compost quality. *The Korean Society for Applied Biology Chemistry*, 63:3, https://doi.org/10.1186/s13765-019-0483-8.

HydroplanIngenieur-GesellschaftmbH, & AEEIC (2013). Local market potential of organic compost fertilizers in Palestine "feasibility study", project no. KFW-DEG/ E8122.

IFC (International Finance Cooperation) (2012). Solid waste management in Hebron and Bethlehem Governorates, assessment of current situation and analysis of new system. Report, Palestine.

IMG (International Management Group) (2010). IMG Assessment Report for Solid Waste Composition in the Southern West Bank, Final report, Jerusalem.

Ittiravivongs, A. (2012) Household waste recycling behavior in Thailand: The role of responsibility. International Conference on Future Environment and Energy IPCBEE vol. 28(2012).

Jalalipour, H., Haghighi, A.B., Ferronato, N., Bottausci, S., Bonoli, A., Nelles, M. (2024). Social, economic and environmental benefits of organic waste home composting in Iran. *Waste Management and Research*, 1-15. https://doi.org/10.1177/0734242X241227377.

Jaza Folefack, A.J. (2009). The substitution of mineral fertilizers by compost from household waste in Cameroon: economic analysis with a partial equilibrium model. *Waste Management and Research*, 27 (3), 207–223. https://doi.org/10.1177/0734242X08090403.

Jia, M.S., Wang, X.J., Chen, S.H. (2014). Nitrous oxide emissions from municipal solid waste landfills and its measuring methodology: a review. *PubMed*, 25(6),1815-24.

Jiang, W., Liu, X., Wang, Y., Zhang, Y., Qi, W. (2018). Responses to Potassium Application and Economic Optimum K Rate of Maize under Different Soil Indigenous K Supply.

Jiang, T., Li, G., Tang, Q., Ma, X., Wang, G., Schuchardt, F. (2015). Effects of aeration method and aeration rate on greenhouse gas emissions during composting of pig feces in pilot scale. *Journal of Environmental Sciences*, http://dx.doi.org/10.1016/j.jes.2014.12.005.

JICA (Japan International Cooperation Agency) (2021). MoLGM-JICA Technical cooperation project for capacity development in solid waste management in Palestine, Phase III.

JICA (Japan International Cooperation Agency) (2019a). Project for Technical Assistance in Solid Waste Management in Palestine. A Technical Cooperation between Palestine and Japan (2015 -2019). Final Report, Palestine.

JICA (Japan International Cooperation Agency) (2019b). Program for Establishing a System of Medical Waste Management in the Gaza Strip. Draft Final Report.

GIZ (German International Cooperation) (2020) Circular economy oriented value chain guideline for HORECA food waste utilization. Belgrade, Serbia.

Jolly, Y.N., Islam, A., Akbar, S. (2013). Transfer of metals from soil to vegetables and possible health risk assessment. *Springerplus*, 2, 385.

Joseph, K. (2006). Stakeholder participation for sustainable waste management. *Habitat International*, 30: 863–871.

JSC-H&B (The Joint Service Council for Solid Waste Management for Hebron and Bethlehem-JSC-H&B) (2021). Supply of cover materials to cover the waste at Al-Menya landfill. Tender documents no. 10/2021. Palestine.

JSC-H&B (The Joint Service Council for Solid Waste Management for Hebron and Bethlehem-JSC-H&B) (2020). Weighting bridge records of solid waste quantities delivered to Al-Menya landfill. Palestine

JSC-H&B (The Joint Service Council for Solid Waste Management for Hebron and Bethlehem-JSC-H&B) (2018). Manual for compost production on the household level. Palestine.

JSC-H&B (The Joint Service Council for Solid Waste Management for Hebron and Bethlehem-JSC-H&B) (2015). Addendum to the Environmental & Social Impact Assessment (ESIA) (Original date: April 2009). Sanitary Closure and Rehabilitation of Yatta Dumpsite. Palestine.

JSC-H&B (The Joint Service Council for solid Waste Management for Hebron and Bethlehem Governorates - JSC-H&B), 2013. Shifting from Random Municipal Waste Dumping into Sanitary Disposal. Palestine.

JSC-H&B (The Joint Service Council for Solid Waste Management for Hebron and Bethlehem Governorates) (2012). Palestinian Municipalities Support Program (PMSP). Medical waste management pilot project in southern West Bank, HEB SW 010 09, Supply, installation, testing and commissioning of treatment plant in southern West Bank, opt. Procurement notice.

JSC-H&B (The Joint Service Council for Solid Waste Management for Hebron and Bethlehem-JSC-H&B) (2011). Southern West Bank solid waste management project (SWBSWMP), contract agreement for construction of sanitary landfill at Al-Menya, southern West Bank, Palestine.

JSI (Jordanian Standard Institution) (2000). Technical regulation for organic fertilizers, Standard no 962/2000, Amman, Jordan.

Kabasiita, J.K, Opolot, E., Malinga, G.M. (2022). Quality and Fertility Assessments of Municipal Solid Waste Compost Produced from Cleaner Development Mechanism Compost Projects: A Case Study from Uganda. *Agriculture*, 12, 582. https://doi.org/10.3390/agriculture12050582.

Karkanias, C., Perkoulidis, G., Moussiopoulos, N. (2016) Sustainable management of household biodegradable waste: Lessons from home composting programs. *Waste Biomass Valorization*, 7, 659–665.

Kavitha, R., Sabramarian, P. (2007). Bioactive Compost - A Value Added Compost with Microbial Inoculants and Organic Additives. *Journal of Applied Sciences*, 7, 2514-2518.

Kaza, S., Yao, L., Stowell, A. (2016). Sustainable financing and policy models for municipal composting. Urban development series knowledge papers, The World Bank, Washington, DC 20433 USA.

Kaza, S., Yao, L., Bhada-Tata, P., Van Woerden, F. (2018). What a waste 2.0: A global snapshot of solid waste management to 2050 (Urban Development Series). Washington, DC: World Bank.

Keener, H.M., Elwell, D.L., Ekinci, K., Hoitink, H.A.J. (2001). Composting and value-added utilizasyon of manure from a highrise swine finishing facility. *Compost Science and Utilization*, 9 (4): 312–321.

Keng, Z.X., Chong, S., Ng, C.G., Ridzuan, N.I., Hanson, S., Pan, G.T., Lau, P.L., Supramaniam, C.V., Singh, A., Chin, C.F. (2020). Community-scale composting for food waste: A life-cycle assessment-supported case study. *Journal of Cleaner Production*, 261, 121220.

Kightley, D., Nedwell, D. B., Cooper, M. (1995). Capacity for methane oxidation in landfill cover soils measured in laboratory-scale soil microcosms, *Applied and Environmental Microbiology*, 61(2), 592–601. https://doi.org/10.1128/aem.61.2.592-601.1995.

Klundert, A. V.D., Anschütz, J. (2001). Integrated sustainable waste management – the concept. Tools for Decision-makers. Experiences from the Urban Waste Expertise Programme (1995-2001). The Netherlands.

Koufodimos, G., Samaras, Z. (2002). Waste management options in southern Europe using field and experimental data. *Waste Management*, 22, 47–59.

Kumar, M., Yan-Liang, O., Lin, J.G. (2010). Co-composting of green waste and food waste at low C/N ratio, *Waste Management*, 30: 602–609, https://doi.org/10.1016/j.wasman.2009.11.023.

Kutos, S., Stricker, E., Cooper, A., Ryals, R., Creque, J., Machmuller, M., Kroegar, M. Silver, W.L. (2023). Compost amendment to enhance carbon sequestration in rangelands. *Journal of Soil and Water Conservation,* 78 (2): 163-177; DOI: https://doi.org/10.2489/jswc.2023.00072.

Lalitha, R., Fernando, S. (2019). Solid waste management of local governments in the Western Province of Sri Lanka: An implementation analysis. *Waste Management*, 84, 194–203.

LAL (Local Authorities Law) No. 1 (1997). Palestinian National Authority (PNA), Gaza, Palestine.

Lalremruati, M. and Devi, A.S. (2021). Duration of Composting and Changes in Temperature, pH and C/N Ratio during Composting: A Review. *Agricultural Reviews*. DOI: 10.18805/ag.R-2197. https://arccjournals.com/journal/agricultural-reviews/R-2197.

Lau, A.K., Lo, K.V., Liao, P.H., Yu, J.C. (1992). Aeration experiments for swine waste composting, *Bioresource. Technology*, 41 (2):145–52. https://doi:10.1016/0960-8524(92)90185-Z.

Levis, J.W., Barlaz, M.A. (2013). Composting process model documentation. North Carolina State University.

Li, Y., Han, Y., Zhang, Y., Fang, Y., Li, S., Li, G., Luo, W. (2020). Factors affecting gaseous emissions, maturity, and energy efficiency in composting of livestock manure digestate. *Science of the Total Environment*, 731, 139157.

Li, X., Zhang, R., Pang, Y., (2008). Characteristics of dairy manure composting with rice straw. *Bioresource Technology,* 99(2):359–67. https://doi:10.1016/j.biortech.2006.12.009.

Liu, L., Wang, S., Guo, X., Wang, H. (2019). Comparison of the effects of different maturity composts on soil nutrient, plant growth and heavy metal mobility in the contaminated soil. *Journal of Environmental Management*, 250, 109525.

