DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

COMPOSTING OF MUNICIPAL SEWAGE SLUDGE USING SEMIFERMENTED SOLID WASTE AND GRASS CUTTINGS

by
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January, 2006

İZMİR

COMPOSTING OF MUNICIPAL SEWAGE SLUDGE USING SEMIFERMENTED SOLID WASTE AND GRASS CUTTINGS

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Mahir YÜCEL

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M. Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"COMPOSTING OF MUNICIPAL SEWAGE SLUDGE USING SEMIFERMENTED SOLID WASTE AND GRASS CUTTINGS"** completed by **Mahir YÜCEL** under supervision of **Prof. Dr. Ayşegül PALA** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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Mahir YÜCEL

COMPOSTING OF MUNICIPAL SEWAGE SLUDGE USING SEMIFERMENTED SOLID WASTE AND GRASS CUTTINGS

ABSTRACT

The awareness of the threat on natural resources have started to impose effects on the handling of sewage sludge and composting of solid wastes by better environmentally friendly techniques. The enormous amounts of sludge that result after the treatment of waste water are a significant economic and environmental issue to be examined. Difficult techniques are available in the disposal of sewage sludge like incineration, land filling – dumping, and land application of the composted material for agricultural purpose. Composting is more beneficial compared to that of other disposal methods because the sludge volume decrease by 40 – 50 % and is sterile due to reductions in pathogenic microorganisms. Treatment plant sludges can be composted alone or along with municipal solid wastes.

The objective of this study was to examine the capability (and possibility) of sewage sludge and further its agricultural use. Aerobic composting of the sewage sludge was investigated by two different mechanisms in three different experiments. In the regard, grass cuttings from university gardens, sewage sludge from İzmir – Çigli Wastewater Treatment Plant, and semi fermented solid waste which were taken from İzmir – Uzundere Compost Plant were used. In 1st and 3rd studies, semi fermented solid waste and sewage sludge were mixed in different rates and systems. In 2nd study, sewage sludge, semi fermented solid waste and grass cutting were mixed.

During the study, moisture, organic matter, temperatures, C/N ratio, pHs were determined. Primary macro (P, K), and secondary plant nutrients (Fe, Cu, Zn, Mn), heavy metals (Cr, Ni) were also measured to investigate for agricultural use of final product.

Results revealed that the method used in Experiment 1 did not end with the expected compost product. However, Experiment 2 and Experiment 3 resulted with a better compost while Experiment 2 being the best in this respect. Effect grass cuttings used in Experiment 2 on composting was positive. Heavy metal contents of the final products were also below the standard values given in the Turkish Regulation of Soil Pollution Control.

Keywords: composting, disposal of sewage sludge, semifermented solid waste, grass cuttings.

BELEDİYE ATIKSU ARITMA ÇAMURLARININ YARI FERMENTE OLMUŞ KATI ATIKLAR VE BİÇİLMİŞ ÇİM KULLANILARAK KOMPOSTLAŞTIRILMASI

ÖZ

Çevresel açıdan dost teknikler kullanılması, katı atıkların kompostlanması ve arıtma çamurunun yönetiminde, doğal kaynakları farkında olmadan tehdit etmesi etkilidir. Atıksuların arıtımı sonucu oluşan büyük miktarlardaki arıtma çamurları ekonomik ve çevresel açıdan ilgi odağı oluşturmaktadır. Arıtma çamurlarının bertarafı veya değerlendirilmesi için yakma, arazide depolanması, kompost materyalin tarımsal amaçla kullanımı gibi farklı teknikler uygulanmaktadır. Kompostlaştırmanın diğer bertaraf yöntemlerine göre atık hacmini %40–50 oranında azaltarak daha az yere ihtiyaç duyma ve termofilik faz boyunca oluşan ısıyla patojenleri yok etme gibi önemli avantajları vardır. Arıtma çamurları yalnız kompostlaştırılabildikleri gibi, kentsel katı atıklarla birlikte de kompostlaştırılabilirler.

