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Haniyeh Jalalipour

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und Stoffstromwirtschaft

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Dissertation

HERAUSGEBER

Prof. Dr. mont. Michael Nelles
Universität Rostock
Agrar- und Umweltwissenschaftliche Fakultät
Professur Abfall- und Stoffstromwirtschaft
18051 Rostock

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Universität Rostock
Universitätsbibliothek, Schriftentausch,
18051 Rostock
Tel.: 0381/498-8639, Fax: 0381/498-8632
E-Mail: tausch.ub@uni-rostock.de

Universität Rostock
Agrar- und Umweltwissenschaftliche Fakultät
Professur Abfall- und Stoffstromwirtschaft
Justus-von-Liebig-Weg 6, 18059 Rostock
Tel.: 0381/498-3401, Fax: 0381/498-3402

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Vorwort

Feste Siedlungsabfälle stellen im Iran ein großes Umweltproblem dar. Systeme zur Bewirtschaftung fester Abfälle haben mit vielen Schwierigkeiten zu kämpfen, wie z.B. dem raschen Bevölkerungswachstum in den städtischen Zentren, dem Mangel an strategischer Planung, dem Fehlen geeigneter Entsorgungseinrichtungen, dem Mangel an ausgebildeten und qualifizierten Arbeitskräften, der geringen technischen Erfahrung und den unzureichenden finanziellen Ressourcen, um nur einige zu nennen. Die Bereitstellung angemessener Abfallbewirtschaftungsdienste ist für die meisten Entwicklungsländer aufgrund der möglichen Auswirkungen auf die öffentliche Gesundheit und die Umwelt ein wichtiges Anliegen.

Im Iran, wo eine getrennte Sammlung von Haushaltsabfällen nicht effizient praktiziert wird und Deponien die wichtigste Entsorgungsmethode im Abfallwirtschaftsplan des Landes sind werden bis zu 80 % der iranischen Abfälle ohne Vorbehandlung auf Deponien abgelagert. Aufgrund des hohen organischen Anteils und des hohen Wassergehalts entstehen große Mengen an Methangas. Nur 5-10 % der wiederverwertbaren Materialien werden aus dem Abfallstrom zurückgewonnen, und es gibt im Iran keine groß angelegten oder staatlich betriebenen Sortier- oder Recyclingprogramme.

Vor diesem Hintergrund hat Frau Jalalipour ein interessantes und praktisches Forschungsthema für ihr Promotionsprojekt gewählt, das sich mit der Ermittlung möglicher Behandlungsansätze befasst, die vor Ort für eine nachhaltige Bewirtschaftung organischer fester Siedlungsabfälle im Iran übernommen und umgesetzt werden könnten.

Die Forschungsarbeit wurde von der Solid Waste Management Organization (SWMO) der Stadtverwaltung von Shiraz finanziert, die alle Voraussetzungen für die Durchführung der Studie in Bezug auf Rohmaterialien, Arbeitsbereich, Maschinen, Ausrüstung, Personal und Laboranalysen bereitstellte. Frau Jalalipour schloss ihre Arbeit an der Universität Rostock ab und reichte ihre Dissertation im März 2021 an der Fakultät für Agrar- und Umweltwissenschaften ein.

Die wissenschaftliche Bedeutung der vorliegenden Arbeit ergibt sich nach Ansicht der Gutachter insbesondere aus den folgenden Punkten:

- Frau Jalalipour hat sich in den letzten 4,5 Jahren intensiv mit dem sehr praxisnahen Thema der organischen Abfallbehandlung beschäftigt. Durch die Bewertung der aktuellen Situation der kommunalen Abfallwirtschaft in der Beispielstadt Shiraz und den Vergleich mit angewandten Lösungen zur Behandlung organischer Abfälle aus Deutschland entwickelte Frau Jalalipour eine Strategie für die Behandlung organischer Abfälle in der Zielregion.

- Auf dieser Grundlage hat Frau Jalalipour umfangreiche Untersuchungen zur Kompostierung von gemischten und getrennten Abfallströmen durchgeführt und den wissenschaftlichen Nachweis erbracht, dass die Herstellung von Kompost der Klasse A aus iranischen, getrennten Abfällen möglich ist. Darüber hinaus konnten durch ihre Untersuchungen nachhaltige Konzepte für den Iran angepasst werden, die auf die gesamte Versorgungskette der Bewirtschaftung organischer fester Abfälle anwendbar sind.

Abschließend wünschen wir Ihnen eine fachlich interessante Lektüre der Dissertation von Dr.-Ing. Haniyeh Jalalipour.

Mit freundlichen Grüßen

Prof. Dr.-Ing. Christina Dornack
Technische Universität Dresden
Institute of Waste Management
and Circular Economy

Prof. Dr. Neematollah Jaafarzadeh
Ahvaz Jundishapur University of
Miedical Sciences,
Toxicology Research Centre

PD Dr. Satyanarayana Narra
Universität Rostock
Professur Abfall- und Stoffstromwirtschaft

Preface

Municipal solid waste in Iran is a major environmental problem. Solid waste management systems must deal with many difficulties such as rapid population growth in urban centers, lack of strategic planning, lack of proper disposal facilities, limited trained and skilled manpower, low technical experience and insufficient financial resources to name a few. Offering adequate solid waste management services is a critical concern for most developing countries due to it's potential impact on public health and the environment.

In Iran, where separate collection is not practiced efficiently and landfills are the primary disposal method in the country's waste management plan up to 80% of Iran's waste is landfilled without being pre-treated. These generate high levels of methane gas due to the high amount of organic content and the high water content. Only 5-10 % of recyclable material is recovered from the waste stream and large scale or government run sorting or recycling schemes are not available in Iran.

Against this background, Mrs Jalalipour has chosen an interesting and practical research topic and her PhD project in dealing with the identification of possible treatment approaches that could be adopted and implemented locally for sustainable organic municipal solid waste management in Iran.

The research work was funded by Solid Waste Management Organization (SWMO) of Shiraz municipality by providing all the requirements needed to perform the study in terms of raw input materials, working area, machineries, equipment, staff and laboratory analysis. Mrs. Jalalipour finalized her thesis at the University of Rostock and submitted her dissertation to the Faculty of Agricultural and Environmental Sciences in March 2021.

In the view of the reviewers, the scientific significance of the present work results in particular from the following points:

- Mrs. Jalalipour has worked intensively on the very practical topic of organic waste treatment for the past 4,5 years. By evaluating the current situation of muncipal solid waste management practices in Shiraz, as an exemplary city, and comparing them to applied organic waste treatment solutions from Germany, Mrs. Jalalipour developed a strategy for the organic waste treatment in the targeted area.

- On this basis, Mrs. Jalalipour has conducted extensive research on the composting treatment of mixed and source-separated waste streams, and provided scientific evidence that the production of class A compost is possible from Iranian source separated wastes. In addition, her investigations were able to adapt sustainable concepts to Iran that are applicable to addressing the whole supply chain of organic solid waste management.

Finally, we wish you an interesting technical read of the dissertation of Dr.-Ing. Haniyeh Jalalipour.

With best regards

Prof. Dr.-Ing. Christina Dornack
Technische Universität Dresden
Institute of Waste Management
and Circular Economy

Prof. Dr. Neematollah Jaafarzadeh
Ahvaz Jundishapur University of
Miedical Sciences,
Toxicology Research Centre

PD Dr. Satyanarayana Narra
Universität Rostock
Professur Abfall- und Stoffstromwirtschaft

Universität Rostock

Traditio et Innovatio

Department of Waste and Resource Management

Universität Rostock

SUSTAINABLE MUNICIPAL ORGANIC WASTE MANAGEMENT IN SHIRAZ, IRAN

DISSERTATION

Submitted in fulfilment of the requirements of

The Academic Board of Rostock University

Faculty of Agriculture and Environmental Sciences

For the Degree of DOCTOR of Engineering (Dr. Eng.)

HANIYEH JALALIPOUR

Born in Shiraz 1988, Islamic Republic of Iran

Rostock, Germany

2021

Gutachter:

1. Gutachter:
   PD Dr. rer. nat. habil. Satyanarayana Narra

   Universität Rostock, Department of Waste and Resource Management

2. Gutachter:
   Prof. Dr.-Ing. Christina Dornack

   Technische Universität Dresden, Institute of Waste Management
   and Circular Economy

3. Gutachter:
   Prof. Dr. Neematollah Jaafarzadeh

   Toxicology Research Centre, Ahvaz Jundishapur University of Medical Sciences

   Ahvaz, Iran.

Tag der Einreichung: 14.04.2021

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Declaration of Independency

I hereby declare that the present work is prepared and submitted by me independently without any assistance other than from those cited and acknowledged in the thesis.

Rostock, 01. 04. 2021

Haniyeh Jalalipour

ACKNOWLEDGMENT

The research work was funded by Solid Waste Management Organization (SWMO) of Shiraz municipality by providing all the requirements needed to perform the study in terms of raw input materials, working area, machineries, equipment, staff and laboratory analysis.

SUMMARY

The purpose of this thesis is to examine the Municipal Solid Waste Management (MSWM) in Iran in order to identify possible treatment approaches that could be adopted and implemented locally for sustainable organic MSWM in the future. This work consists of five phases.

The first phase evaluates the current situation of MSWM practices in Shiraz, Iran. In this phase, a comprehensive overview of the current situation of the SWM system in the study area is undertaken ***(Chapter 2)***.

The second phase maps the functional key factors of the state-of-the-knowledge in the field of organic waste treatment and disposal in Germany. The practiced concept in Germany is employed in this research as a blueprint to set up new applicable strategies in the targeted area ***(Chapter 3)***.

The third phase assesses the compost derived from mixed and source-separated waste streams. The study explores the physical and chemical properties of compost made from different bio-waste raw materials. The produced compost is monitored in terms of moisture content, bulk density, pH, Electrical Conductivity (EC), total organic carbon, total organic matter, total nitrogen, total phosphorus, total potassium and C/N ratio, heavy metal concentrations and germination index. Final product quality is examined and assessed against the quality specifications of the German and Iranian standards. Final product of source-separated organics appears to be stable and considered as class A, making it suitable for cultivation of any agricultural crops. In the case of the mixed waste compost, more energy and measures were required to secure a quality final product **(Chapter 4)**.

The fourth phase adapts sustainable concepts that are applicable to addressing the whole supply chain of organic SWM systems. It draws up the functional management and treatment aspects: legal, institutional, financial, technical and capacity building as well as the involvement of the stakeholders concerned. Practically, the designed conceptualization model produces four approaches: scaling-up separate collected and high quality organic waste, eco-treatment concepts for mixed and separated organic waste streams, setting up technical adjustments to the pre-treatment process as well as the mitigations needed for handling leachate and providing the guidelines for final product quality assurance and marketability **(Chapter 5).**

The fifth phase examines the approaches to provide the ideal conditions during dry seasons. Four composting piles are monitored against temperature and moisture in summer. Different quality and amounts of irrigation water are applied. The chemical properties of the compost produced (moisture content, pH, EC, total organic matter, total nitrogen, NH_4^+ and C/N ratio) is assessed using lab analyses. The relationship between different parameters is outlined and the ideal condition is modeled using statistical analyses. The findings are used to project the model to the capital cities of Iran's provinces **(Chapter 6)**.

ZUSAMMENFASSUNG

Der Zweck dieser Arbeit ist es, das Management von kommunalem Restmüll (MSW) im Iran zu untersuchen. Dadurch sollen mögliche Behandlungsansätze identifiziert werden, die vor Ort für ein nachhaltiges Management der Organischen Abfälle genutzt werden kann. Diese Arbeit besteht aus fünf Phasen.

In der ersten Phase wird die aktuelle Situation der Siedlungsabfallentsorgung in Shiraz, Iran, bewertet. In dieser Phase wird ein umfassender Überblick über die aktuelle Situation des MSW-Systems im Untersuchungsgebiet erstellt **(Kapitel 2)**.

In der zweiten Phase werden die funktionalen Schlüsselfaktoren des Standes des Wissens im Bereich der Behandlung und Entsorgung organischer Abfälle in Deutschland dargestellt. Das in Deutschland praktizierte Konzept wird in dieser Untersuchung als Blaupause verwendet, um neue anwendbare Strategien für das Zielgebiet zu entwickeln **(Kapitel 3).**

In der dritten Phase wird der aus gemischten und sortenreinen Abfallströmen gewonnene Kompost untersucht. Die Studie untersucht die physikalischen und chemischen Eigenschaften von Kompost, der aus verschiedenen Bioabfall-Rohstoffen hergestellt wurde. Der hergestellte Kompost wird hinsichtlich des Feuchtigkeitsgehalts, der Schüttdichte, des pH-Werts, der elektrischen Leitfähigkeit (EC), des gesamten organischen Kohlenstoffs, der gesamten organischen Substanz, des gesamten Stickstoffs, des gesamten Phosphors, des gesamten Kaliums und des C/N-Verhältnisses, der Schwermetallkonzentrationen und des Keimungs-indexes überwacht. Die Qualität des Endprodukts wird anhand der Qualitätsspezifikationen der deutschen und iranischen Standards für Komposte untersucht und bewertet. Das Endprodukt des sortenreinen Bioabfalls scheint stabil zu sein und wird als Klasse A eingestuft, so dass es für den Anbau jeglicher landwirtschaftlicher Nutzpflanzen geeignet ist. Im Falle des gemischten Abfallkomposts waren mehr Energie und Maßnahmen erforderlich, um ein qualitativ hochwertiges Endprodukt zu sichern **(Kapitel 4).**

Die vierte Phase adaptiert nachhaltige Konzepte, die auf die gesamte Lieferkette von organischen MSW-Systemen anwendbar sind. Sie erarbeitet die funktionalen Management- und Behandlungsaspekte: rechtliche, institutionelle, finanzielle, technische und kapazitätsbildende Aspekte sowie die Einbeziehung der betroffenen Akteure. In der Praxis ergeben sich aus dem entworfenen Konzept vier Ansätze: Skalierung der getrennt, gesammelten hochwertigen organischen Abfälle, Öko-Behandlungskonzepte für gemischte und getrennte organische Abfallströme, Einrichtung von technischen Anpassungen des Vorbehandlungsprozesses sowie die erforderlichen Abhilfemaßnahmen für den Umgang mit Sickerwasser und Bereitstellung der Richtlinien für die Qualitätssicherung und Marktfähigkeit des Endprodukts **(Kapitel 5).**

Die fünfte Phase untersucht Möglichkeiten zur Schaffung idealer Bedingungen während der Trockenzeiten. Vier Kompostierhaufen werden im Sommer auf Temperatur und Feuchtigkeit überwacht. Es werden unterschiedliche Qualitäten und Mengen an Bewässerungswasser

eingesetzt. Die chemischen Eigenschaften des produzierten Komposts (Feuchtigkeitsgehalt, pH-Wert, EC, gesamte organische Substanz, Gesamtstickstoff, NH_4^+ und C/N-Verhältnis) werden bewertet. Die Beziehung zwischen den verschiedenen Parametern wird dargestellt und der Idealzustand wird mit Hilfe statistischer Analysen modelliert. Die Ergebnisse werden verwendet, um das Modell auf die Hauptstädte der Provinzen des Irans zu projizieren **(Kapitel 6).**

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LIST OF ABBREVIATIONS

AD: Anaerobic Digestion

C&D: construction and demolition

Cd: Cadmium

CLO: Compost-Like Output

Cr: Chrome

Cu: Copper

DOE: Department of Environment

EC: Electric Conductivity

EPR: Extended Producer Responsibility

EU: European Union

FYNDP: Five Year National Development Plan

GHG: Greenhouse Gas

GI: Germination Index

Hg: Mercury

HSE: Health, Safety and Environment department

IRR: Iranian Rial

ISWM: Integrated Solid Waste Management

LFG: Landfill Gas

MBT: Mechanical Biological Treatment

MC: Moisture Content

MoA: Ministry of Agriculture (Jihad)

MoE: Ministry of Energy

MoHME: Ministry of Health and Medical Education

MoI: Ministry of Interior

MoIM: Ministry of Industry and Mining

MoP: Ministry of Petroleum

MRF: Materials Recovery Facility

MSW: Municipal Solid Waste

MSWMO: Municipal Solid Waste Management Organization

Ni: Nickel

NWMMP: National Waste Management Master Plan

Pb: Lead

QAO: Quality Assurance Organization

QAS: Quality Assurance System

RDF: Refuse Derived Fuel

SWM: Solid Waste Management

TKN: Total Kjeldahl Nitrogen

UNEP: United Nations Environment Program

Zn: Zinc

1. INTRODUCTION AND PROBLEM STATEMENT

Solid waste management (SWM) is one of the most significant challenges facing urban communities around the world (Bundela et al., 2014). In the last two decades, it has become a major concern (Nandan et al., 2014). Rapidly growing populations, booming economies, rapid urbanization and the rise in community living standards have greatly accelerated the solid waste (SW) generation rate. As waste quantum increases, more effort and capacities are needed to manage it in an environmentally safe manner (Santibanez-Aguilar et al., 2013).

Municipalities are generally responsible for SWM in cities; they should address the challenges by affording an efficient and effective system for their residents. Nevertheless, there are problems beyond their abilities to cope with the immense increases in the volume of SW generated as well as the qualitative changes in its composition. Principally, the incapability of SWM systems results from the lack of financial resources, proper organization, complexity and system multi dimensionality. This status is observed in numerous developing countries worldwide (Guerrero et al., 2013; Marshall & Farahbakhsh, 2013).

In Iran, as a developing country, SW is a major environmental problem. SWM systems must deal with many difficulties: population growth in urban centers, lack of strategic planning, lack of proper disposal facilities, limited trained and skilled manpower, low technical experience and insufficient financial resources, which often cover collection costs, leaving no resources for safe final disposal. Offering adequate SWM services is a critical concern due to its potential impact on public health and the environment.

Mostly, practiced SWM systems are doomed to failure due to the absence of a comprehensive legal and policy framework as well as the shortage of the legal tools to monitor and improve the system efficiently, effectively and sustainability. Enforced legislation is implemented poorly, which decreases the flexibility of the system to overcome the gaps.

The fees collected for managing waste are very low; it covers only 60% of the actual costs in the mega cities and no more than 30% in small cities. The lack of economic feasibly is observed by unequal distribution. As observed in most developing countries, up to 80% of the funds available go to logistics and only 20% remains for treatment. Furthermore, in some cases, the fees go to a central treasury and are distributed with unclear criteria. The funding system for waste management is mainly characterized by the absence of financial incentives and effective cost recovery mechanisms.

From a technical point of view, most of the treatment and disposal approaches were adopted in the past without full understanding of the process, which is attributable to the lack of the know-how and the absence of the local skilled manpower. In fact, there are number of facilities for waste treatment in Iran, many of these facilities face operational problems and some even no longer operate.

Their malfunction results from their mismanagement and the unsuitable technology chosen, which do not work well with the local conditions. All of these issues result in high operating costs and frequent mechanical breakdowns through poor maintenance due to the lack of know-how and waste treatment oriented-background and training of personnel for the operational procedures of the facilities. Simultaneously, the lack of assessment and monitoring tools for the performance of waste treatment technologies and their output quality and utilization are considered some of the main problems.

Landfills are the primary disposal method in the country's waste management plan. Separate collection is still not practiced efficiently in Iran. Municipal solid waste (MSW) is collected as mixed waste containing all kinds of waste including hazardous materials. Up to 80% of it is sent to different controlled landfills and dumping sites without any treatment, which generates high levels of methane gas due to the high amount of organic and water content. Only 5-10% of recyclable material is recovered from the waste stream, as there is no large scale and effective government-run SW sorting practice or recycling system yet in place. The SW recycling industry in Iran has not yet been launched completely and most of the existing and operating SW recycling activities are dominated by the private sector.

The problem represents a measurable threat to public health and the environment and requires national attention of the highest priority and urgency. A new vision is mandatory and there is a need for action. In order to overcome these problems, a technical solution should be made with the crucial modifications and proper implementation considering the legal, financial and management aspects. The viability of SWM systems depends on the effective treatment concepts, technologies and practices adopted.

All technologies and systems adopted must ensure the protection of public health and the environment. The ultimate goal of zero-waste management can be achieved by utilization of available alternative waste management approaches and strategies which limit the residual amounts ending up in landfill sites. Proper and effective waste management systems control the polluting effects of SW on the environment and turn it into a precious resource (Rechberger, 2011; Rotter, 2011; Scaglia et al., 2013).

Composting remains the most widespread method of organic waste recycling worldwide. It is traditionally defined as the aerobic biological decomposition and stabilization of organic substrates. Under ideal conditions, the final product is stable, mature, pathogen-free and can be beneficially applied to agricultural land (Oazana et al., 2017). Composting is a reliable waste treatment option that could be beneficial in the recycling of the organic fraction of the SW, reducing by as much as 30% the volume of organic matter entering the already overcrowded landfill sites (El-Sayed, 2015). Diverting organic waste material from landfills by composting has many economic and environmental benefits: reducing the waste volume, greenhouse gas emissions (GHG), leachate quantities, organic residues disposal cost as well as providing an income by virtue of compost being used as a substitute for other fertilizers that may be quite expensive (Proietti et al., 2016; Wei et al., 2017). To this end, this research focuses on municipal organic waste composting in developing countries, particularly under arid and semi-arid weather conditions.

Aim of thesis

The objective of this study is to examine the potential of producing compost from the available municipal organic waste in Shiraz, Iran. Composting is a biological process in which aerobic microorganisms stabilize organic waste by using carbon as a source of energy and nitrogen as a source for their cells' growth.

The goal of this study is to explore measurable changes of organic material's physical, chemical and biological properties over the period of the composting process as well as determining the final product quality.

This study aims to provide practical and applicable solutions to produce market-oriented compost and move towards adopting a sustainable organic waste management concept.

Questions

The potential of producing soil amendments with quality concerned for agricultural purposes is addressed by composting municipal organic waste from different sources; the organic raw input materials in two composting runs include: 1) a fine fraction of mixed municipal waste treated in Shiraz's Material Recovery Facility (MRF); and 2) a source-separated market and garden waste. These experiments aim to answer the following questions:

- *How do different raw organic materials affect the composting process, especially in terms of stability and maturity of the final product?*
- *How do proper operational processes (monitoring, in-situ measurement and analysis) improve the quality of the final product?*
- *Does the final product fulfil the nutrient content requirements for agricultural cultivation in the study area? If yes, what is the recommended application rate?*
- *Does Shiraz's MRF facility have the capability of producing acceptable raw input material? If not, which kinds of impurities end up in windrow piles?*

Adopting sustainable treatment strategies concerning state-of-the-art, applicable options address the gaps in the study area. The practical solution targets the following concerns:

- *Does the waste management system currently practiced meet the state-of-the-art requirements for applying composting technology? If not, which kind of adjustments should the material recovery concept be subjected to?*
- *How can the input raw organic material of lower quality be improved?*
- *How can a higher quality final product be ensured?*

2. REVIEW OF SOLID WASTE MANAGEMENT IN SHIRAZ, IRAN

Iran, located in the Middle East in western Asia, is considered to be an upper middle-income country. Major economic activity is based on oil and natural gas resources. The total population is around 80 million inhabitants with 1.24% annual growth and a surface area of 1,648,195 Km^2 (Iran Statistical Yearbook, 2018). The average annual rainfall is about 250 mm and more than 82% of Iran's territory is located in arid and semi-arid zones. Immigration from rural to urban areas has resulted in the creation of cities at an increasing rate, particularly during last 20 years (Figure 2-1). Further, 74% of inhabitants are settled in urban areas (Iranian Statistics Center, 2018). Currently, Iran has eight mega cities with more than 1 million inhabitants in each.

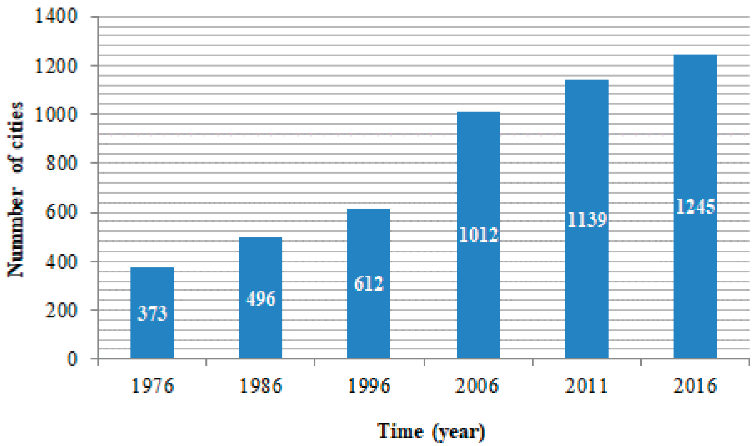

Figure 2-1: *Number of cities in Iran from 1976 to 2016 (Iran Statistical Yearbook, 2018).*

Shiraz, the fifth populated city, is home to around 1.6 million people. It is the capital of Fars Province, located in the southwest of Iran (Figure 2-2). The city has semi-arid climate conditions with hot and dry summers and relatively mild winters. The average annual rainfall is 342.2 mm, which usually occurs from November to April. It is close to major UNESCO historical sites (Persepolis, Necropolis and Pasargadae). Agricultural production counts as the major economic activity in Fars Province, while electronics, food and petrochemicals are the main active industries.

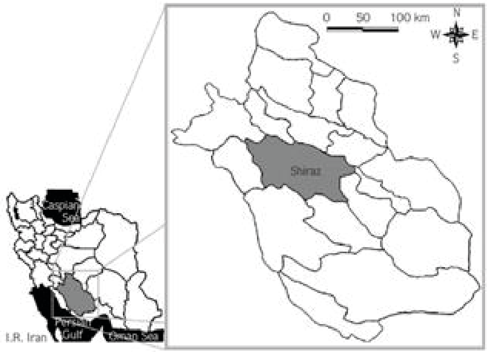

Figure 2-2: The location of Shiraz city in Iran (Shoorijeh et al., 2008).

2.1. CURRENT SITUATION OF SOLID WASTE MANAGEMENT

The excessive amount of SW is the inevitable by-product of rapid population growth and urbanisation in Iran. Facing numerous human health and environmental threats, the country aims to improve SWM schemes into more integrated approaches. The basic infrastructure for the establishment of SWM systems are not available in most cases. The decision makers' have access to limited tools for selecting appropriate treatment/disposal techniques and increasing the effectiveness of the systems. The main problems are the lack of operational enforcement, financing, public awareness, trained staffs, reliable data and basic know-how (Figure 2-3). The U.S.A.'s sanctions are the other burden for the financing and development of SWM in Iran. Despite the fact that source separation of dry recyclables, mechanized collection systems, recycling, composting and sanitary landfilling is now being implemented in big cities, the country still does not benefit from coherent and well-defined SWM structures and faces substantial challenges.

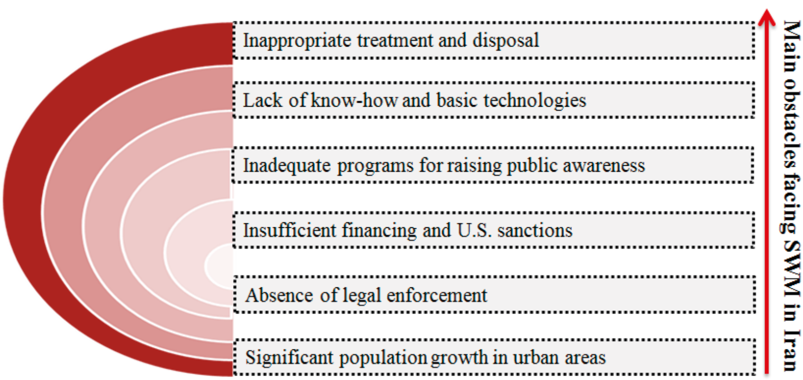

Figure 2-3: The challenges facing the SWM systems in Iran (MOI, 2018).

Existing systems in Iran are not able to cope with the generation of SWM at such an alarming rate. A lack of effective incentive programs results in low willingness of the local community to cooperate with the municipality for the separation of dry recyclable materials from household waste: up to 93% of MSW is collected as mixed wet and dry. The public awareness campaigns have been unsuccessful in changing the behavior of citizens and municipalities face challenges such as the illegal dumping of waste. There is no policy for utilizing the informal sector in SWM systems and municipalities are not able to control the recycling markets effectively.

Degradable waste comprises the main fraction of household waste and around 30 - 35% of SW are dry materials (Figure 2-4). About 6 - 7% of dry waste is collected at source, mainly by informal sectors. The existing waste collection systems in Iran lack proper timing, efficient frequency and scheduled routing in most cities. It creates many operational problems and high maintenance cost for municipalities. In most large cities, the unsanitary condition of transfer stations leads to environmental and hygiene problems (MoI, 2018; Rupani et al., 2019).

The financing mechanisms cannot cover the operations completely and extended producer responsibility (EPR) is in its initial stages. The common practice of SW treatment is still landfilling; around 38% of SW is disposed in dump sites. About 25% of MSW is processed in an MRF, which retrieves 4 – 5% of contaminated recyclables. The fine fraction is used to produce compost in some of these MRFs. The low-quality final product results in the unwillingness of farmers to utilize the compost in agriculture (Rupani et al., 2019).

Decomposition of untreated SW in dumpsites/landfills generates leachate and gases, which pose serious threats to air, waste and soil resources. It is well documented that greenhouse gasses (GHGs) contribute significantly to climate change. Unsanitary landfilling counts as one of the main sources of GHGs, mainly in the form of CH_4 and CO_2. Mostly, landfills in Iran are not equipped with landfill gas (LFG) collection system, which initiates self-heating and frequent fire incidents. In Iran, for example, direct dumping of about 92% of the waste generated in Tehran emits 18×106 tons of CO_2 equivalents into the atmosphere (Nabavi-Pelesaraei et al., 2017).

Overall, many studies report that the amount of landfill CH_4 and CO_2 emissions from different standard landfills in mega cities are estimated to range from 1.34×105 to 7.66×104 and from 2.36×105 to 3.81×104 ton/year, respectively (Atabi et al., 2014; Pazoki et al., 2015; Rezaee et al., 2014;). Moreover, landfill leachate is one of the major threats for ground and surface water pollution. Leachate percolation to the water aquifers may occur as a result of improper landfill design and the absence of collection and treatment systems.

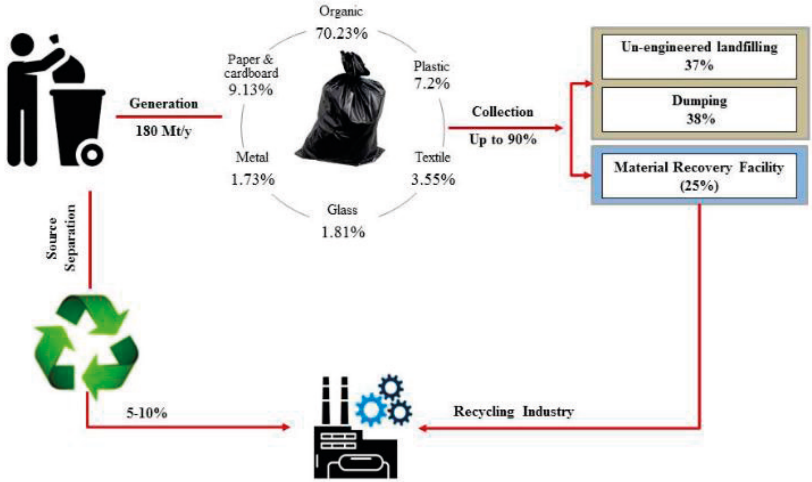

Figure 2-4: *Materials flow in the SWM system in Iran (MOI, 2018).*

Many steps have taken over the past 15 years towards the improvement of the SWM system in Iran. The government bodies realized the negative impacts of increasing volumes of SW, which pose serious risks to public health and the environment. Despite the many efforts put in place by various stakeholders, SWM is still facing many challenges and does not benefit from a well-defined national policy and practical legislative framework. It can be observed that several improvements still need to be targeted in terms of policy, strategy, institutional set-up, legal framework and capacity building. Indeed, there is a need for immediate action to establish an integrated system for SWM in Iran. A fresh look for a new SWM system considering waste reduction, recycling, resource recovery and landfill diversion is required. This must begin with issuing coherent policy, legal and institutional frameworks and enhancing cost recovery.

2.2. LEGAL FRAMEWORK

The legal framework respecting SWM in Iran can be distinguished into international, national and local levels. Table 2-1 presents the several laws, acts, guidelines and plants that are linked to management of SW. The latest SWM act was issued in 2004, in a collaborative manner between governmental bodies. The basic principle of waste management legislation is established upon the 5th Principle of the Iran Constitutional Law (ICL). By categorizing SW, the executive management of each stream is assigned to different governmental sectors. Solid waste is considered in five groups: ordinary, medical, special, agricultural and industrial waste. Special wastes are considered as SW containing poisonous, pathogenesis, explosives, and inflammabile and corrosive components. Local governments, municipalities or rural administrative authorities are in charge of the executive management of all SW, excluding special and industrial waste. The Ministry of Health and Medical Education (MoHME), Ministry of Industry and Mining (MoIM), Ministry of Petroleum (MoP) and the Ministry of

Agriculture Jihad (MoA) are the main governmental entities concerned with the executive management of special and industrial waste.