Loan, L.T.T., Takahashi, Y., Nomura, H., Yabe, M. (2019). Modeling home composting behavior toward sustainable municipal organic waste management at the source in developing countries. *Resources, Conservation and Recycling*, 140, 65–71.

Luangwilai, T., Sidhu, H. S., Nelson, M. I., Chen, X., 2011. Modelling the effects of moisture content in compost piles. In: CHEMECA 2011, *Australian Chemical Engineering Conference Australia*, Engineers Australia.

Luangwilai, T., Sidhu, H.S., Nelson, M.I. (2012). Understanding the role of moisture in the self-heating process of compost piles. CHEMECA 2012: *Australasian Chemical Engineering Conference* (pp. 1-13). Australia: Engineers Australia.

Lu, X., Yang, Y., Hong, C., Zhu, W., Yao, Y., Zhu, F., Hong, L., Wang, W. (2022). Optimization of vegetable waste composting and the exploration of microbial mechanisms related to fungal communities during composting. *Journal of Environmental Management*, 319, 115694. https://doi.org/10.1016/j.jenvman.2022.115694.

Lu, S.G., Imai, T., Li, H.F., Ukita, M., Sekine, M., Higuchi, T. (2001). Effect of enforced aeration on in-vessel food waste composting. *Environmental Technology*, 22(10):1177–82, https://doi:10.1080/09593332208618200.

Macias-Corral, M.A., Cueto-Wong, J.A., Morán-Martínez, J., Reynoso-Cuevas, L. (2019). Effect of different initial C/N ratio of cow manure and straw on microbial quality of compost. *International Journal of Recycling of Organic Waste in Agriculture*, 8, 357–365. https://doi.org/10.1007/s40093-019-00308-5.

Mahapatra, S., Ali, M.H., Samal, K. (2022). Assessment of compost maturity-stability indices and recent development of composting bin. *Energy Nexus*, 6, 100062, https://doi.org/10.1016/j.nexus.2022.100062.

Malakahmad, A., Idrus, N.B., Abualqumboz, M.S., Yavari, S., Kutty, S.R.M. (2017). In-vessel co-composting of yard waste and food waste: an approach for sustainable waste management in Cameron Highlands, Malaysia. *International Journal of Recycling of Organic Waste in Agriculture*, 6,149–157.

Malwana, C. (2008). Solid Waste Management in Sri Lanka. *Econ. Rev.*, 34–37.

Mangundu, A., Makura, E.S., Mangundu, M., Tapera, R. (2013). The importance of integrated solid waste management in independent Zimbabwe: The Case of Glenview Area 8, Harare. *Global Journal of Biology, Agriculture and Health Sciences*, 2 (3), 85–92.

Mayer, A., Haas, W., Wiedenhofer, D., Krausmann, F., Nuss, P., Blengini, G.A. (2019). Measuring progress towards a circular economy: a monitoring framework for economy-wide material loop closing in the EU28. *Journal of Industrial Ecology*, 23 (1), 62–76. https://doi.org/10.1111/jiec.12809.

McAllister, J. (2015). Factors influencing SWM in the developing world. All Graduate Plan B and other Reports. Paper 528. Utah State University.

MDLF (Municipal Development and Lending Fund) (2018). Local governance and service improvement program (LGSIP). Project agreement. Palestine.

Mengistu, T., Gebrekidan, H., Kibret, K., Woldetsadik, K., Shimelis, B., Yadav, H. (2017). Comparative effectiveness of different composting methods on the stabilization, maturation and sanitization of municipal organic solid wastes and dried fecal sludge mixtures. *Environmental System Research*, 6:5. DOI; http://10.1186/s40068-017-0079-4.

Milea, A. (2009). Waste as a social dilemma: Issues of social and environmental justice and the role of residents in municipal solid waste management, Delhi, India. Master's thesis, Lund University. Lund, Sweden.

Misra, R., Roy, R., Hiraoka, H. (2003). On-Farm Composting Methods; UN-FAO: Rome, Italy; pp. 7–26.

MoA (Ministry of Agriculture) (2011). Reality and the use of compost in Palestine, general Administration of Soil and Irrigation, the Department of Soil, 2011 (internal report). Ramallah, Palestine.

MoLG (Ministry of Local Government) (2021). List of local authorities in the West Bank. Ramallah, Palestine.

MoLG (Ministry of Local Government) (2019). Solid waste statistics for joint service councils for the year 2016. Ramallah, Palestine.

MoLG (Ministry of Local Government) (2018). JSC Today. Ramallah, Palestine.

MoLG (Ministry of Local Government) (2017). Solid waste statistics for joint service councils for the year 2016. Ramallah, Palestine.

MoLG (Ministry of Local Government) (2016). Manual of joint service councils for solid waste management. Ramallah, Palestine.

Mohee, R., Mauthoor, S., Bundhoo, Z.M.A., Somaroo, G., & Gunasee, S. (2015). Current status of solid waste management in small island developing states: a review. *Waste Management*, 43, 539–549.

Mohee, R., Soobhany, N. (2014). Comparison of heavy metals content in compost against vermicompost of organic solid waste: past and present. *Resources, Conservation and Recycling*, 92, 206-213.

Monni, S., Pipatti, R., Lehtilä, A., Savolainen, I., Syri, S. (2006). Global climate change mitigation scenarios for solid waste management. Espoo, Technical Research Centre of Finland. VTT Publications, No. 603, pp 51.

Mukai, S., Oyanagi, W. (2021). Evaluation on maturity and stability of organic fertilizers in semi-arid Ethiopian Rift Valley. *Scientific Reports*, 11, 4035.

Muttamara, S., Visvanathan, C., Alwis, K.U. (1994). Solid waste recycling and reuse in Bangkok. *Waste Management & Research*, 12,151–63.

MWM Bylaw (Medical Waste Management Bylaw) (2012). Palestinian National Authority (PNA), Ramallah, Palestine.

Nada, W.M. (2015). Stability and maturity of maize stalks compost as affected by aeration rate, C/N ratio and moisture content. *Journal of soil science and plant nutrition*, 15(3):751–64. http://dx.doi.org/10.4067/S0718-95162015005000051.

Nassour. A., Elnaas, A., Hemidat, S., Nelles, M. (2016). Development of Waste Management in the Arab Region. TK Verlag Karl Thomé-Kozmiensky. ISBN 978-3-944310-29-9.

Neumayer, E. (2004). The Impact of Political Violence on Tourism: Dynamics Cross-National Estimation. *The Journal of Conflict Resolution*, 48(2), 259-281.

Nitivattananon, V., Suttibak, S. (2008). Assessment of factors influencing the performance of solid waste recycling programs. *Resources, Conservation and Recycling*, 53,45–56.

NRDC (Natural Resource Defense Council) (2021). https://www.nrdc.org/stories/greenhouse-effect-101. Accessed on 15/10/2021.

NSSWM (National Strategy for Solid Waste Management in Palestine: 2017 - 2022) (2017). State of Palestine.

Oliveira, L.S.B.L., Oliveira, D.S.B.L., Bezerra, B.S., Pereira, B.S., Battistelle, R.A.G. (2017). Environmental analysis of organic waste treatment focusing on composting scenarios. *Journal of Cleaner Production*, 155, 229–237. http://hdl.handle.net/11449/178408.

Olson, N.E., Neher, D.A., Holden, V.I. (2024). On-farm conversion of cannabis sativa waste biomass into an organic fertilizer by microbial digestion. *Compost Science & Utilization*. https://doi.org/10.1080/1065657X.2023.2296947.

Onwosi, C.O., Igbokwe, V.C., Odimba, J.N., Eke, I.E., Nwankwoala, M.O., Iroh, I.N., Ezeogu, L.I. (2017). Review Composting technology in waste stabilization: On the methods, challenges and future prospects. *Journal of Environmental Management*, 190,140-157.

Oviedo-Ocaña, E.R, Hernández-Gómez, A., Dominguez, I., Parra-Orobio, B.A., Soto-Paz, J., Sánchez, A. (2022). Evaluation of Co-Composting as an Alternative for the Use of Agricultural Waste of Spring Onions, Chicken Manure and Bio-Waste Produced in Moorland Ecosystems. *Sustainability*, 14, 8720. https://doi.org/10.3390/su14148720.

Pace, M.G., Miller, B.E., Farrel-Poe K.L. (1995). The Composting Process. Cooperative Extension, Utah State University. AG- WM 01.

Pajura, R. (2024). Composting municipal solid waste and animal manure in response to the current fertilizer crisis - a recent review. *Science of The Total Environment*, 912(20): 169221. https://doi.org/10.1016/j.scitotenv.2023.169221.

Palestinian Federation of Industries (2009). The current status of Industrial Sector in Palestine. Palestine.

PA (Palestinian Authority) (2010). (National Strategy for Solid Waste Management – NSSWM (2010 -2014), Ramallah, Palestine.

Pane, C., Spaccini, R., Piccolo, A., Celano, G., Zaccardelli, M. (2019). Disease suppressiveness of agricultural green waste composts as related to chemical and bio-based properties shaped by different on-farm composting methods. *Biological Control*, 137, 104026. DOI:10.1016/j.biocontrol.2019.104026.