Bu çalışmanın amacı, İzmir–Çiğli Atıksu Arıtma Tesisi'nde oluşan çamurun kompostlaştırılarak tarımsal amaçla kullanılabilirliğinin incelenmesidir. Arıtma çamurunun aerobik kompostlaştırılabilirliği, iki farklı düzenekte üç farklı çalışmayla araştırılmıştır. Bu amaçla; üniversite kampus alanından biçilen çim, İzmir – Çiğli Atıksu Arıtma Tesisi'nden alınan arıtma çamuru ve İzmir Uzundere Kompost Fabrikası'ndan alınan yarı fermente katı atık kullanılmıştır. Birinci ve üçüncü çalışmada, farklı oranlarda arıtma çamuru ve yarı fermente katı atık karıştırılmıştır. İkinci çalışmada ise arıtma çamuru, yarı fermente katı atık ve çim karıştırılmıştır.

Çalışma boyunca, nem, organik madde, sıcaklık, C/N oranı ve hesaplandı. Elde edilen son ürünün tarımda kullanılabilirliğini araştırmak için; birincil (P, K) ve ikincil bitki besin (Fe, Cu, Zn, Mn) maddeleri ile ağır metal (Cr, Ni) miktarları da ölçülmüştür.

Sonuçlar gösterdi ki birinci Deneydeki yöntem beklenen kompost ürünüyle sonlanmadı. Bununla birlikte, Deney 2 ve Deney 3, daha iyi bir kompostla sonlandı. Deney 2, diğerlerine göre daha iyi sonuç verdi. Deney 2'de eklenen çim olumlu sonuç verdi. Son ürünün ağır metal içeriği Toprak Kirliliği Kontrolü Yönetmeliği'nde verilen standard değerlerin altında çıkmıştır.

Anahtar kelimeler: Kompostlama, arıtma çamurlarının bertarafı, yarı fermente katı atık, yeşil atıklar.

CONTENTS

Page

THESIS EXAMINATION RESULT FORM ii
ACKNOWLEDGEMENTS iii
ABSTRACT iv
ÖZ vi

CHAPTER ONE – COMPOSTING 1
1.1 Introduction 1
1.2 Objective and Scope 3
1.3 Literature Review 4

CHAPTER TWO – CHARACTERIZATION OF THE SEWAGE SLUDGE .. 10
2.1 Sewage Sludge 10
2.2 Basic Parameters 11
2.2.1 Total Solids 11
2.2.2 Suspended Solids 11
2.2.3 Volatile Solids 11
2.2.4 Type of Sludge 11
2.3 Physical Features 12
2.4 Chemical Features 12
2.4.1 Process Parameters 12
2.4.1.1 pH and Alkalinity 13
2.4.1.2 Volatile Fatty Acids 13
2.4.2 Nutrients Content 14
2.4.3 Pollution Level 14
2.5 Biological Features 15
2.5.1 Biological Stability 15
2.5.2 Pathogenic Features 15

CHAPTER THREE – COMPOSTING OF THE SOLID WASTES 16
3.1 Composting 16
3.2 Process Microbiology.....18
3.3 Process Description.....19
3.4 Design Considerations for Aerobic Sludge Composting Process. 20
3.4.1 Type of Sludge..... 20
3.4.2 Amendments and Bulking Agents 21
3.4.3 Carbon – Nitrogen (C/N) Ratio..... 21
3.4.4 Volatile Solids..... 22
3.4.5 Air Requirements 22
3.4.6 Moisture Content..... 23
3.4.7 pH Control..... 24
3.4.8 Temperature 24
3.4.9 Mixing and Turning 25
3.4.10 Heavy Metals and Trace Organics 25
3.4.11 Site Constraints 25
3.4.12 Control of Pathogens..... 25
3.5 Operating and Performance Parameters 26
3.5.1 Oxygen Uptake 27
3.5.2 Temperature 28
3.5.3 Moisture 29
3.5.4 pH..... 29
3.5.5 Odor 29
3.5.6 Color..... 29
3.5.7 Destruction of Volatile Solids 30
3.5.8 Stability 30
3.6 Composting Systems 31
3.6.1 Aerated Static Pile 31
3.6.2 Windrow..... 32
3.6.3 In-Vessel Composting System 33
3.7 Co-composting with Municipal Solid Wastes..... 35

CHAPTER FOUR – MATERIAL AND METHOD 36
4.1 Composting Ingredients 36
4.1.1 Sewage Sludge 36
4.1.2 Semi Fermented Solid Waste 37
4.1.3 Grass Cuttings 38
4.2 Experimental Research 38
4.2.1 Composting at the Static Pile (Experiment 1) 38
4.2.2 Composting at the Barrels (Experiment 2) 39
4.2.3 Composting at the Barrels (Experiment 3) 40
4.3 Experimental Methods 42
4.3.1 Moisture 42
4.3.2 Temperature 42
4.3.3 pH 42
4.3.4 Organic Carbon 42
4.3.5 Total Nitrogen 43
4.3.6 Primary (P, K), and Secondary Plant Nutrients (Fe, Zn, Mn, Cu), and ..... Heavy Metals (Cr, Ni) 43