Table 2-1: *The existing SWM legislation in Iran (Ahmadia et al., 2013)*

Name of legislation	Year	Main emphasis
International Level		
Basel Convention on the Control of Transboundary Movements of Hazardous Waste and their Disposal	1994	Transboundary movement and management of hazardous and other wastes. Hazardous and other waste control system
The Stockholm Convention on Persistent Organic Pollutants	2001	Protect human health and the environment from persistent organic pollutants
National level		
Article 50 of the Constitution of Iran	1979	Preservation of the environment
Clean Air Act	1995	Air pollution control
The Amendment of Water Pollution Prevention Guideline	1994	Prohibits water pollution
Islamic Penal Code of Iran	1996	Punishment for polluting the environment
The Environmental Protection and Enhancement Act (EPEA)	1974	Prohibits environmental pollution Impose penalties
Environmental Impact Assessment (EIA) Guidelines and Framework	1995	Conducting an EIA for solid waste management projects
Municipality law	1955	Solid waste disposal
Article 44 of the Constitution	1979	Privatization
Waste Management Act (WMA)	2004	Legal framework for waste management
FYNDP: Article 61 ,64 and 66	2005	Green management program
FYNDP: Article 193	2010	Recycling and compost
Vision 2025	2015	Disposal of hazardous waste
		Recycling
		Implementation of WMA
		Revitalization of landfill
electrical and electronic waste management	2010	Management of waste electrical and electronic equipment (WEEE)
National Integrated Waste Management Plan	2015	Modernization of current system Planning for waste-to-energy concept
Local level - Approved by Islamic City Council		
Waste Management Master Plan		
Guidelines for Calculating Urban Waste Management Fees		

The concerned governmental bodies have the responsibility for planning, arranging and monitoring all operational activites related to raising public awarness, SW generation, collection, storage, separation, transportation, recycling, treatment and disposal. They have permission to deal with the private sector in terms of performing waste source separation, collection and disposal activities. Supervising and monitoring the implementation of SWM regulation is administered by the Department of Environment (DoE), which is the most important governmental entity for the development of SWM standards, regulations and strategies on a national level.

The government considers SWM in several national plans; Five Year National Development Plans (FYNDP) and the National Waste Management Master Plan (NWMMP) (Table 2-1). This has resulted in the adoption of several international standards and guidelines at national level regarding SW sampling, collection, transportation, recycling and treatement technolgies. These regulatory principles are mostly impractical under existing SWM systems. For example, the law for electrical and electronic waste management policies, published in 2010, is rarely put into practice (Mirgerami et al., 2018). Further, most target goals in the FYNDP (2004) have not been fulfilled. Although the construct of waste incineration facilities was addressed in the NWMMP, issued in 2015, to date there is no law regarding waste-to-energy technologies. Therefore, the lack of well-defined and comprehensive legal enforcment and effective operational planning is an issue standing against the development of proper SWM systems in Iran.

2.3. INSTITUTIONAL FRAMEWORK AND RESPONSIBILITY

The institutional framework of SWM in Iran involves numerous government organizations at national, regional and local levels (Figure 2-5). The DoE is the main stakeholder at national level for the planning and establishment of regulation and policy frameworks. It has the responsibility to supervise the implementation of SWM laws at a local level. The municipalities should give an annual report to their local DoE.

The Ministry of Interior (MoI), after the DoE, has the most pivotal role in the institutional framework of SWM in Iran. The MoI has responsibility for the determination of landfill site location in cooperation with the DoE and the MoA Jihad. The MoI also provides all necessary credits, facilities and equipment for the operation and construction of waste disposal sites. The Municipality and Rural Management Organization of the MoI manages SWM activities at regional and local levels and establishes the cooperation between these stakeholders.

The Ministry of Energy (MoE) is the government entity that creates the platform for private sector investment in renewable and clean energy through financial and infrastructural support. The Renewable Energy and Energy Efficiency Organization (SATBA) of the MoE determines the fees in tariffs for waste to energy facilities. The other ministries are responsible for planning effective policies for handling related SW.

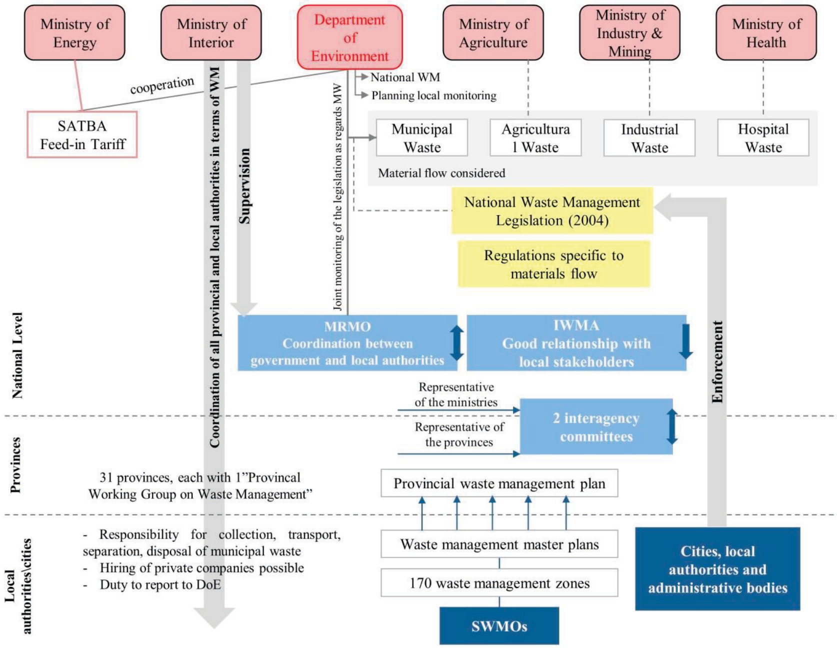

Figure 2-5: *Institutional framework of SWM in Iran (Eisinger & Stock, 2016).*

At a provincial level, waste management working groups are considered in the institutional framework of SWM in Iran. The committee includes representatives from provinces and concerned ministries. The issues related to SWM are discussed within working groups to make decisions that have an impact at regional levels.

Municipalities and rural authorities are responsible for the implementation of all SWM activities on a local level. In cities with more than 200,000 citizens, the municipality has a Municipal Solid Waste Management Organization (MSWMO); in less populated cities, urban department within the municipality run the services. In Shiraz, the MSWMO was established in 1998. The private sector is significantly involved in the implementation of SWM activities. Figure 2-6 shows the institutional framework of Shiraz's MSWMO. The Executive Affairs Department has responsibility for handling activities regarding storage, source separation, collection and transportation. The Technical Affairs Department supervises recycling, material recovery and landfilling of municipal, hospital, construction and demolition waste.

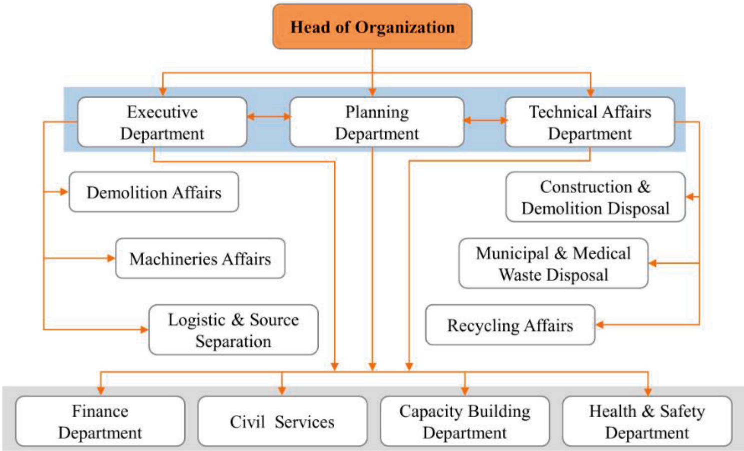

Figure 2-6: *Institutional framework of MSWMO in Shiraz*

The Health and Safety Department (HSD) of the municipality controls the health and safety condition of executive agents. The Capacity Building Department design incentive programs such as face-to-face training, workshops, games, etc., to increase public awareness for reducing SW generation, better source separation and cooperation with MSWMOs for disposing their waste in collection points to a scheduled timetable. Planning departments have responsibility for coordinating the development of master and detailed plans of Shiraz's SWM and supervising their implementation by concerned departments.

2.4. FINANCIAL FRAMEWORK

Municipalities are responsible for financing SWM systems and projects in Iran. Urban waste management fees paid by households and commercial sectors are the main economic instruments. The city council of each city calculates annual fees based on the guidelines published by the MoI. The cost of SWM operations for each houshold is determined using following equation:

$$C = F \times D \times R \times (C_t + C_d) \times E_1 \times E_2 \quad (1)$$

Where:

C: annual waste management fees for each household in different urban district
F: family size in each urban district/person
D: number of days that SWM systems are active/day
R: per capita waste generation in the city/Kg/d/ca.
C_t : the annual fees for collection and transportation of 1 Kg SW/IRR
C_d : the annual fees for treatment and disposal of 1 Kg SW/IRR
E_1: the ratio of urban utilities fees for each household to the average value of district
E_2: the ratio of unsorted SW to the total generated value

The MSWMO declares the waste tariffs in equation 1 ($C_t + C_d$) to the city council. The different collection and transportation fees in each urban district are calculated considering the area of the district, mechanized collection system coverage and the distance to landfill sites. As for Shiraz, waste tariffs (Table 2-2) vary from 8.5 to 21.25 € (400,000 to 100,000 IRR). It should be noted that the exchange rate is considered to be 0.000021 IRR/€ (March 2020).

The populated districts in the northern part of the city (1, 4, 6 and 10) have the longest distance to landfill site (located in southeast of Shiraz) and the highest values of waste tariff. The old part of the town (district 8) with least population and area has the lowest fees.

Table 2-2: *Household waste tariffs for different urban districts in Shiraz (MSWMO, 2018)*

District	Area (ha)	Population (person)	Waste tariffs/€ /y
1	2,556	164,000	21.25
2	1,780	183,127	11.69
3	1,447	144,367	14.87
4	2,354	261,663	21.25
5	1,680	160,496	10.62
6	2,426	123,000	21.25
7	1,716	133,946	10.62
8	368	36,732	8.5
9	2,943	144,677	14.87
10	3,187	141,160	21.25
11	1,214	116,446	14.87
Total	21,670	1,609,614	171.04

The annual SWM fees for commercial sectors is detemined based on the quantity of produced waste. Two categories are used: low waste producers (< 5 kg/d) and high waste producers (> 5 kg/d). The first group's fees are covered by the annual urban utility tariffs, while the second pays extra fees per each storage bin, as presented in Table 2-3 for Shiraz.

Table 2-3: *Commercial waste tariffs in Shiraz (MSWMO, 2018)*

Storage bin (L)	Frequency	Fee (€)
240	Every other day	69.14
	Every day	140.45
660	-	484.01

Another economic instrument for the financing of activities in the waste management sector is the budget, which is collected from monetary penalties. According to Article 21 of the Waste Management Act, trade, recycling and disposal of medical waste in the environment and discharging ordinary waste in illegal sites have monetary penalties, which are used for fulfilment of waste management operations (Islamic Republic of Iran, 2004).

2.5. SOLID WASTE GENERATION

Population growth, the rapid rate of urbanization and industrialization, the changes in consumption patterns as well as higher standards of living affects the amount and characteristics of SW generation (Kolekar et al., 2016). The amount of MSW generation is a matter of concern in all steps of waste management from storage containers to landfill cells capacity design (Gallardo et al., 2015). The amount of MSW produced per capita in Iran is 0.5 and 0.745 kg per day in rural and urban areas, respectively (MoI, 2018). At the moment, more than 180 million tons of SW is produced in Iran. In 2002 and 2017, the urban population produced 9 and 18 million tons of waste annually, respectively, which shows a sharp increase (Rupani et al., 2019). This is the consequence of remarkable urban population growth with the greatest rate occurring during 2007-2014, whereas produced waste per capita had the highest amount of about 0.9 kg per day in 2007 (SABTA, 2019).

According to previous research, lifestyle affects MSW generation (Keser et al., 2012; Khan et al., 2016; Kolekar et al., 2016); therefore, per capita MSW generation varies in different cities in Iran. Figure 2-7 displays the population and per capita waste generation in eight mega cities with >1 million populations. Tehran, the capital of Iran, shows the highest amount of MSW generation for each person, which represents 16% of total MSW production in the country (Rupani et al., 2019). The cities located in the central provinces, Isfahan and Qom, have lower MSW generation per capita due to their lifestyle. Karaj, Tabriz and Shiraz present high rates of waste production per person (Rezazadeh et al., 2014). Additionally, the coastal provinces near the Caspian Sea, one of the main touristic zones, face serious challenges with 5,800 tons per day of MSW generation (MoI, 2018).

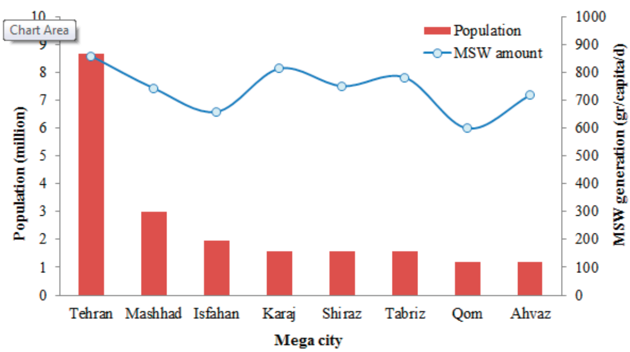

Figure 2-7: *Population and MSW generation (gr/capita d^{-1}) in mega cities in Iran.*

Shiraz, the capital of Fars Province, is one of the most populated urban areas in the southern part of Iran. The MSWMO of Shiraz makes successful attempts to control waste generation rates in the city by development of incentive programs and implementation of SWM laws in the city. In 2018, about 7,865 tons of SW was generated in Shiraz. Table 2-4 indicates the amount of waste produced from different streams during 2016 - 2018 (MWMO, 2018).

Table 2-4: *The amount of SW generated in Shiraz (MWMO, 2018)*

Solid Waste	amount (t/d)		
	2016	2017	2018
Municipal Solid Waste	1246	1282	1234
Medical Waste	7.1	7.3	6.5
Construction and Demolition Waste	7708	6602	6625
Total	8961.1	7891.3	7865.5

The amount of generated MSW and medical waste rose slightly in 2017, mainly due to breaking sanctions and a better economic situation from 2015 to 2017. In general, SW generation in the last 10 years shows insignificant changes while per capita produced waste varies in different districts (Figure 2-8); District 8, located in the old part of the city, has the highest waste generation per capita. There are major historical sites in this area as well as hotels and restaurants, which produce great amounts of MSW. The least populated part of city (District 11) has the lowest per capita SW generation. District 4, with the highest number of inhabitants, has 0.606 (kg/d) per capita SW and produced 15.4% of total MSW generated in Shiraz in 2018 (MWMO, 2018).

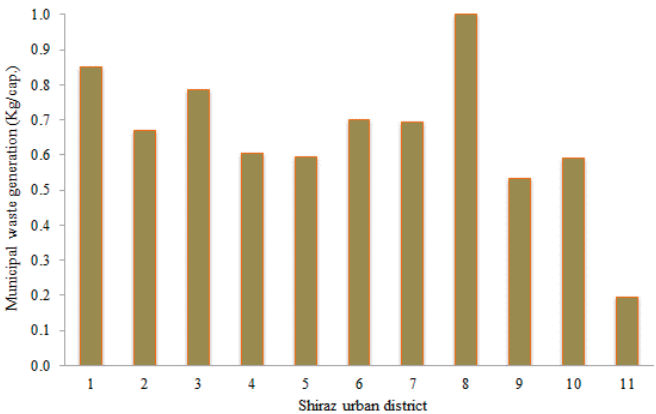

Figure 2-8: *Municipal solid waste generation per capita in Shiraz districts.*

2.6. COMPOSITION OF SOLID WASTE

Composition of MSW reflects the development level of a society (Liu et al., 2017). Solid waste contains more organic materials in developing countries, whereas inorganic materials form a large share of waste in developed countries (Ayodele et al., 2018; Mboowa et al., 2017). Composition of MSW is a matter of concern in the determination and designing of treatment strategies (Tisserant et al., 2017).

Table 2-5 shows the major components of MSW in Iran; on average, MSW is characterized by 70.23% organic contents, 7.2% plastic, 9.13% paper and cardboard, 1.73% metal, 1.81% glass, 3.55% textiles and the remainder includes hygienic, wood, leather and other miscellaneous types of wastes.

Table 2-5: *The composition of SW generated in the mega cities of Iran.*

Component (%) / City	Organic	Paper & Cardboard	Plastic	Metal	Glass	Textile
Tehran [1]	71.20	9.60	7.20	2.50	1.60	3.60
Mashhad [2]	76.33	4.98	7.05	2.17	1.77	2.33
Isfahan [3]	70.23	4.16	14.04	0.65	1.17	3.37
Karaj [4]	69.8	6.6	8.3	1.9	2.1	3.10
Shiraz [5]	69.10	4.32	13.15	1.43	2.51	3.79
Tabriz [6]	67.00	8.00	5.00	4.00	3.00	4.50
Qom [7]	66.80	4.30	8.40	2.10	2.30	2.00
Ahvaz [8]	64.84	5.50	6.70	3.86	4.29	4.17
Iran	70.23	9.13	7.2	1.73	1.81	3.55

[1](Rupani et al., 2019); [2] (Farzadkia et al., 2012); [3](Shumal et al., 2020); [4] (Naghibzadeh et al., 2014); [5] (MWMO, 2018); [6](Benis et al., 2019); [7](Farzadkia et al., 2015); [8](Foladi et al., 2018).

Organic waste is the predominant content, ranging from 64.84% of the total MSW generated in Ahvaz to 76.33% in Mashhad. This could be attributed to standards of living, industrial activities, environmental conditions and the population of the regions (Abu-Salah et al., 2013). The major oil and natural gas industries are located in Ahvaz city, while Mashhad is the main pilgrim city in Iran. The touristic cities, Isfahan and Shiraz, have higher quantities of plastic waste production. Tehran, as the capital city, has the highest paper and cardboard generation, which is due to excessive bureaucracy in the Iranian governmental system.

2.7. SOLID WASTE MANAGEMENT PRACTICES

2.7.1. SOURCE SEPARATION OF DRY SOLID WASTE

Incentive programs and source separation of dry MSW were initiated in Iran after the enactment of the municipal solid waste management law in 2004. In a few mega cities, the MSWMO tries to increase public awareness to dispose of dry and wet SW separately. The practice is divided into two concepts in these cities. The first concept includes the establishment of waste banks, where the citizens can exchange dry SW with sanitary products. This method has higher financial benefits for the municipality since no collection and transportation costs are incurred. In the second concept, the municipalities provide households and offices with storage containers and collect mixed dry SW. The private sector is the main actor in performing the latter concept in terms of providing collection services. The low value of mixed dry waste (high fraction of non-recyclable packaging) and activity of the informal sector (picking the valuable items) usually result in failing to fulfil the terms of reference assumed. About 7% of the total waste generated is collected by municipalities as dry SW (MoI, 2018).

A lack of legal enforcement, weak cooperation of citizens and the effect of informal sectors are the main challenges facing the development of source-separation programs over the last 10 years. Figure 2-9 illustrates dry SW collected by municipality in Shiraz over a period of 10 years.

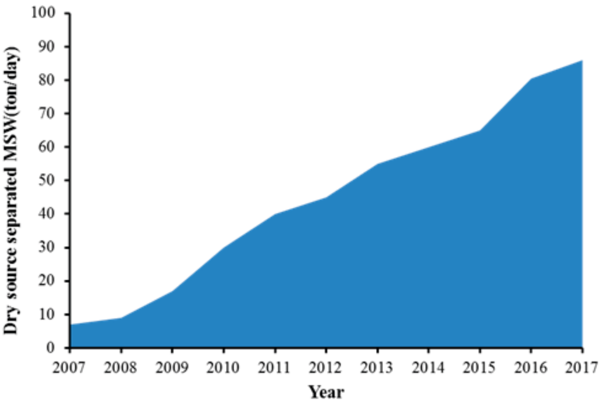

Figure 2-9: *The amount of recyclables collected by the municipality in Shiraz, 2007 – 2017.*

The amount increased from 7 tons in 2007 to 86 tons per day in 2017, equal to 7.3% of the total collected MSW. Additionally, in a few cities, the MSWMO has considered a policy to control the informal sector. In Shiraz, the MSWMO organizes the informal sector's involvement by giving legal permissions and identifying them with a code. In this way, they have to sell the recyclables to legal dealers under supervision of the municipality. As a result, in 2019, 160 organized informal sectors operators cooperated with Shiraz's MSWMO.

2.7.2. Source separation of organic waste

Organic waste is the predominant fraction of MSW in Iran. The citizens have limited knowledge about the environmental adverse effects of mismanaged organic waste. The municipalities face several challenges to deal with leachate and LFG produced from SW disposal. The solid waste management Act of 2004 does not regulate the collection of organic waste separately. In a few mega cities such as Shiraz, the MSWMO segregates a small fraction of municipal organic waste from market and garden waste. In 2019, about 2,550 tons of organic waste from markets and 800 tons of garden space were collected by Shiraz's MSWMO. The inorganic materials are separated manually, and small branches are chipped to be used as raw material for composting processes.

2.7.3. Solid waste collection and transportation

In Iran, the private sector is mainly responsible for waste collection and transportation on a day-to-day basis. The rate of SW collection is estimated to be more than 90%. Collection methods consist of curbside and door-to-door systems. Several machines are used including compactor trucks equipped with lifting units (mainly in mega cities) of different sizes, as well as a smaller number of box trucks (in small cities and rural areas). Depending on the available budget, standardized bins made from fiberglass, plastic or steel with 120, 240 and 660 liter storage are used (MoI, 2018). In many regions of Iran, at the end of each collection trip, collected waste is moved to specific transfer stations to reduce fuel and maintenance costs. Trailers with a capacity of about 40 tons transport the mixed SW either to landfill or MRFs. Indeed, the collection services face many challenges; the restricted access to the waste bins is due to the narrow streets and parked cars limiting the performance of the services. Up to 80% of the total SWM budget allocated for waste management is consumed by logistics services (Esmaeilizadeh, et al., 2020).

In Iran, MSW collection systems lack proper schedules, frequency and optimal routes. Furthermore, the recent U.S sanctions result in shortages in equipment and collection devices and transportation vehicles. Route optimization is established in mega cities to reduce travel distances as well as operational costs. In Shiraz, an Automatic Vehicle Location (AVL) system has been launched to automatically verify and transmit the location of MSW collection system vehicles using Global Positioning System (GPS) technology. The MSWMO manages the travel distance of vehicles using data from the tracking system. The MSW collection system has posed numerous operational costs and problems for municipalities due to low cooperation of citizens for picking up SW at a scheduled time from collection points. Shiraz's MSWMO attempts to increase public awareness by distributing collection timetables as leaflets in city districts

2.8. Material recovery of dry solid waste

2.8.1. Recyclable Fraction of waste

Recycling industries have been established in Iran for about 70 years ago. The foundation of recycling facilities for paper in Karaj (1951) and cardboard in Tehran (1956 and 1957) are such examples. Economic issues, inflation and U.S sanctions have significantly affected the development of these facilities in the last decade. Lack of investment, technology, equipment, and devices are the main burdens in this regard. Main recycling facilities are located in the central part of Iran with access to mega cities providing raw materials. Additionally, technical infrastructures are more available in central provinces due to the presence of major industries such as steel, metal, aluminum, etc.

Dry recyclable SW in large cities in Iran is collected by the municipality and informal sectors. In small cities and rural areas, the informal sector picks up the saleable SW. In mega cities, the solid waste management organization defines a structure to control the recycling market. In

Shiraz, as one of those cities, each private contractor company has a warehouse for dry SW collected from households and waste banks (Figure 2-10). Organized informal sectors are obliged to sell their SW to these warehouses. Collected materials are sorted manually and sold to related industries. These warehouses benefit from secured quantities of input materials and usually become the main trade centers in cities.

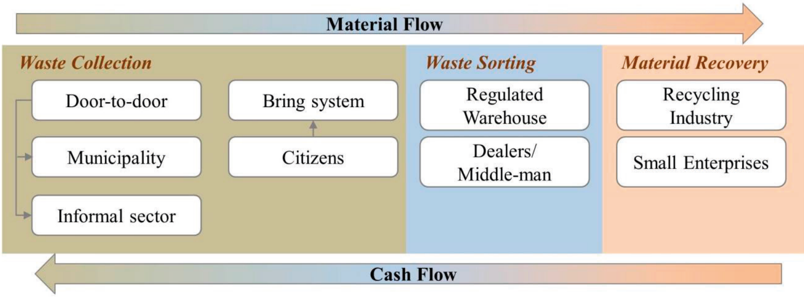

Figure 2-10: *Existing recycling approaches practiced in Shiraz city.*

Consequently, the municipality can supervise the fees in the recycling market. The main fraction of waste collected by the informal sector is sold to traders. They usually cooperate or own small-scale recycling factories in big cities. The process of material recovery has low efficiency in these industries and the final products have low quality. More than 90% of SW is collected as mixed waste in Iran. The first MRF for mixed SW was established in 1969 in Isfahan. The solid waste management act of 2004 implies that the MoI has the responsibility to provide municipalities with credits for establishing recovery facilities (Waste Management Law, 2004). Furthermore, the NWMMP (2015 - 2020) includes target goals for recycling and recovery to increase:

- Material recovery from 23% to 90%;
- Organic waste recycling from 12% to 80%;
- Dry waste recycling from 5% to 25% and
- Energy recovery from 1% to 3%

Currently, 42 MRFs are established in Iran (MoI, 2018). The technical structures of MRFs are simple and cost effective. This results from a lack of funding and investment due to the economic situation under sanctions and the low market price for contaminated recyclable output. Figure 2-11 displays the configuration of Shiraz MRF, including two sorting lines with 250 - 300 t/d capacity. Both lines were constructed in Iran and consist of two rotary drums with 70 mm diameters, and magnets. The second line is equipped with a bag opener and one extra magnet on the organic output line; in the first line, waste bags are opened manually with knives. The workers pick up the recyclable material from conveyors on the lines. Recyclables count for 4% of input waste. The private companies charge for the operation and maintenance of MRF and sell the materials to legal dealers or related industries directly. The fine fraction contains mainly organics (56%) of input and the remaining 50% is rejected waste that is landfilled.

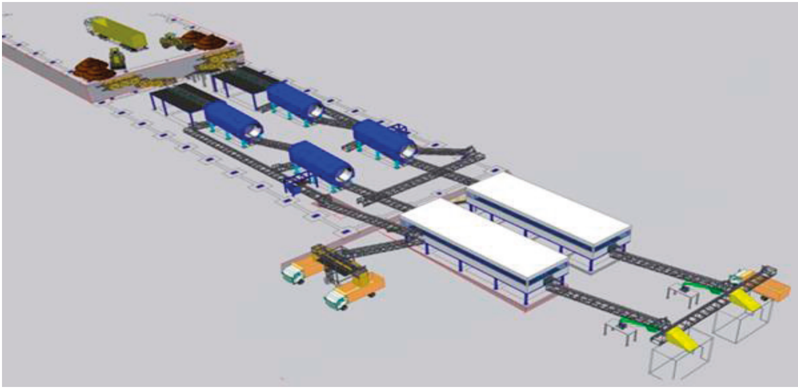

Figure 2-11: *The layout of the MRF in Shiraz (MSWMO, 2018).*

The economic crisis in recent years has led to higher prices for raw materials and, consequently, more demands for recycling. The market price for recycling trade on a national level is mainly determined from a website established by a private company. Through the national platform, the different types of waste are categorized by types and class of quality. It is possible to buy and sell materials online at national level.

2.8.2. Organic waste

Organic waste is the largest MSW fraction in developing countries. In Iran, more than 70% of collected MSW is organic materials, including kitchen waste, fruits and vegetables from markets, garden and park waste. Actually, organic materials have no value in waste stream. In households, it makes up a small share of kitchen waste; dried bread is segregated. In metropolitan areas with upper urbanization indexes such as Shiraz city, part of market and garden waste is collected separately, which includes around 1% of total MSW stream.

The high proportion of organic materials of waste streams implies high moisture content ranging between 55% and 60% with thermal values expected to be about 7 - 8 MJ/kg (Pohlmann, 2017). Excessive amounts of leachate and landfill gas is, consequently, generated in dump/landfill sites. Mixed collection systems with dry SW containing hygiene and hazardous waste causes high loads of organic and heavy metals in leachate. This leads to serious environmental threats in dump/landfill sites such as contamination of soil, surface and underground water. Degradation of organic waste in landfills generates landfill gas mainly containing CH_4 and CO_2. Self-heating and fires occur frequently in dump/landfill sites in Iran. An explosion in a Shiraz landfill in 2013 caused seven casualties.

Dump sites remain the common waste disposal method in Iran. By developing SWM systems after the act of 2004, the number of sanitary landfills increased in the country. In order to control the volume of waste entering these landfills, composting processes were implemented. The composition of SW regarding impurities makes it difficult to use other treatment methods such as anaerobic digestion. There is only one anaerobic digestion plant in Tehran which uses municipal organic waste as a fraction of input materials. Source separation programs for organic waste should be considered in order to achieve a final product of high quality.

Composting

Composting is one of the best approaches for organic waste management. Stabilizing the degradable material reduces moisture content as well as waste volume by up to 30%, which helps to prevent leachate and landfill generation and increases the life expectancy of landfills. The first compost facility in Iran was established in Isfahan in 1969 alongside an MRF. Mixed MSW are used in compost production as the main raw input materials. Further, 18% of all MSW converted to disposal facilities are entered into composting process mainly in large cities.

Composting facilities are usually asphalted with a slope for better collection of leachates. The impurities in mixed MSW have adverse effects on compost production. There is a high load of organic compounds and heavy metals in the leachate produced (Esfandiari et al., 2010). Impurities absorb heat by increasing the temperature during the process and release toxic emissions. The final product is of a low quality and farmers are not willing to use compost produced from MSW (Abdoli et al., 2016; Mahdavi et al., 2008).

The practiced method for composting in Iran is windrow. The facilities in the northern part of the country (Gilan, Mazandaran, & Mashad), with higher levels of rainfall, produces compost under covered roof, whereas the other facilities produce compost in an open area. Compost production is monitored weekly in terms of temperature, moisture and aeration. There is not enough irrigation during the composting process to keep the moisture in the desired range of 50 - 60% while the country lacks fresh water sources. To avoid evaporation, the windrow piles are not turned frequently, and the materials are dried instead of composted in warm seasons. The MSWMO can afford to buy one turning machines (except for Tehran) and they face many problems supplying equipment under U.S. sanctions. To omit impurities, especially broken glass, the output of composting is sieved in two steps, which decreases the efficiency of the process considerably. In Shiraz, 50% of collected mixed waste is subjected to material recovery and the remaining amount (50%) is directed to the landfill for the purpose of producing landfill gas (Figure 2-12).

Fine fractions (mainly organics) and recyclables are the main outcomes of MRF processing. The fine fraction of about 43% is treated using windrow composting. Evaporation and leachate generation contribute to the mass reduction of organic material; where up to 26% reduction is achieved. At the end of the biological treatment, only 2% of the main input is converted to compost-like output (CLO) product.

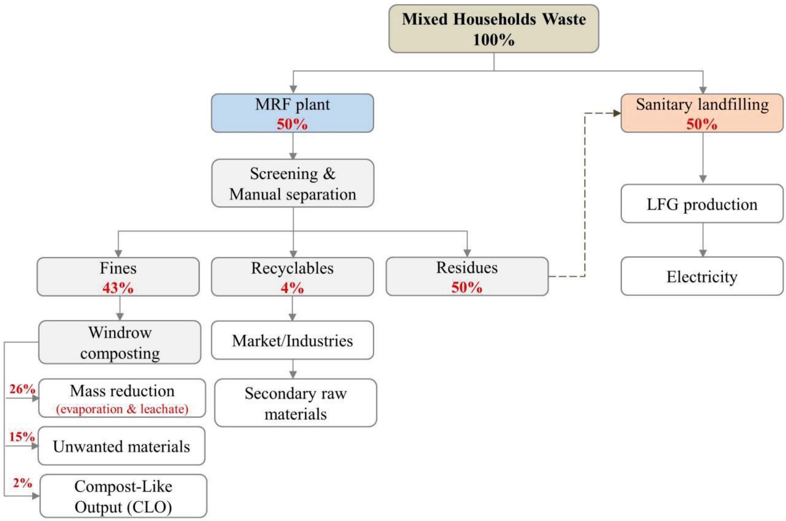

Figure 2-12: *Mass balance of solid waste streams in Shiraz.*

2.9. Energy recovery

Landfill Gas Utilization

Landfill gas (LFG) is produced by anaerobic processes in landfilled MSW. Globally, most dump sites are not equipped with LFG collection systems. Further, GHGs, methane (50 - 60%) and carbon dioxide (30 - 40%) are emitted to the atmosphere by LFG (Faitli et al., 2015). Decreasing the GHG, emission should be taken into consideration in order to alleviate the risk of global temperature change (Narra et al., 2011). Methane, as the main fraction of LFG, can be captured and utilized as a renewable energy source. It has 23 times more adverse effect on global warming than the same volume of carbon dioxide (IPCC, 2006; Themelis & Ulloa, 2007).