Papachristou, E., Hadjianghelou, H., Darakas, E., Alivanis, K., Belou, A., Ioannidou, D., Paraskevopoulou, E., Poulios, K., Koukourikou, K., Kosmidou, N., Sortikos, K. (2009). Perspectives for integrated municipal solid waste management in Thessaloniki, Greece. *Waste Management*, 29, 1158–1162.

Papafilippaki, A., Paranychianakis, N., Nikolaidis, N.P. (2015). Effects of soil type and municipal solid waste compost as soil amendment on Cichorium spinosum (spiny chicory) growth. *Scientia Horticulture*, 195, 195-205.

Paradelo, R., Villada, A., Devesa-Rey, R., Moldes, A.B., Dominguez, M., Patino, J., Barral, M.T. (2011). Distribution and availability of trace elements in municipal solid waste composts. *Journal of Environmental Monitoring*, 13, 201–211.

Park, J. K., Mahoney, J., Clark, T., Krueger, N. (2017). A Review of Urban Mining in the Past, Present and Future. *Advanced Recycling Waste Management*, 2:127. http://doi:10.4172/2475-7675.1000127.

Park, S., Brown, K.W., Thomas, J.C. (2002). The effect of various environmental and design parameters on methane oxidation in a model biofilter, *Waste Management and Research*, 20, 434–444. https://doi.org/10.1177/0734242X0202000507.

Paul, N., Giri, U., Roy, G. (2019). Composting, book chapter. Organic Fertilizers - History, Production and Applications. ISBN: 978-1-78985-148-9.

Pergola, M., Piccolo, A., Palese, A. M., Ingrao, C., Celano, G. (2018). A combined assessment of the energy, economic and environmental issues associated with on-farm manure composting processes: Two case studies in South of Italy. *Journal of Cleaner Production*, 172, 3969-3981.

Petric, I., Helic, A., Avdic, E.A. (2012). Evolution of process parameters and determination of kinetics for co-composting of organic fraction of municipal solid waste with poultry manure. *Bioresource Technology*, 117, 107-116.

PCBS (Palestinian Central Bureau of Statistics) (2019). Socio-Economic Conditions Survey 2018. Ramallah, Palestine.

PCBS (Palestinian Central Bureau of Statistics) (2018). Preliminary results of the population, housing and establishments, census 2017. Ramallah, Palestine.

PEAP (Palestinian Environmental Assessment Policy) (2000), Palestinian National Authority (PNA), Palestine.

PEL (Palestinian Environmental Law No. (7) (1999). Palestinian National Authority (PNA), Gaza, Palestine.

PSI (Palestinian Standards Institution) (2012). Standard specification for organic fertilizer (compost). PS/-2652, Ramallah, Palestine.

Peng, L., Tang, R., Wang, G., Ma, R., Li, Y., Li G., Yuan, J. (2023a). Effect of aeration rate, aeration pattern, and turning frequency on maturity and gaseous emissions during kitchen waste composting. *Environmental Technology & Innovation*, 29, 102997. https://doi.org/10.1016/j.eti.2022.102997.

Peng, X., Jiang, Y., Chen, Z., Osman, A.I., Farghali, M., Rooney, D.W., Yap, P.S. (2023b). Recycling municipal, agricultural and industrial waste into energy, fertilizers, food and construction materials, and economic feasibility: a review. *Environmental Chemistry Letters*, 21, 765–801. https://doi.org/10.1007/s10311-022-01551-5.

Phong Le, N., Nguyen, T.T.P., Zhu, D. (2018). Understanding the Stakeholders' Involvement in Utilizing Municipal Solid Waste in Agriculture through Composting: A Case Study of Hanoi, Vietnam. *Sustainability*, 10, 2314.

Pisuttu, C., Adducci, F., Arena, S., Bigongiali, D., Callea, L., Carmignani, P., Cavicchi, A., Chianura, M., Ciulli, L., Contaldo, M., et al. (2024). A Master's Course Can Emphasize Circular Economy in Municipal Solid Waste Management: Evidence from the University of Pisa. *Sustainability*, 16, 1966. https://doi.org/10.3390/su16051966.

Pos, J. (1991). Composting—theoretical applications, municipal and commercial composting workshop, University of Guelph.

Pose-Juan, E., Igual, J.M., Sánchez-Martín, M.J., Rodríguez-Cruz, M.S. (2017). Influence of herbicide triasulfuron on soil microbial community in an unamended soil and a soil amended with organic residues. *Frontiers in Microbiology*, 8, 378. https://doi.org/10.3389/fmicb.2017.00378.

Prokic, D., Curcic, Lj., Stepanov, J., Stojic, N., Pucarevic, M. (2022). The role of circular economy in food waste management in fulfilling the United Nations' sustainable development goals. *Acta Univ. Sapientiae, Alimentaria*, 15, 51–66. https://doi.org/10.2478/ausal-2022-0005.

PHL (Public Health Law) No. (20) (2004). Palestinian National Authority (PNA), Palestine.

Qadomi, N. (2014). Good compost quality. Soil Department, Ministry of Agriculture (MoA). Ramallah, Palestine.

Qasim, W., Moon, B.E., Okyere, F.G., Khan, F., Nafees, M., Kim, H.T. (2019). Influence of aeration rate and reactor shape on the composting of poultry manure and sawdust. *Journal of the Air and Waste Management Association*, 69(5):633–645. https://doi.org/10.1080/10962247.2019.1569570.

Rajaie, M., Tavakoly, A.R. (2016). Effect of municipal waste compost and nitrogen fertilizer on growth and mineral composition of tomato. *International Journal of Recycling of Organic Waste in Agriculture*, 5, 339–347.

Ramachandra, T., V., Bharath, H. A., Kulkarni, G., Han, S., S. (2018). Municipal solid waste: Generation, composition and GHG emissions in Bangalore, India. *Renewable and Sustainable Energy Reviews*, 82 (1): 1122-1136.

Rathi, S. (2006). Alternative approaches for better municipal solid waste management in Mumbai, India. *Waste Manage*, 26 (10), 1192–1200.

Rashid, M.I., Shahzad, k. (2021). Food waste recycling for compost production and its economic and environmental assessment as circular economy indicators of solid waste management. *Journal of Cleaner Production*, 317, 128467. https://doi.org/10.1016/j.jclepro.2021.128467.

Rashwan, M.A, Alkoaik, F.N., Saleh, H.A., Fulleros, R.B., Ibrahim, M.N. (2021) Maturity and stability assessment of composted tomato residues and chicken manure using a rotary drum bioreactor. *Journal of the Air & Waste Management Association*, 71(5), 529-539, DOI: 10.1080/10962247.2020.1859416.

Rau, S. (2019). Options for Urban Mining and Integration with a Potential Green Circular Economy in the People's Republic of China. ADB BRIEFS, 124. DOI: http://dx.doi.org/10.22617/BRF190606-2.

Raut, M.P., William, S.M.P.P., Bhattacharyya, J.K., Chakrabarti, T., Devotta, S. (2008). Microbial dynamics and enzyme activities during rapid composting of municipal solid waste e a compost maturity analysis perspective. *Bioresource Technology*, 99, 6512-6519.

Ravi, A., Vishnudas, S. (2017). Conceptual framework for evaluating the sustainability of domestic organic waste management techniques. *International Journal of Civil Engineering and Technology (IJCIET)*, 8(6): 283–289.

Ravindran, B., Sekaran, G. (2010). Bacterial composting of animal fleshing generated from tannery industries. *Waste Management*, 30, 2622-2630.

Raza, S., Ahmad, J. (2016). Composting process: a review. International Journal of Biological Research, 4 (2), 102-104.

Razza, F., D'Avino, L., L'Abate, G., Lazzeri, L. (2018). The Role of Compost in Bio-waste Management and Circular Economy. *Research Gate*. http://doi:10.1007/978-3-319-66981-6_16.

ROU (Recycled organic units) (2007). Composting Science for Industry: An overview of the scientific principles of composting processes, 3rd edition. The University of New South Wales.

RRC.AP (Regional Resource Center for Asia and the Pacific) (2010). Municipal waste management report: status-quo and issues in southeast and east Asian countries. ISBN: 978-974-8257-73-0.

Rynk, R., van de Kamp, M., Willson, G.B., Singley, M.E., Richard, T.L., Kolega, J.J., Gouin, F.R., Laliberty Jr. L., Kay, D., Murphy, D.W., Hoitink, H.A.J., Brinton W.F. (1992). On-Farm Composting Handbook. Natural Resource, Agriculture, and Engineering Service. Ithaca, New York, USA.

Sadasivam, B.Y., Reddy, K.R. (2014). "Landfill methane oxidation in soil and bio-based coversystems: a review." *Reviews in Environmental Science and Biotechnology*, 13(1), 79-107. https://doi.org/10.1007/s11157-013-9325-z.

Saha, J.K, Panwar, N., Singh, M.V. (2010). An assessment of municipal solid waste compost quality produced in different cities of India in the perspective of developing quality control indices. *Waste Management*, 30, 192–201.

Samal, K., Dash, R.P., Bhunia, P. (2018). Effect of hydraulic loading rate and pollutants degradation kinetics in two stage hybrid macrophyte assisted vermifiltration system. *Biochemical Engineering Journal*, 132, 47–59, doi: 10.1016/j.bej.2018.01.002.

Sánchez-Monedero, M.A., Cegarra, J., García, D., & Roig, A. (2002). Chemical and structural evolution of humic acids during composting. *Biodegradation*, 13, 361–371.

Santos, A., Bustamante, A., M., Moral, R., Bernal, M., P. (2014). Carbon conservation strategy for management of pig slurry by composting: initial study of the bulking agent influence. *Mitigation and Adaptation Strategies for Global Change*, 21(17). DOI: http://10.1007/s11027-014-9593-0.

Sayara, T., Sánchez, A. (2021). Gaseous Emissions from the Composting Process: Controlling Parameters and Strategies of Mitigation. Processes, 9, 1844. https://doi.org/10.3390/pr9101844.

SBTAC (Sharabati Brothers Trading and Agricultural Company) (2021). Prices of chemical fertilizers.

Sehnem, S., Ndubisi, N.O., Preschlak, D., Bernardy, R.J., Santos Junior, S. (2020). Circular economy in the wine chain production: maturity, challenges, and lessons from an emerging economy perspective. *Production Planning and Control*, 31 (11–12), 1014–1034. http://doi:10.1080/09537287.2019.1695914.

Seo, S.A., Aramaki, T., Hwang, Y., Hanaki, K. (2004). Environmental impact of solid waste treatment methods in Korea. *Journal of Environmental Engineering*, 130, 81-89.

Shadeed, S.M., Judeh, T.G., Almasri, M.N. (2019). Developing GIS-based water poverty and rainwater harvesting suitability maps for domestic use in the Dead Sea region (West Bank, Palestine). *Hydrology and Earth Sciences*, 23, 1581–1592.

Shah, G.M., Tufail, N., Bakhat, H.F., Imran, M., Murtaza, B., Farooq, A.B.U., Saeed, F., Waqar, A., Rashid, M.I. (2017). Anaerobic degradation of municipal organic waste among others composting techniques improves N cycling through waste-soil-plant continuum. *Journal of Soil Science and Plant Nutrition*, 17 (2), 529–542. http://dx.doi.org/10.4067/S0718-95162017005000038.

Shen, Y.J., Meng, H.B., Zhao, L.X., Li, G.X., Zhou, H.B., Cheng, H.S., Ding, J.T., Zhang, X. Wang, J. (2019). Analysis of composting standards at home and abroad and its enlightenment to China. *Transactions of the Chinese Society of Agricultural Engineering*, 35, 6.

Shimizu, N. (2018). Process Optimization of Composting Systems. *Journal of Dairy and Veterinary Sciences*, 7(3): 555712. DOI: 10.19080/JDVS.2018.07.555712.

Shukor, F.A., Mohammed, A.H., Sani, S.I., Awang, M. (2011). A Review of the Success Factors for Community Participation in Solid Waste. In: Management. *International Conference on management Proceedings*, pp. 963.–976.

Silva, M.E.F., Saetta, R., Raimondo, R., Costa, J.M., Ferreira, J.V., Brás, I. (2024). Forest waste composting—operational management, environmental impacts, and application. *Environmental Science and Pollution Research*. https://doi.org/10.1007/s11356-024-32279-0.

Slater, R.A., Frederickson, J. (2001). Composting municipal waste in the UK: some lessons from Europe. *Resources, Conservation and Recycling*, 359–374.

Slide share, https://www.slideshare.net/aberland/composting-poultry-offal-january-2014. Accessed on 13/10/2021.

Slorach, P.C., Jeswani, H.K., Cu´ellar-Franca, R., Azapagic, A. (2020). Assessing the economic and environmental sustainability of household food waste management in the UK: current situation and future scenarios. *Science of the*

Total Environment, 710, 135580. https://doi.org/10.1016/j.scitotenv.2019.135580.

Smith, S.R., Jasim, S. (2009). Small-scale home composting of biodegradable household waste: overview of key results from a 3-year research program in West London. *Waste Management and Research*, 27, 941–950.

Sonmez, S. (1998). Tourism, Terrorism, and Political Instability. *Annals of Tourism Research*, 25(2), 416-456.

Sonmez, S.F., Graefe, A.R. (1998). International Vacation Decisions and Terrorism Risk. *Annals of Tourism Research*, 25(1), 112-144.

Soobhany, N. (2018). Assessing the physicochemical properties and quality parameters during composting of different organic constituents of Municipal Solid Waste. *Journal of Environmental Chemical Engineering*, 6, 1979–1988.

Sudharsan, V.V., Kalamdhad, A.S. (2015). Evolution of chemical and biological characterization during thermophilic composting of vegetable waste using rotary drum composter. *International Journal of Environmental Science and Technology*, 12, 2015-2024.

Sullivan, D.M., Bary, A.I., Miller, R.O., Brewer, L.J. (2018). Interpreting compost analyses. Oregon State University, the U.S. Department of Agriculture, and Oregon counties, USA. https://catalog.extension.oregonstate.edu/sites/catalog/files/project/pdf/em9217.pdf.

Sun, X., Tan, Z., He, X., Zhang, H., Xi, B., Zhou, H., Zhu, H.X. (2022). Initial Active Phase of In-Vessel Composting of Sewage Sludge, Leaves and Rice Straw. *Nature Environment and Pollution Technology*, 21(1): 83-90.

Sungsomboon, P., Chaisomphob, T., Ishida, T., Bureecam, C., (2012). Implementation of a new composting technology, serial self-turning reactor system, for municipal solid waste management in a small community in Thailand, Songklanakarin. *Journal of Science and Technology*, 34 (1): 109-115.

Swati, A, Hait, S. (2017) Fate and bioavailability of heavy metals during vermicomposting of various organic wastes—a review. *Process Safety and Environmental Protection*, 109,30–45. https://doi.org/10.1016/j.psep.2017.03.031.

SWM Bylaw (Solid Waste Management Bylaw) (2019). Palestinian National Authority (PNA), Ramallah, Palestine.

Talahmeh, I. (2005). Good Planning for Sanitary Landfill: Hebron District as a Case Study. Master Thesis, Faculty of Graduate Studies, Birzeit University, West Bank, Palestine.

Tamimi, A.H., Gerba, C.P. (2012). Characterization of Municipal Solid Waste at Yatta Landfill, Hebron, West Bank, Palestine.

Tang, R., Liu, Y., Ma, R., Zhang, L., Li, Y., Li, G., Wang, D., Lin, J., Li, Q., Yuan, J. (2023). Effect of moisture content, aeration rate, and C/N on maturity and gaseous emissions during kitchen waste rapid composting. *Journal of Environmental Management*, 326, 116662. https://doi.org/10.1016/j.jenvman.2022.116662.

Tanthachoon, N., Chiemchaisr, C., Chiemchaisr, W. (2007). Utilization of Municipal Solid Waste Compost as landfill cover soil for reducing greenhouse gas emission. *International Journal of Environmental Technology and Management*, 7(3/4): 286 – 297.

TAS (Triple super phosphate) (2021). https://www.tasflowrance.com/product/triple-super-phosphate-tsp#. Accessed on 20/11/2021.

Te Ma (2020) Effect of Processing Conditions on Nitrogen Los of Sewage Sludge Composting. *Compost Science & Utilization*, 28:3-4, 117-128, DOI: http://10.1080/1065657X.2021.1949410.

Tembo, M., Mwanaumo, E.M., Chisumbe, S., Aiyetan. A.O. (2020). Factors affecting effective infrastructure service delivery in Zambia's local authorities: A Case of Eastern Province. *Supporting Inclusive Growth and Sustainable Development in Africa*, 2, 65-81.

Then, Y.H., Lai, J.C., Then, Y.L. (2021). Study of forced aeration system for fruit and vegetable waste composting. 32nd Symposium of Malaysian Chemical Engineers (SOMChE2021). *IOP Conf. Series: Materials Science and Engineering* 1195, 012059, doi:10.1088/1757899X/1195/1/012059.

The World Bank (2019). Economic monitoring report to the ad hoc liaison committee. Washington, D.C. http://documents.worldbank.org/curated/en/410061568815090051/Economic-Monitoring-Report-to-the-Ad-Hoc-Liaison-Committee. Accessed on 7/1/2022.

The World Bank (2017). The performance of the Palestinian local governments: an assessment of service delivery outcomes and performance drivers in the West Bank and Gaza. Report No: ACS22456.

The World Bank (2009). Project Appraisal Document. Southern West Bank Solid Waste Management project in the West Bank and Gaza.

The World Bank (2007). West Bank and Gaza investment and climate assessment: unlocking the potential of the private sector.

Taylor, D.C. (2000). Policy incentives to minimize generation of municipal solid waste. *Waste Management and Research*, 18 (5), 406–419.

Tibihika, P.D., Okurut, T., Lugumira, J.S., Akello, C., Muganga, G., Tumuhairwe, J.B., Nsereko, M., Kiguli, D., Mugambwa, R. (2021). Characteristics of municipal fresh solid wastes from the selected large urban centres in Uganda: Implication for re-use and soil amendment strategies. *Journal of the Air & Waste Management Association*, 71, 923–933.

Tippawan, P., Jienkulsawad, P., Limleamthong, P., Arpornwichanop, A. (2022). Composting time minimization of mature vermicompost using desirability and response surface methodology approach. *Computers & Chemical Engineering*, 167, 108037, https://doi.org/10.1016/j.compchemeng.2022.108037.