There is high potential for recovery and use of LFG in Iran due to the high percentage of organic waste. Two mega cities, Shiraz and Mashhad, have biogas plants. In the Shiraz biogas power plant, LFG is used for electricity production using engines with 1 MW capacity. The electricity generated in this plant is estimated to be 8 million kWh per year (Maghanaki et al., 2013). The Mashhad biogas plant captures 2 million cubic meters of biogas annually using engines with 2 MW capacities (Maghanaki et al., 2013). The development of biogas systems for LFG recovery in Iran can prevent fire and explosion in landfills as well reducing GHG emissions.

Incineration

Municipal solid waste incineration involves the combustion of waste in a controlled process. The thermal value of MSW has great importance for automatic combustion without using other fuels. This method is implemented to reduce the volume and mass of MSW and turn it into inert materials as well as the recovery of energy. Incineration is a complex process which needs a skilled labor force for the operation of high-tech systems. This approach is utilized more in developed countries. In developing countries, the composition of mixed MSW usually does not meet the threshold for automatic combustion, which requires > 7 MJ/kg on average over a year.

In Iran, incineration is considered a proper waste management method for populated urban areas with limited landfill capacity in north coastal provinces. According to the MoI, eight incineration facilities should be established in northern provinces of the country to manage the produced MSW. The main obstacles for the development of waste to energy strategies are the low thermal value of MSW, and the lack of legal and financial frameworks in Iran (Rezaei et al., 2018). The heating value of the waste stream with moisture content ranged between 60-70% and was found to be around 4MJ/kg (Bazdidi Tehrani, & Haghi, 2015).

2.10. LANDFILLING

As mentioned in section 2.1, the disposal of SW in Iran is implemented up to 70% in dumpsites and unsanitary landfills. The solid waste management act of 2004, states that the DoE is responsible for locating the landfill sites in cooperation with the MoA. The location of the disposal areas in most cities is determined without considering the environmental impact assessment. The SW is disposed in trenches without utilization of liners, leachate or LFG collection systems. Landfills in Iran are operated by municipalities (MSWMO in mega cities), while the DoE supervise the operation of those landfills on a local level.

The SWM systems in Iran lack a proper disposal of waste. Mixed MSW without treatment are taken to landfill/dump sites. A lack of attention to the sanitary landfilling of SW causes serious environmental problems in Iran (Yazdani et al., 2017). Leachate produced in these facilities is not managed and LFG is emitted to atmosphere. There is only one leachate treatment facility in Tabriz, while a few other mega cities (Tehran, Isfahan and Shiraz) have storage lagoons without further management. Heavy rainfall in northern coastal provinces generates excessive amounts of leachate, which is a contamination threat to water resources. The leachate contains high loads of heavy metals and toxic organic compounds due to the lack of source separation systems (Eskandari et al., 2015).

In large cities, the capacity of disposal areas is controlled using compactor machines. The SW is covered with a 30-50 cm soil layer. The degradation of SW under anaerobic conditions produces LFG. The lack of gas collection leads to emission of GHG, toxic compounds and combustion in these facilities (Gholamalifard et al., 2017). In small cities and rural areas, open burning of SW is still practiced. The consequence of unsanitary landfilling on public health has not yet been identified in Iran. Solid waste should be subjected to treatment before landfilling. Proper disposal methods should receive more attention in order to improve SWM systems in the country.

2.11. OUTLOOKS

2.11.1. STATUS OF SHIRAZ'S MATERIAL RECOVERY FACILITY (MRF)

Shiraz's compost facility faces many management and operational problems: improper management, unsuitable technologies, the lack of know-how, frequent breakdowns through poor maintenance, the lack of trained personal as well as the lack of assessment and monitoring tools. This was examined through a pilot study carried out over one year in Shiraz's MRF facility, from September 2017 to August 2018. The aforementioned MRF is fully described in section 2.8.1. The study aimed to examine the operational efficiency of the MRF facility in terms of producing raw organic material of acceptable quality. To this end, seasonal changes in physical composition of MSW were explored.

Sampling was carried out on a monthly basis; after receiving the fresh raw MSW in the input hall, from different points, samples weighing more than 500 kg were taken (Martin et al., 1995). A quartering method was adopted to achieve a representative sample; it was then placed in the MRF's main feeder. The so-called organic fraction of < 70 mm derived from the drum screen equipped to each line, samples of ≥ 90 kg (ASTM D 4687) were subjected to manual characterization (Figure 2-13). The area under investigation (< 70 mm) was used as the raw input material for the windrow pile composting technology in an open site area located in the nearby Shiraz MRF facility.

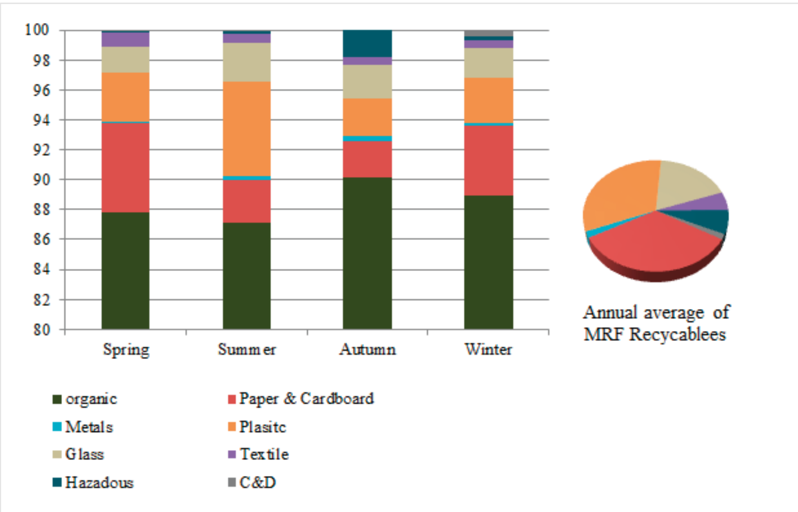

Figure 2-13: *The physical composition of MRF fine fraction (< 70 mm) (%).*

Up to 90% of the mixed MSW treated by the MRF facility was organic fraction. The composition of fine fraction (< 70 mm) had a lower proportion of organic waste in spring and summer due to the consumption of fruits such as melon and watermelon as well as the high temperature. The dominant impurities in the output of < 70 mm were paper and cardboard, plastic and glass, with the highest ratio in summer. The high proportion of paper and cardboard indicated the poor separation system at source, which resulted in losing natural material resources. Collection of industrial waste separately as well as magnetic separation of ferrous and non-ferrous materials resulted in less than 1% of metals.

From a composting prerequisites point of view, the raw input material cleanness guaranteed a high quality of the final product. The research experiment demonstrated the presence of impurities of different natures: construction, demolition and hazardous materials of about 2% had a negative impact on the biological processes as well as the final product's chemical properties. Glass was crushed by mechanical turning, which caused poor physical quality of the produced compost. In order to assess the amount of compost produced using source-separated organic materials, the following assumptions were made:

- The amount of household waste generated was 1100 tons per day
- The collection working days were 300d/y
- The amount of household waste generated per year was 330000 t/y
- 69% of the household waste generated was compostable organic waste (227700 t/y)
- The collection efficiency was 80%
- The collected organic material generated 182160ton/y
- Composting lasted for 12 weeks
- Volume reduction in windrow piles by 30% (evaporation & leachate)

The amount of compost produced was:

182160ton/y X 30% (volume reduction after 12 weeks) = 127,500 ton/y

The availability of 500 t/d organics indicated that composting can be adopted as a promising technique in the study area. Poor source separation, weak implementation of material recovery concept (low MRF efficiency), lack of know-how regarding the effect of the impurities within windrow piles' raw materials restricted the full exploitation of this opportunity. In order to overcome those challenges, the following concerns were taken into consecration:

Management level

- Most of the decision makers in the administration levels do not have full understanding of the waste management concept as well as the operational procedure of the facility.
- The official employees are not aware of the economic and environmental benefits that could be achieved from proper utilization of organic waste.
- The main input raw materials to be composted include fine fractions derived from pre-treatment processes of mixed MSW at the MRF. The poor quality of input raw materials (high level of impurities) affects the efficiency of the composting process (long period) and the quality of the final product.
- Despite the high potential to receive high quality organic waste (separated) from the markets, the existing collection system does not have the capability to cover those areas due to its low capacity and efficiency.

Technical level

- Low operational efficiency of the MRF: the sequence of applied processing technology does not fit the nature of input waste, which results in the presence of impurities.
- The MRF pre-treatment process should be redesigned to achieve an organic fraction of a high quality (low level impurities).
- The arrangement of windrow piles in the area covering the composting site should be modified by allocating buffer zones between piles of organic wastes of different origin. It prevents the contamination of source-separated materials by leachate generated from mixed wastes.
- The leachate collection system is not well-designed; the actual drainage system is constructed in such a way that allows the leachate flow along the windrow piles. The design criteria for establishing an efficient drainage system should consider sub-collectors for each kind of windrow pile according to its raw materials.
- Freshwater shortages limit the irrigation of composting piles and available water sources have high salinity.
- There is a lack of know-how and skilled manpower to set up a proper daily activity program in the compost facility. The staff are characterized by low qualifications and do not have the capability to monitor, analyze and evaluate the biological processes derived by the microbial community.
- There is no systematic monitoring program regarding the daily activity, sampling, lab analysis, the quality required, marketability, etc. of the compost.
- The laboratory does not have the capability to deal with the frequent samples collected due to the shortage of skilled staff. Moreover, the staff do not have relevant educational backgrounds to explain the values obtained and the proper action that should be performed to improve them.

Financial level

- The economic crisis, US sanctions and inflation decreases the willingness of the private sector to invest in increasing the MRF's capacity. Today, the MRF processes half amount of the total MSW generated from Shiraz city.
- The absence of the required financial support to supply the facility with new machinery, spare parts and construction works (i.e. installation of roof cover, creation of new composting zones and construction of drainage system).
- The cost recovery does not cover the actual costs of composting operational processes. The price of the final product is very low price due to its low marketability (low quality).
- The municipality cannot afford the international technologies. Most of the equipment and tools needed in the facility are designed and manufactured in the local market, which are not well-adapted to the required performance.

3. State of the knowledge

In light of the rapidly growing population, people's increasing desire for prosperity as well as the rising costs of resources, the protection and efficient management of natural resources is a challenge. Unsustainable treatment of municipal, commercial and industrial wastes affects human health and puts extra pressure on the environment. Moreover, valuable resources are lost irretrievably. Decision makers and communities are called upon to face these challenges and to develop viable and sustainable SW management and treatment solutions (Bundela et al., 2014; Vasudevan et al., 2012).

Previous experience in many countries has shown that an advanced waste management sector has the capability to address these challenges. Germany has been moving towards a modern circular economy since the 1970s (Morscheck & Nelles, 2014; Nelles et al., 2020). Today, about 79% of municipal waste is recovered and 65% is recycled (Nelles et al., 2012). This creates job for more than 200,000 people with an annual turnover of some 40 billion euros; an economic sector in its own right has emerged. Germany continues to pursue these targets focusing on the efficiency of resource recovery and recycling (BMU, 2018).

An integrated SWM sector cannot be established to a standard formula. The situation, local waste properties and economic conditions varies significantly from region to region. However, other countries (municipalities) can learn from Germany's practical experience and gain the know-how of waste management technology. Numerous areas should be considered to develop the waste management system comprising technical, economic, environmental and social aspects (Santibanez-Aguilar et al., 2013) as follows:

- Strategic and political governance
    - Legal basis
    - Establishment of state institutions
    - Establishment of entities in charge of waste management
    - Constructing and monitoring the waste management infrastructure
- Social development
    - Environmental awareness
    - Informal sector involvement
    - Building education and training capacity
- Costs and funding
    - Policy instruments ensuring finance and cost coverage

3.1. Sustainable Solid Waste Management Concept

Municipal solid waste consists of everyday items such as product packaging, yard waste, bulky waste, clothing, bottles, cans, kitchen waste, papers, electronics and batteries. Municipal waste is generated from different sources including residential, commercial and institutional sectors such as businesses, schools and hospitals. Industrial, hazardous, construction and demolition (C&D) waste are not included in the U.S. Environmental Protection Agency's (EPA) definition of MSW. The managing of waste comprises of collection recycling, composting, incineration, co-processing and landfilling. Once the waste is landfilled, many materials that could be reused, recycled or converted to energy to displace the use of raw materials will be lost (EPA, 2018).

Article 2 (b) of the European Union Landfill Directive (EU Landfill Directive, 1999) expanded the MSW definition to include any kind of SW of a similar nature and composition to household waste (EEA, 2009). As a management concept, MSW can be organized, handled, operated and owned by both public and private sectors in the form of public-private participation (PPP) formula. Christensen (2011) defines MSW as the waste that is generated by citizens and civil work, and similar waste from small businesses and industry.

The management of MSW represents the process of collection, transportation, treatment, recycling, material recovery, energy recovery and landfilling of solid waste (Sasikumar, 2009). Nowadays, urban areas host around half of the world's growing population, leading to increased pressure on environments and infrastructures. Insufficient waste management imposes serious risks in terms of environmental pollution and human health. This is a challenge for societies to take on a sustainable waste management system in an economically and socially acceptable manner (Ludwig et al., 2003).

Solid waste management concerns all the activities at stage end-of-life a product. Typically, proper waste management concepts (safe landfill, recycling, etc.) turns waste from a zero-value good to value-added products; transforming it physically and chemically to become valuable again as a raw material for new or secondary products (Ludwig et al., 2003).

Simply, MSW management is the organization of the life cycle of waste, including the source of generation, collection, recovery treatment and disposal (Sasikumar, 2009). Uriarte (2008) stated that MSW management should emphasize the organizational, financial, legal, planning, and processing of functions that lead to providing optimal solutions to all SW problems (Tchobanoglous et al., 1993).

3.2. INTEGRATED SOLID WASTE MANAGEMENT (ISWM) SYSTEMS

Although integrated solid waste management systems (IMSW), over the years, have encouraged the use of many sophisticated technologies and recommended the adoption of several smart strategies, they still face many challenges such as the lack of a proper waste management system, insufficient capacity or funding to meet the growing demand for services, strict environmental regulations, financially sustainable resources and shrinking space for landfills (Lohri et al., 2014; Reza et al., 2013; Stantibanez-Aguilar et al., 2013). Poorly managed waste has an enormous impact on the local, regional and global environment, health and economy. Improperly managed waste usually results in higher down-stream costs than would have occurred if the waste had been properly managed in the first place. The global impacts of MSW are growing fast. It is a large source of methane, which is a powerful GHG that is particularly impactful in the short-term as well as the remarkable contribution of this waste which is associated with ozone depletion and acid rain (UNEP, 2005; World Bank, 2012).

ISWM can be defined as the adoption of appropriate concepts, technologies, and management programs to achieve precise waste management goals in a way that favors the best interests of public health and considers the economic and environmental concerns (Elnaas, 2016).

The main purpose is to make waste management practices as environmentally sound as possible. The goal of ISWM is the recovery of more valuable products from waste with the use of less energy, and a more positive environmental impact. It also involves evaluating local needs and conditions, and then selecting and combining the most appropriate waste management activities for those conditions; it also responds to the regulations developed to implement the various laws (Chandrappa & Das, 2012).

Indeed, ISWM strategies are based on the six-tier SW management hierarchy. The hierarchy's main purpose is to make waste management practices as environmentally sound as possible. Moreover, their components are the avoidance waste, source reduction, combustion with energy recovery, reuse, recycling/composting and landfilling. Municipal solid waste should be managed under an ISWM hierarchy. The hierarchy is represented in many different ways and forms. However, the general principle, as shown in Figure 3-1, gives top priority to avoidance of waste in the first place. When waste is created, it then gives priority to reducing waste, followed by combustion with energy recovery; subsequently, it gives priority to preparing it for re-use, then recycling, and last of all disposal, which is situated at the bottom (Chandrappa & Das, 2012).

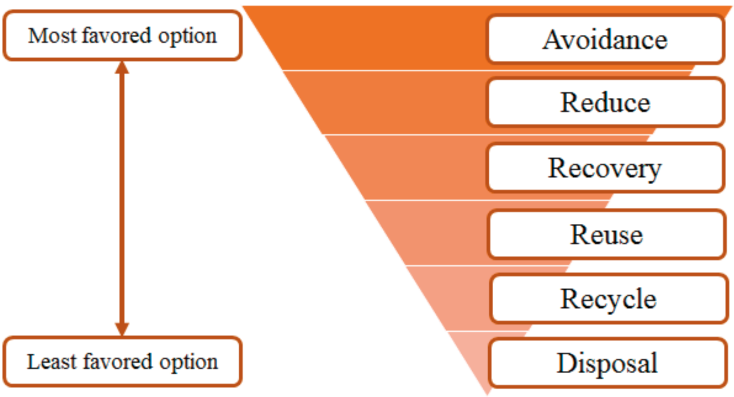

Figure 3-1: *ISWM hierarchy.*

There is no global applicable formula for a SW management system. Each community must design a plan for a SW management system considering the amount and properties of its waste, financial status, know-how and treatment capability as well as energy prices (Uriarte, 2008).

Typically, the implementation of an ISWM system involves the use of numerous technologies. Some waste management practices are more costly than others, and integrated approaches facilitate the identification and selection of low-cost solutions. Further, some waste management activities cannot bear any charges; some will always be net expenses, while others may produce an income. An integrated system can result in a range of practices that complement each other in this regard (UNEP, 2005). This means that the hierarchy cannot be followed strictly since, in particular situations, the cost of a prescribed activity may exceed the benefits, when all financial, social and environmental considerations are taken into account.

3.3. Solid Waste Treatment techniques

The technological solutions already exist; they simply need to be adapted to specific local circumstances. Experience shows that the best outcomes for recycling and the environment are attained through segregated collections. Keeping waste fractions separate at source and collecting them separately is the first step towards the recovery of secondary resources. Plastics, glass, paper, metals, organic waste and minerals can best be reused if they are clean and unmixed (EPA, 2018).

Recyclable materials can be reclaimed from waste by separate collection or by using sorting and separation technologies. For efficient and effective recycling, each material requires a different set of processes: separately collected glass, for example, is sorted, cleaned and crushed before being made into new products in a glassworks. Paper, plastic and metals need sorting into grades and types and recycling in paper mills, plastics processing plants and metal foundries. The processing of mixed municipal waste is rather more complex.

Biological treatment is a viable option for the material recovery of source-separated collected organic waste (Morscheck et al., 2011; Nelles et al., 2017). The latter can be composted or used for biogas production in fermentation plants depending on its composition. Suitable processing turns the fermentation residues into a valuable soil conditioner and fertilizer, much like compost, for agricultural and horticultural use (Fischer, 2013).

As well as being burnt in incinerators, mixed residual waste can also be treated in mechanical-biological treatment (MBT) facilities. A series of treatment stages extracts recyclable materials such as metals and produces quality-assured refuse-derived fuel (RDF) for energy recovery. In 'waste-to-energy' processes, energy is recovered from waste in several ways by generating electricity and heat in waste incineration plants, the co-processing of RDF in the cement industry, combined heat and power (CHP) plants as well as the fermentation of organic waste for biogas production (Rechberger, 2011; Rotter, 2011).

Up-to-date, properly managed, environmentally friendly sound landfilling is still in the initial stage in some countries. Landfills should be designed in a way that ensures safe enclosure to prevent leachate from escaping into the soil and ground water as well as limiting the emissions arising in the landfill body (LFG). Raising the resource and energy prices in the near future will make unusable residues a major energy resource (EPA, 2018).

3.4. State-of-the-Art organic waste management in Germany

Over the last two decades, the European Union (EU) Member States decreed that composting and anaerobic techniques of separately collected biodegradable waste is an option to increase material recycling, to decrease the quantity of organic waste reaching landfills, and applying the waste hierarchy according to the EU policy. This was achieved by creating a quality assurance system (QAS), which includes an organization with the capability to monitor the quality of compost and digestate, i.e. the Quality Assurance Organization (QAO) (BMUB, 2017).

In Germany, source-separated organic waste composting started in the mid-1980s on a voluntary basis. Up to 1989, the compost had poor reputation due to its quality. To this end, the owner of a composting facility established the state-independent quality assurance organization (BGK) in order to improve the compost quality as well as its marketability.

Afterwards, Germany gradually introduced a legal framework for organic waste management. Successful enactment of the law for segregated organic waste collection in 2015 has contributed to the efficient recycling of biodegradable waste by composting or anaerobic digestion (Hemidat, 2019).

Among the EU Member States, Germany has been effectively running a QAS since 1989, issuing different quality labels as well as offering a QAO. Accordingly, Germany has many years experiences in the field of organic waste management and treatment and its related operational process, performing in-situ measurements, sampling and analysis as well designing compost and digestate treatment concepts.

3.4.1. Legal framework on bio-waste in Germany

Germany has adopted EU biodegradable waste legislation into its national legal and policy framework, which includes numerous acts and ordinances in the same field (Figure 3-2).

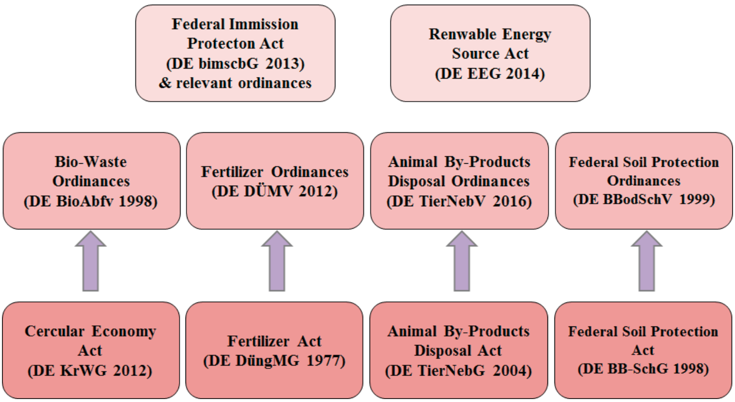

Figure 3-2: *Legal framework of the German bio-waste management.*

The circular economy concept has been adopted and widely implemented in the field of waste management in Germany under the Circular Economy Act (DE KrWG 2012). The latter ensures the fulfillment of the EU Waste Framework Directive (EU WFD, 2008), which aims to protect natural resources, human health and the environment. New regulations enforced the separate collection of biodegradable waste across the whole country from 1 January 2015. It also drew up the outlines for the compost and digestate quality assurance system (UBA, 2016).

The Bio-Waste Ordinance (1998) is one of the Circular Economy supplementary acts, which was enacted to address the supply chain of composting and anaerobic techniques starting from generation, collection and treatment to the utilization of the final product. Moreover, it identified the mandatory prerequisites in terms of proper raw input organic materials, efficient operational process, pathogen-free and maturity of the final product (BMUB, 2017).

The Fertilizer Ordinance of 2012 (DE DüMV) accomplished the Fertilizer Act of 2009 (DE DüMG) by setting the limits of chemical and physical properties of compost or digestate finished product (DE DüMG, 2012). The Animal By-Products Disposal Ordinance (DE TierNebV), together with the Animal By-Products Disposal Act (DE TierNebG), established the obligatory source-separated collection of kitchen/food waste from canteens and restaurants to be treated in an anaerobic digestion facility (DE TierNebV, 2006; DE TierNebG, 2004).

The application of compost for landscaping and re-cultivation was addressed by the Federal Soil Protection Act (DE BBodSchG) as well as the Federal Soil Protection Ordinance (DE BBodSchV). The latter specified the application rate of finished compost in landscaping considering the limitations for organic pollutants: polychlorinated biphenyls, naphthalene, etc. (DE BBodSchG, 1998; DE BBodSchV, 1999).

3.4.2. Development of the organic waste management concepts

Germany started to collect biodegradable waste around 30 years ago; in 1986, for the first time, the German Waste Act regulated the segregated waste collection. The act gave municipalities the right to collect segregated household biodegradable waste on a voluntary basis. Accordingly, numerous municipalities decided to collect bio-waste separately in so-called "bio-waste bins". The first pilot project was performed in the city of Witzenhausen, in the Hesse state. This project laid the foundation for the source-separated collection system used across Germany; up to 100 composting plants were established over the period of 1986 - 1989 (BMUB, 2017; Dollhofer and Zettl, 2017).

Setting up the QAO for compost (BGK, 1989), issuing the law banning the landfilling of untreated SW (DE BioAbfV, 2005) as well as mandatory separate collection of biodegradable waste (DE KrWG, 2015), increased the amount of high quality compost and digestate produced (UBA, 2016).

Germany uses EU Waste Framework Directive to distinguish biodegradable waste into two categories: food/kitchen waste and green waste. The first group is collected using door-to-door curbside systems from households and commercial sectors; green waste is collected via bring-systems at recycling stations. Several financing mechanisms were identified as pay-as-you-throw (PAYT) systems; the system assigned higher fees for mixed residual waste than those segregated at source (UBA, 2016).

Nowadays, up to 46% of households' food/kitchen waste is disposed of in brown bins; about 16 million tons are collected, treated and utilized yearly (Figure 3-3). The rest, accounting for 54%, is disposed in mixed waste bins (black bin) due to the unwillingness and/or the absence of the infrastructure for this purpose (UBA, 2016).

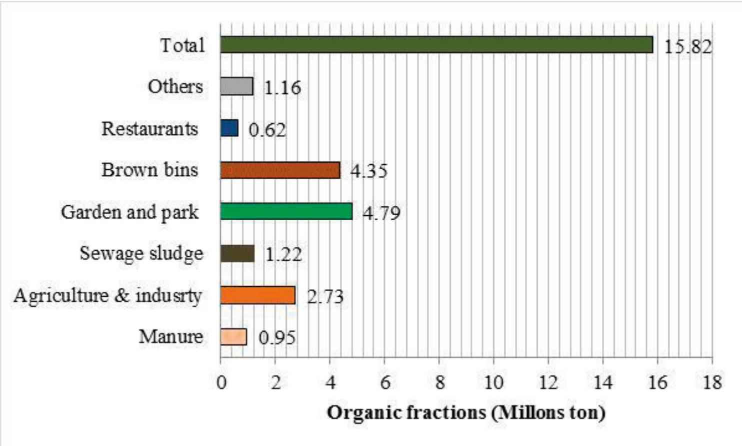

Figure 3-3: *The composition of the bio-waste generated in Germany (BMUB, 2017).*

The proportion of food/kitchen waste produced from brown bins accounts for 27%, which is equal to 47.8 kg per capita household waste generation. This amount counts for 4%, which is equal to 5.5 kg per capita from commercial sectors (restaurants, canteens, etc.). This means food/kitchen fraction accounts for around 31% of the total amount of organic waste generated. In 2017, 844 composting facilities (213 for food/kitchen waste; 631 for garden and park waste) and 297 fermentation facilities were active in Germany, which produced 3.96 million tons of compost and 3.4 million tons of digestate, including digestion plants for renewable raw materials (BMUB, 2017).

3.4.3. ORGANIC WASTE TREATMENT IN GERMANY

The organic waste treatment concept in Germany rests upon the type and composition of biodegradable waste, which is highly dependent on the collection method. The received input raw materials affect the efficiency of the treatment facility: the higher quality of raw materials, the higher the final product quality as well as the less environment impacts produced (UBA 2016).

The two categories defined by the EU Waste Framework Directive are subject to different waste treatment concepts: windrow pile composting, anaerobic digestion and incineration (Figure 3-4). Separately collected biodegradable waste is either directed towards recycling composting or anaerobic digestion. Mainly, food and kitchen waste, collected separately from households and the commercial sector, is treated using anaerobic digestion. Garden and park waste is utilized by windrow pile composting technology in an open site area. Incineration is considered an optimal solution to treat the woody green and biodegradable waste remaining in mixed municipal waste. The first two concepts (composting and anaerobic digestion) address the material recovery; incineration aims for energy recovery. The latter contributes to the loss of valuable nutrients and resources (BMUB, 2017; EC, 2008).

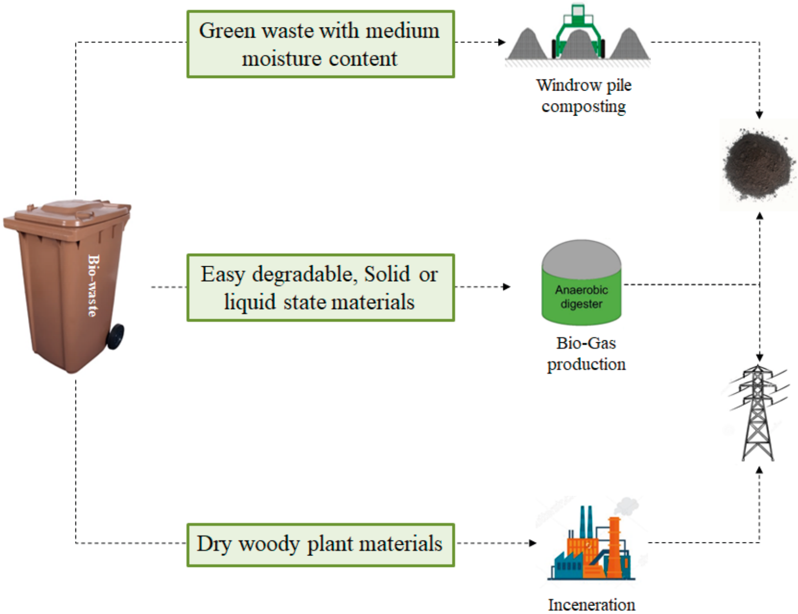

Figure 3-4: *Bio-waste treatment options in Germany.*

Composting

Composting is a process in which biodegradable waste is converted into solid stabilized materials by microorganism activities under aerobic conditions (with the presence of oxygen). During the composting of biodegradable waste aerobically, the raw input material is subjected to several pre-treatment processes; it is shredded, inspected for the removal of impurities, well-blended for homogenization and, finally, either put into a closed vessel or aligned into windrow piles with certain dimensions. Nutrient-rich soil amendment is the main by-product of the decomposition, curing and maturation phases (Figure 3-5).

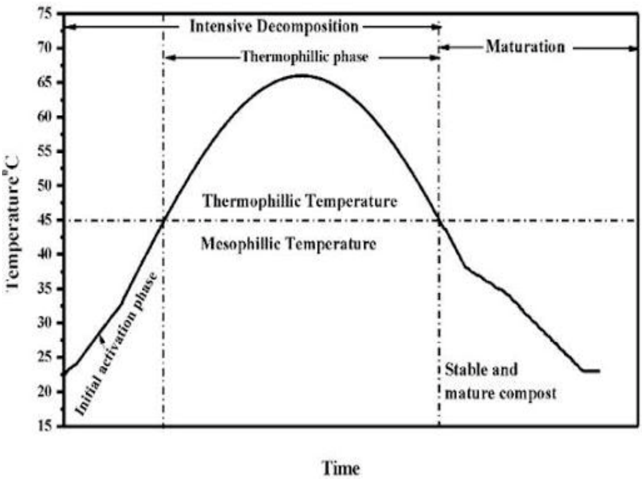

Figure 3-5: *The phases of the composting process (Salama et al., 2017).*

The decomposition phase allows the breakdown of the biodegradable waste under ideal conditions of oxygen level and moisture content inside the raw waste. The temperature trend varies by means of microorganism activities into three phases. The temperature rises during the thermophilic phase reaching up to 70°C, which ensures the elimination of pathogens, weeds and seeds. During the curing and maturation phases, the temperature profile slightly declines as well as the rate of microbial activities; the compost produced in this phase turns into a stabilized matured finished product containing humus substances (UBA, 2016).

Anaerobic Digestion

Anaerobic digestion is a process in which biodegradable waste is transformed into biogas as well as a liquid and/or solid digestate by microorganism activities under anaerobic conditions (with the absence of oxygen). In order to digest the biodegradable waste anaerobically, the raw input material is subjected to several pre-treatment processes: it is shredded, inspected for removal of impurities, well-blended for homogenization and, finally, put into a closed vessel. Methane (biogas) is the main by-product of anaerobic digestion, where the materials breakdown through several phases of energy transformation by the means of microbial activities.