UNCTAD (United Nations Conference on Trade and Development) (2015). The Besieged Palestinian Agricultural Sector. New York and Geneva. https://unctad.org/system/files/official-document/gdsapp2015d1_en.pdf. Accessed on 10/1/2022.

UNDP (United Nations Development Program), 2016. Provision of services to prepare a Green House Gases (GHG) emission inventory and the mitigation chapters of Palestine’s Initial National Communication Report (INCR).

UNEP (United Nations Development Program) (2017). Organic Waste Management in Latin America: Challenges and Advantages of the Main Treatment Options and Trends. Technical report with contributions from the Seminar “Management and utilization of municipal organic waste: the challenges of Latin America”.

UN-HABITAT (United Nations Human Settlements Program) (2012). State of Latin American and Caribbean Cities–Towards a New Urban Transition; UN-HABITAT: Rio de Janeiro, Brazil.

UN-HABITAT (United Nations Human Settlements Program) (2015) The challenge of the local government financing in the developing countries, the City of Barcelona and the Province of Barcelona.

UNPF (United Nations Population Fund) (2021). population matters. https://palestine.unfpa.org/en/population-matters-0. Accessed on 21/10/2021.

USAID (United States Agency for International Development) (2017). Climate change risk profile: West Bank and Gaza. Fact sheet. https://www.climatelinks.org/sites/default/files/asset/document/2017Mar06_GEMS_Climate%20Risk%20Profile%20West%20Bank%2BGaza.pdf.

USCC (United States Composting Council) (2001). Field guide to compost use. http://compostingcouncil.org/admin/wpcontent/plugins/wppdfupload/pdf/1330/Field_Guide_to_Compost_Use.pdf.

USEPA (United States Environmental Protection Agency) (2020) Landfill gas emission model (LandGEM) version 3.03. Office of Research and Development Center for Environmental Solutions and Emergency Response (CESER) and Clean Air Technology Center (CATS), Research Traiangle Park, North Carolina. https://www.epa.gov/sites/production/files/2020-06/landgem-v303.xlsm. Accessed on 16/11/2021.

USEPA (United States Environmental Protection Agency) (2002). Cover up with compost, Fact sheet. https://archive.epa.gov/epawaste/nonhaz/municipal/web/pdf/f02022.pdf. Accessed on 19/11/2021.

USNAS (United States National Academy of Sciences) and the Royal Society (RS) (2020). Climate change evidence and causes, update 2020.

Van der Wurff, A.W.G., Fuchs, J.G., Raviv, M., Termorshuizen, A.J. (2016). Handbook for Composting and Compost Use in Organic Horticulture. BioGreenhouse COST Action FA 1105, www.biogreenhouse.org. ISBN: 978-94-6257-749-7.

Van Iperen International B.V (2021). Iperen Humic 12 + 3 Liquid. https://www.vaniperen.com/products/iperen-humic-12-3-liquid/. Accessed on 20/11/2021.

Varma, V.S., Das, S., Sastri, C.V. and Kalamdhad, A.S. (2017). Microbial degradation of lignocellulosic fractions during drum composting of mixed organic waste. *Sustainable Environment Research*, 27, 265-272. https://doi.org.10.1016/j.serj.2017.05.004.

Ventorino, V., Pascale, A., Fagnano, M., Adamo, P., Faraco, V., Rocco, C., Fiorentino, N., Pepe, O. (2019). Soil tillage and compost amendment promote bioremediation and biofertility of polluted area. *Journal of Cleaner Production*, 239, 118087.

Vilela, R.N.D.S., Orrico, A.C.A., Junior, M.A.P.O., Borquis, R.R.A., Tomazi, M., de Oliveira, J.D., de Ávila, M.R., dos Santos, F.T., Leite, B.K.V. (2022). Effects of aeration and season on the composting of slaughterhouse waste. *Environmental Technology & Innovation*, 27, 102505. https://doi.org/10.1016/j.eti.2022.102505.

Vochozka, M., Maroušková, A., Šuléř, P. (2017). Obsolete laws: economic and moral aspects, case study—composting standards. *Science and Engineering Ethics*, 23(6):1667–1672. https://doi.org/10.1007/s11948-016-9831-9.

Vining, M.A., (2002). Bench-Scale Compost Reactors System and The Self Heating Capabilities, Master of Science thesis, Texas A&M University Department of Civil and Environmental Engineering.

Visvanathan, C., Tränkler, J. (2003). Municipal Solid Waste Management in Asia-A Comparative Analysis. Workshop on Sustainable Landfill Management, 3–5 December, 2003; Chennai, India, pp. 3-15.

Wang, K., Mao, H., Li, X. (2018). Functional characteristics and influence factors of microbial community in sewage sludge composting with inorganic bulking agent. *Bio-resource Technology*, 249,527–35.

Wang, Y., Tang, Y., Li, M., Yuan, Z. (2021). Aeration rate improves the compost quality of food waste and promotes the decomposition of toxic materials in leachate by changing the bacterial community. *Bioresource Technology*, 340, 125716. https://doi.org/10.1016/j.biortech.2021.125716.

Wang, N., He Y., Zhao, K., Lin, X., He, X., Chen, A., Wu, G., Zhang, J., Yan, B., Luo L., Xu, D. (2024). Greenhouse gas emission characteristics and influencing factors of agricultural waste composting process: A review. *Journal of Environmental Management*, 354, 120337. https://doi.org/10.1016/j.jenvman.2024.120337.

Waqas, M., Hashim, S., Humphries, U.W., Ahmad, S., Noor, R., Shoaib, M., Naseem, A., Hlaing, P.T., Lin, H.A. (2023). Composting processes for agricultural waste management: a comprehensive review. *Processes*, 11:731.

Washington State University, http://tfrec.cahnrs.wsu.edu/organicag/compost-2/compost-images/compost-systems/. Accessed on 13/10/2021.

WERL (Woods End Research Laboratory) (2005). Interpretation of waste and compost tests. *Journal of the Woods End Research Laboratory*, 1(4), 1–5.

WERL (Wood End Research Laboratory) (2000). Compost quality standards & guidelines. Final Report.

Whalen, S.C., Reeburgh, W.S., Sandbeck, K.A. (1990). ‘Rapid methane oxidation in a landfill cover soil’. *Applied and Environmental Microbiology*, 56(11), 3405–3411. https://doi.org/10.1128/aem.56.11.3405-3411.1990.

WRAP (2021). In-vessel composting. https://wrap.org.uk/resources/guide/vessel-composting-ivc. Accessed on 5/10/2021.

WRAP (The Waste and Resources Action Program (2002). Comparison of Compost Standards Within the EU, North America and Australasia: Main Report. Banbury, United Kingdom.

Wei, Y., Zhao, Y., Lu, Q., Cao, Z., Wei, Z. (2018). Organophosphorus-degrading bacterial community during composting from different sources and their roles in phosphorus transformation. *Bioresource Technology*, 264, 277–284.

Wei, Y., Li, J., Shi, D., Liu, G., Shimaoka, T. (2017). Environmental challenges impeding the composting of biodegradable municipal solid waste: A critical review. *Resources, Conservation and Recycling*, 122, 51-65.

Widyatmika, M.A., Bolia, N.B. (2023). Understanding citizens’ perception of waste composting and segregation. *Journal of Material Cycles and Waste Management*, 25:1608–1621. https://doi.org/10.1007/s10163-023-01636-5.

Wikipedia (2022). Climate of Delhi. https://en.wikipedia.org/wiki/Climate_of_Delhi. Accessed 2/12/2022.

Wilson, D.C. (2007). Development drivers for waste management. *Waste Management & Research*, 25, 198–207.

World Economic Forum (2024). Circular transformation of industries: the role pf partnership, white paper. Geneva, Switzerland.

XACT-Systems. https://xactsystemscomposting.com/images/. Accessed 13/10/2021

Xiu-lan, Z., Bi-qiong, L., Jiu-pai, N.I., De-ti, X.I.E. (2016). Effect of four crop straws on transformation of organic matter during sewage sludge composting. *Journal of Integrative Agriculture*, 15, 232-240.

Yang M., Chen L., Wang J., Msigwa G., Osman A.I., Fawzy S., Rooney D.W., Yap P.S. (2023). Circular economy strategies for combating climate change and other environmental issues. *Environmental Chemistry Letters*, 21:55–80. 80. https://doi.org/10.1007/s10311-022-01499-6.

Yang, H., Zhang, H., Qiu, H., Anning, D.K., Li M., Wang, Y., Zhang, C. (2021). Effects of C/N Ratio on Lignocellulose Degradation and Enzyme Activities in

Aerobic Composting. *Horticulturae*, 7(11), 482. https://doi.org/10.3390/horticulturae7110482.

Yang, L., Z. Chen, T., Liu, Z., Gong, Y., Yu, Wang, J. (2012). Global trends of solid waste research from 1997 to 2011 by using bibliometric analysis. *Scientometrics*, 1, 1-14.

Yasmin, N., Jamuda, M., Panda, A.K., Samal, K., Nayak, J.K. (2022). Emission of greenhouse gases (GHGs) during composting and vermicomposting: Measurement, mitigation, and perspectives. *Energy Nexus*, 7, 100092, https://doi.org/10.1016/j.nexus.2022.100092.

Ye, Z., Xiao, Z., Gong, Q., Peng, Y., Li, J., Zhao, X., Zhang, B., Wang, S. (2024). Preparation of landscape gardening soil using undersized fraction from aged MSW by EDTA or citric acid coupled with humic acid: Effect assessment, properties, and optimization. *Journal of the Air & Waste Management Association*, 74(3). https://doi.org/10.1080/10962247.2023.2290727.

Yeo, D., Dongo, K., Mertenat, A., Lüssenhop, P. Körner, I., Zurbrügg, C. (2020). Material Flows and Greenhouse Gas Emissions Reduction Potential of Decentralized Composting in Sub-Saharan Africa: A Case Study in Tiassalé, Côte d'Ivoire. *International Journal of Environmental Research and Public Health*, 17, 7229; doi:10.3390/ijerph17197229.

Yılmaz, H., Ozyakar, H.D., Dag˘, M.M. (2024). Exploratory factor analysis of manure utilization for sustainable dairy farming: Evidence from crop-dairy farming systems in Turkey. *Waste Management Bulletin*, 1,164–171. http://creativecommons.org/licenses/by-nc-nd/4.0/.

Yin, J., Xie, M., Yu, X., Feng, H., Wang, M., Zhang, Y., Chen, T. (2024). A review of the definition, influencing factors, and mechanisms of rapid composting of organic waste. *Environmental Pollution*, 342, 123125. https://doi.org/10.1016/j.envpol.2023.123125.

Yoshida, M. (2018). Situation of Municipal Solid Waste Management in African Cities – An Interpretation of the Information provided by the First ACCP Meeting. The Second Meeting of African Clean Cities Platform (ACCP). Discussion paper.

Yuan, J., Chadwick, D., Zhang, D., Li, G., Chen, S., Luo, W., Du, L., He, S., Peng, S. (2016). Effects of aeration rate on maturity and gaseous emissions during sewage sludge composting, *Waste Management*, 56, 403-410. https://doi.org/10.1016/j.wasman.2016.07.017.

Zgallai, H., Zoghlami, R.I., Annabi, M. Zarrouk, O., Jellali, S., Hamdi, H. (2024). Mitigating soil water deficit using organic waste compost and commercial water retainer: a comparative study under semiarid conditions. *Euro-Mediterranean Journal for Environmental Integration*, 9, 377–391. https://doi.org/10.1007/s41207-023-00437-4.

Zaulfikar, Sudarno, Budiyono (2020a). Landfill mining dominated by organic solid waste: a review on its benefits, potential and challenges to recovery landfills in growing cities in Indonesia. *IOP Conf. Series: Materials Science and Engineering 845, 012052*. http://doi:10.1088/1757-899X/845/1/012052.

Zaulfikar, A., Sudarno, U., Budiyono (2020b). Analysis of Optimum Garbage Heaps Age on Recovery of Landfills Dominated by Organic Solid Waste. *Journal of Ecological Engineering*, 21(8), 91-98. https://doi.org/10.12911/22998993/127092.

Zhou,Y., Zhou, Q., Gan, S., Wang, L. (2018). Factors affecting farmers' willingness to pay for adopting vegetable residue compost in North China. ActaEcologicaSinica, In press, corrected proof, Available online 18 May 2018. doi.org/10.1016/j.chnaes.2018.04.001.

Zhou, G., Qiu, X., Chen, L., Zhang, C., Ma, D., Zhang, J. (2019). Succession of organics metabolic function of bacterial community in response to addition of earthworm casts and zeolite in maize straw composting. *Bioresource Technology*, 280, 229–238.

Zhu, Da, Asnani, P.U., Zurbrügg, C., Anapolsky, S., Mani, S. (2008) Improving municipal solid waste management in India: A sourcebook for policy makers and practitioners. Washington, DC, The World Bank.

Zeidan, K, Daas, G, Awwad, Y. (2020). Municipal bonds as a tool for financing capital investment in local government units in Palestine. *Investment Management and Financial Innovations*, 17 (1), 213-226.

Zewdie, I., Reta, Y. (2021). Review on the role of soil macronutrient (NPK) on the improvement and yield and quality of agronomic crops. Direct Research. *Journal of Agriculture and Food Science*, 9(1), 7-11. DOI: https://doi.org/10.26765/DRJAFS23284767.

Zhang, H., Li, G., Gu, J., Wang, G., Li, Y., Zhang, D. (2016). Influence of aeration on volatile sulfur compounds (VSCs) and NH_3 emissions during aerobic composting of kitchen waste. *Waste Management*, 58, 369-375. https://doi.org/10.1016/j.wasman.2016.08.022.

Zurbrügg, C., Caniato, M, Vaccari, M. (2014). How assessment methods can support solid waste management in developing countries - a critical review. *Sustainability*, 6, 545-570.

ANNEXES

Annex I: Questionnaire used for data collection

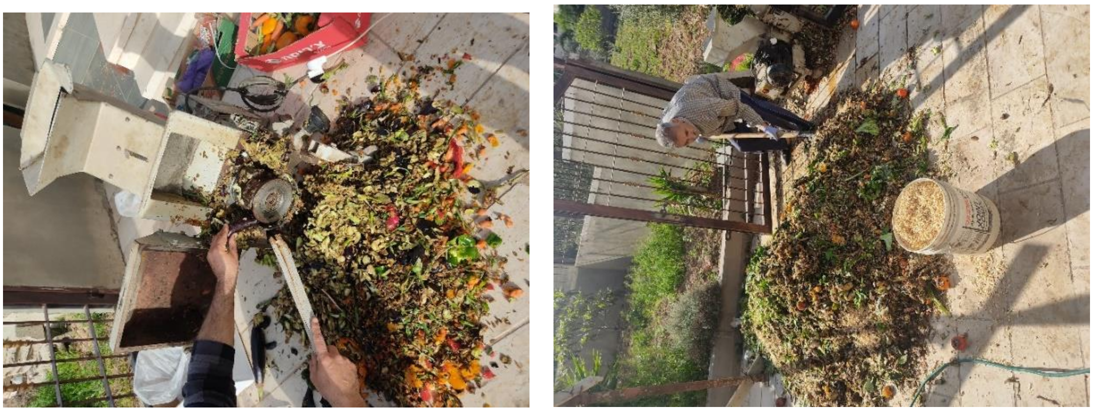
Variable No.	**Variable Description**
V01	Type of local authority: 1- Municipality 2- VC 3- Joint service council (JCSPD & JSC)
V02	Classification of the local authority: 1- A 2- B 3- C 4- Not classified
V03	No. of population served the local authority: _____________
V04	Does the local authority provide SWM collection service? 1- Yes 2- NO
V05	If the answer of V04 is NO, who is providing the collection service? ____
V06	What is the total solid waste quantity generated per month? ____________
V07	Are there debts on the local authority? 1- Yes 2- NO
V08	How much the monthly cost of SW collection? ___________
V09	How much the monthly cost of SW disposal? ___________
V10	How much the tariff (fees) of the SW service per household _____________, if you have another tariff system, please indicate __________________
V11	What is the rate of fee collection? 1- Less or equal 20% 2- (21 – 40)% 3- (41 – 60)% 4- (61 – 80)% 5- (81 – 100)%
V12	How many SW collection vehicles do you have? ____________
V13	How many SW workers do you have? _____________
V14	Do you plan to apply SW separation at the source? 1- Yes 2- NO
V15	Do you plan to compost the organic fraction of MSW? 1- Yes 2- NO
V16	If the answer of V15 is NO, why? Please tick the following if you think these are challenges (the answer could be more than one): ☐ We haven’t knowledge and experience in composting;

	☐ Waste sorting at the source is difficult to apply due to absence of awareness; ☐ We haven't the proper equipment and machinery to conduct composting; ☐ The available refuse collection vehicles are not enough to collect the waste fractions separately; ☐ There is no market for the compost; ☐ There are no incentives from the government; ☐ Composting is not forced by law; ☐ SW composting is costly; ☐ Unavailable proper place for composting; ☐ Lack of financial resources; ☐ Farmers may not accept use compost produced from MSW; ☐ It is not feasible due to the small quantity of organic waste generated; ☐ Tariff system was built on waste collection and disposal only; ☐ The rate of SW fees collection is low.
V17	Do you think that composting of organic fraction can contribute to the reduction of environmental pollution? 1- Yes 2- NO
V18	In your opinion, do you think that composting the organic fraction can contribute to SW reduction? 1- Yes 2- don't know 3-NO
V19	Do you have a proper machinery to conduct composting? 1- Yes 2- No
V20	Do you have enough refuse collection vehicles to collect SW fractions separately? 1- Yes 2- NO
V21	Do you have appropriate area of land to use it for composting? 1- Yes 2- NO
V22	Have you enough financial resources to employ modern technology in SW composting? 1- Yes 2- NO
V23	Do you have the financial capacity to conduct composting? 1- Yes 2- Yes, but limited capacity 3- No
V24	Do you receive financial support from the government to develop SWM such as waste reduction through composting?