The biogas produced is mainly utilized in a combined heat and power plant as fuel for combustion engines; it is then converted into mechanical energy by powering an electric generator to produce electricity and heat. The remaining liquid and/or solid digestate can be utilized in the form of soil amendment; the digestate residue should be subjected for composting for further stabilization. The optimum results can be achieved by using easily degradable raw input materials such as food and kitchen waste (UBA, 2016).

Energy recovery

Another option to treat biodegradable waste is energy recovery through combustion processes. Woody green and biodegradable waste remaining in mixed municipal waste are the main input fractions for thermal treatment (incineration) in combined heat and power plants as fuel (UBA, 2016). The viability of the incineration technology to treat the organic fraction of MSW is mostly impacted by the organic matter and moisture contents of the wastes. As moisture increases, the calorific value of the waste decreases due to the heat of the vaporization of water. The MSW mixtures with ash content $\leqslant$ 60%, water content $\leqslant$ 50% and combustible (organics) content $\geqslant$ 25% can maintain self-sustained combustion without use of external fuel. Mixtures outside of these ranges can still burn, but only with the support of external fuel (Komilis et al., 2014).

Incineration is mainly used for reducing the quantities of waste, sanitation and the utilization of energy. The creation of energy is not the main goal of the incineration. Nevertheless, it is a proven technology in industrialized countries, and it has been used in waste disposal for many years. Flue gas cleaning is a very important process for the environment. Incineration could be applied to the treatment of organic waste. It is an effective MSW treatment option that contributes to waste stabilization and the maximum reduction of waste volume, as well as to sanitation and energy recovery (Liu, 2005).

3.4.4. Quality assurance in Germany

The compost quality and its fulfillment of the relevant standards and legislation is one of the most important aspects for any treatment facility to increase the marketability of its product.

The German Institute for Quality Assurance and Certification (RAL) was established in 1925. It set up the standards as well as the required properties of the products to enable it to meet the RAL's quality label and/or certification. To obtain the latter, all kind of products from different sector are subjected to frequent sampling processes and analysis according to the standard's protocol. Specific standards and labels are used to distinguish the output quality of biodegradable waste treated using several techniques; the compost quality standard was developed in 1991, followed by the digestate quality standard in 2000 as well as the RAL quality label for the ashes from woody green waste incineration (BGK, 2010). The RAL quality standards aims to map the stakeholders involved in the field of biodegradable waste treatment to create a comprehensive inter-link between legal authorities, farmers, treatment facilities and end users (BMUB, 2017).

4. Composting production using municipal organic waste

Worldwide, the development of urban areas as well as the sharp growth of populations has resulted in the production of waste with an alarming ratio. Many countries face serious environmental, social and economic challenges to managing different waste streams (Awasthi et al., 2014; Sukholthaman & Sharp, 2016). Proper treatment strategies should be adopted by SWM systems to address these concerns. Among all management options for organic waste, composting is the most approved method (Onwosi et al., 2017; Qian et al., 2014). It is an effective strategy to divert SW from landfills and improve the heating value of feedstock in cases of energy recovery (Abu Qdais & Hamoda, 2004; Storino et al., 2016). Previous studies confirmed that composting reduces the volume of organic materials by more than 30% (El-Sayed, 2015; Raut et al., 2008) and converts waste into a hygiene and valuable product (Kulikowska, 2016).

Composting is the most globally practiced method for recycling organic wastes. It is defined as the aerobic putrefaction and stabilization of organic materials. The biological process gives rise to temperatures through microbial activity. Thermophilic conditions secure the final product from pathogens and weeds (Oazana et al., 2017). Composting can be implemented by using closed or open systems. In the close method, the process is carried on in reactors or boxes by automatic control of aeration, temperature, moisture and odor-control. Open air systems are classified based on aeration methods into windrow piles using machinery turning and static piles with forced aeration system (Aspray et al., 2015).

The activity of the microbial community is affected by temperature, pH, particle size, moisture content, aeration and electrical conductivity of organic waste (Juárez et al., 2015; Li et al., 2013). CO_2, NH_3 and H_2O are the by-products of the process which lead to recovery of mineral nutrients: nitrogen (N), phosphorus (P) and potassium (K) (Wang et al., 2015). The stabilization of organic wastes is a sustainable approach for reducing GHG emission and leachate production in landfills (Wei et al., 2017). The final product, rich in humus, can be utilized for sustainable agricultural purposes. Compost has the potential to be used for bioremediation of polluted soil by heavy metals, as it can immobilize them in the soil matrix (Kulikowska et al., 2015).

From an economic perspective, compost can decrease the total fees for SW disposal as well as being a source of income as a cost- efficient fertilizer (Proietti et al., 2016). The final product benefits from these advantages when the process is controlled thoroughly (Storino et al., 2016). Effective controlling is essential in order to achieve high quality finished compost (Awasthi et al., 2016). The management process includes the proper fraction of different raw materials in the initial mixture (Zang et al., 2016). The parameters that affect the procedure, i.e. the C/N ratio, bulking agents, moisture content and aeration rate should be effectively monitored in situ (Azim et al., 2014; Chowdhury et al., 2014; Hurerta-Pujol et al., 2010; Kazemi et al., 2016).

The availability of organic waste is influenced by weather and geographical conditions; characteristics of food and garden waste may also vary in different seasons in any area. Composting segregated green waste is considered more environmentally friendly than sludge-based compost due to its lower heavy metal content (Benito et al., 2005).

Utilization of organic residuals produce soil conditioner has gained the attention of local authorities in Iran. The source of organic waste includes biomass residues from agricultural and industrial activities as well as the organic fraction of MSW and animal manure. The potential of providing raw material in countries as well as the low content of organic matter in soil means that composting can play a pivotal role in SWM and improving soil fertility in the country.

The fine fraction of MRFs has been composted on an industrial scale for over 40 years in Iran, which could not effectively fulfil the desired goal to be used as organic fertilizer. Organic residuals that can be collected separately by municipalities, i.e. market organic waste (fruit and vegetables) as well as garden and park wastes are not yet composted on a large scale. Composting different raw organic materials requires scientific investigation to be launched on an industrial scale. Practiced knowledge and know-how should be shared with executive authorities for efficient management of the procedures.

To this end, the focus of the present experimental study is on the following:

(1) Investigating the potential of aerobic composting processes by monitoring operational parameters;
(2) Examining the physical and chemical characteristics of different degradable solid waste streams to be used in composting in Iran;
(3) Assessing the quality of the final product attained from practicing the state-of-the-art windrow composting process.

4.1. MATERIALS AND METHODS

4.1.1. EXPERIMENTAL SITE

The study was conducted in an established composting plant, located at Barmshor landfill site, which is 18 km south east of Shiraz, capital of Fars Province, Iran. The province is located in the southwest of the country and is identified by various climate conditions and different agricultural activities. Shiraz has semi-arid climate conditions with limited freshwater resources. The total population of Shiraz is around 1.6 million inhabitants on a surface area covering 217 km^2 (MSWMO, 2018).

The current situation of SWM in Shiraz is presented in Figure 4-1; the main ratio of MSW is collected as mixed (93%) and low fractions of recyclable (6%) and organic (0.4%) waste are segregated. Part of the produced medical waste, about 0.6% of total SW generated, is collected and landfilled separately. The informal sector affects MSW streams significantly, and half of the dry valuable wastes are collected by them. Further, 50% of mixed waste is subjected to material recovery and 50% is landfilled directly. There is no energy recovery and 50% of MRF output is landfilled. The raw material for composting is mainly fine fraction of MRF mixed with dry household waste. Partial amounts of high-quality compost are produced from market and garden waste. Leachate is stored in lagoons with liners to be evaporated.

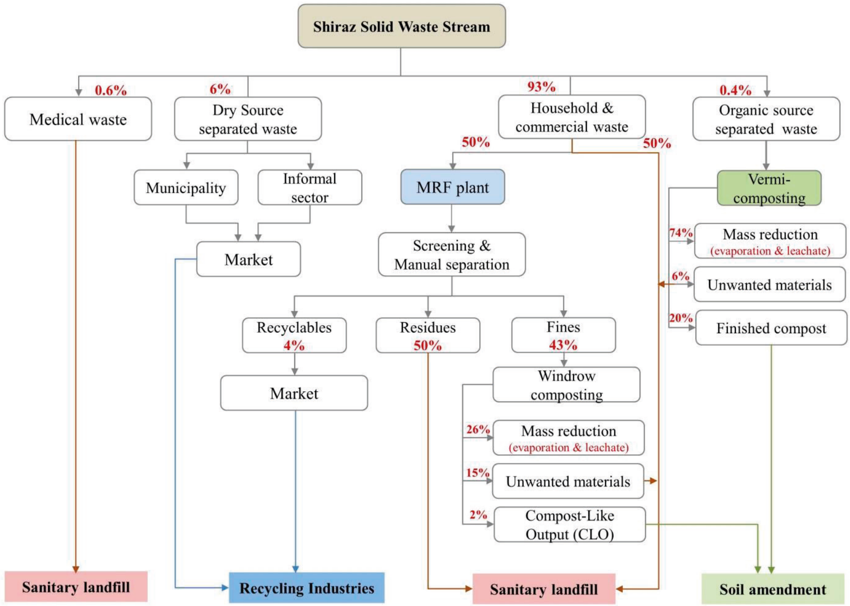

Figure 4-1: *Material flow of municipal solid waste in Shiraz.*

4.1.2. RAW MATERIALS

Different available types of organic waste, fine fraction of MRF output (< 70 mm), market waste (fruits and vegetables) and garden waste (plant residues), were used as the composting input material. Organic waste from MRF was directly used for composting processes. Market waste includes inorganic materials such as plastic bags that need to be sorted manually. Garden waste mainly comprises dry leaves and clippings, which are subjected to screening. Wood particles are shredded into wood chips of 60 - 70 mm size.

Table 4-1 presents the physical property of < 70 mm fraction of MRF plant used as raw input material for composting processes. There are 8.29% of impurities with the highest ratio coming from plastic, glass and sanitary inorganic wastes. Around 0.36% of total input materials are metal and hazardous waste, which have adverse effects on the chemical quality of the final product (Cerda et al., 2018; Sharifi & Renella, 2015).

Table 4-1: *Physical analysis of the MRF fine fraction (Jalalipour et al., 2019)*

Waste type	Organic	P&C*	Plastics	Metals	Glass	Textile	Hazardous	Sanitary
Content (%)	91.71	0.78	4.17	0.11	1.62	0.42	0.25	0.95

*paper and cardboard

The characteristics of the initial raw materials used in source-separated waste composting experiment are presented in Table 4-2. Plant residues were used as bulking agents to provide the required C/N ratio necessary for effective decomposition.

Table 4-2: *The characteristics of initial raw materials used in composting*

Parameter	Fruits and Vegetables	Plant Residues
Physical properties		
Bulk density kg/m3	628.69	314.2
Moisture Content MC (%)	80	7
Chemical properties		
Organic matter (%)	54.30	55.00
Total organic Carbon (%)	30.17	30.56
Total Nitrogen (%)	1.4	1.1
C:N Ratio (w/w)	24.55	27.78
pH	7.10	7.7
EC (dS/cm)	2.72	2.98
Total P (%)	0.24	0.14
Total K (%)	1.2	1.4

4.1.3. METHODOLOGY

After receiving the different raw organic materials, two different types of compost pile were prepared in the compost site near the MRF plant. Fractions < 70 mm output of MRF (including kitchen waste and impurities), mixed fruit and vegetables as well as plant residues were used to form the following piles:

P1: Mixed organic waste (100%)

P2: Fruits, vegetables and plant residues (25%: 75%)

Table 4-3 displays the trial ingredients and composting time. As for P1, around 286 tons (56% of total MRF input) was aligned in a long windrow pile with certain dimensions using a front-end loader. In the source-separated organic waste experiment (P2), different source-separated raw organic materials, around 50 tons of fruit and vegetables and 17 tons of plant residues, were combined in 1:3 ratios to ensure the C/N ratio required for effective decomposition.

Table 4-3: Compost runs ingredients and period.

Trials	Raw input material	Initial weight	Pile dimension (W, H, L)	Duration
P1	Mixed organic waste	285.99 tons	4 m, 1.5 m, 60 m	24.02.19 -25.05.10
P2	Fruits and vegetables	50.40 tons	3.5 m, 1.2 m, 20 m	24.02.19 -25.04.19
	Dry leaves	16.80 tons		

Kitchen and organic waste usually represents the source of nitrogen. Available market waste, fruits and vegetables, do not meet the required C/N ratio, therefore materials rich in C (plants residues) must be combined (Abbassi et al., 2015). The appropriate mixing of carbon and nitrogen benefit the procedure by providing the microbial community with an adequate source of food and energy (high level of carbon). The mixture ratio was chosen with respect to meeting the needed C/N ratio of 25 - 30 for start of the process. Theoretically, C/N ratio can be calculated using the following equation (Abbassi et al., 2015; Amlinger et al., 2005):

$$C/N_R = \frac{\sum_1^n (w \times C \times (100 - M))}{\sum_1^n (w \times N \times (100 - M))} \quad \textbf{(2)}$$

Where,
C/N_R: C/N ratio of resulting mixture.
C: carbon content of individual components of the mixture (%).
N: nitrogen content of individual components of the mixture (%).
M: moisture content of individual components of the mixture (%).
$w_{1...n}$: wet weight of individual components of the mixture.

Organic materials were aligned in long windrow piles using a front-end loader (Figure 4-2). The dimension of a windrow has high importance in the maintenance of composting processes; height ranges of 1-2 m are crucial for heating up in pile, and an arched surface shape with a slow slope allows higher absorption of irrigation/ rainfall water. The height and width of a pile is usually set according to the operating range of the machinery turner. The types of the raw materials and the mixture ratio affect the process duration and properties of final products.

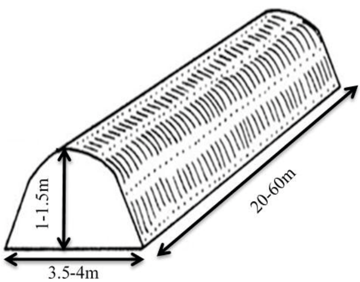

Figure 4-2: *The dimensions of the prepared composting windrow piles.*

The composting method implemented in the Shiraz plant was based on the principles of windrow technology in an open site area. Once the windrow pile had an adequate C/N ratio and bulk density, then the aerobic composting process was dependent on providing moisture and oxygen as the necessary requirement for the activity of the microbial community. In-situ monitoring of the composting process is a must for the production of a secured final product. A turning schedule provides the microbial population with oxygen and, meanwhile, adjusting the moisture content and temperature to optimum levels can speed up stabilization of the organic material (Parkinson et al., 2004; Petric & Selimbasic, 2008; Rich & Bharti, 2015).

Over the period of the composting process, temperature and moisture content were monitored on a daily basis. The temperature was measured using a digital thermo-meter (model TESTO 925) in at least five points along the windrow pile and at three depths (30cm from top, middle, 30 cm from bottom). The organic wastes, used in this research work, contained adequate moisture to start the decomposition process. A portal moisture-meter (model REOTEMP) was used to determine the moisture content inside the pile. Water was added when needed and the moisture was kept close to 50% for the first 4 - 6 weeks.

A specialized windrow turner (Komptech Topturn x53, Austria) was used to turn the piles. A turning schedule was adopted based on the temperature and moisture level. The turning schedule for the pile contained mixed organic waste derived from MRF(P1) was as follows: it was turned twice in the first week, once per week from the second to eighth week, and from the ninth week onward, it was turned once every two weeks when heating occurred. The compost pile with source-separated fruit and vegetable waste (P2) had the following turning schedule: it was turned three times in the first and second weeks, twice in the third to the fifth week, and from the sixth week onwards it was turned once a week if the microbial activity continued. In order to monitor the physical and chemical operating parameters in different phases of the composting process, samples were taken. The sample taking intervals for determination of each parameter are presented in Table 4-4. Each time, at least five points along the windrow piles were chosen for sampling.

Table 4-4: *Frequency of sample taking for each physical and chemical parameter.*

Parameter	Frequency
Moisture Content (MC)	Once a week
Density	Every two weeks
EC	Every two weeks
pH	Every two weeks
Ash Content	Every two weeks
Total Organic Carbon (TOC)	Every two weeks
C/N Ratio	Every two weeks
Total Nitrogen	Every two weeks
NH_4	Every two weeks
NO_3	At the end
Total P and K	Start and end
Phytotoxicity	At the end
Pathogen Content	At the end
Heavy Metals	At the end

A section was created by a mini loader in a way that the materials from top, middle and bottom part of the pile could be picked and mixed thoroughly (Figure 4-3). A representative sample of > 2 kg was taken using a three times quartering method; it was then placed in plastic containers with lids and immediately sent to the lab.

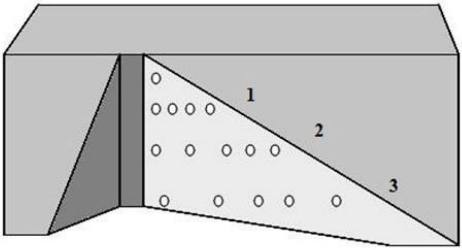

Figure 4-3: *A cross section of the windrow pile for collecting samples from different points.*

Laboratory analysis was carried out at Shiraz's MSWMO laboratory and the central laboratory of Isfahan University of Technology. The standard methods for analysis were retrieved from Iran's national standard international methods for municipal compost sampling and analyzing (Table 4-5). Moisture content was measured using the equation below; the representative sample was placed in a ceramic crucible and placed in an oven set at 105ºC for at least 24 hours or until there was no difference in the weight measurement. The moisture was measured three times and the average was taken.

$$\text{Moisture Content (WC)\%} = \frac{(\text{Wet sample weight} - \text{Dry sample weight})}{(\text{Wet sample weight})} \times 100\% \quad \textbf{(3)}$$

As for ash content measurements, 10 g of the prepared samples were placed in a ceramic crucible and subjected to muffle furnace heating up to 550 ± 10ºC for 6 hours under strict time-controlled conditions, sample mass and equipment specifications. The ash content was identified by calculating the residual mass after heating.

The total amount of organic carbon was calculated from the ash content using the following formula developed by Mercer and Rose (1968):

$$\textbf{TOC (\%)} = \frac{\textbf{VS (\%)}}{\textbf{1.8}} = \frac{\textbf{100 – Ash(\%)}}{\textbf{1.8}} \quad \textbf{(4)}$$

Where,

TOC (%): percentage of total organic carbon.

VS (%): percentage of volatile solids.

Ash (%): percentage of ash content.

The C/N ratio was calculated using the following formula:

$$\frac{\textbf{C}}{\textbf{N}} = \frac{\textbf{Carbon Content\%}}{\textbf{Nitrogen Content\%}} = \frac{\textbf{TOC (\%)}}{\textbf{TKN (\%)}} \quad \textbf{(5)}$$

Total Kjeldahl Nitrogen (TKN) and ammonium were analyzed using the regular Kjeldahl Method by Gerhardt Vapodest 30S Analyser Unit. Nitrate and total phosphorus (P) were measured using the spectrophotometry method (WTW Model photo Lab 6600 uv-vis, Weilheim, Germany). For heavy metals, an Inductively Coupled Plasma-Spectrometer (Perkin Elmer, 7300 DV) was used. Total potassium (K) was measured using flame photometry (APHA, 2005).

The Germination Index (GI) was measured using laboratory experiment. About 10 mm of 1:10 compost extract was added to 10 garden cress plants placed in petri dishes with three replications. The petri dishes were placed in the dark for 24-48 hours at room temperature. Water was used as witness and the GI was calculated as follows:

$$\textbf{GI (\%)} = \frac{\text{(Number of germinated seed} \times \text{root length) in compost extract}}{\text{(Number of germinated seed} \times \text{root length)in distilled water}} \times 100 \qquad \textbf{(6)}$$

Finally, the final product was subjected to purification processes. A drum screen was then used to categorize the finished compost into different categories according to its particle size and impurities content for the purpose of marketing. According to Iran's national standard of soil organic improver (10716), the diameter of the final product is up to 8, 8 - 20 and > 20 mm for the first, second and third (poor quality) class, respectively. As per the first class of finished compost, 15 mm and 5 mm drum screens were used in two steps to achieve the required particle size (> 8mm). Consequently, the end product was categorized into three classes: > 15 mm (as rejected materials and to be landfilled), 5 - 15mm (as covering and reshaping material in landfill) and < 5 (as finished compost and to be used in agricultural sector). As per P2 (source-separated organic raw material), it was necessary to screen the final product by 15 mm only (low impurities) to obtain a high quality of compost.

The activity of microorganisms is dependent on a preferred range of moisture (50 - 60%) and the presence of oxygen, which leads to changes in the temperature profile in the compost pile into four stages of mesophilic, thermophilic, curing and saturation. The thermophilic stage is defined by a temperature between 52 - 60˚C, which plays an important role in the sanitation of the compost pile from pathogens and weed seeds (Insam et al., 2007; Zhang & Sun, 2016). Overall, the composting process took 8 - 12 weeks (up to 84 days) for the microbial community to mineralize nutrients and convert the organic compounds into stabilized organic matter.

Table 4-5: *Standard methods for measurement of compost parameters.*

Parameter	Method	Reference
Moisture Content (MC)	Oven method (105°C for 24 hours)	(Breitenbeck et al., 2004)
Bulk Density	Test Methods for the Examination of Composting and Compost (TMECC)	(Breitenbeck et al., 2004)
EC	1:10 w/v sample: water extract by an EC meter with a glass electrode.	(Pan & Sen, 2013)
pH	1:10 w/v sample: water extract by a pH meter with a glass electrode.	(Breitenbeck et al., 2004)
Total organic matter (DM%)	100- Ash content (%)	(Larney et al., 2005)
Ash Content	Muffle furnace by ignition at 550˚C for 6 hours.	(Oviedo-Ocana et al., 2019)
Total Organic Carbon (TOC)	TOC (%) = (OM÷1.8)	(Mercer & Rose, 1968)
C/N Ratio	(TOC/TKN)%	(Saad et al., 2013)
Total N	Kjeldahl Method	(APHA, 2005)
NH_4^+	Kjeldahl Method	(APHA, 2005)
Total P and K	Atomic absorption spectrometric methods	(Ryan et al., 2003)
Phytotoxicity	10 cress seeds in Petri dish with 1:10 w/v sample: water extract for 24 - 48 hours in dark conditions	(Zucconi et al., 1981b)

4.2. RESULTS AND DISCUSSIONS

This section describes the results obtained from the composting trials. The experiments consisted of two runs, which were comprised of different raw input materials. The process was monitored against several parameters such as temperature, moisture content, pH, EC, C/N ratio, bulk density and nutrients. Samples were taken over the period of the composting process to monitor the biological process. Lab analysis was carried out and the results obtained were evaluated and compared with the Iranian and German standards.

4.2.1. CHARACTERIZATION OF COMPOSTING TRIALS

As mentioned in Section 4.1.3, there were two compost runs, P1 and P2, each containing different mixtures. The full portion in P1 was made from < 70 mm fraction derived from MRF. P2 was formed from three portions of fruits and vegetables and one portion of garden waste. The initial characteristic of raw organic materials plays an important role in composting processes; among them, the C/N ratio is the most important factor. Table 4-6 presents the initial physical and chemical characteristics of the raw materials used in the composting experiments. P1 had a C/N ratio of around 25. The mixing ratios in P2 were considered according to the formula suggested by Amlinger et al. (2005) to obtain a C/N ratio ranging from 25 to 30 based on the weight of input organic wastes.

Table 4-6: *The characteristics of initial raw materials used in composting experiments.*

Parameter	P1	P2
Physical properties		
Bulk density kg/m^3	594.97	417.6
Moisture Content (MC) (%)	67	61
Chemical properties		
Organic matter (%)	79.90	53.42
Total organic Carbon (%)	44.39	29.68
Total Nitrogen (%)	1.80	1.16
C:N Ratio (w/w)	24.66	25.58
pH	5.90	7.13
EC (dS/cm)	5.78	2.04
Total P (%)	0.52	0.24
Total K (%)	0.79	1.3

The initial mixture with low C/N ratio was more vulnerable to loss of N through leachate generation and evaporation. N, which is an easily available source for microbes, is evaporated in form of NH_3, as a result of the ammonification process. Particularly, this occurs when the piles are aerated. A limited turning schedule creates anaerobic conditions, unpleasant odors and methane (CH_4) generation. To this end, wider ranges of C/N ratios for raw input materials are required. Carbon sources should be turned into easily available forms with pre-processing such as screening and shredding.

A pile with proper porosity needs less turning. Impurities in P1 and screened green space in P2 contributes to obtaining reasonable particle size and porosity for the composting process. Impurities and a wide range of materials such as meat, dairy, etc., in P1 caused higher values of EC but lower pH than in P2 with fruits, vegetables and dry dead leaves as original material. Materials with higher protein content such as meat have higher N (%) and P (%), in contrast, organic materials such as fruits, vegetables and plant residues have higher K (%), which can be seen clearly in P2. Meat, as one of the major ingredients in Iranian cuisine, has less leftovers due to the high price. As a result, P1 had higher N but a lower content of P. Both piles had almost the same ranges of initial dry matter (100% moisture); consequently, P1, with higher dry organic content, had a higher bulk density. The results indicated suitable conditions to begin the composting process.

4.2.2. Physical properties

Temperature

The oxidation of carbon sources through microbial activities produces abundant energy in the form of heat during the decomposition process (Barton, 1979; Norbu et al., 2005). The changes in temperature are considered as a proper indicator for efficient composting processes (Norbu et al., 2005; Xiao et al., 2009).

The temperature was monitored daily and showed the clear difference in the raw input material between the two trials (Figure 4-4). Accurate conditions in P2 led to rising temperatures in the thermophilic phase (> 50°C) in first week, reaching its highest level in day seven. The rapid change in the temperature profile during the first week indicated extreme reductions in the organic matter in the active phase of composting (Epstein, 1996; Norbu et al., 2005; Stentiford et al., 2010). P1 reached the highest temperature > 50˚C after two weeks due to the increased air space in the mixture by impurities and loss of heat through surface convection in the early stages (Yuan et al., 2019).

During the active decomposing phase, P2 produced more temperature fluctuation and, consequently, more frequent turnings to maintain the process in sanitation phase. The heat absorbed by impurities in P1 caused higher average temperatures in the pile during the whole process as well as the need for a weekly turning. Both trials fulfilled the requirement for sanitation (pathogens-free), insect larvae and weed seeds by reaching the temperature ≥ 60˚C for more than two weeks (Böhm, 2007; Haug, 1993; Insam et al., 2007; Zhang & Sun, 2016).

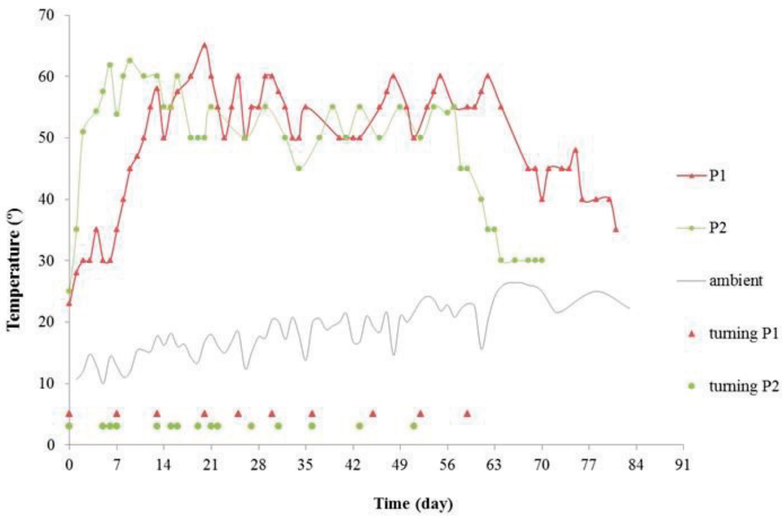

Figure 4-4: *Temperature profiles during composting experiments.*

The decomposition of the different raw materials (i.e. lignocellulosic) in P2 took place over the period of composting: eight weeks (Chiumenti et al., 2005; Francou et al., 2008; Tuomela et al., 2000). No rises in temperature from day 56 onwards demonstrated decreasing microbial activities. The temperature reached to an ambient in weeks nine and ten, whereas the temperature remained higher than 50˚C until week nine. The temperature profile demonstrated an incomplete curing phase in P1, as, after 11 weeks, the temperature of pile did not reach ambient.

One of the aims of this study was to determine how different raw organic materials affect the composting process. Different patterns in temperature fluctuation, especially in the maturation phase, are part of the answer to this question. This is an important matter in arid and semi-arid zones with frequent sunny days all year round. The higher ambient temperature would increase the temperature in the piles. In this experiment, performed in winter, it took more than eight weeks for the pile with mixed origin waste to cool down. The longer duration of the active phase increases the labor costs and requires more space for development of a compost facility. The pile should be turned more and, consequently, more irrigation water is needed. The final product of such a process has more ash content and lower moisture.

The most obvious finding to emerge from the temperature profile is not only that it took less time for source-separated organic materials to cool down, but the piles also reached lower temperatures compared to the pile with mixed origin waste. These specifications make the development and production of source-separated market waste more profitable. The availability of raw materials is, however, the limiting factor. These results further support the idea of less temperature fluctuation due to less foreign materials. A sustainable solution would be, therefore, removing impurities from the pile as soon as the thermophilic phase has taken place and continuing the second mesophilic phase after the sieving process. In this case, ensuring a complete sanitation process is essential.

Moisture

Moisture is an essential factor in maintaining the metabolic process. Microbial metabolism requires aqueous medium to gain nutrients and energy from chemical reactions. Moisture content impacts the process in terms of oxygen uptake rate, free air space and temperature (Petric et al., 2012). According to Norbu et al. (2005), optimal effective decomposition depends on the waste's nature. Previous studies confirmed that the moisture content should be at 40 - 60% during composting (Bernal et al., 2009; Norbu et al., 2005).

There was no leachate production during the composting process, indicating that water was only lost through evaporation. This was due to the fact that the composting process was carried out under optimal conditions: a well-blended pile structure (mixing ratio). Moreover, the cold weather in winter (the composting process period) inhibited the generation of leachate. The moisture content of experimental piles was kept close to 50% throughout the entire process (Figure 4-5). Proper moisture content, adequate porosity and accurate aeration accelerated the organic matter's aerobic degradation. Further, 163 mm rainfall during the composting experiments (February to June 2019) provided the piles with adequate moisture content. Usually, the evaporation rate is higher than water added in semi-arid areas and, as a result, the moisture content decreases during composting. The moisture content was in the same range in each experiment piles up to the third week. The difference in raw organic material resulted in different moisture profiles in the thermophilic phase. The active decomposition rate in the initial weeks in P2 led to a sharp reduction of moisture inside the pile. Higher moisture content indicated lower decomposition rate in P1 due to impurities. At the end of the composting process, the moisture content values ranged from 36% to 39% for different types of compost.

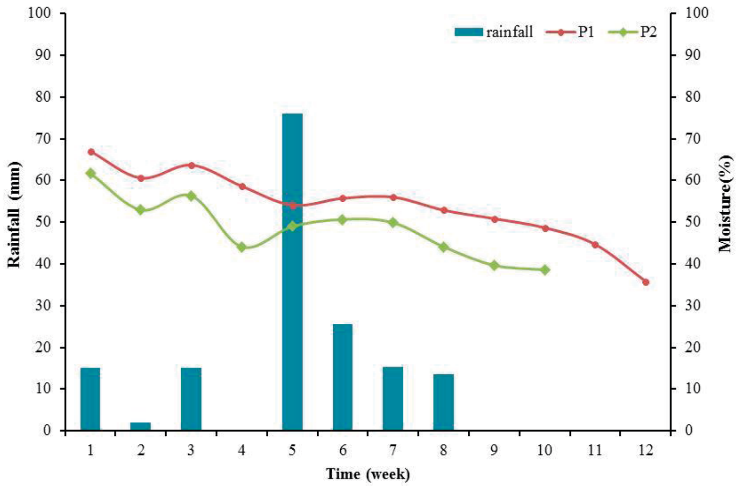

Figure 4-5: *Rainfall frequency and moisture profiles during composting experiments.*

The moisture content of the final product can give insight into the processing and storage conditions, which is a matter of concern in semi-arid regions. Both piles were subjected to purification and the moisture content was found to be 21% for < 5mm fraction of P1 and 24% for < 15mm fraction of P2 as final products. Consistent with the literature, these findings broadly support the links between in-situ measurement and the quality of final products. Proper moisture content by the end of the biological process (Figure 4-5) makes it possible to achieve standard moisture content after the sieving process. The final moisture content of 21% and 24% met the values set by the Iranian Standard, which should be < 15% for first class compost and < 35% for second class compost. Further, the results obtained are in line with Elnaas's (2015) findings, who found moisture content varies from 7.4% to 33% with an 18.5% median value in the MENA region.

An initial objective of the project was to identify proper operational processes and achieve state-of-the-art application of composting technology. The findings indicate that moisture content as the most limiting factor in the study area is properly handled. This was mainly due to the abundant rainfall during the research period. This result may be explained by the fact that the better quality of rainfall, compared to saline groundwater, improved the biological process and quality of the final product. It can thus be suggested, to increase the potential of producing compost in the rainy seasons that rainwater is collected for irrigating compost piles. A critical point in semi-arid areas is to consider the production rate based on the available water and not the available raw organic materials. The windrow piles should be handled according to their final applications: bio-drying and soil amendment.

Bulk density and weight of piles

During composting, aerobic microorganisms decompose the organic materials into stabilized substances through several chemical reactions: mineralization, ammonification, denitrification, etc. The byproducts of the biological processes are heat, carbon dioxide, ammonia and a humus containing product of lower weight and volume (Abbassi et al., 2015; Yue et al., 2008). Mass and volume reduction during composting of several raw materials is a key factor in the design and operation of composting facilities (Breitenbeck & Schellinger, 2004).

Table 4-7 shows the changes in mass, volume and bulk density of the composting experiments. The reduction values for P1 and P2 met the results of Breitenbeck and Schellinger (2004), who reported that mass loss during the composting of six different feedstocks ranged from 11.5% to 31.4% of the initial weight and 18.5% to 57.9% loss of the initial volume.

Table 4-7: *Mass, volume and density of composting experiments.*

Trials	week	Mass loss by initial%	Volume loss by initial%	Bulk density kg/m^3
P1	0	29.42	45.40	594.97
	12			385.47
P2	0	26.58	22.01	417.60
	10			504.19

The P2 trial, with its balanced proportion of carbon and nitrogen under ideal conditions of moisture and temperature during the composting process, consequently had around 22% reduction in volume. P1 showed higher volume reduction of about 45% mainly due to the shrinkage of impurities such as paper, cardboard and sanitary waste during the mesophilic phase. Mass and volume reduction significantly affect the bulk density value over the composting process period. The latter is highly influenced by the moisture of fresh raw material (Larney et al., 2000; Mohee & Mudhoo, 2005; Mohee et al., 2008; Raviv et al., 1987). The bulk density of compost is an indicator for the mass of material within a specified volume. It defines the quantity of compost that can be placed at a certain site as well as considering the machinery size for transportation (Agnew & Leonard, 2003).

The high moisture content of about 70% in P1, as well as the presence of impurities, resulted in a final product of lower bulk density compared to the initial values. It demonstrated that there is a strong relation between the level of organic matter decomposition and bulk density: the more organic decomposition, the higher the bulk density achieved (Hemidat, 2019). This was clearly seen in P2: a remarkable increase in the bulk density of about 20.74% was observed. As for P1, the findings demonstrated a reduction in bulk density of 35.21% due to impurities inside the windrow pile (Figure 4-6). A screening process improved the density value for the final product of P1 (< 5mm) to reach 589.39 and 747.21 kg/m^3 for P2 (< 15mm). These results confirmed those of Sullivan and Miller (2001), who revealed that composts with moisture content of 35 - 55% generally have a bulk density of 0.5 - 0.7 g/cm^3.

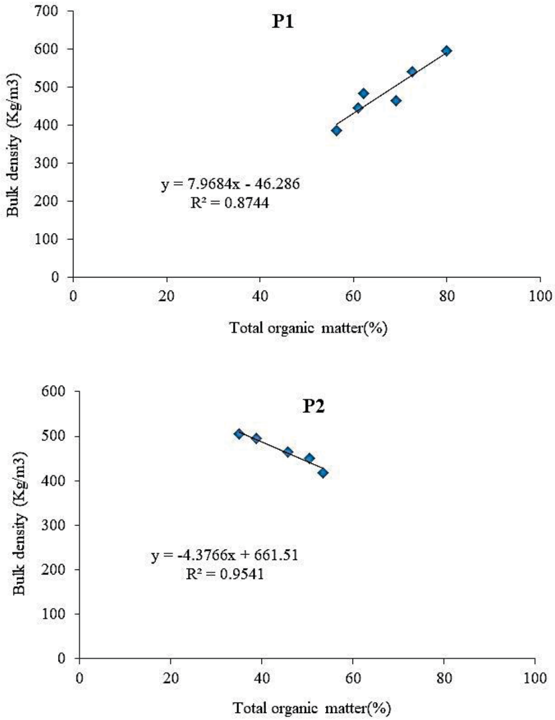

Figure 4-6: *The relationship between bulk density and total organic matter.*

One of the questions this study sought to determine was whether the MRF facility had the capability of producing acceptable raw input material. This finding confirms the significant difference during the composting process in the piles with different origins. P1 contained impurities in a manner that affected the bulk density. The MRF pre-treatment process, therefore, should be improved in a way that means less bulking agent (glass, plastic, etc.) ends up in piles.

4.2.3. Chemical properties

pH

The pH value indicates the acidic or basic behavior of an aqueous solution, based on the calculation of hydrogen ions at room temperature. pH is an important chemical property for compost final product; microbial activity and the availability of different nutrients for the plant's root are considerably affected by the pH of growth medium added to agricultural soils (Alam et al., 1999). Formation of fatty acids during the early stages of the composting process may decrease the pH and, consequently, the decomposition rate. The optimal value for microbial activity is suggested to be around the neutral ranges of 6.5 to 7.5 (Gage, 2003; Rynk et al., 1992; Wong et al., 2009). During the mesophilic phase, the mineralization of nitrogenous compounds increases the pH value by forming ammonia (NH_3) and ammonium (NH_4^+). In the curing phase, the oxidation process transforms ammonium to nitrate (NO_3^-), which is defined as the nitrification process (Gajalakshmi & Abbasi, 2008). Depending on composting feedstocks, the pH value of a final product reaches a constant level ranging from 7.2 - 8.3 (Nakasaki et al., 1993).

The composting process in the P1 experiment began in the acidic range due to the formation of organic acids through the early decomposition of food wastes inside the pile (Figure 4-7). Consequently, the breakdown of proteins and the formation of ammonia, due to the domination of thermophilic microorganisms during the first week, led to an increase in the pH (Oviedo-Ocaña et al., 2019). Several feedstocks and impurities in the P1 experiments represented a lower pH value of 7.6 at the end of process. In P2, the pH reached a value of 8 faster as a result of a higher putrefaction rate supported by the higher turning frequency during the initial weeks of the process. The final product of P1 (< 5 mm) and P2 (< 15 mm), after purification, had pH values of 7.9 and 8.35, which are both within reasonable ranges for finished compost (Sullivan & Miller, 2001).

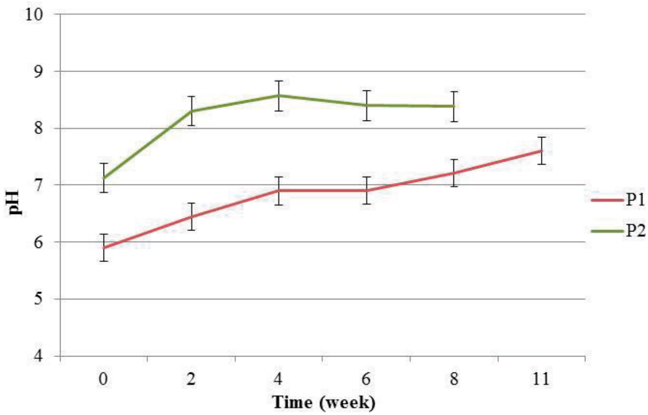

Figure 4-7: *pH values of two windrow composting experiments.*

The sodic and saline soil and water in the study area limited the application of fertilizers. The preferred pH ranges of compost produced make the adjustment of soil organic matter and addition of other nutrients, in form of mineral fertilizer, possible. The latter is an important factor in commercializing the final product.

<u>Electric Conductivity (EC)</u>

Electrical conductivity (EC) is usually measured in soil and compost to estimate the salinity of growth media (Thompson et al., 2002; Van der Gheynst et al., 2004). It is an indicator of total salt content of materials and commonly defined in the water extract of the samples (Epstein

1996; Wilson, 1983). The EC is an important chemical property for end users of compost products due to toxic effects on plant growth (Chan et al., 2016). The addition of compost with high EC to soil increases the salt accumulation in the root zone and, consequently, inhibits water absorption by roots (Van der Gheynst et al., 2004). Crops can resist different ranges of salinity according to their species. The EC of the final product has a high importance under arid and semi-arid conditions due to lower organic matter content and the higher salinity levels of soils in these areas.

The initial EC values of the composting experiments clearly indicated the difference of raw materials inside the piles (Figure 4-8). P1 contained numerous types of feedstocks and had an EC value (5.78 dS/m) higher than P2 (2.04 dS/m). The degradation of organic materials by microbial activity released soluble salt during the composting process and, consequently, increased the EC value (Agnew & Leonard, 2003; Chan et al., 2016; Grebus et al., 1994).

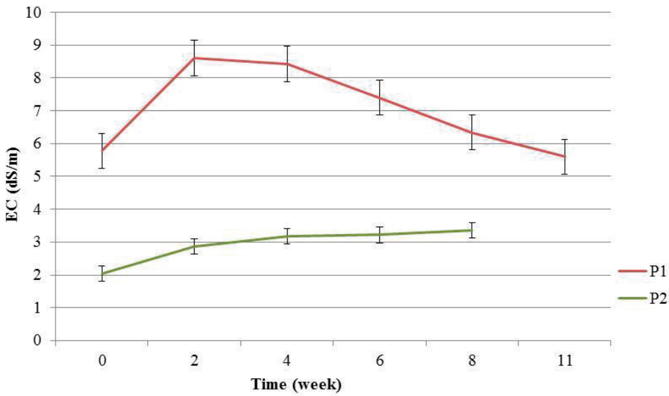

Figure 4-8: *EC profiles of composting experiments.*

The decomposition of proteins in P1, and the formation of ammonia, gave a rapid rise to the EC level at the start of the theomorphic phase. A subsequent decrease can be observed, which was due to the lower decomposition rate and oxygen uptake due to the turnings. In P2, the EC slowly increased to be around 3.18 dS/m and this range remained more or less stable until the end of the composting process; this resulted in a final EC of 3.36 dS/m after eight weeks. Compared to the preferred range of EC value for growth medium, 2 - 4 dS/m, the final product from the P1 experiment, with 5.45 dS/m, had lower potential to be used as soil conditioner.

C/N ratio

The relative ratio of carbon and nitrogen is one of the major parameters in controlling the nutrient balance in composting processes (Norbu et al., 2005). Carbon acts mainly as a source of energy for the microorganisms. The population growth of bacteria depends on nitrogen while their structure is mainly formed from proteins (Gajalakshmi & Abbasi 2008; Norbu et al., 2005). The ideal range for stimulating nitrogen immobilization or mineralization in composting processes falls in the initial substrate to about a 25 to 35 C/N ratio (Golueke, 1992; Tchobanoglous et al., 1993).

The decomposition process is slowed down by limiting nitrogen sources; whereas the mixture containing low carbon content losses extra nitrogen as ammonia during turnovers (Gajalakshmi & Abbasi 2008). It is essential that carbon is provided in easy degradable forms. To improve the decomposition process, materials of high cellulose content should be shredded prior to pilling. The microbial activity significantly decreases by < 20 C/N ratio; for that reason, the C/N ratio is mostly used as a stability index ranging from 15 to 20 for a finished final product. Jiménez and Garcia (1992) developed a stability index (C/N_{final})/ $C/N_{initial}$); stable compost should have a value of not less than 0.75 and 0.6 for a composting period of > 120 days and 180 days, respectively.

Decreasing the C/N ratio during the composting process in P1 and P2 indicated degradation of organic waste as well as nitrogen immobilization (Figure 4-9). The same range of initial C/N ratio was observed in both composting runs; however, it took less time in P2 to obtain a lower final C/N ratio. A significant reduction took place in the C/N ratio by the end of the composting period, which was found to be 29% and 36% in P1 and P2, respectively.

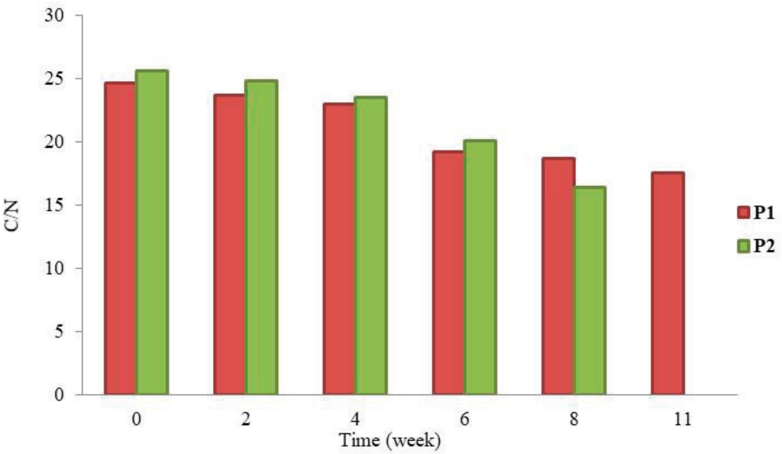

Figure 4-9: *C/N ratio profiles during composting runs.*

Higher decreases in P2 demonstrated the better availability of carbon and nitrogen sources in the pile, which resulted from the screening of garden waste before piling. The wide range of raw organic materials in P1 resulted in the decomposition process taking longer to complete. The final value of the C/N ratio was found to be 13.3 and 13.87 in P1 (< 5 mm fraction) and P2 (< 15 mm fraction), respectively.

Nitrogen transformation during the composting process

Composting substrates contain nitrogen mainly in organic forms. Insubstantial amounts of organic nitrogen are mineralized to ammonia (NO_3^-) through microbial activity. Ammonification reaction speeds up through the rapid degradation of organic materials during the thermophilic phase. Depending on pile condition, the ammonia produced is transformed; it turns into ammonium when there is proper moisture in a pile to be dissolved in; it is volatilized from a pile when the temperature rises, and basic pH is predominant in a pile. The volatilization rate is higher in windrow piles systems compared to static piles due to air circulation in the pile due to turnovers (Witter & Lopez-Real, 1988).

In the second mesophilic phase, when the microbial activity slows down and the temperature decreases to < 40˚C, ammonium is turned into nitrate (NO_3^-) through the nitrification reaction in presence of favorable oxygen. Under undesirable conditions, the bacteria use the oxygen of NO_3^- in the denitrification process. The inorganic forms of nitrogen can be absorbed by plants' root directly; consequently, the end user has an interest in the concentration of ammonium and nitrate (Gajalakshmi &Abbasi, 2008; Sanchez-Monedero et al., 2001).

Temporal changes of total nitrogen in the experimental composting piles indicated decreases during the active phase (Figure 4-10). Some ammonia was lost due to evaporation, which resulted in a lower content of nitrogen. However, the final product of higher density contained slightly higher values of nitrogen.

By providing both piles with proper oxygen and moisture, ammonium was generated in P1 and P2, with the highest level occurring in the third week; a sharp reduction was observed in P2 to obtain a final value of 0.01%, which was due to the frequent turning scheme. In P1, impurities absorbed the heat and prevented the pile from cooling down; ammonium decreased slowly as a result and reached the final value of 0.04%. Nitrate reached to the measurable concentrations at the end of the composting process. The final product of both piles contained about 0.01% of nitrate. Results showed the fulfillment of the curing phase in P2 (Figure 4-10). The higher value of ammonium than nitrate in P1 implied an immature final product. These relationships may partly be explained by the higher EC value in P1 during the composting process.

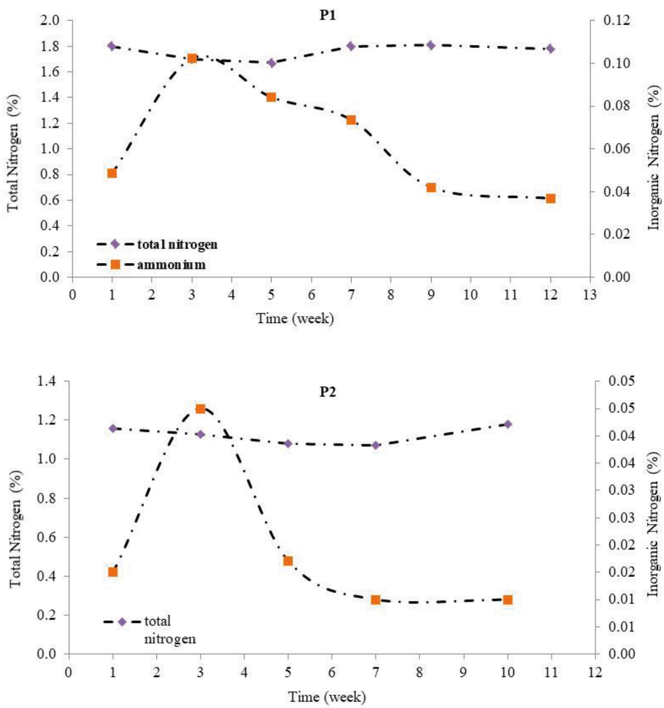

Figure 4-10: *Nitrogen transformation in experimental piles.*

Potassium (K), Phosphor (P)

From an agricultural point of view, the fertilizers should provide the soil with essential nutrients and elements to support the crops' development stages. Nitrogen (N), potassium (K_2O) and phosphorus (P_2O_5) are the macro nutrient elements that significantly affect plant growth. According to Golueke, (1992), a mixture with an initial C/N ratio between 25 and 35 has the potential for rapid and complete humification, whereas small parts of nutrients are mineralized by microbial activity. The reduction in mass and volume of organic materials increases the nutrient content of the final product (Figure 4-11).

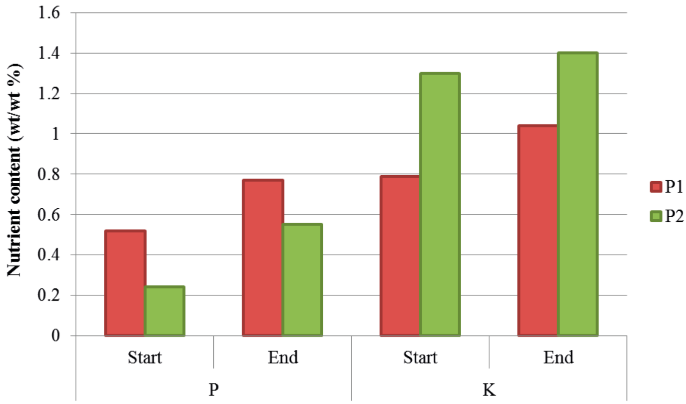

Figure 4-11: *Nutrient content during composting runs.*

The trend of potassium and phosphorous content obviously shows the difference in origin of experimental piles. P2, which included vegetable and plant residue, had higher potassium content. More phosphorous was found in P1, which contained mixed households and business sector waste. Comparison of the value of phosphorus in kitchen waste (P1) with those of other studies implies lower consumption of protein products in Shiraz (Hemidat, 2019; Yousefi et al., 2013).

Nutrient content was increased in the experimental windrow piles. The concentration of phosphorus measured 32% and 56% more in the final products of P1 and P2, respectively. Potassium was increased to 24% by the composting process in P1. Overall, P2 underwent a lower mineralization reaction due to the limited variation of organic materials. The concentration of phosphorus in the final products of both piles met the second class of Iran's national standard for soil organic improver. The latter leads to low marketability and, therefore, nutrient adjustment should be applied prior to marketing.

Total organic matter

In order to define the degradation rate, the total amount of organic matter is determined by measuring the biodegradable volatile solids content of oven dried samples using an ignition method at 550˚C. The organic matter for class I compost product is set by the Iranian national standard > 35% (dry matter %) and > 25% for class II. The poor organic matter content of soil in semi-arid regions heightens the necessity of using organic fertilizer in agriculture to enhance soil fertility, improve plant growth and prevent degradation. German standard suggests 15 - 45% organic matter in the final product because large organic particles require long decomposition time (BMUB, 2017).

Volatile solids, indicating organic matter, was about 80% and 53% in P1 and P2 (Figure 4-12). The organic matter content was reduced by 29% and 35% for P1 and P2 throughout the composting period. The reduction of volatile solids, and the subsequent increase of the ash content, in the samples points out the decomposition process by microbial activity.

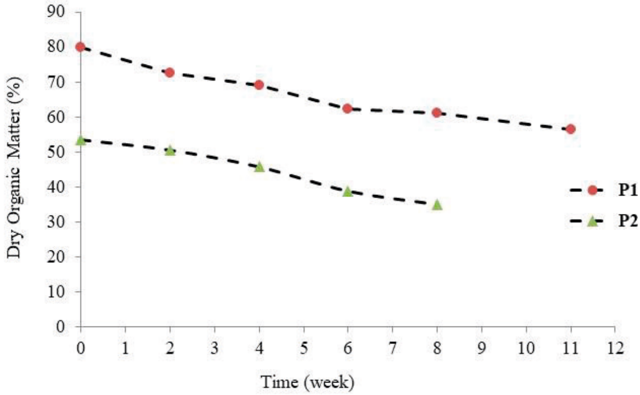

Figure 4-12: *Organic matter content in the analyzed compost samples.*

The value of organic matter after eight weeks of composting reached 34.87%, while in P1 the impurities slowed down the degradation process and less reduction was observed in the organic matter content. The organic matter of the final product in P1 (< 5 mm), after two step sieving, was adjusted to 45.5%, which may contain large particles of organic materials according to the German standard (BMUB, 2017).

<u>Heavy metals</u>

The content of heavy metals in the final product of composting depends on the raw materials' properties and the collection method (Zhang & Shao, 2008). Composting is widely practiced, immobilizing the heavy metals and changing them into unavailable forms for plant uptake (Barker & Bryson, 2002; Singh & Kalamdhad, 2012). Mass and volume reduction of waste during decomposition processes through microbial activity increases the concentration of heavy metals in the final product (Smith, 2009).

The utilization of compost with high heavy metals content can affect soil properties, reduce crop productivity and contaminate the food chain in long term (Wong & Selvam, 2006). The standard limit of heavy metals varies in different countries; most developing countries have no or low limitation levels regarding heavy metals in compost produced from mixed waste.

The concentrations of heavy metals in the finished compost are shown in Table 4-8. Source-separated raw input materials in P2 had lower heavy metals content than the P1 experiment. All parameters in P1 met the Iranian standard; regarding the German standard, only Cu had a higher value than expected.

Table 4-8: *Heavy metal concentrations of final products.*

Parameter	P1	P2	Iranian standard	German standard	
				Class A	Class B
Pb mg/kg	94	27.35	200	150	100
Cd mg/kg	0.5	0.04	10	1.5	1.0
Cr mg/kg	6	8.32	150	100	70
Cu mg/kg	166	56.89	650	100	70
Ni mg/kg	17	15.34	120	50	35
Hg mg/kg	-	-	5	1.0	0.7
Zn mg/kg	231	95.26	1300	400	300
Co mg/kg	6.82	0.4	25	-	-

These results show the importance of waste segregation to ensure a high quality of final product (P2). All of the compost samples analyzed had lower heavy metals concentrations than those values set by the German standard. This was due to proper management of industrial and hospital waste streams in Shiraz, which is collected separately.

Pathogen content

The metabolic reactions under aerobic composting are mainly controlled by temperature fluctuation (Norbu et al., 2005). It has considerable effects on the type, number and species of microorganisms involved in biological processes (Hassen et al., 2001). Most of pathogens are deactivated and destroyed at high temperature (Gajalakshmi & Abbasi 2008).

Several authors have reported that the thermal death point of 55 – 60°C, for at least 24 hours, along with moisture content of about 50%, fully deactivates most pathogens (Barton 1979; Hassen et al., 2001; Norbu et al., 2005; Polprasert, 1996). Fertilizers can contaminate soil and plants' root if they contain pathogens such as E.coli and Salmonella (Strauch, 1996). Therefore, maintaining composting processes with favorable moisture and heat has high importance in securing the quality of final products. The results, presented in Table 4-9, indicate that the efficient in-situ monitoring of composting processes in both piles resulted in pathogen free final products.

Table 4-9: *Pathogen content of produced composts compared with Iranian standar.*

Type of pathogen	Content (MPN/g)		Iran Standard
	P1	P2	
E. coli	11	< 3	1×10^3 (MPN/g)
Salmonella	Absent	Absent	3 (MPN/4g)

Phytotoxicity

A phytotoxicity test is used to describe the degree of maturity in the final product (Gajalakshmi & Abbasi 2008). During the second mesophilic phase, called curing, the microbial activity decreases, and the pile temperature drops down to meet the ambient (Cesaro et al., 2019). Under optimum composting conditions, organic acids produced during the mesophilic phase are degraded in the curing phase; salt and heavy metals are mineralized or immobilized (Kim et al., 2018). Nitrification in this phase contributes to lowering NH_4^+/NO_3 (Morisaki et al., 1989). The absence of phytotoxic substances (ammonia, organic acids, etc.) and unavailable forms of salt and heavy metals are essential for seed growth (Barberis & Nappi, 1996; Barral et al., 2007; Himanen et al., 2006; Prasad & Hagemeyer, 1999); therefore, germination tests of sensitive seeds such as cress and Chinese radish are widely used to determine the toxicity of final products (Barral & Paradelo, 2011).

According to the Iranian standard, the final product should obtain GI > 70%; further, a NH_4^+/NO_3^- ratio of between 0.5 - 3 counts as mature compost. Zucconi et al. (1981a, 1981b, 1985) and Emino and Warman (2004) reported high contents of phytotoxic substance by GI < 50%, moderate phytotoxicity by 50% to 80% GI, and the absence of phytotoxicity by GI > 80%. Compost produced from P1 and P2 had 65% and 80% GI, respectively; the NH_4^+/NO_3^- ratio was 3.47 for P1 and 1.48 for P2 (Table 4-10).

Table 4-10: *The degree of maturity in final product of composting experiments.*

Trails	NH_4^+/NO_3^-	Germination index (%)
P1	3.47	65
P2	1.48	80

It can be clearly observed that the NH_4^+/NO_3^- ratio in P1 (3.47) was higher than the value in P2 (1.48). This was mainly due to the delay in the curing phase (using high temperature for long periods) in P1, which resulted in an incomplete nitrification process. High GI in the final product of P2 indicated that phytotoxic free compost was produced with moderate content of toxic substances in P1. The results obtained are in line with the several studies which have reported the negative correlation of ammonia with GI (Barberis & Nappi, 1996; Wong et al., 1983; Wong, 1985).

4.3. ADOPTING STATE-OF-THE-ART COMPOSTING

This study set out to assess the importance of source separation for adapting state-of-the-art techniques composting of municipal organic waste. The obtained results clearly indicate the difference between the physical and chemical properties of the final products (Table 4-11). The aim was, indeed, to examine the desired quality of the finished composts for enhancing the soil's physical, chemical and biological properties. This was obtained through analysis of critical elements, as mentioned in Chapter 3. It was hypothesized that quality control parameters would be classified into two groups: the factors related to agronomic aspects and the risk-free use of the final products. The C/N ratio, organic matter, nutrient content (NKP), pH, EC, germination rate, particle size, caption exchange capacity and humic substances are defined as the major fertility related indicators by Van Fan et al. (2016). Usually the rules and standards give higher priority to the cleanness of MSW compost, and particularly to heavy metals, while fertility is a matter of marketability. The absence of quality assurance systems in most developing countries such as Iran impose significant risks to the environment and human health through the uptake of heavy metals into crops and contamination of the food chain.

Table 4-11: *Final physical and chemical characteristics of produced compost.*

Parameter		P1	P2
Ash Content (%)		58.30	66.3
Total Organic Matter (%)		45.5	33.7
TOC (%)		25.28	18.72
TKN (%)		1.9	1.35
C/N Ratio (w/w)		13.30	13.87
Moisture Content (%)		36	39
pH		7.9	8.35
EC (dS/m)		5.45	3.45
Total N (%)		1.9	1.35
Total P (%)		0.77	0.55
Total K (%)		1.04	1.4
Final Bulk Density Kg/m^3		589.39	747.21
Heavy metals mg/kg	Pb mg/kg	94	27.35
	Cd mg/kg	0.5	0.04
	Cr mg/kg	6	8.32
	Cu mg/kg	166	56.89
	Ni mg/kg	17	15.34
	Hg mg/kg	-	-
	Zn mg/kg	231	95.26
	Co mg/kg	6.82	0.4

An assessment system developed by Saha et al. (2010) indicates the agronomical and environmentally viable application of compost produced from MSW. Following this approach, composts produced in this research were of high fertility and clean; all of the final product samples analyzed appeared to be stable and considered as class A, making it suitable for the cultivation of any agricultural crops.

In the case of source-separated organic waste, the findings indicate that the state-of-the-art composting process was performed successfully under ideal conditions. The chemical and physical characteristics of the final products demonstrated a complete degradation of organic waste within a relatively short period of time (10 weeks).

Overall, the results obtained from the research experiments look good and the compost produced has the potential to be utilized in agricultural purposes: practically, the compost derived from P2 (source-separated organic waste). In the case of the mixed waste compost, more energy and measures were required to secure a quality final product. A note of caution for cultivating food crops is due here, however, since the current study does not reflect the actual status of the Shiraz's compost facility. In this research, the raw organic wastes were subjected to ideal conditions in terms of pilling, in-situ measurements (temperature, moisture, etc.), daily monitoring activities (aeration, turning, sampling) and lab analysis. Specifically:

- A specified area with linear and lateral slopes was allocated for performing the two trials. The location was selected in such a way that ensured the drainage of extra moisture (leachate) through the piles.
- The raw organic materials were blended using different types of organic waste with different ratios to provide the required initial C/N ratio for efficient microbial activity.
- In-situ measurements were carried out on daily basis; temperature and moisture were monitored and, accordingly, each pile was subjected to different operational activities such as aeration, turning, etc. Watering and turning schedules differed due to origin of input materials in the experimental piles.
- Sampling was carried out periodically; representative samples were taken every alternative week to monitor and ensure an accurate degradation process.
- Lab analysis was performed in equipped laboratories against several key parameters: moisture content, bulk density, pH, EC, nitrogen, ammonium, C/N and organic matter.
- The final product was subjected to a strict evaluation. The finished compost was examined against pathogens, heavy metals and phytotoxicity content and the obtained results were compared with the values set by national and international standards. Accordingly, different utilization purposes were identified based on the compost quality achieved.

4.4. OUTLOOKS

4.4.1. APPLICATION RATE OF COMPOST FROM NUTRIENTS PROSPECTIVE

Micro and macro nutrients play a pivotal role in the germination, development, growth and yield of agricultural crops. Well-adjusted nourishment throughout their growth cycle is, therefore, essential. Most of the required nutrients are supplied by the soil, but they are often in deficient amounts to secure high productivity. After each harvest, nutrients are partially removed from the soil, with crops resulting in depleting the soil. In order to provide the unavailable nutrients, replace the exported fraction and increase the yield's quality and quantity, fertilizers are applied to the soil.

Fertilizers have significant impacts on crop productivity; chemical fertilizers contain inorganic and quick release forms of nutrients while it takes longer for the organic forms in composts to become available to plant roots. From the market point of view, when introducing compost for the end user, they want sufficient nutrient content in the final product to increase plant/crop productivity. The latter is influenced by the application rate of fertilizers, which can be calculated as a function of several key elements (Figure 4-13).

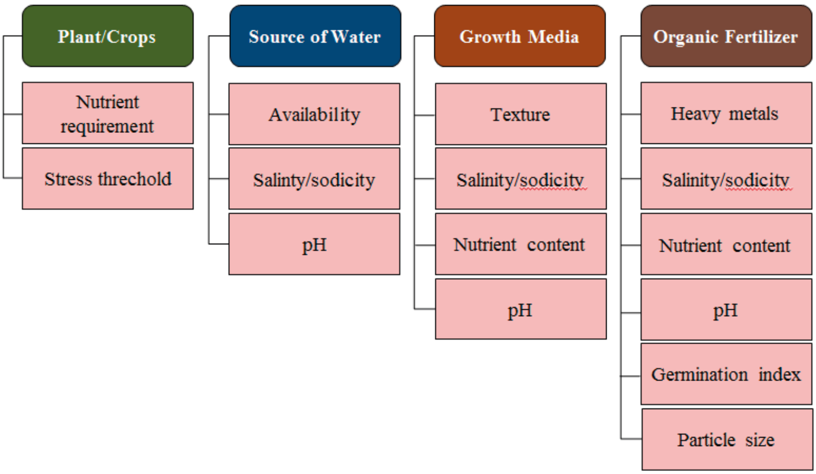

Figure 4-13: *Key elements for fertilizer application rate.*

The application rate of compost is estimated based on the type of plant/crops and their growth requirements (nutrients and tolerance), the nature of water (source, availability) as well as the growth media's properties in terms of its physical and chemical analyses. Compared to the chemical fertilizers, the available form of nutrients in the compost produced is lower, which raises the need for higher rates of application to provide the plant/crop with the required level of nutrients (Table 4-12).