	1- Yes 2- Sometimes 3- NO
V25	Are you familiar with composting systems? 1- Yes 2- NO
V26	If the answer of V25 is yes, which of the following composting systems do you prefer? 1- Pile composting 2- Windrow composting 3- full mechanical controlled system
V27	If a new rapid composting system is developed, have you the ability to accept and use this system for SW composting? 1- Yes 2- NO
V28	Has any of your staff attended training on compost production? 1- Yes 2- NO
V29	Does any of your staff have previous experience in compost production? 1- Yes 2- NO
V30	Have you conducted awareness on organic waste composting in the community? 1- Yes 2- NO
V31	In case the local authority has started SW composting program, do you think that the residents will participate through sorting of organic waste at the source? 1- Yes 2- Yes, but Partially 3- NO
V32	Do you think that compost produced from municipal SW can have good market in Palestine? 1- Yes 2- don't know 3- NO
V33	Do you think that farmers will accept to use compost produced from municipal SW in agriculture? 1- Yes 2- don't know 3- NO
V34	Are you familiar with SWM bylaw? 1- Yes 2- NO
V35	Do you think that SW composting is within your local authority responsibilities? 1- Yes 2- NO

Annex II: Photos

Experiment 1



Raw material preparation and mixing

Filling the compost device

Monitoring the composting process

Final compost

Experiment 2

Raw material preparation

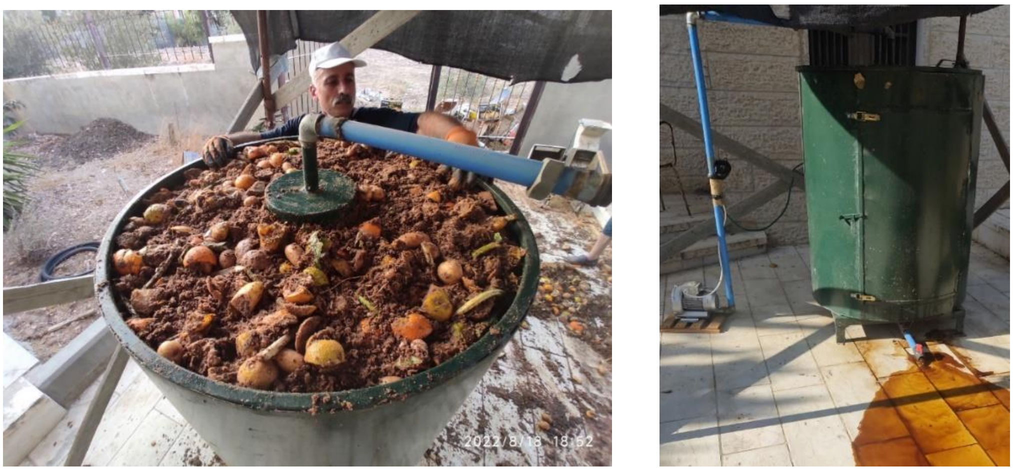
Raw materials mixing and filling the compost bin

Compost process monitoring

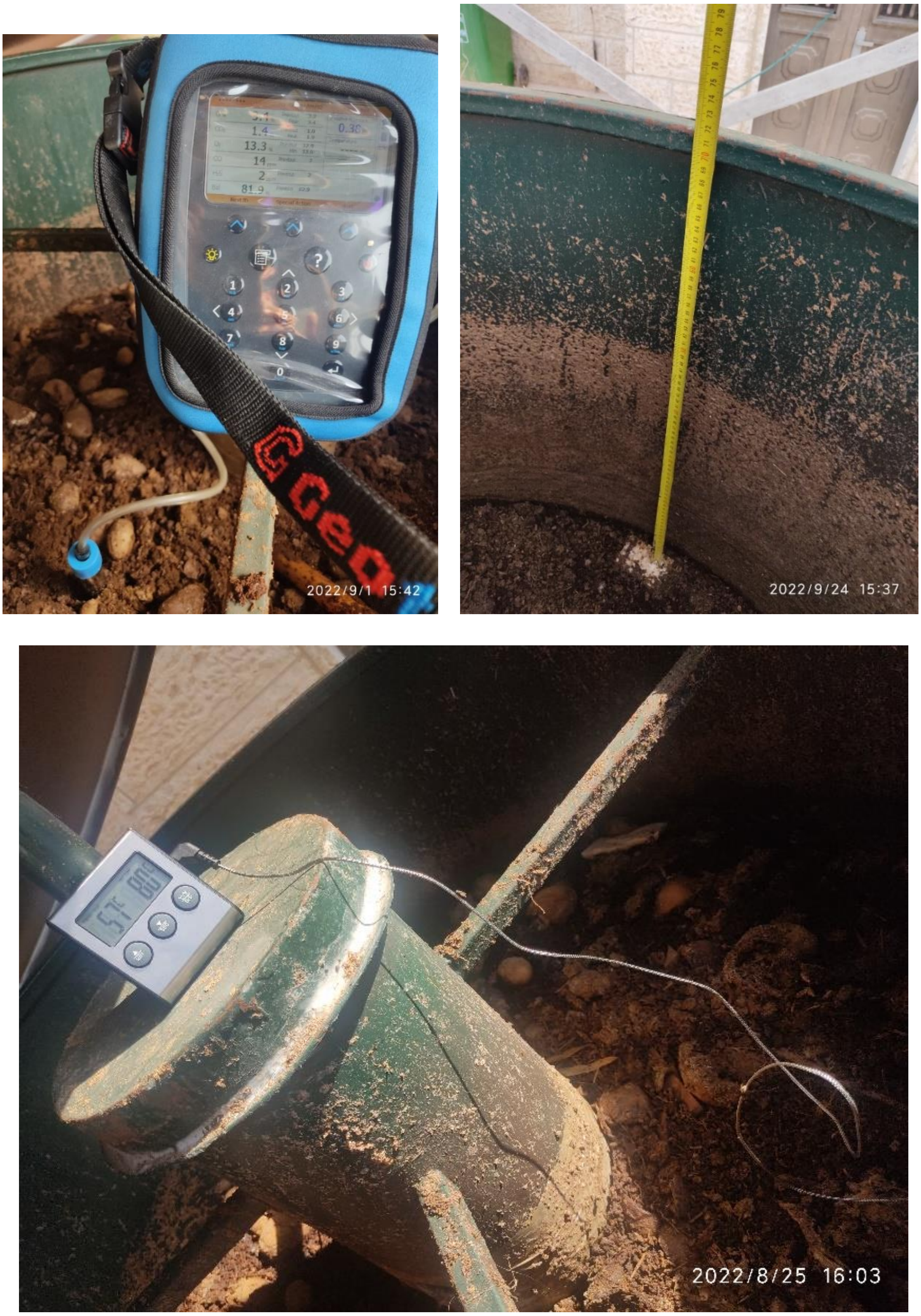
Final compost

Experiment 3

Preparation and mixing of the raw materials



Filling the compost device



Monitoring the composting process

Final compost

Annex III: List of Publications

1- Al-Sari', M.I., Haritash, A.K. (2023). Managing the Organic Municipal Waste in Palestine: Linking Policy, Practice and Stakeholders' Attitude Towards Composting. *Journal of the Air & Waste Management Association*, 73(1): 80-93. https://doi.org/10.1080/10962247.2022.2141919.

2- Al-Sari', M.I., Haritash, A.K. (2024). A logistic regression model to facilitate setting of organic waste composting policy for sustainable waste management. *Environment, Development and Sustainability*. https://doi.org/10.1007/s10668-024-04934-6.

3- Al-Sari', M.I., Haritash, A.K. (2024). A Multi-Criteria Approach to Test and Evaluate the Efficiency of Two Composting Systems Under Two Different Climates. *Journal of the Air & Waste Management Association*, 74(8): 540-555. https://doi.org/10.1080/10962247.2024.2365707.

4- Al-Sari', M.I., Haritash, A.K. (2024). Municipal Organic Solid Waste Management in the Concept of Urban Mining and Circular Economy: A Model from Palestine. *Journal of Material Cycles and Waste Management*, 26, 2980–2995. https://doi.org/10.1007/s10163-024-02018-1.

5- Al-Sari', M.I., Haritash, A.K. (2024). Review of Municipal Organic Waste Composting: Methods, Process Parameters, and Climate Benefits. *Environmental Engineering and Management Journal*. Accepted for publication.

Annex IV: List of Conferences

1- Al-Sari', M.I., Haritash, A.K. (2022). Organic Solid Waste Composting for Sustainable Agriculture: Experience from Palestine. Seminar on Modern Pollution Abatement Techniques to Achieve Sustainability in Industries. Organized by The Institution of Engineers (India) in association with Delhi Technological University and Perfact Group, August 5-6, 2022, New Delhi, India.

2- Al-Sari', M.I., Haritash, A.K. (2023). A Systems thinking approach to determine the factors affecting the attitude of local authorities towards composting: the case of southern West Bank. The First International Conference & Expo on Innovation and Sustainability in Engineering & Technology (ICEISET-23), June 14-15, 2023. An-Najah National University, Nablus, West Bank Palestine.

3- Participation in the conference "International conference on recent advances in chemical and environmental sciences (RACES – 2024)". Department of Chemistry and Environmental Science, Faculty of Science, SGT University, Gurugram. February 23rd – 24th, 2024.