Table 4-12: *Standard rates of fertilizer application for agricultural crops per kg nutrient/ha (Perrier & Salkini, 2012)*

Crops	Nitrogen (N)	Phosphorus (P_2O_5)	Potassium (K_2O)
Cereals			
Irrigated land	150 to 200	100 to 120	50
Arid land	50 to 60	40 to 50	-
Cereals for seed	180 to 220	120 to 140	85 to 90
Rice	200 to 220	140 to 145	150 to 180
Cotton			
Average fibers	215 to 240	145 to 165	95 to 110
Fine fibers	230 to 250	155 to 165	100 to 110
Kenaff	160 to 180	130 to 140	80 to 90
Tobacco	120 to 150	80 to 100	40 to 45
Potatoes	120 to 150	85 to 100	60 to 75
Vegetables	145 to 200	100 to 110	70 to 75
Gourds	50 to 75	100 to 110	45 to 80
Fodder roots	220	90	60
Maize for silage	200	90	60
Established alfalfa	100	90 to 100	50 to 60
Orchards and vineyards	120 to 130	85 to 90	65

The high rate of municipal compost application is a matter of concern for increasing the potential of toxicity as a result of its salt and heavy metals content. In order to avoid such conditions in root zones and support plant growth, the addition of small amounts of MSW compost, in combination with inert mineral material such as peat, is suggested by several studies. Chrysargyris et al. (2018) evaluated the germination and seedling growth of pepper (Capsicum annuum L.) using different concentrations of MSW compost. Pure application inhibited germination while positive results were found using 15 – 30% of MSW added to peat and mineral fertilizer. Similarly, Soobhany et al. (2017) reported significant positive effects on the growth and yield of green beans (Phaseolus vulgaris) in the treatment with 40% MSW vermicompost and compost. A mixture of 3:1 MSW and pine bark compost improved the growth of garden cress (Lepidium sativum) in comparison to 100% peat control treatment (Moldes et al., 2006).

German guidelines recommend a 20 and 30 tons/ha application rate of compost for class B and A, respectively. It also states that the specified application rate should be within a period of three years. The rate identified by the German guidelines does not fit the soil conditions in the majority of Iran. Only 23% of agricultural areas have desirable levels of EC (< 8 ds/m) in Fars Province; the soil is characterized by high salt content of about 34, 10 and 47% of saline, sodic and saline-sodic, respectively.

The available macro nutrients in the compost produced from municipal organic SW in this research fulfilled the plant requirements of most types (listed in Tables 4-12 and 4-13); additional chemical fertilizer would mainly be needed for phosphorous. It is worth mentioning that the application of mineral fertilizer, in combination with compost when it is not necessary, would decrease the capability of plants' roots for utilizing compost-based nutrients, especially in case of nitrogen. Plants with higher nitrogen demand or longer growth periods can utilize more nitrogen from applied compost (Biala, 2011).

Table 4-13: *Nutrient content of compost produced during the research.*

Nutrients kg/ton$_{compost}$	P1	P2
TKN	19.00	13.50
P (P_2O_5)	7.70	5.50
K (K_2O_5)	10.4	14.00

Another possibility to focus on is the different mixing ratios of P1 (high EC, fine particle size) and P2 (low N & P), considering the plants' tolerance to salinity, drought, irrigation water EC as well as the soil's chemical and physical properties, texture, EC and pH. Overall, under arid and semi-arid conditions, greater fertilizer management is required. Several aspects should be taken into consideration including the amount and frequency of compost addition, the plant's tolerance, quality, amounts and frequency of irrigation water or rainfall.

The efficient use of nutrients increases over several years of compost application. Nitrogen, as the most important macro element, has often < 5% efficiency during the first year of application and, hence, >15% efficiency for more than three years' application (Amlinger et al., 2003). The quality of the applied compost is a key factor for implying the nutrient use efficiency rate and should be considered in calculating the fertilizer requirement of the field. For example, 20-35% of nitrogen in high quality compost supports plant growth in a three to four cycle application, whereas immature compost or compost with limited raw input materials such as garden waste can support plant growth by up to 5% (Biala, 2011). These considerations would, on one hand, save the budget for fertilizer application and prevent environmental contamination by nitrogen leaching and, on the other hand, provide the crops with a balanced diet during the growth cycle.

4.4.2. CLIMATE CHANGE MITIGATION THROUGH COMPOST APPLICATION

Industrial agriculture has enormously changed land use and soil management. Excessive use of mineral fertilizers, inappropriate tillage and unmanaged irrigation schemes have resulted in soil degradation. It is assumed that one third of the world's soil has noticeably lost its fertility (Borrelli et al., 2017). The degenerative farming method depletes soil organic matter and causes substantial GHG emissions, thus contributing to climate change. Only the change in land use is responsible for 7-14% of global GHG emissions. One effective solution to this concern is the application of organic fertilizers to mitigate land erosion, nutrient loss, soil compaction, salinity and etc., as well as increasing soil organic carbon and its water holding capacity (Balogh, 2020).

The role of organic fertilizer application in climate change mitigation can be distinguished into two main aspects: inhibiting desertification and increasing carbon sequestration. The implementation of sustainable management practices improves soil health and, ultimately, increases the productivity of arable areas. This would cut down land use change and save more natural vegetation. Furthermore, the soil is a carbon sink and has the capability to store up to 50-300 tons of carbon per each hectare (Amelung et al., 2020). Table 4-14 displays the changes in soil organic carbon by the application of organic fertilizers for several years.

Table 4-14: *The effect of organic fertilizer application on carbon sequestration (Biala, 2011).*

Country	**Time interval (year)**	**Compost type**	**Application rate**	**Carbon retention/ Organic carbon increase**
England	20	Digested bio-solids cake	-	56%
		garden organic compost	50 t ha^{-1}	43%
		manure	-	23%
		straw	-	7%
Germany	12	garden organic compost	10 t DM ha^{-1} yr^{-1}	0.82 t ha^{-1} yr^{-1}
		bio-waste compost	10 t DM ha^{-1} yr^{-1}	0.97 t C ha^{-1} yr^{-1}
		pasteurized bio-waste compost	10 t DM ha^{-1} yr^{-1}	1.13 t C ha^{-1} yr^{-1}
Austria	13	bio-waste compost	8, 15 and 22 t ha^{-1} yr^{-1}	1900 to 6500 Kg C ha^{-1}
Canada	3	bio-waste compost	50 Kg N ha^{-1}	43%

The results obtained in this study were used to quantify the benefits of compost application in terms of climate change. To calculate the increase in the soil organic carbon and carbon sequestration, based on the report of Gilbert et al. (2020), the following assumptions were made:

- Quality compost was derived from source-separated organics (P2)
- The composting process was quality assured
- The increase in the soil organic carbon was moderate (50 Kg ha^{-1} y^{-1} t^{-1} dry mass)
- The stoichiometric ratio of CO_2 was 3.67
- The average dry matter of finished compost was 0.7

The benefit of compost application in the study area was evaluated over periods of 10 and 20 years. Figure 4-14 illustrates a direct relationship between the amount of soil organic carbon and the compost application rates. The highest amount of carbon sequestration, therefore, occurs when a higher rate of compost is applied. Over the periods of 10 and 20 years, soil organic carbon would be increased 10.5 t. ha^{-1} and 21 t. ha^{-1} with 30 tons per hectare compost application, which would also have a considerable positive effect on the available soil water content. However, these results may not be attained due to the lower application rate of compost on the basis of crop nutrient demands.

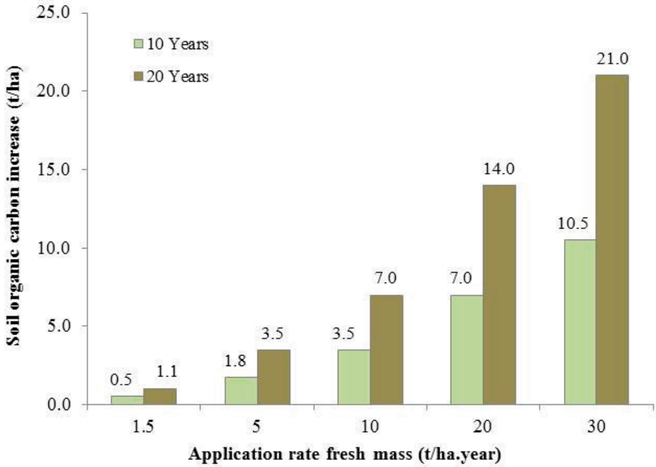

Figure 4-14: *Soil organic carbon increases under different compost application rates.*

Assuming a moderate range of soil organic carbon increase, the application of each ton of compost has the potential to sequester 128.45 kg CO_2 equivalent on a fresh mass basis (50×0.7×3.67). The carbon sequestrated in the soil, stated as carbon dioxide equivalents for different compost application rates, is shown in Table 4-15, over the periods of 5, 10, 15 and 20 years.

Table 4-15: *Sequestered carbon in carbon dioxide equivalents.*

Compost application rate (tons/hectare)	Time (year)			
	5	**10**	**15**	**20**
1.5	0.96	1.93	2.89	3.85
5	3.21	6.42	9.63	12.85
10	6.42	12.85	19.27	25.69
20	12.85	25.69	38.54	51.38
30	19.27	38.54	57.80	77.07
1.5	0.96	1.93	2.89	3.85
5	3.21	6.42	9.63	12.85
10	6.42	12.85	19.27	25.69
20	12.85	25.69	38.54	51.38

Carbon sequestration is significant at the application rate of 20 and 30 tons of compost per hectare. This would also have the effect of preventing soil erosion, which is in agreement with Sustainable Development Goal target 15.3, i.e. combat desertification and restore degraded land and soil by 2030.

5. CONCEPTUALIZING A MODEL FOR MUNICIPAL ORGANIC WASTE MANAGEMENT

Waste management activities have been given high priority on the political agenda in most developing countries. Nowadays, collection, recycling, treatment and disposal of increased quantities of SW are the main challenges facing municipalities and decision makers (Plavac et al., 2017). Municipal solid waste is an inevitable by-product of urbanization. As SW quantum heightens, more effort and capacity for efficient and eco-friendly treatment solutions are urgently needed (Santibanez-Aguilar et al., 2013). A technical solution should be found with the required modifications and proper implementation considering the financial, legal, technical and institutional framework as well as involving major actors in the field of SWM.

Solid waste has great potential to become a precious alternative for future sustainable resources and energy. An effective SWM system involves the adoption of various treatment methods, technologies and practices. Globally, utilization of organics, by means of composting, has drawn merited attention due to its associated economic and environmental benefits. It contributes to waste purification, conversion of waste to value-added products, diverting organic material from landfills and reducing GHG emissions as well as leachate quantities (Storino et al., 2016).

Iran's SWM system does not benefit from a well-defined national policy and implementable legislative framework. Moving from dumping towards sanitary landfilling, increasing the rate of valuable material recovered from waste streams are their strategies. The enacted law and regulations do not have the capability to cope with the existing waste management system due to the weak executive enforcement. Still, to date, the frequent question raised by officials and authorities is how to collect and dump the increasing amounts of waste. Recycling and treatment of waste are not put on the table for debate; therefore, they remain at the initial level. To this end, this chapter is an attempt to provide applicable waste treatment solutions through adapting the technical requirements to the local conditions.

5.1. FUNCTIONAL FRAMEWORK OF ORGANIC WASTE MANAGEMENT

Administrative entities, legislation, financial and technical aspects are the fundamentals of any SWM system. Keep in mind, to adopt a grand strategy, considering only the previous core elements will not guarantee the successful implementation. All the stakeholders involved need to be taken into account, i.e. waste producers, NGOs, the informal sector and manpower in the field of SWM (Figure 5-1).

Legislation is one of the most important waste management elements. Laws, regulations, ordinances, decrees and standards are the legal tools for defining and regulating roles, responsibilities, timeframes, restrictions and the quality of final products. The legal framework must distinctly outline the policy principles, which gives clear indications to the long-term goals. Referring to the SWM law enacted in 2004, the law and regulations in force are not in line with the desired objectives of policy. The said policy recommends decreasing the environmental pollution, through enhancing material and energy recovery, in parallel with adapting sanitary landfilling. The existing ordinance does not address the management of organics as one of the main mitigation tools.

As part of the enacted law, the waste is categorized into five groups: ordinary, industrial, agricultural, medical and special waste. Among the five categories of waste defined, only the ordinary waste is managed by the municipality. The responsibility of managing the rest of waste groups is assigned to their producers, which makes the proper implementation of this assignment questionable.

For example, appointing the duty of managing special waste included in the stream of household waste imposes significant threats to the environment and human health. Waste streams such as this are well-known as the main source of pollution, ending up in raw input materials to be treated. Consequently, before adapting any strategy or treatment technology, the existing regulations must be revised to guarantee the proper handling of the distinguished waste stream categories. Assessment and monitoring tools for the evaluation of the treatment technologies and their output quality must be strongly integrated in the revised legal frameworks.

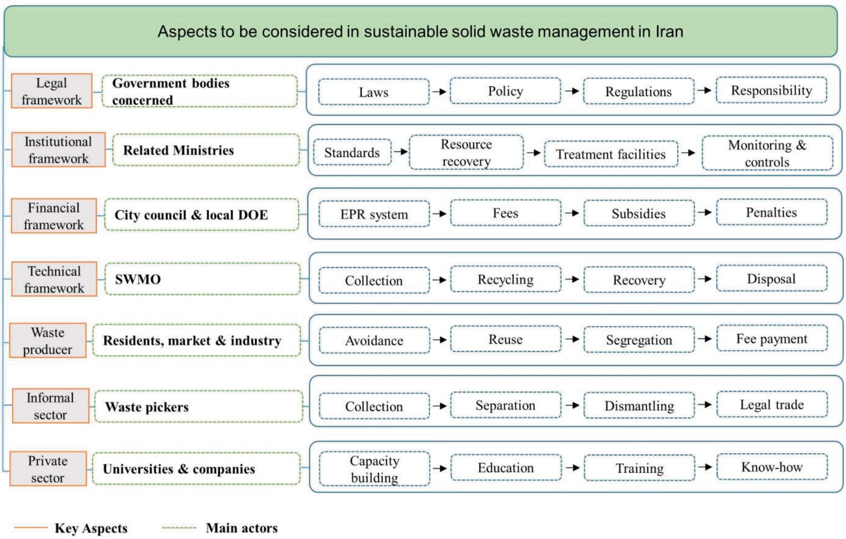

Figure 5-1: *Aspects and stakeholders to be considered in a waste management system.*

Solid waste planning and management is usually performed by several government institutions, with precise mandates and responsibilities and clear lines of authority. The transparent interaction between active institutions is a crucial issue for the effective functioning of the sector and minimum procedures, in terms of information sharing and actions, should be established.

Waste management in Iran is undertaken through the public sector; the private sector is also a significant player in this field. The government bodies involved in planning and managing the waste sector have no collaborative framework. Related ministries are not able to share their know-how and experience. Due to the lack of coordination between the ministries, the dealers become the main players in the field of organics utilization. The latter are aware of the benefits that could be achieved from this fraction.

They benefit from the public's insufficient understanding to buy bulk quantities of organics from the food industry, agricultural and market sectors for the purpose of producing fertilizers. The absence of government bodies as a control tool, as well as the availability of unsecured raw materials, makes the private sector unwilling to invest and construct compost facilities on a large scale.

In order to move towards a well-established institutional framework, several prerequisites must be made; revised legislation should provide the effective framework for dialogue and cooperation. In the same context, different working areas should be focused on: well-distinguished waste streams, explicit remit and flexible know-how exchange involving the least number of institutions.

The financial aspects determine the viability of any business in the long-term and constant attention should be paid to them. Most developing countries suffer from a lack of financial resources. Running a proper SWM system requires good knowledge and understanding of the financial issues. Municipalities' financial problems regularly include an imbalance between income and expenses due to high costs and insufficient revenue.

The financial system in Iran is unequally distributed in the waste sector: up to 75% of the funds available goes to logistic activities and only 25% is left for treatment. Sometimes, the fees collected for waste management are utilized in unclear areas. The practiced scheme for collecting fees from the industrial sector is a voluntary mechanism; only 1% of their profit and/or the revenue generated from one in every 1,000 products ends up in the DoE treasury. This "so-called" EPR benefits the industry sector by reducing their annual taxes.

A new efficient financial concept should be introduced to ensure the cost recovery of actual expenses of waste management activities. Over the past decades, the EPR concept has gained high credit as one the most efficient economic tools. This has been examined in many developed countries, where their waste management sector becomes more powerful.

Municipalities are the responsible governmental bodies for waste management including preparation of an SWM plan, waste collection and treatment, the design, construction and operation of facilities, data analysis as well as conducting incentive awareness campaigns. The technical system can engage the private sector to fulfil some of their duties; for example, private companies might perform the collection or operate an SW facility.

One of the crucial issues in waste management planning is the involvement of the stakeholders. Waste producers and the informal sector are considered two of the main players in the field of SWM. Robust cooperation with the waste producers contributes to waste reduction and efficient source-separation. Moreover, waste pickers/scavengers are the one who know the ultimate value of recyclables. As such, they performs high rates of segregation and recycling. Integrating this group into the waste management plans by providing safe working conditions and stable incomes will lead to systematized and cost-effective material recovery.

Working staff in the field of waste management, at different levels (officials, engineers, labor force, etc.), should be subjected to qualification and education programs. This highlights the need for coherent connections between educational institutions (universities, vocational training centers) and operational entities run by either municipalities or private companies.

5.2. SCALING-UP COLLECTING SOURCE-SEPARATED ORGANICS

Shiraz City has two main organic waste streams: commercial and household sectors. Solid waste management organization is fully responsible for organic waste collection operations. The service is offered on a day-to-day basis for commercial sectors and every alternative day for the household fractions.

Subjecting the household waste to a source-separated collection system is inapplicable under the current waste management system practiced. The absence of legal enforcement, uncertain quality of raw materials, small daily quantity generated and difficulty in storage for long periods makes this option impossible.

Up to 30% of the commercial market areas are covered with a source-separated collection system using five vehicles with different capacities, ranging from 2 – 5 tons. This collected fraction accounts for 7 – 10 tons/day of fruits and vegetables. The remaining fraction of organics, commercial and household waste is operated through a mixed waste collection system. Partial amounts, of organics are garden waste; this is collected seasonally (from November to January) and accounts for around 800 tons/year.

Actually, the existing source-separated waste collection system does not have the capability to cope with the amount of organic waste generated; the system lacks sufficient collection means (vehicles) and manpower. Up to 70% of market organics are, therefore, not covered through the segregated collection system. A plan should be developed to upgrade the source-separated collection system. Guaranteed available amounts, impurities-free, homogenous mixture of the market organic waste creates high potential of the raw organic input materials ending up in a composting facility.

For full optimization of such potential, many working areas should be addressed including the vehicle fleet (number and capacity), working staff size, collection schedule (time and frequency) and incentives for producers. To this end, involvement with the private sector as a new operator in a source-separated collection system should be practiced. The financial flexibility, professional experience and measured productivity make the participation of the private sector a viable option.

Parallel to the source-separated collection service, covering the whole amount of organic waste generated from market, attention should be paid to the quality of the collected segregated organics. This could be guaranteed through making the waste producers an active part of the desired system. Usually, market stores, with high amounts of organics, pay fees per each extra bin, which makes them unwilling to cooperate with segregation. Performing incentive programs and awareness campaigns for them are the major tools to obtaining the desired collaboration and contribution.

Another area that should be focused on is the commercial sector for catering (restaurants, hotels and canteens). This sector is considered one of the main sources of providing organics containing rich nutrients with a wide range of protein-based products. Overall, guaranteed availability of such a mixture (fruits, vegetables, food waste and garden waste) creates considerable potential for producing compost of a high quality.

5.3. ECO-CONCEPT FOR TREATMENT OF ORGANICS

This secession offers a technical waste treatment concept, taking into account distinguished waste streams, source-separated organic waste and household mixed waste (Figure 5-2). It recommends that each waste stream is subjected to different treatment options: biological treatment (composting, anaerobic), mechanical biological treatment and thermal treatment. Suggested concepts aim to reduce valuable fractions ending up in landfills, reduce GHG emissions and preserve natural resources.

The state-of-the-art technology for the proposed concept is the biological treatment of organic fractions derived from both waste streams: source-separated organic waste and household mixed waste. Two biological treatment technologies are considered to address the organics: aerobic and anaerobic technology.

Despite the fact that the aerobic approach has been already practiced in Iran for a long time, the facility still faces many operational problems to produce a final product of high quality. This is due to their mismanagement, i.e. dealing with raw organic materials containing high level of impurities (mixed waste origin) as well as the lack of full understanding of the mechanism of biological treatment. It is worth mentioning that the mixed waste is the only waste stream in the country; to date, the source separation of organics waste remains in its initial stages. Small-scale practices can be noticed, particularly in mega cities.

Basically, the first proposed strategy introduces the concept of material and energy recovery through mechanical biological treatment (MBT) as well as thermal treatment (e.g., incineration) for handling the mixed waste stream (Table 5-1).

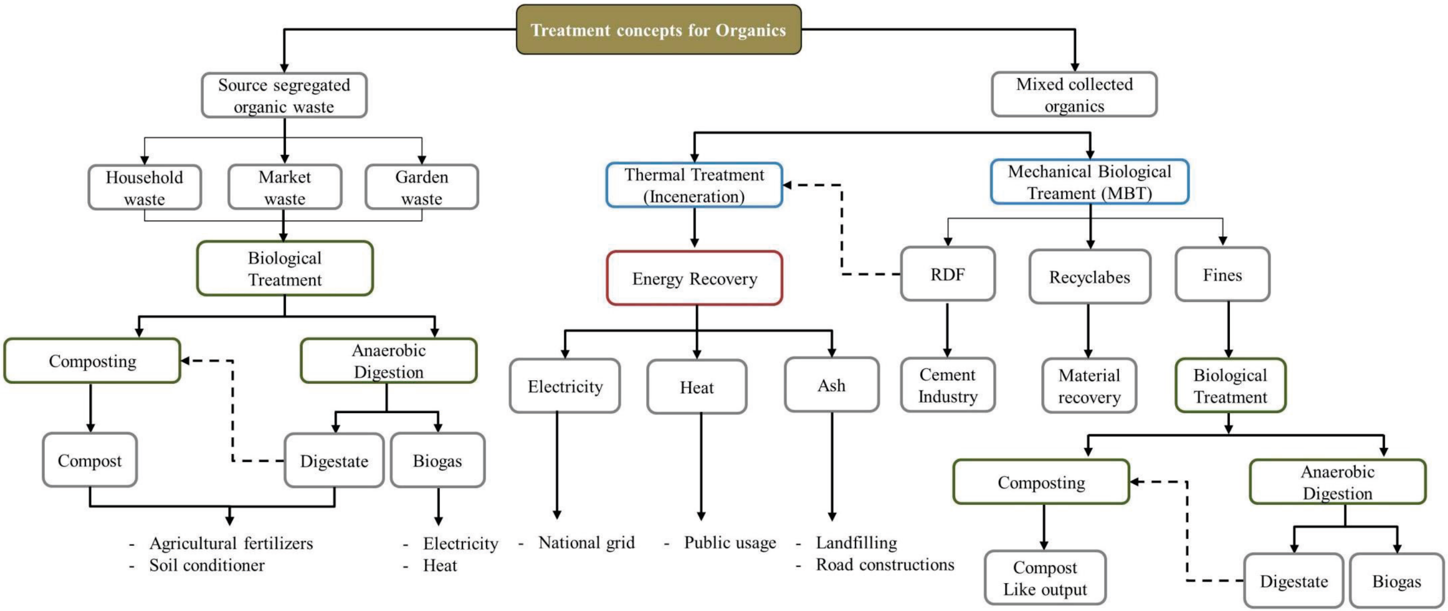

Figure 5-2: *Technical treatment concepts for municipal solid waste.*

The mixed waste undergoes the MBT pre-treatment technology, passing through several stages: removing bulk waste, shredding, screening, impurities elimination, recyclables and metals separation as well as fine organic fractions. The organics derived from MBT are subjected to stabilization processes to be used in landfilling activities, i.e. covering and re-shaping materials. Over the implementation of this strategy, the fine fractions would be subjected to a bio-drying process in form of windrow piles for 2 - 4 weeks without adding water. During the process, a turning schedule would be implemented frequently depending on the moisture status inside the piles.

Table 5-1: *Processes of municipal waste treatment before landfilling (BMU, 2018).*

Concept	Preparation (MBT/MPS)	Thermal treatment
Target	Production of defined and inert material flows for environmentally friendly landfilling and recovery	Production of defined and inert material for environmentally friendly landfilling and reducing the waste quantities for landfill
Process	- Mechanical treatment - Aerobic biological treatment - Anaerobic biological treatment - Biological stabilization (Drying) - Physical stabilization (Drying)	- Incineration of municipal waste in waste incineration plant - Mono combustion for the use of alternative fuels - (Pyrolysis in combination with the burning of the pyrolysis products for power generation)
Result	- Material flows for recycling (approx. 5 - 10% metal, plastic, etc.) - Alternative fuels (approx. 30 - 50%, depending on the treatment and input) - Material for disposal (approx. 50 - 30%, depending on the treatment and input)	- Material flows for recycling (approx. 5% metal) - Power (electricity and heat); depending on the input - Material for disposal (approx. 30%, depending on the composition of the waste)

The second proposed strategy is to treat the at-source segregated organic fractions converting it into value-added products. Development of such treatment plants, dealing with clean organics, has many advantages in terms of low investment costs, the possibility of securing raw materials easily, thus ensuring that the station is not interrupted, in addition to the ease of management and follow-up (Schüch et al., 2016). The strategy recommends that the raw materials be well-blended to ensure obtaining optimal initial conditions (pile dimensions, porosity, moisture, C/N ratio, etc.) for rapid decomposition. The approach suggests providing all the equipment and tools required for an efficient composting process including in-situ measurement tools (temperature, oxygen, carbon dioxide, pH, etc.), turning machines, watering systems, laboratories for the purpose of samples analysis.

The raw materials would be subjected to a windrow pile composting system in an open-site area for 10 - 12 weeks. In-situ measurements would be carried out over the period of the composting process. Water would be added when it required moisture, to be kept close to 50%, for the first 6 - 8 weeks. Samples would be taken periodically, and for the final product. Lab analysis would be conducted to monitor the biological process to ensure the quality of the final product.

The absence of qualified and well-trained staff is a burden that hinders the proper management of the proposed facility. At the outset phase, due to the lack of experience and knowledge, as well as the absence of qualified staff, the involvement of the experienced private sector is assumed as part of the operation of an established composting facility.

Despite the fact that high contents of nitrogen and potassium in the output of biogas plants can be used directly as liquid fertilizer (Narra et al., 2013), anaerobic technology is not considered as one of the proposed options due to its demanding requirements; this includes high initial investment, restricted monitoring system, advanced know-how of operating and maintenance, skilled manpower and uncertain marketability of outcomes (bio-gas, electricity, and heat).

5.4. TECHNICAL MODEL FOR FULL EXPLOITATION OF SHIRAZ'S COMPOSTING FACILITY

Three main working areas must be addressed to fully exploit Shiraz's composting plant, namely:

- Nature of raw materials to be treated
- MRF efficiency
- Biological treatment process

The importance of the aforementioned areas depends on the waste stream that would be subjected to the composting process. In case of dealing with organic material of a source-separated nature, full understanding of the biological process is the only working area that should be highlighted; well-structured windrow piles, scheduled in-situ measurement, systematic sampling and analysis (constant monitoring system).

Handling of contaminated organic waste (mixed nature) is a complex process that requires well-structured pre-treatment processes. In this light, the operational efficiency of the MRF plays a significant role in the effective up-grading process ensuring good quality of input composting raw materials. At present, Shiraz's MRF processes result in about 10% impurities ending up in the compost windrow piles. The presence of such an unwanted fraction interrupts the aerobic metabolism of the microbial community, resulting in a long degradation process and an immature final product. To increase the MRF's operational efficiency, essential modifications should be made. Screening is one of the most important functional elements of the MRF: it affects the nature of the final product. The screening system in Shiraz's MRF is not well designed; applying only two drum screens limits the flexibility, and the chosen diameter of 70 mm results in an unsuitable or poor mechanism.

The insulation of different types of sieves, with different functions respecting the nature of input raw waste, is therefore a must. Moreover, screening the fresh mixed raw materials at 40 mm instead of the applied one (70 mm) is needed to decrease the amount of the impurities of the fine output fractions.

Leachate is a by-product of micro-organisms' activities when the moisture content goes above the waste's field capacity (El-Fadel et al., 2002). Leachate formation in compost facilities is influenced by several factors including type of organics, climate conditions, pre-processing and pile structure. It contains dissolved and suspended matter from the raw input materials. Leachate quantity varies based on its nature: segregated waste generates less leachate quantity than the amount produced by mixed waste streams. This is due to wide variety of mixed waste fraction contents such as paints, inks, dairy products, lubricants, oils, etc. (Slack et al., 2005). In the case of Shiraz's MRF, the highest leachate generation rate was measured in summer and was found to be 0.76 m^3/ hour. Further, high content of toxic substances in leachate creates critical environmental threats to ground water and soil. This was examined during many studies, which have been reported high Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD) and heavy concentrations (Table 5-2).

Table 5-2: *Chemical properties of leachate collected in Shiraz's landfill.*

Parameter	Min.	Max.	Average
COD mg/L	48,552	62,150	55,351
BOD_5 mg/L	41,900	56,900	49,400
BOD_5/COD	0.71	0.91	0.81
pH	5.88	6.74	6.31
Mn mg/kg	8.17	20.57	14.370
Zn mg/kg	0.221	2.182	1.2015
Cu mg/kg	0.0	0.103	0.0515
Ni mg/kg	0.091	2.03	1.061
Fe mg/kg	31.79	741	386.395

Indeed, there is a drainage system to collect the quantity of leachate produced in the compost plant. It consists of a main canal designed to collect the leachate by gravity. All the leachate produced, either from mixed SW streams or source-separated streams, is collected by the same canal, thus allowing the leachate flow to pass along the windrow piles. This may affect the quality of materials in the compost pile by increasing the salt and heavy metals concentrations. To overcome this issue, a drainage system to collect leachate from each pile should be established. A simple and cost-effective design is considered in the proposed leachate collection system (Figure 5-3). The established drainage system suggests that each windrow pile is subjected to linear and lateral slope speeding up the depletion of leachate. The sub-canals prevent leachate spreading in compost plant and consequently contamination of other piles.

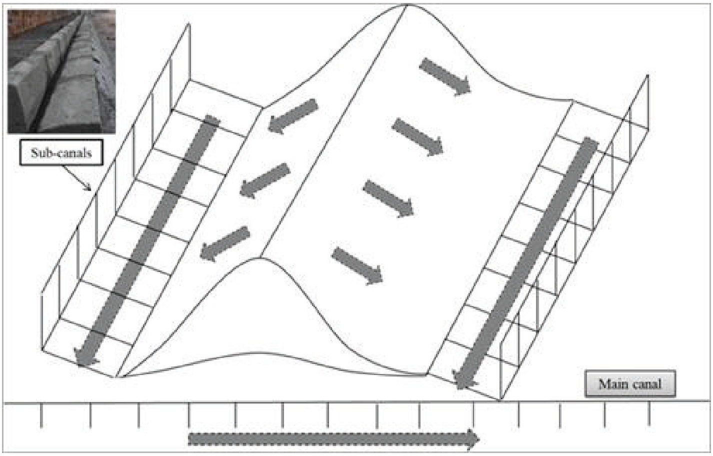

Figure 5-3: *Proposed leachate collection system for Shiraz's compost facility.*

5.5. QUALITY ASSURANCE AND MARKETABILITY

Compost marketability seeks one primary objective: it provides end users with the finished product. The availability of markets provides an important source of profits covers some of the operational costs and contributes to the financial viability of an overall waste management strategy. The latter is an important consideration in reducing the number of residues to be landfilled. Quality and consistency are the most crucial features in the use and marketability of the compost products. The quality of final product compost is a function of its chemical, biological and physical characteristics. Typically, stability, maturity and heavy metals are the major parameters set by restricted national standards limits.

Maturity is an important parameter from an agronomic point of view; it has significant effects on plant growth, particularly in the early stages. A mature final product means that the toxic substances generated during the decomposition process are transformed into stabilized compounds that can be absorbed safely by plants. Immature compost, therefore, decreases the marketability significantly; it has no value to be used as an agricultural enhancement (fertilizers, soil conditioners).