Annex V: Curriculum Vitae

☐ Personal Information

Name	Majed Ibrahim Issa Al-Sari’
Date of Birth	01.02.1975
Country	Palestine

☐ Education

Year	Institution	Degree
2021 - 2024	Delhi Technological University, India	PhD. Scholar, Environmental Engineering
2007 – 2010	Birzeit University, Palestine	Master Degree, Water and Environmental Engineering
1993 – 1998	Birzeit University, Palestine	BSc. Degree, Civil Engineering

☐ Membership in Professional Associations

Palestine and Jordan Engineers Association

☐ Publications

Journal Articles:

1- **Al-Sari’, M. I.**, Haritash, A.K. (2024). Municipal Organic Solid Waste Management in the Concept of Urban Mining and Circular Economy: A Model from Palestine. *Journal of Material Cycles and Waste Management*, 26, 2980–2995. https://doi.org/10.1007/s10163-024-02018-1.

2- **Al-Sari’, M. I.**, Haritash, A.K. (2024). A logistic regression model to facilitate setting of organic waste composting policy for sustainable waste management. *Environment, Development and Sustainability*. https://doi.org/10.1007/s10668-024-04934-6.

3- **Al-Sari’, M. I.**, Haritash, A.K. (2024). A Multi-Criteria Approach to Test and Evaluate the Efficiency of Two Composting Systems Under Two Different Climates. *Journal of the Air & Waste Management Association*. https://doi.org/10.1080/10962247.2024.2365707.

4- **Al-Sari’, M.I.**, Haritash, A.K. (2024). Review of Municipal Organic Waste Composting: Methods, Process Parameters, and Climate Benefits. Environmental Engineering and Management Journal. Accepted for publication.

5- **Al-Sari’, M.I.**, Haritash, A.K. (2023). Managing the Organic Municipal Waste in Palestine: Linking Policy, Practice and Stakeholders’ Attitude Towards Composting. *Journal of the Air & Waste Management Association*, 73(1): 80-93.

6- Al-Khatib, I., Anayah, F., **Al-Sari’, M. I.**, Al-Madbouh, S., Salahat, J.I., Jararaa, B.Y.A. (2023). Assessing Physiochemical Characteristics of

Agricultural Waste and Ready Compost at Wadi Al-Far'a Watershed of Palestine. *Journal of Environmental and Public Health*, 23, 6147506, 13.

7- Al-Khatib, I.A., **Al-Sari', M. I.**, Kontogianni, S. (2020). Scavengers' contribution in solid waste management sector in Gaza Strip, Palestine. *Journal of Environmental and Public Health*, 192:354.

8- Al-Khatib, I.A., **Al-Sari', M. I.**, Kontogianni, S. (2020). Assessment of Occupational Health and Safety among Scavengers in Gaza Strip, Palestine. *Environmental Monitoring and Assessment*, 1 – 9.

9- Salah, M.M., **Al-Sari', M. I.**, Khatib, I.A., Kontogianni, S. (2019). Local residents' perception of landfill impacts in Palestine: the case of Zahrat Al-Finjan landfill. *Journal of Material Cycles and Waste*, DOI: 10.1007/s10163-019-00959-6.

10- Al-Madbouh, S., Al-Khatib, I. A., **Al-Sari', M. I.**, Salahat, J., Jarraraa. B., Y., A. (2019). Socioeconomic, agricultural, and individual factors influencing farmer's perceptions and willingness of compost production and use: an evidence from Wadi Al-Far'a watershed Palestine. *Environmental Monitoring and Assessment*, 191: 209.

11- **Al-Sari', M. I.**, Sarhan, M. A., Al-Khatib, I. A. (2018). Assessment of compost Quality and usage for agricultural use: A case study of Hebron, Palestine. *Environmental Monitoring and Assessment*, 190:223. https://doi.org/10.1007/s10661-018-6610-x.

12- Al-Khateeb, J. A., **Al-Sari', M. I.**, Al-Khatib, I. A., Anayah, F. (2017). Factors affecting the sustainability of solid waste management system – the case of Palestine. *Environmental Monitoring and Assessment*, 189:93. DOI 10.1007/s10661-017-5810-0.

13- Al-Khatib, I.A., Kontogianni, S., Al Rajabi, H., **Al-Sari', M. I.** (2014). Current trends in solid waste management in higher education institutions; the case of west bank region, Palestine. *Environmental Engineering and Management Journal*, 17 (8): 1887 1896.

14- Al-Khatib, I.A., Kontogianni, Abu Nabaa,H., Alshami, N., S., **Al-Sari', M. I.** (2014). Public perception of hazardousness caused by current trends of municipal solid waste management. *Waste Management*, 36: 323 -330.

15- Al-Khatib, I.A., Ajlouny, H., **Al-Sari', M. I.**, Kontogianni, S. (2014). Residents' concerns and attitudes toward solid waste management facilities in Palestine: A case study of Hebron district. *Waste Management & Research*, 32(3), 228–236.

16- **Al-Sari', M. I.**, Al-Khateeb, I. A. (2012). Workers' Safety in the Construction Industry in Southern West Bank of Palestine. *Eastern Mediterranean Health Journal*, 18 (10): 1028 – 1033.

17- **Al-Sari’, M. I.**, Al-Khateeb, I. (2012). A Study on the Attitudes and Behavioural Influence of Construction Waste Management in Occupied Palestinian Territory. *Waste Management and Research*, 30 (2): 122 – 136.

Books:

1- Al-Khateeb, A., Al-Khatib, I.A., **Al-Sari, M.I.**, Anayah, F. (2019). Chapter 4: Municipal Solid Waste Management in Two Cities of Palestine: A Comparative Study. Book title: Advances in Waste-to-Energy Technologies. Edited By Rajeev Pratap Singh, Vishal Prasad, Barkha Vaish, 1st Edition, DOI: https://doi.org/10.1201/9780429423376, 288 pages. eBook ISBN 9780429423376. Publisher: Taylor & Francis group.

2- **Al-Sari', M. I.**, Al-Khatib, I. (2011). Workers safety in the construction industry in developing countries: southern West Bank Palestine as a case study. Lambert Academic Publishing (LAP).

3- **Al-Sari', M., I.**, Al-Khatib, I. (2011). Behavioral and attitudes factors in construction waste management: southern West Bank – Palestine as a case study. Lambert Academic Publishing (LAP).

Conferences:

1- **Al-Sari’, M.I.**, Haritash, A.K. (2023). A Systems thinking approach to determine the factors affecting the attitude of local authorities towards composting: the case of southern West Bank. The First International Conference & Expo on Innovation and Sustainability in Engineering & Technology (ICEISET-23), June 14-15, 2023. An-Najah National University, Nablus, West Bank Palestine.

2- **Al-Sari’, M.I.**, Haritash, A.K. (2022). Organic Solid Waste Composting for Sustainable Agriculture: Experience from Palestine. Seminar on Modern Pollution Abatement Techniques to Achieve Sustainability in Industries. Organized by The Institution of Engineers (India) in association with Delhi Technological University and Perfact Group, August 5-6, 2022, New Delhi, India.

3- **Al-Sari', M. I.** (2019). Pile composting efficiency in organic waste management. The second international conference on civil engineering (ICCE), November 25th and 26th, 2019. Bethlehem, West Bank - Palestine

☐ **Employment Records:**

Year	Organization / Company	Position
Jan. 2009 – ongoing	The Joint Service Council for Solid Waste Management for Hebron and Bethlehem Governorates (JSC-H&B)	Head of the Engineering Unit
July 2003 – June 2008	Oxfam GB	Project Officer / Engineering

Dec. 2002 – June 2003	CHF-International	Senior Engineer
Dec. 2001- Oct. 2002	Palestinian Hydrology Group (PHG)	Project Coordinator
Feb. 2001- July 2001	United Nations Development Program (UNDP)	Site Engineer
Aug. 1998 – Jan. 2001	The Building Center for Materials Testing and Engineering Studies	Technical Manager

☐ **Consultation Assignments:**

Year	Organization / Company	Position
June 2022 – Oct. 2024	SUIS-NFB (Turkish Consortium), Palestine Office	Environmental and Social Specialist for the project "Water Security Development- Gaza Central Desalination Program: Associated Works Project Phase I (AWP-Phase 1) (2022- 2024).
June 2020 – July 2021	The Joint Council for Services, Planning and Development (JCSPD), Dura, Palestine	Environmental Expert for the project "Construction of Khallet Al-Sabbar Solid Waste Transfer Station".
March – Apr. 2019	GFA Consulting Group GmbH, Palestine Office	Environmental Expert for the project: "Treated wastewater reuse in Nablus north-west area - West Bank/Palestine"
Dec. 2018 – Sept. 2024	Cowater International, Palestine Office	Environmental Specialist for the project "Generation Revenue Opportunities for Women Youth (GROW)".
Sept. 2018 – May 2019	Consolidated Consultants, Palestine	Environmental Expert for the project "Design of Military Sport City".
Apr. 2015 - Jan. 2018	GFA Consulting Group GmbH, Palestine Office	Water Expert for the project "Rehabilitation of agricultural water ponds and canal in the West Bank".
Aug. 2015 – Jan. 2016	Consolidated Consultants, Palestine	Environmental Expert for the project "Construction of Rehabilitation Centre (Prison) and Police Station".
Jan. 2013- Dec. 2015	Consolidated Consultants, Palestine	Environmental Specialist for the Municipal Development Program – MDP (Phase II- cycle 1).
Aug. 2011 – Oct. 2023	Union of Agricultural Work Committees – UAWC, Palestine	Water and Wastewater Specialist for all wastewater and water related activities.