In the Shiraz case study, maturity could not be obtained despite the mixed waste being subjected to ideal conditions. This is clearly observed in the moderately low of GI, which was found to be 65%. To this end, a new biological approach was examined to improve the quality of compost produced from mixed waste. The proposed approach suggests adding an effective microorganism (EM) to the final compost product.

An EM is a microbial product that is used in the fermentation of organic materials. It contains helpful microorganisms that exist in nature, i.e. lactic acid bacteria, yeast and phototrophic bacteria.

The addition of EM in composting processes can speed up the activity of putrefying bacteria and requires less turning. Consequently, amino acids are produced during decomposition of proteins, instead of ammonia, and directly absorbed by plant roots. The EM is usually added to the windrow piles over the period of the composting process. The latter could not be achieved during the research experiments with the composting mixed waste due to the presence of impurities.

Following the instructions of manual application, EM was added to the finished product derived from the P1 experiment. The materials, 500 kg of compost, were subjected to three different concentrations of EM, 30 and 40%, for trial one and two, respectively. The raw material had a cone-shaped pile and the initial moisture content was kept close to 50%.

Compost produced from the mixed MSW (P1) was subjected to a second composting process under anaerobic conditions. Different concentrations of EM were added to the prepared piles from the final product of mixed waste compost under the same conditions and at the same interval.

A dilution from the two concentrations of EM was added to the prepared piles; 3 and 4 liters of EM solution were diluted in 10 liters of water for each ton of compost material. The piles were covered afterwards with plastic sheets to start the anaerobic process continued for 10 days. Sampling was carried out at the end of the processing period. Samples were taken from at least five different points in the pile; then, using a quartering method three times, a representative sample around 2 kg was collected for the purpose of GI lab analysis.

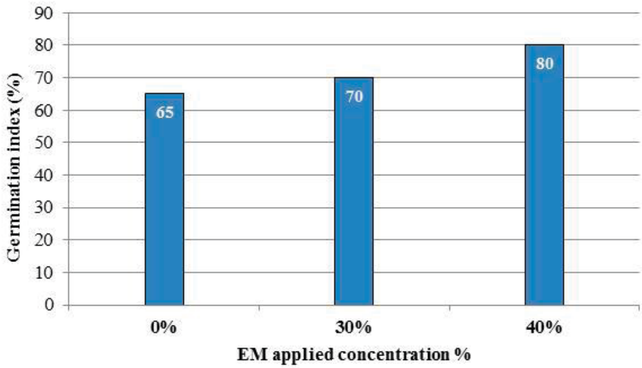

Figure 5-4: *Germination index values as a result of adding EM in different concentrations.*

The results demonstrate the positive effect of the EM (Figure 5-4): a significant increase of GI took placed by adding 40% of EM, where 80% GI was achieved. Adding 30% of EM had fewer effects. Further, a GI with 70% could not fully remove phytotoxcity. The ammonium ratio decreased to 5.26% and 7.97% through the addition of 30% and 40% EM, respectively. As for the other chemical properties (C/N ratio, pH and EC) no changes were observed. These results show that EM can be used in combination with mixed waste compost to minimize phytotoxicity effects.

The finding obtained is in line with the statement that beneficial microorganisms in soil have positive effects for plant growth through the mineralization of organic matter (transform nutrients in adsorbate form) and increasing plant resistance to environmental stress by producing growth hormones (Goh et al., 2013).

Enhancing the quality of produced compost is possible by using an additive, but this affects the pricing of the final product. Moreover, municipalities are not usually capable of quality control; they have neither knowledge nor financial capability. The absence of the government creates a good atmosphere for dealers or soil amendment businesses to take advantage of the composting sector chain.

Municipalities should set criteria to identify the possible final products that could be produced based on the available raw materials and their contents. An example of such a system is presented in Figure 5-5. Green space residuals, commercial organic waste and source separated household waste have higher potential for production of compost of high quality, which is more beneficial from an environmental and economical point of view.

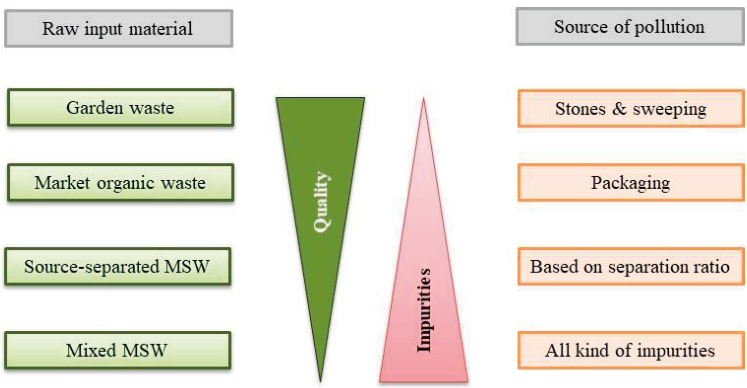

Figure 5-5: *Proposed criteria to identify the possible quality of final product (Rouse et al., 2008).*

Further, more cooperation between the concerned governmental bodies, in particular the MoA and the municipality, must be established in order to create a model for effectively involving the private sector. It is the latter who could viably produce market-oriented soil amendments.

6. Examination of municipal compost quality under using statistical models

Traditionally, composting methods were used by farmers for handling their agricultural waste. In the last few decades, there has been a surge of interest in the implementation of this method using the organic fraction of MSW. In fact, at the moment, it is one of the most common methods practiced for management of municipal organic waste. Windrow composting, in particular, has emerged as a powerful technique to reduce the volume of organic waste and turn it into a value-added final product. In this method, aerobic microorganisms play a fundamental role in the development of biological processes over 8-12 weeks. Actually, the performance of composting methods is limited by the activity of the microbial community.

The last two decades have seen a growing trend towards the establishment of MBT facilities in industrialized countries. Initially, the composting method was implemented in these facilities using mixed waste. Germany, as a pioneer, had 16 mixed waste composting facilitates during the 1950s. Further development of SW management in these countries has resulted in source separation of household waste into different fractions. Source-segregated bio-waste are only used to produce compost for agricultural purposes. The existing body of research on aerobic composting suggests that final products of mixed waste origin may be toxic and contain high amounts of heavy metals and organic pollutants (Saha et al., 2010). Furthermore, physical impurities such as glass may deteriorate soil's physical structure in the long term.

A lack of proper SWM systems in most developing countries is a common problem. The booming amount of municipal waste is one of the most frequently stated challenges. Organic waste is the major component of municipal waste in developing counties. The issues related to the mismanagement of municipal organic waste has been a controversial and much disputed subject within the field of climate change and environmental pollution. Therefore, composting, as the most affordable waste management method, has been the subject of intense debate within the scientific community.

Semi mechanized MRF are frequently used in these regions to separate different fractions of MSW. Little is known about the quality of MRFs' output and it is not clear which factors have the most effect on fine fractions, which are used as raw input material in composting piles. The issue of in-situ measurements in large scale municipal composting sites has attracted very little attention. This is mainly due to the poor cooperation between municipalities and scholarly communities. In Iran, for example, research has paid more attention to comparisons of crop performance under different application rates. No previous study has used a method for analyzing multiple factors related to providing ideal conditions over the period of composting.

This study set out to better understand the effect of providing ideal conditions during a 6-8 weeks biological process on the quality of the final products. The key research question of this study was whether or not the quality and quantity of irrigation water affected the chemical properties of the compost produced. In particular, this chapter will examine the production of compost from mixed waste during dry seasons in arid and semi-arid areas. Part of the aim of this project was to develop a model for producing compost of better quality in the study area and then project it to the other large cities in Iran. This investigation took the form of a case study in Shiraz's composting plant during the summer. A combination of analysis of variance (ANOVA), regression, correlation and principle component analysis (PCA) were used in the data analysis.

The study presented in this chapter of the thesis is one of the first investigations to focus especially on providing the ideal conditions for producing compost from mixed municipal organic waste. Understanding the link between nature of mixed waste and other environmental conditions (season, location, lifestyle, etc.) on the quality of final product will help the decision makers to implement this method. It is hoped that this research will contribute to a deeper understanding of municipal organic waste management in developing countries under arid and semi-arid weather condition. This investigation also shed light on the application of final product for agricultural purpose. However, it is beyond the scope of this study to examine the application of compost produced from agronomic point of view.

6.1. MATERIALS AND METHODS

6.1.1. SITUATION OF STUDY AREA

Shiraz, the study area, is located in a semi-arid zone of Iran. This weather condition is well known for producing hot and dry summers with mild winters. The precipitation occurs mainly in late autumn and early spring (Figure 6-1). During the summer, temperatures exceed 30˚C and humidity falls between 10-30% (Shiraz Municipality, 2018). Since rainfall and groundwater are the source of fresh water in Shiraz, a shortage of drinking water is most common in summer.

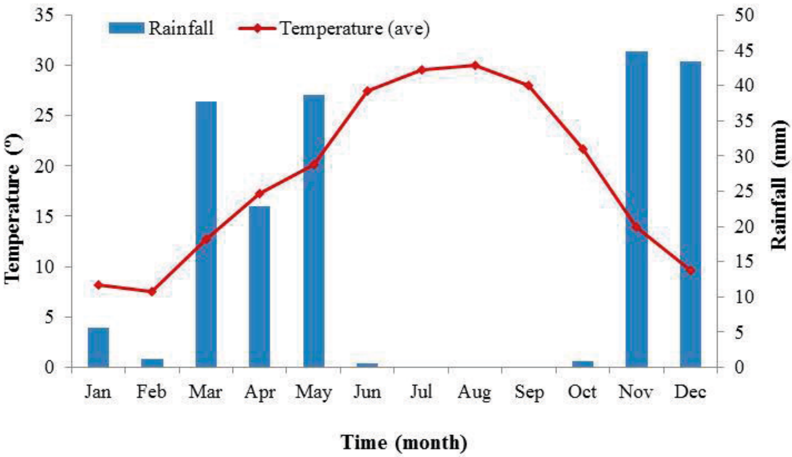

Figure 6-1: *Average of temperature and rainfall in Shiraz (MSWMO, 2018).*

Shiraz's landfill site is established at the southeast of the city in the Barmshor area. This region is identified as having saline soil and water resources. In fact, one of the largest seasonal salt lakes in Iran is located in this area. In order to provide the landfill's green space with irrigation water, groundwater with more or less low quality has been used. However, most of the irrigation wells in the landfill are currently out of service as a result of climate change over the past 10 years. Therefore, irrigation water is frequently transported from other groundwater sources near to the landfill site. The provided water is of moderate quality in terms of salinity and is usually classified as permissible.

6.1.2. EXPERIMENTAL METHOD

The fine fractions of MRF output (< 70 mm) were used as raw input materials to set up windrow piles in the composting site located in Shiraz's landfill. The experiment was conducted during the dry season (July-September). Prior to commencing the study, the quality of the available irrigation water was examined by taking samples from groundwater sources. The irrigation treatments in composting trials were determined accordingly.

Table 6-1: *Quality of irrigation water in composting runs.*

Parameter	Trial 0	Trial 1	Trial 2	Trial 3
Electric conductivity (µmhos/cm)	-	1400	1400	<250
Amount (m^3/ m^3 raw input)	0	0.27	0.3	0.3

Four piles, approximately 212 m^3 (4 m width, 1.5 m height and 60 m length), were prepared and monitored against temperature and moisture over the period of composting with the same method explained in Section 4.1.3. Different qualities and amounts of irrigation water (Table 6-1) were used in the composting trials. It was assumed that at least 0.3 m^3 of irrigation water is required per 1 m^3 of raw input materials to keep the moisture close to 50% for the first 6 - 8 weeks. This assumption was made based on the experience achieved in the field. Since compost piles are not irrigated during dry seasons in the study area, one pile (T0) was not irrigated to simulate existing conditions. T1 and T2 were irrigated using groundwater of permissible quality (1400 µmhos/cm); T1 received 10% less irrigation water each time to examine the effect of less moisture content during the composting process on the quality of the final product. In order to explore the quality of compost produced under different qualities of irrigation water, T3 was irrigated using high quality irrigation water (<250 µmhos/cm), which was transported weekly from Shiraz.

The duration of the summer trial was shorter than the winter trial mainly due to low humidity in the study area. Once the composting experiments had finished (ten weeks), the chemical properties of the final products were examined by taking samples from several points along the windrow piles. Three representative samples of 1.5 kg were taken from each pile using a quartering method; they were placed in a plastic container with a lid and immediately sent to the lab. Finally, lab analysis of the moisture content, total organic matter, ash content, total nitrogen, ammonium, C/N Ratio, pH and EC were carried out, as explained in chapter 4 (Table 4-5), in order to evaluate the quality of compost produced.

6.1.3. Statistical analysis

The statistical analysis was performed by means of general factorial design to explore the response of moisture content, total organic carbon, ammonium, C/N ratio, pH, and EC in compost produced from MSW under different irrigation treatments. The general factorial design includes a group of empirical methods that evaluates the existing relationship between a cluster of controlled experimental factors and measured responses according to one or more number of levels. It creates an experiment that includes all possible combinations of different factor levels.

Statistical analysis was performed using XLSTAT software (version 2020.1). The mean score of treatments were compared using ANOVA; where significant F-values ($p=0.05$) were achieved, differences between categories were tested using pairwise comparisons analysis. Further, PCA was performed for the results from trial 1 and 2 (where lower quantity and quality of irrigation water were used) and trial 0 (not irrigated) to find out which chemical parameters are most strongly correlated with irrigation water. The PCA analysis can give better insight into the quality of final products in the case of using low quality irrigation water, rather than no irrigation, during the composting process, which is the present situation in study area.

In order to investigate the application of the final product, the amount of compost required to meet the nutrient demand of the three main cultivated crops in the study area was estimated in the last section. The nutrient uptake for selected crops was taken from the literature and experimental research in the study area. The provided method can be used to evaluate the fertilizer demand for any crops under different soil fertility conditions.

6.2. Results and discussions

The outcomes obtained from the composting trials are displayed in this section. The experiments consisted of four runs which comprised different qualities and quantities of irrigation water. To assess the quality of the final products, lab analyses were used. Changes in chemical properties were compared by means of statistical analyses. Regression analysis was used to predict the possibilities of applying low quality and quantity of irrigation water. Then, PCA was also applied to determine the relationship between different parameters of the biological process. The fertilizer demanded by cultivated crops in the local area was estimated using obtained results.

6.2.1. Temperature evolution during composting trials

The evolution of temperature in a compost pile is usually used as a key factor to monitor the biological process. In fact, temperature displays the activity of the microbial community over the decomposition process and is used to estimate the composting phase. For example, during the thermophilic phase, the activity of microorganisms is in the highest range, as is the temperature. In the lower range of activity, as in the maturation phase or when the piles lack proper conditions (moisture, porosity, etc.), the temperature also tends to be lower. In this study, temperature was used as the main parameter to observe the biological process under different moisture content and water quality (Figure 6-2).

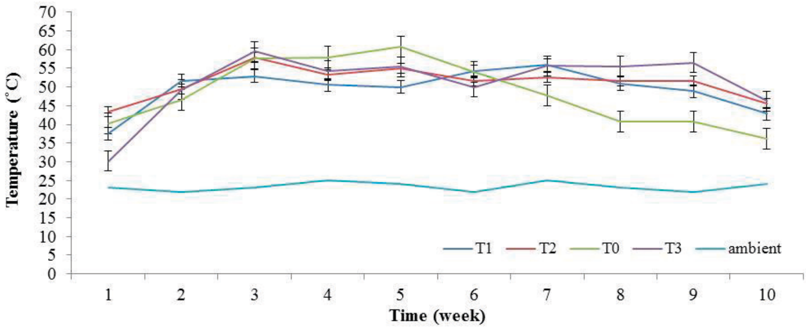

Figure 6-2: *Temperature profile of different composting trials.*

All composting piles reached thermophilic temperature (>50˚C) in the second week. The temperature increased to the highest level in the next two weeks and remained within the thermophilic range until the sixth week. The time interval met the standards to reduce the pathogens and secure the final products. From the data in Figure 6-2, it is apparent that T0 had the highest thermophilic temperature and the shortest length of the phase compared to other trials. The temperature in T0 increased steadily until the fifth week and then decreased rapidly to the mesophilic phase. In the other three composting experiments, the temperature fluctuated until the ninth week.

As Figure 6-2 shows, there were temperature profiles when using less irrigation water. T1 had lower temperature fluctuation compared to T2 and T3. The highest fluctuation rate occurred in T3, which had the highest temperature during the mesophilic phase. The longer duration of the thermophilic temperature in the irrigated trials reveals the higher activity of microbial community in these piles and, consequently, the better stabilization of organic materials.

6.2.2. MOISTURE CONTENT DURING COMPOSTING TRIALS

Moisture plays a pivotal role in the development of biological processes. The metabolic and physiological activity of the microbial community is dependent on a proper moisture content of about 50% in the compost pile. Providing such a range of water content for 6-8 weeks, under the semi-arid weather conditions of Shiraz City, is a limiting factor. The latter is considered a major problem during the dry season. In order to preserve the water content inside the pile, some literature suggests the addition of a bulking agent such as saw dust (Yousefi et al., 2013). However, this was not possible in our case due to the high amount of about 300 tons per day of raw input material. The moisture profile of the composting trials is shown in Figure 6-3.

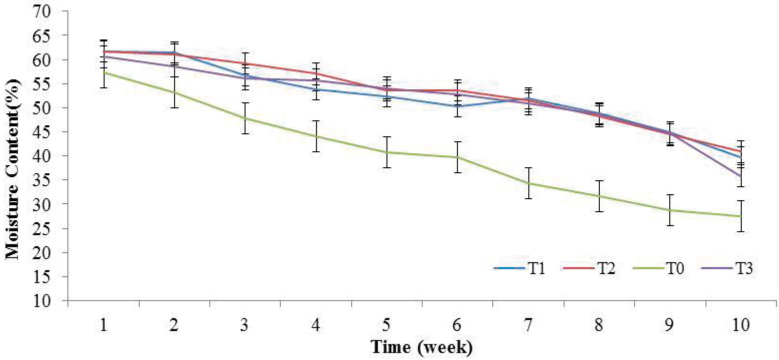

Figure 6-3: *Moisture profile of different composting trials.*

The piles were monitored and irrigated until the eighth week as the evaporation rate was extremely high during the summer. It can be seen that the moisture content on the first day of the pile formation was between 55 and 60% in all trials. After a week, the moisture content started to decrease. It remained around 50% in T0 until the second week; then it started to decrease gradually. What stands out in this figure is the rapid decrease in moisture content of T0 after the third week, reaching 27.46% at the end of the composting process. There was no significant difference between T1, T2 and T3 with respect to monitoring the moisture content. The results suggest that lower amounts of irrigation water (T1), about 10%, can be applied to keep the moisture content around 50% with no evidence of significant effect. The moisture content in T1, T2 and T3 reached 39.72%, 40.89% and 35.8%, respectively, at the end of the composting process. The proper moisture content of the final products in the irrigated trials indicates that the ideal conditions of the biological process were provided.

6.2.3. CHEMICAL PROPERTIES OF COMPOST PRODUCED

After landfilling, producing compost from mixed waste is the most common method of municipal organic waste treatment in developing countries. The scarcity of water in arid-zones such as the MENA region is an obstacle to monitoring the process against water content. In terms of Iran, there is a large volume of published studies describing the effect of municipal compost on cultivation of different crops (Ayyobi & Peyvast, 2014; Bagheri et al., 2018). However, there is a relatively small body of literature that is concerned with providing the ideal conditions through biological processes. The greater parts of the existing literature from developed countries suggest application of leachate or wastewater to provide proper moisture content during the composting process. This method is not practical in developing countries where mixed raw material contains hazardous waste and the leachate usually has high amounts of salt and heavy metals. Therefore, one of the aims of this study was to investigate the required irrigation water in terms of quality and quantity to provide the ideal conditions during the composting process. The latter was achieved by examining the quality of the final products under different irrigation treatments.

Moisture Content

The results obtained from the lab analysis of samples from the different piles are illustrated in Figure 6-4. The lab analysis was conducted on the final product of less than 5mm after the purification process. As was expected, the final products of T2 and T3 had higher moisture content than T1 and T0. The moisture content of around 30% in T2 and T3 would facilitate the application of compost for agricultural purposes, whereas the lower moisture content, of about 21%, in T1 would require adjustment before application. In case of T0, with 12.4% moisture content, its application would face challenges and the dry, fine particles could create dust problems.

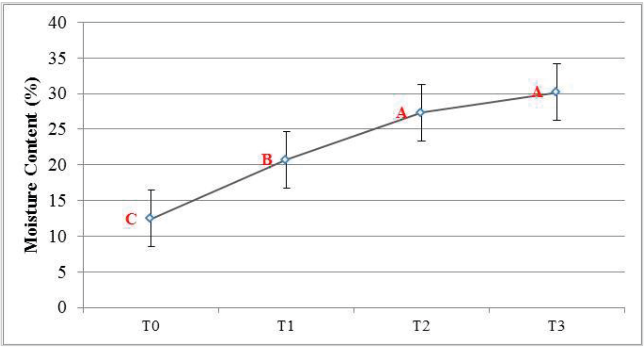

Figure 6-4: *Moisture content of compost produced under different trials.*

The ANOVA (one way) showed that mean value for the moisture content of the compost produced under different trials are not statistically equal (Table 6-2). The low p-value of <0.0001 is an indication for the rejection of the null hypothesis. There is significant difference between the non-irrigated treatment (T0) and the other trials. Well irrigated treatments (T2 and T3) have also significant difference with T1, which was irrigated 10% less (Figure 6-4). These findings indicate the importance of monitoring moisture content during the composting process, by addition of water, in arid and semi-arid conditions.

Table 6-2: *Analysis of variance for moisture content of composting trials.*

Source	DF	Sum of squares	Mean squares	F	Pr > F	R^2	Adjusted R^2
Model	3	558.57	186.19	66.97	**<0.0001**	**0.962**	**0.947**
Error	8	22.24	2.780				
Corrected Total	11	580.82					

Figure 6-5 shows the actual and predicted values determined by the ANOVA test using the regression analysis. It is apparent that the actual values are distributed very close to the straight line (y=x). It indicates high correlation between the observed and the predicted values, which is confirmed by R-squared (0.962) and the adjusted R-squared (0.947) of close to 1. Comparing these findings with those of the winter trial supports the assumption of providing ideal conditions by applying irrigation water of 0.3 m^3 water per each m^3 of raw input materials.

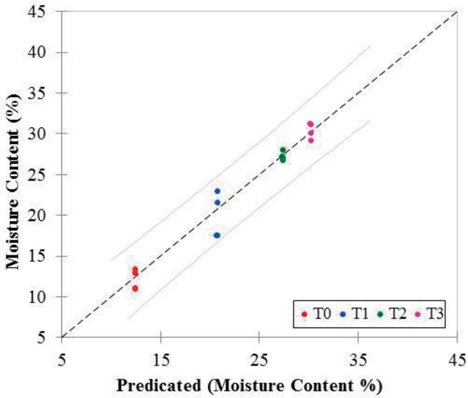

Figure 6-5: *Regression analysis for the response moisture content in composting trials.*

<u>Organic Matter</u>

The content of organic matter in the final products of the different trials represents the degree of decomposition under each treatment (Figure 6-6). The lower the organic matter is, the higher the degradation rate that occurred. Trial 2 and 3 had the lowest organic matter of about 46%, which met the values set by the German standards. Trial 1 had around 50% organic matter, indicating a lower rate of stabilization. More than 50% content of organic matter in T0 implied an incomplete composting process due to a lack of moisture content after the third week.

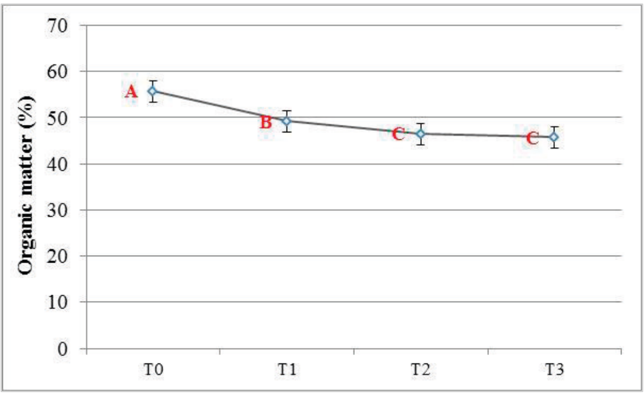

Figure 6-6: *Organic matter of compost produced under different trials.*

The low p-value of <0.0001 (Table 6-3) shows that the mean values for organic matter of compost, produced under different trials, are not statistically equal. There is significant difference between the non-irrigated treatment (T0) and other trials. Well irrigated treatments (T2 and T3) also have significant difference with T1, which was irrigated 10% less (Figure 6-6). These results suggest that lower amounts of irrigation water have adverse effects on the quality of final products. They also confirm the association between moisture content and the activity of the microbial community during the biological process.

Table 6-3: *Analysis of variance for organic matter of composting trials.*

Source	DF	Sum of squares	Mean squares	F	Pr > F	R^2	Adjusted R^2
Model	3	185.162	61.721	37.35	**<0.0001**	**0.933**	**0.908**
Error	8	13.218	1.652				
Corrected Total	11	198.380					

Figure 6-7 shows the actual and predicted values determined by ANOVA test using the regression analysis. It is apparent that the actual values are distributed very close to the straight line (y=x). It indicates high correlation between the observed and the predicted values, which is confirmed by R-squared (0.933) and the adjusted R-squared (0.908) of close to 1.

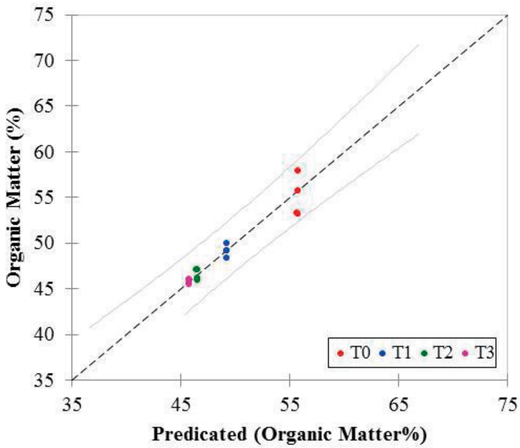

Figure 6-7: *Regression analysis for the response organic matter in composting trials.*

C/N ratio

The C/N ratio is among the most widely used parameters to describe the quality of final products. It shows the degree of microorganism activity and stabilization rate of final products. Typically, the stabilized compost has a C/N ratio <20; nevertheless, it is not a proper parameter to define the maturity of the compost produced (Saha et al., 2010). In this study, as shown in Figure 6-6, the irrigated piles had lower content of organic matter, which resulted in lower content of organic carbon. Consequently, a lower C/N ratio can be observed in T1, T2 and T3 (Figure 6-8). A C/N ratio<15 in the final products of the irrigated piles demonstrates the establishment of ideal conditions as well as a complete biological process.

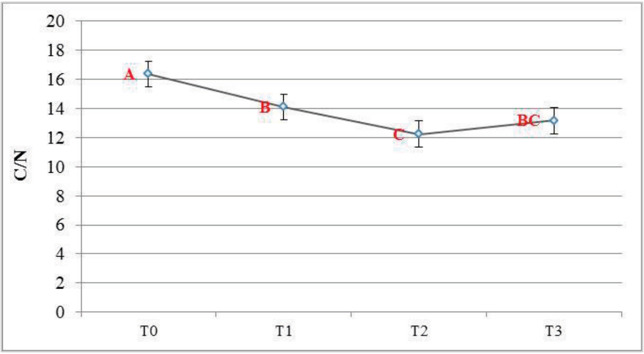

Figure 6-8: *C/N ratio of compost produced under different trials.*

The low p-value of <0.003 (Table 6-4) shows that the mean value for the C/N ratio of compost produced under the different trials are not statistically equal. There is significant difference between the non-irrigated treatment (T0) and other trials. However, there is no significant difference between the C/N ratio of T3, irrigated with standard water amounts, and the high-quality irrigation of and T2 and T3 (Figure 6-8). These findings confirm that the organic matter in all irrigated piles is well stabilized and the activity of the microbial community decreased considerably at the end of the process. This result may also be explained by the fact that the raw input materials in T0 were not fully stabilized and, instead, dried due to a lack of proper moisture content.

Table 6-4: *Analysis of variance for C/N ratio of composting trials.*

Source	DF	Sum of squares	Mean squares	F	Pr > F	R^2	Adjusted R^2
Model	3	28.129	9.376	11.95	**<0.003**	**0.818**	**0.749**
Error	8	6.279	0.785				
Corrected Total	11	34.408					

Figure 6-9 shows the actual and predicted values determined by ANOVA test using the regression analysis. It is apparent that the actual values are distributed very close to the straight line (y=x). R-squared (0.818) and the adjusted R-squared (0.749) of the observed and the predicted values are less than those value for moisture content and organic matter. A possible explanation for the lower degree of correlation between the observed and the predicted values might be that all irrigated piles were stabilized and there was less difference in the value of the C/N ratio.

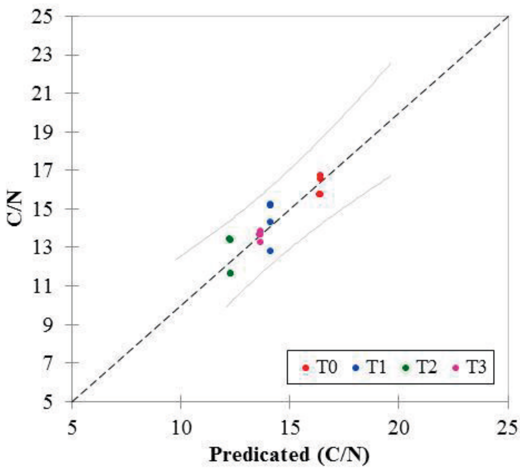

Figure 6-9: *Regression analysis for the responding C/N ratio in composting trials.*

<u>Nitrogen transformation</u>

Municipal organic wastes are rich in easily degradable materials with high nitrogen content. The mineralization of nitrogen through composting considerably decreases the risk of environmental pollution in landfills. Over the period of biological activity, part of the nitrogen transfers to ammonia and then nitrate. Typically, the total amount of nitrogen is not changed noticeably during process. Therefore, it is not used as an indicator for describing the degradation process. Ammonia, on the other hand, is usually used as a parameter to define the maturity of the final product. The compost with a value of NH_4^+<500 is considered mature (Brewer et al., 2003). Figure 6-10 displays the total amount of nitrogen and ammonium in the composting experiments.

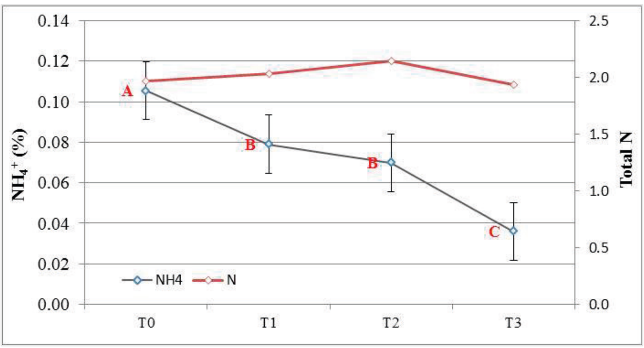

Figure 6-10: *Total nitrogen (N) and ammonium (NH_4^+) of compost produced under different trials.*

In Figure 6-10, there is a clear trend of decreasing ammonium (NH_4^+), whereas total nitrogen (N) remained in the same range. The latter is due to the same origin of raw input material. Consequently, the p-value of <0.355 is an indication for not rejecting the null hypothesis of equal means (Table 6-5). As for ammonium, the mean values are not statistically equal. T0, with the highest value of ammonia, has significant difference with the other trials. There is also significant difference between T2 and T3 using different qualities of irrigation water. These findings prove that the quality of irrigation water has adverse effects on the maturation rate of final products. Another important finding is that less irrigation water does not have adverse effects on the maturity of compost produced.

Table 6-5: *Analysis of variance for total nitrogen and ammonium of composting trials.*

Source	**DF**	**Sum of squares**	**Mean squares**	**F**	**Pr > F**	**R^2**	**Adjusted R^2**
Model	3	0.007	0.0025	26.237	**0.00017**	**0.908**	**0.873**
Error	8	0.001	0.0001				
Corrected Total	11	0.008					
Model	3	0.079	0.026	1.249	**0.355**		
Error	8	0.168	0.021				
Corrected Total	11	0.247					

Figure 6-11 shows the strong correlation between the actual and predicted values determined by ANOVA test using the regression analysis. Distribution of values close to the straight line (y=x) can be predicted from the high R-squared (0.908) and the adjusted R-squared (0.873). The most obvious finding to emerge from the analysis is that compost produced using low quality irrigation water requires maturation adjustment before applying in agriculture.

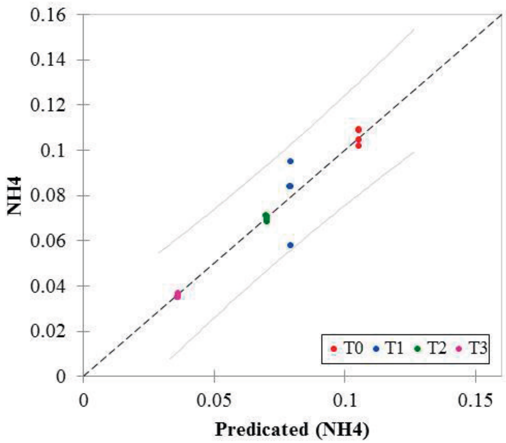

Figure 6-11: *Regression analysis for the response ammonium (NH_4^+) in composting trials.*

<u>pH and EC</u>

Over the period of the composting process, organic materials are decomposed and then turned into stabilized compounds. This results in increasing the pH and EC value of final products. These parameters have high importance for final users of fertilizers and should be set in accordance to the thresholds of cultivated crops. The results indicate that higher decomposition rates in the irrigated trials leads to a pH in the basic phase of around eight, which is reported by many authors (Nakasaki et al., 1993; Sullivan & Miller, 2001). The EC, on the other hand, has lower value in the irrigated trials and, particularly, T3, which used a higher water quality (Figure 6-12). These findings suggest that the quality of irrigation water has more effect on EC than the pH of compost produced (Figure 6-13).

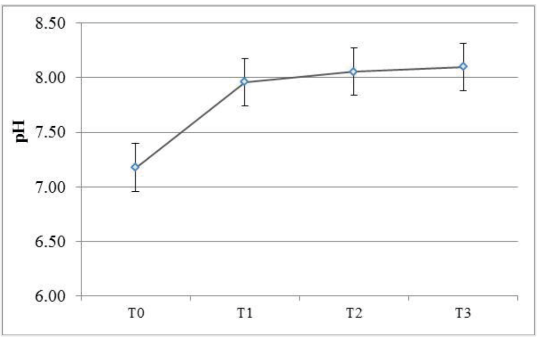

Figure 6-12: *pH of compost produced under different trials.*

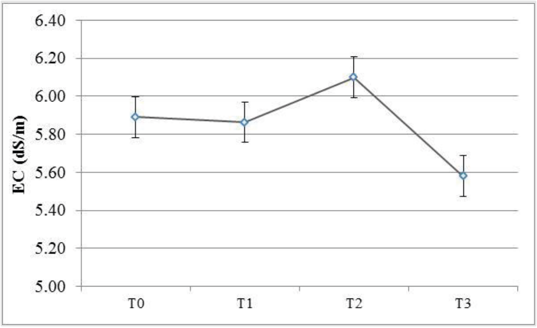

Figure 6-13: *EC of compost produced under different trials.*

In this study, materials of the same origin (municipal organic waste) were used for composting experiments, resulting in no significant changes between the different trials (Table 6-6). The p-values of <0.433, with respect to EC, and 0.098, with respect to pH, are indications for not rejecting the null hypothesis of equal means.

Table 6-6: *Analysis of variance for pH and EC of composting trials.*

Response	Source	DF	Sum of squares	Mean squares	F	Pr > F
EC	**Model**	3	0.411	0.137	1.021	0.433
	Error	8	1.072	0.134		
	Corrected Total	11	1.483			
pH	**Model**	3	1.699	0.566	2.961	0.098
	Error	8	1.530	0.191		
	Corrected Total	11	3.229			

6.2.4. Projecting the quality of municipal compost in Iran

One of the aims of this study was to determine the sustainable approaches to improve the quality of municipal compost produced under arid and semi-arid weather conditions in Iran. The raw input materials in countries such as Iran are frequently mixed waste. Very little was found in the literature on the question of improving the chemical properties of final product compost from mixed waste. This research, therefore, tried to provide some solutions to creating the ideal conditions under the existing waste management system. Accordingly, the following assumptions were made:

- The raw input materials are collected from urban areas in cities with > 1 million populations.
- The origin of input materials is MSW and they do not contain industrial or hospital waste.
- The amount of hazardous waste is less than 3% in the fine fraction of MRF

- The process is monitored at least weekly for temperature and moisture over the period of composting
- A machine turner is used to turn over the piles
- The finished piles are subjected to a purification process
- The quality of final products is evaluated periodically using lab analysis

These conditions are musts for providing the ideal conditions. Another aspect that should be considered is leachate management. This is a matter of concern, especially in warm seasons. For example, in summer, most cities face obstacles to leachate collection and treatment. A lack of rainfall during this season is another problem that makes the production of compost during summer questionable in some parts of Iran. Figure 6-14 shows the result of PCA for the capital cities of Iran's provinces in response to maximum temperature, average annual rainfall and per capita municipal waste generation.

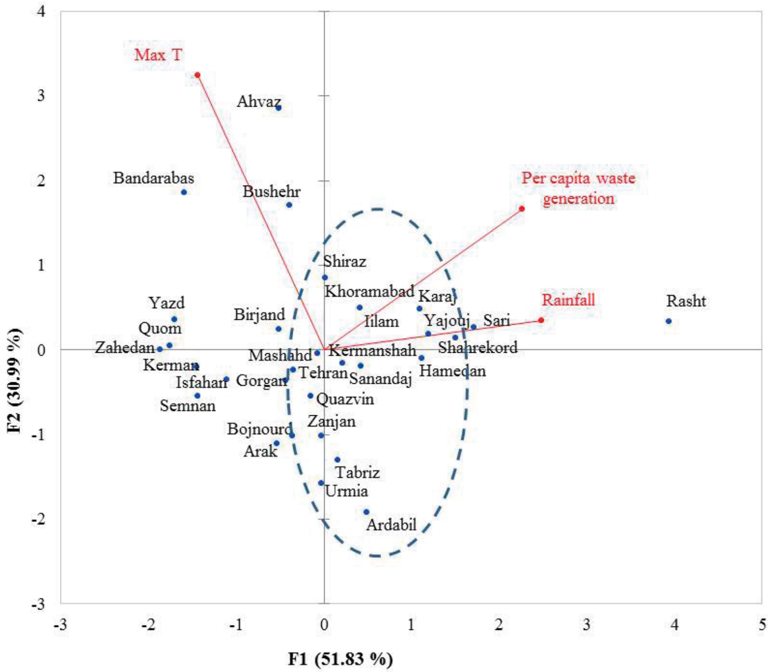

Figure 6-14: *Principal component analysis between maximum temperature, annual rainfall and per capita waste generation in capital cities of Iran's provinces.*

From the PCA graph, we can see that there is positive correlation between per capita waste generation and precipitation. For example, in coastal cities in northern Iran, waste generation is reported significantly more than in cities in central and southern parts. In fact, Sari and Rasht has the highest rainfall, with per capita waste generation of more than 800 gr per day. A possible explanation for these results is the touristic attraction of this region. As a result, SWM faces serious challenges in coastal regions due to the restricted volume of landfills. Composting facilities require closed areas to control moisture over the period of composting. This would increase the operation costs, which is a burden for municipalities. Compost produced from mixed waste has a poor market, since the final product contains broken glass and rice is the most commonly cultivated crop in this area.

The cities in the blue circle have the most suitable weather conditions for the implementation of composting methods in Iran. Most are located in the north-west, west and south-west of Iran's territory. The annual rainfall of these 16 cities falls between 183.4 mm to 842.4 mm with a 291.7 mm median (Table 6-7). Maximum temperature varies between 17.1 to 26.8˚C, with a 22.95˚C median. Together these results provide important insights into the geographical conditions required for the establishment of composting facilities in open areas. A proper amount of rainfall would provide the moisture for the biological process. It is assumed, under such conditions, that irrigation water is available from groundwater sources in the dry season. Lower temperatures in summer decrease the rate of evaporation, which results in less irrigation water being required.

Table 6-7: *Summary of weather condition in cites with proper conditions for composting.*

Parameter	T max (˚C)	Annual Rainfall (mm)
Count	16.00	16.00
Mean	22.51	353.41
Median	22.95	291.70
Minimum	17.10	183.40
Maximum	26.80	842.40

The cities in the left part of Figure 6-14 have lower annual rainfall and higher temperatures. These weather conditions are challenging for providing ideal conditions during composting processes. However, Isfahan city, in this region, has the oldest composting facility in Iran. On the one hand, this results from the existence of populated urban areas in this region. On the other hand, due to the poor soil conditions in the central part of Iran (near the Iranian central desert), most produced compost is used to improve the soil fertility and develop green space in urban areas. What emerges from the results reported here is that if the ideal conditions for producing compost from mixed waste, especially in terms of moisture and temperature, are not considered, then the opportunity for organic waste management and enhancing soil fertility may turn into threats of final products of low quality that are highly toxic to plants.

Consistent with the literature, this research found that in-situ measurement of temperature and moisture has the highest importance in the production of high-quality compost. This also accords with our earlier observations in the winter trial. According to the data provided, we can infer that there are correlations between the quality and quantity of water provided and other chemical parameters (Table 6-8).

__Table 6-8:__ Results of Pearson correlation analysis between different parameters.

Variables	MC	EC	NH_4^+	pH	OM	N	C/N
MC	**1**						
EC	-0.032	**1**					
NH_4^+	**-0.879**	0.291	**1**				
pH	**0.743**	0.075	**-0.689**	**1**			
OM	**-0.915**	0.096	**0.789**	**-0.615**	**1**		
N	0.025	**0.670**	0.080	0.316	-0.035	**1**	
C/N	**-0.798**	-0.299	**0.637**	**-0.706**	**0.837**	-0.561	**1**

As can be seen, a Pearson correlation analysis was conducted in order to assess the relation between different parameters. Values in bold are different from null hypothesis with a significance level of alpha=0.05. Moisture content has high correlation with all parameters excluding EC and total nitrogen. There is a strong correlation between moisture content and organic matter. This result confirms the importance of monitoring moisture content during the process. The most interesting finding is that moisture content has higher negative correlation with ammonium than the C/N ratio. It means that the final product from the uncontrolled process may be stabilized but not mature. Consequently, it should be used for covering landfill and not agricultural purposes. The low correlation of EC and pH with other parameters shows the same nature of raw input materials. However, piles that are rich in nitrogenous materials and have higher EC and pH tend to increase when the C/N ratio and organic matter are decreased. The latter indicates the basic range of final products. The findings also indicate that the ammonium value can be used as an indicator to estimate the level of maturation. Over the period of the decomposition process, the value of organic matter and ammonium tends to decrease as well as the C/N ratio. In accordance with these findings, final products are categorized based on their quality (Figure 6-15).

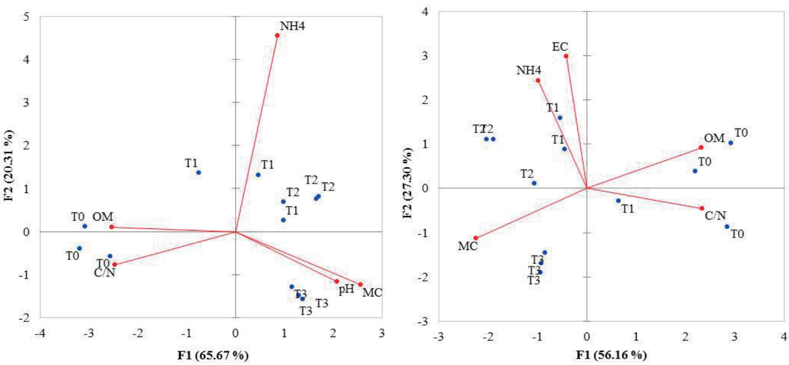

__Figure 6-15:__ Results of principal component analysis for (a) pH (b) EC and other parameters.

The results from the PCA demonstrate that the quality of irrigation water has significant effects on the quality of the final product. It is obvious from Figure 6-15 that the final products from piles irrigated with high water quality have the highest quality. The lower amount of water has less affect the quality of compost produced, particularly in response to the pH value compared with the EC. It seems that the lower quality of applied water results in a higher EC value of the final products. From these findings, it can be concluded that compost produced during winter would be of the highest quality, since the rainfall provide the piles with the moisture required. The compost produced has a darker color and fewer odors, which are the signs of a mature final product. In the case of composting in summer, the pile irrigated with groundwater would have the lower quality, whereas the non-irrigated piles should only be used for landfill covering.

6.2.5. THE AMOUNT OF COMPOST REQUIRED FOR AGRICULTURAL PURPOSE IN THE STUDY AREA

The soil in arid and semi-arid areas usually has a low fraction of organic matter, resulting in high pH and moderate to high salinity content. The application of fertilizer in such soil may improve the fertility as well as increase the salinity of soil and groundwater. Municipal compost, with typical salinity of 4 dS/m <EC < 6.5 dS/m, is therefore recommended in the cultivation of the crops' resistance to salinity such as cotton and sunflower. The amounts of recommended nitrogen, potassium and phosphorus for these crops, based on the soil's chemical properties in the study area, are displayed in Table 6-9. These two crops were selected only as examples to illustrate the utilization rate of the compost produced.

Table 6-9: *Nutrient requirements according to soil analysis.*

N(Kg/ha)			P(Kg/ha)			K (Kg/ha)		
Organic carbon %	Cotton	Sunflower	Phosphoru s (mg/Kg)	Cotton	Sunflower	Potassium (mg/Kg)	Cott on	Sunflower
<0.5	138	161	<5	92	69	<150	100	100
0.5-1	115	138	5-10	69	46	151200	75	75
1-1.5	115	115	11-15	46	23	201250	50	50
>1.5	92	92	>15	0	0	251300	25	25

In order to define the amount of fertilizer required per hectare, it was assumed that the final product of mixed waste compost contained nitrogen, potassium and phosphorus of about 1.5, 1.3 and 0.5%. Since the nitrogen has the highest fraction in municipal compost, the nutrient recommendation is usually calculated upon percent of it. Using phosphorus or potassium to calculate the compost required per hectare leads to an overestimation of nitrogen, which increases the risks of groundwater pollution by leaching. Equation 6-1 is used to estimate fertilizer utilization rate.

$$F_r = NR_c \times \frac{100}{NC_F} \quad (1)$$

Where:

F_r: The amount of fertilizer required

NR_c: The amount of nutrients required by different crops

NC_f: The nutrient content of fertilizer

For example, for cultivating cotton in soil with <0.5% of organic carbon, <5 mg/Kg of phosphorus and <150 mg/Kg of potash, it needs 138 Kg/ha of nitrogen, 92 Kg/ha of phosphorus and 100 Kg/ha of potash. In order to meet the recommended amount of nitrogen, 9200 Kg of municipal compost is required per hectare. By applying this amount of municipal compost, 46 Kg/ha of phosphorus and 120 Kg/ha of potash are provided for the soil. The calculation steps are as follows:

$$138 \times \frac{100}{1.5} = 9200 \text{ Kg/ha compost}$$

$$9200 \times \frac{0.5}{100} = 46 \text{ Kg/ha phosphorus}$$

$$9200 \times \frac{1.3}{100} = 120 \text{ Kg/ha potash}$$

The estimated amount of municipal compost does not meet the crop requirement for phosphorus and more phosphorus (P_2O_5) of 46 Kg/ha (92-46=46) should be applied as mineral fertilizer. In case of potash, it is 20 kg/ha over (100-120= -20); however, potash is not a known pollutant; it is rarely present in concentrations that are toxic to humans or wildlife. Table 6-10 shows the application rate of compost to meet the nitrogen requirement as well as the amount of phosphorus and potash provided by this amount under different soil quality.

Table 6-10: *Required compost and nutrient balance based on nitrogen ratio.*

Compost (Kg/ha)			P(Kg/ha)			K (Kg/ha)		
Organic carbon %	Cotton	Sunflower	Phosphorus (mg/Kg)	Cotton	Sunflower	Potash (mg/Kg)	Cotton	Sunflower
<0.5	9200	10733	<5	46	15	<150	-20	-40
0.5-1	7667	9200	5-10	31	0	151200	-25	-45
1-1.5	7667	7667	11-15	8	-15	201250	-50	-50
>1.5	6133	6133	>15	-31	-31	251300	-55	-55

As can be seen from Table 6-10, approximately 10 tons of compost per hectare is required in most scenarios. It is also recommended that compost is spread on the surface of soil before crop cultivation and is tilled into the soil using a plough. It should be noted that nutrients contained in organic fertilizers are not fully available to the crops in the first year of application. Many authors suggest that utilization of compost for at least three years would result in higher crop performance (Horrocks et al., 2016).

7. Conclusion

Shiraz, the fifth populated city in Iran, has realized that the practiced waste management strategy does not cope with rising amounts of SW. Therefore, the decision makers have decided to move from waste disposal towards sustainable waste management.

Separate collection of dry waste, composting, segregation of medical waste, recycling, resource recovery and sanitary landfills are starting to be implemented, while energy recovery and incineration are still at the initial stages. Only 7% of recyclable materials such as paper, cardboard, plastic and metals are separately collected; 50% of these materials are sorted by the informal sector. Mixed household waste is collected containing all the types of waste which generate high levels of GHG and leachate due to the large number of organic fractions; more than 60% of the MSW generated is organics.

Landfilling is still the main practiced treatment method in Shiraz. The only engineered landfill is equipped with a leachate and LFG collection system. Over 50% of the waste generated in the city is disposed in landfill sites without any pre-treatment; remaining 50% is subjected to material recovery treatment technology, in an MRF, and biological treatment (i.e. composting).

Pilot composting projects of organic waste were conducted in Shiraz's composting facility under different weather conditions. Organics derived from two main waste streams, commercial and households were subjected to ideal conditions in terms of pilling, in-situ measurements (temperature, moisture, etc.), daily monitoring activities (aeration, turning and sampling) and lab analysis.

In the case of source-separated organic waste, the findings indicate that the state-of-the-art composting process was performed successfully under ideal conditions. The chemical (organic matter, total organic carbon, total nitrogen, potassium, heavy metals) and physical characteristics (bulk density, moisture content, etc.) of final the product demonstrated a complete degradation of organic waste within a relatively short period of time (10 weeks). The finding demonstrates that high quality finished compost can be achieved, which can be utilized for agricultural purposes.

Over the periods of 10 and 20 years, soil organic carbon will be increased 10.5 t. ha^{-1} and 21 t. ha^{-1} with 30 tons per hectare by application of source-separated organics compost, which also has a considerable positive effect on the available soil water content. Assuming a moderate range of soil organic carbon increase, the application of each ton of compost has the potential to sequester 128.45 kg CO_2 equivalent on a fresh mass basis.

As for the mixed fraction, the composting period takes longer; temperature remains higher than ambient after 10 weeks. Overall, the finished compost obtained had a desired range of chemical and physical values. The heavy metals concentrations were lower than those values set by the German standards except for copper (Cu). Maturity could not be obtained despite the mixed waste being subjected to ideal conditions. This was clearly observed by the moderately low GI, which was found to be 65%.

The findings of the summer trials confirm that at least 0.3 m^3 of water is required per each ton of raw input material. In case of non-irrigated piles, the temperature profile rapidly decreased after the second week and organics were dried out instead of stabilization. The quantity of irrigation water correlated with the stabilization rate (C/N and organic matter), whereas its quality had more effect on the maturation level of final products (NH_4^+). There was no significant change between the different trials of irrigation water in terms of EC and pH, due to materials having the same origin (mixed municipal organic waste); however, the piles irrigated with lower water quality had a final product with higher EC. The less the pile was irrigated with saline water, the lower the accumulation of salt the compost produced.

Through PCA, the conditions in capital cities of all provinces for producing compost were evaluated based on the per capita waste generation, average temperature and moisture. It seems that 16 cities located in the north-west, west and south-west have the proper weather conditions for windrow composting. This method will be feasible when the municipalities could at least separate the industrial and hospital waste streams from the household stream and provide adequate infrastructure (irrigation water, lab, machineries).

To optimize organic waste management, two approaches are recommended: scaling-up collecting source-separated organics and treatment concepts for different streams of organics, i.e. organics derived from household mixed waste stream and segregated market and garden waste.

Treatment strategies for organics were considered; the first proposed strategy for the treatment of organics derived from mixed waste stream aimed to stabilize organic materials to be used in landfilling activities, i.e. covering and re-shaping materials. Fine fractions were subjected to a bio-drying process in the form of windrow piles for 2 - 4 weeks without adding water. During the process, a turning schedule was implemented frequently depending on the moisture status inside the piles.

The second proposed strategy was to treat the segregated organic fractions, converting it into value-added products. The strategy recommends that the raw materials are well-blended, thus obtaining optimal initial conditions (pile dimensions, porosity, moisture, C/N ratio, etc.) for rapid decomposition. The approach suggests providing all the equipment and tools required for an efficient composting process: in-situ measurements tools (temperature, oxygen, carbon dioxide, pH, etc.), turning machine, watering system, laboratories for the purpose of samples analysis.

A technical model for full exploitation of Shiraz's composting facility was provided. The model addressed two challenges facing the operating Shiraz compositing facility: the high level of impurities and leachate contaminations. To this end, modifications of MRF sieves are highly recommended and the raw materials should be screened at 40 mm instead of 70 mm.

A simple and cost-effective design was considered in developing a leachate collection system. The proposed drainage system suggests that each windrow pile has its sub-canals and is subjected to linear and lateral slope, thus speeding up the depletion of leachate into the main canal.

A new biological approach was examined for improving the quality of compost produced from mixed waste. The proposed approach suggests adding an EM to the final compost product. Compost produced from mixed MSW (P1) was subjected to a second composting process under anaerobic conditions. Different concentrations of EM were added to the prepared piles from the final product of mixed waste compost, under the same conditions and at the same interval. The results demonstrated the positive effect of EM; a significant increase of GI took place by adding 40% of EM, achieving 80% GI. Adding 30% of EM had a lower effect on GI; it produced 70% GI, which could not remove phytotoxicity. The ammonium ratio decreased to 5.26% and 7.97% through the addition of 30% and 40% of EM, respectively. The results obtained show that EM can be used in combination with mixed waste compost to minimize phytotoxicity effects. Consequently, the amount of quality compost required for agricultural purpose in study area is calculated.

The proposed solutions for municipal organic waste were selected based on many factors such as the availability and nature of raw organic materials, operational parameters, quality assurance for marketability and the need for soil amendment products with precise attention to environmental issues.

8. RECOMMENDATIONS

Switching from waste disposal towards sustainable waste management must be carried out step-by-step. Legal framework (laws, regulations and ordinance) are the basic components of successful waste management. The first step must be introducing a packaging ordinance together with banning landfilling of untreated solid waste. Otherwise any proposed technologies would be doomed to failure.

Sustainable waste management solutions should be made through adopting the technical requirements to the local conditions considering the management, financial, institutional, and technical aspect. When considering the framework of SWM, high attention should be paid to avoidance. Waste avoidance plays an important role in reducing the cost of all waste management activities. Despite waste reduction is the most effective approach, it is always a challenging matter and hardly achieved since it is influenced by several stakeholders.

Biological treatment process should be adopted to deal with source-separated organics. As for the mixed waste stream, mechanical-biological treatment (MBT) should be considered as a mandatory treatment before thermal utilization; incineration. In MBT, the mixed waste is separated by mechanical processing into different fractions; high-calorific fraction (RDF) to be utilized for co-processing in cement industry, recyclables materials and fine fraction, mainly organics, that is biologically treated. Applying MBT approach contributes to reduce the volume, increase the calorific value and the rate of material recovery.

Suggested new solutions or technologies require a sufficient budget. Municipalities should consider several ways to enhance their economic situation. Enhancing the cost recovery (fees collected) ensures the covering of different waste management activities; collection, storage, treatment and disposal. Develop the polluter-pays principle focused on recycling and composting in order to generate an income from the sale of such products.

The current institutional framework of waste management planning and implementation needs to be revised; the responsibilities of the involved waste management institutions and organizations should be clearly identified. Coherent interlink between the educational initiations (universities, vocational training centers) and operational entities run by either municipalities or private companies is essential.

The existing practiced standards must be revised considering the nature of raw input materials, applying the proper operational conditions and expected final product quality. Assessment and monitoring tools therefore should be set-up to evaluate the adopted technologies and their output quality. Clear standards criteria should be established identifying the quality of the final market-oriented products, particularly in the case of composting.

Most of the decision makers in the administration levels don not have full understanding of the waste management concept as well as the operational procedure of the facility. Working staff in the field of waste management at different levels (officials, engineers, labor force, etc.) should be subjected to qualification and education programs.

The stakeholders are not aware of the economic and environmental benefits that could be achieved from proper utilization of organic waste. Public awareness should be considered and targeted the waste producer to ensure their full understanding of the SWM system and adverse effects of its mismanagement; this will guarantee the community engagement in the process.

Cooperation model should be established to create dynamic inter-link between the government bodies involved in planning and managing the waste sector. Related ministries are will be able to share their know-how and experience among each other, this was on one hand. On the other hand, cooperation between private and public sectors involved in the SWM system is a matter of its sustainability from the technical, financial and social point of view.

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Appendix I: status of Shiraz's material recovery facility (chapter 2)

The physical composition of fine fraction derived from 2 line of MRF

Component	Spring			Summer			Autumn			Winter			Ave
	L 1	L 2	Ave	L 1	L 2	Ave	L 1	L 2	Ave	L 1	L 2	Ave	
Organic	89.9	85.7	87.8	87.9	86.3	87.1	89.8	90.5	90.2	88.7	89.2	89.0	88.5
Paper & Cardboard	5.3	6.6	6.0	2.5	3.3	2.9	2.5	2.4	2.4	5.0	4.2	4.6	4.0
Metals	0.1	0.1	0.1	0.2	0.3	0.3	0.4	0.3	0.3	0.2	0.2	0.2	0.2
Plastics	2.2	4.5	3.3	6.4	6.1	6.3	2.7	2.3	2.5	2.8	3.2	3.0	3.8
Glass	1.9	1.6	1.7	2.4	2.9	2.7	2.4	2.2	2.3	1.9	2.0	2.0	2.2
Textile	0.4	1.3	0.9	0.5	0.7	0.6	0.5	0.4	0.4	0.5	0.7	0.6	0.6
Hazardous	0.1	0.2	0.1	0.2	0.2	0.2	2.5	2.9	2.7	0.3	0.2	0.3	0.8
Construction and Demolition	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.5	0.2	0.5	0.4	0.4	0.2

Appendix II: composting production using municipal organic waste (chapter 4)

Average measured temperatures during composting runs

Week	Ambient Temp.	Pile 1 (P1) Temp.	Pile 2 (P2) Temp.
0	12.49	30.13	48.34
1	14.71	49.29	59.50
2	16.14	59.50	53.33
3	15.91	54.29	52.50
4	18.20	55.36	50.00
5	19.57	50.00	52.50
6	18.94	55.63	53.33
7	22.49	55.50	53.50
8	21.26	56.50	42.50
9	25.97	46.25	30.00
10	22.90	44.60	-
11	22.2	38.33	-

Average moisture content during composting runs

Week	Rainfall	Pile 1 (P1)	Pile 2 (P2)
0	15.2	67.00	61.7
1	2	60.58	52.94
2	15.2	63.70	56.34
3	0.2	58.63	44.1
4	76	54.10	48.96
5	25.6	55.73	50.67
6	15.4	56.00	49.87
7	13.5	52.87	44.1
8	0	50.85	39.68
9	0	48.7	38.59
10	0	44.69	-
11	0	35.83	-

Average nutrients content wt/wt (%) during composting runs

	P		K	
	start	end	start	end
P1	0.52	0.77	0.79	1.04
P2	0.24	0.55	1.3	1.4

Average EC and pH values during composting runs

Week	EC		pH	
	P1	P2	P1	P2
0	5.78	2.04	5.90	7.13
2	8.60	2.86	6.45	8.3
4	8.42	3.18	6.90	8.57
6	7.40	3.22	6.91	8.4
8	6.34	3.36	7.21	8.38
11	5.6	-	7.6	-

Average Organic matter, total N and NH_4^+ measured during composting runs

Week	Organic matter		Total N		NH_4^+	
	P1	P2	P1	P2	P1	P2
0	79.90	53.42	1.80	1.16	0.05	0.015
2	72.50	50.46	1.70	1.13	0.10	0.045
4	69.09	45.68	1.67	1.08	0.08	0.017
6	62.13	38.7	1.80	1.07	0.07	0.010
8	61.03	34.87	1.81	1.18	0.04	0.010
11	56.35		1.78		0.037	

Appendix III: examination of municipal compost quality under different irrigation scheme (chapter 6)

Average measured temperatures during composting runs

Week	Ambient	T0	T1	T2	T3
1	23.00	57.38	61.75	61.75	60.58
2	22.00	53.13	61.39	61.03	58.63
3	23.00	47.75	56.69	59.22	56.00
4	25.00	44.00	53.81	57.06	55.73
5	24.00	40.83	52.36	53.63	54.10
6	22.00	39.75	50.38	53.63	52.87
7	25.00	34.33	52.00	51.46	50.85
8	23.00	31.58	48.75	48.21	48.68
9	22.00	28.79	44.96	44.42	44.69
10	24.00	27.46	39.72	40.89	35.83

Average moisture content during composting runs

Week	T0	T1	T2	T3
1	40.17	43.33	37.50	30.13
2	46.47	49.38	51.67	49.29
3	57.60	57.78	52.86	59.50
4	58.00	53.33	50.56	54.29
5	60.67	55.00	50.00	55.36
6	54.08	51.67	54.17	50.00
7	47.67	52.50	55.83	55.63
8	40.83	51.67	50.83	55.50
9	40.67	51.67	48.89	56.50
10	36.17	45.56	42.80	46.25

Average Chemical properties measured during composting runs

Compost run	Chemical properties						
	MC	EC	NH_4^+	pH	OM	N	C/N
T0	12.467	5.890	0.105	7.177	55.700	1.970	16.367
T1	20.700	5.863	0.079	7.960	49.200	2.033	14.100
T2	27.323	6.100	0.070	8.053	46.453	2.147	12.249
T3	30.190	5.580	0.036	8.100	45.743	1.933	13.162

Haniyeh Jalalipour

Justus-Von-Liebig Weg 6a, 18059 Rostock, Germany
haniyeh.jalalipour@uni-rostock.de

EDUCATION

(Expected) Ph.D.
Department of waste and resource management, University of Rostock
2017- Ongoing

- Research topic: sustainable Municipal Organic Waste Management in Shiraz, IRAN
- Supervisors: Satyanarayana Narra

MSc
Irrigation and Drainage, University of Shiraz
2011- 2014

Thesis topic: Analysis of drainage performance and wheat yield using SWAP model

---

BSc
Water engineering, University of Shiraz
2006- 2010

Project title: The ability of Vetiver grass to refine Shiraz landfill soil and leachate

SCHOLARSHIPS

PhD scholarship from Landesgraduiertenförderungsgesetzes von Mecklenburg-Vorpommern
1.10.2019-30.09.2020

PUBLICATIONS

- Jalalipour, H., Jafarzadeh, N., Morscheck, G., Narra, S., & Nelles, M. (2020). Adoption of Sustainable Solid Waste Management and Treatment Approaches: A case study of Iran. Waste Management & Research. https://doi.org/10.1177/0734242X20978300
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- Jalalipour, H., Binayi Haghighi, A., Truong, P. (2015). VETIVER phytoremediation technology for rehabilitating Shiraz municipal landfill. 6th International Conference on Vetiver (ICV‐6), Da Nang, Vietnam.

RESEARCH AND WORK EXPERIENCE

Research Assistance
Hochschule Trier
Project: Wertschöpfungsketten in der Peripherie Urbaner Regionen
10.2020-12. 2020

Local expert
Project: "ImPact Iran"Vorbereitung der Markterschließung für deutsche KMU im Iran
10.2018-12. 2019

Environmental engineer
Shiraz Solid Waste Management Organization
Job description: public capacity-bulling, R&D, compost expert
01.2014-09. 2019

TEACHING EXPERIENCE

Co-supervisor in Ph.D. project
Title: Evaluating different scenarios of municipal solid waste management using Life Cycle Assessment in Shiraz, Iran
09.2019-Onging

Shiraz University
Teaching assistance for Drainage Systems Lab
09.2012-09.2013

COMPUTER SKILLS

Microsoft office: Advanced
R: Intermediate
AutoCAD: Intermediate
ArcGIS: Basic

LANGUAGE SKILLS

English: Advanced (Toefl IBT score 95)
Deutsch: Intermediate (getting ready for B2)

OTHER ACTIVITES

- Member of International Solid Waste Association (ISWA) Young Professional Group (YPG)
  04.2020-Ongoing

- Collaboration in local standard development
  Iranian National Standardization Organization
  Modification of ASTM D 5283: Generation of environmental data related to waste management activities; Quality assurance, quality control planning and implementation-Practice

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