CHAPTER FIVE – RESULTS AND DISCUSSION 44
5.1 Experiment 1 44
5.1.1 Moisture 44
5.1.2 Temperature 45
5.1.3 pH 46
5.1.4 Organic Carbon 47
5.1.5 Total Nitrogen 48
5.1.6 C/N Ratio 48
5.1.7 Primary (P, K), and Secondary Plant Nutrients (Fe, Zn, Mn, Cu), and ..... Heavy Metals (Cr, Ni) 49
5.2 Experiment 2 50
5.2.1 Moisture 50
5.2.2 Temperature 51
5.2.2.1 Temperature at Up of the Piles 52

5.2.2.2 Temperature at Middle of the Piles 53
5.2.3 pH 54
5.2.4 Organic Carbon 55
5.2.5 Total Nitrogen 56
5.2.6 C/N Ratio 56
5.2.7 Primary (P, K), and Secondary Plant Nutrients (Fe, Zn, Mn, Cu), and ..... Heavy Metals (Cr, Ni) 57
5.3 Experiment 3 59
5.3.1 Moisture 59
5.3.2 Temperature 60
5.3.2.1 Temperature at Up of the Piles 60
5.2.2.2 Temperature at Middle of the Piles 61
5.3.3 pH 62
5.3.4 Organic Carbon 63
5.3.5 Total Nitrogen 64
5.3.6 C/N Ratio 65
5.3.7 Primary (P, K), and Secondary Plant Nutrients (Fe, Zn, Mn, Cu), and ..... Heavy Metals (Cr, Ni) 65

CHAPTER SIX – CONCLUSION 67
CHAPTER SEVEN – RECOMMENDATION 69
REFERENCES. 70
APPENDIX I. 74
APPENDIX II. 81

CHAPTER ONE
COMPOSTING

1.1 Introduction

As a result of economic growth and increasing number of treatment plants, the amount of sewage sludge has increased which lead to rise in cost of stabilization and disposal of sewage sludge and limited capacity of the final disposal lands drastically. In our country, increasing environmental conscious played an important role in seeking new ways of reducing sewage sludge. In economically developing our country difficulties related to economics, technology and qualified personal have affected the use of treatment and disposal options. Appropriate options include stabilization, minimization, recycling, incineration, dumping on land or in the sea, and composting.

Stabilization processes are used to minimize environmental affects of treatment plant sludges before final disposal. Composting is one of the widely used stabilization methods. However, because of the lack of regulation and order, scientific knowledge, exploration and data deficiency, the sludge almost totally has been stored and removed with sewage sludge in the regular or irregular store lands. This application is caused environment pollution and decreasing capacity of regular dumping lands. Additionally, nutrients and inorganic components in the sewage sludge are squandered by this method. Although there are lots of methods for disposal of treatment sludges, it has been emphasized earnestly on land application of these sludges. By applying treatment sludges having proper characteristics as a soil amendatory and as organic fertilizer on agricultural lands, both sludge disposal and economical advantage in agricultural production will be achieved.

Composting has gained wide acceptance as a key component of integrated solid waste management. The capacity of reducing the volume and weight approximately by 50% and resulting in a stable product that can be beneficial in agriculture made composting a promising alternative (He et al., 1992). Composting offers a unique

opportunity to reduce the overall quantity of waste land filled by converting organic wastes into a useful product that can be used to enhance the quality of life and solve of the environmental problems (Vesilind et al., 1990).

Gray & Sherman (1969) stated that composting is the biological decomposition of organic matter under controlled aerobic conditions. In contrast, fermentation is the anaerobic decomposition of organic matter. Many factors affect the composting process; "So many factors are involved, nearly all interrelated, that this complex ecological process is unlikely to succumb to rigorous scientific analysis for many years". According to Epstein (1997), some of these factors play a major role in the process while other can influence its direction or extent. Since 1969 new chemical and physical techniques have provided scientists with the tools to examine and manipulate these factors and to delve into the composting process in a rigorous manner. Stabilization processes are used to minimize environmental effects of treatment plant sludges before final disposal. Composting is one of the widely used stabilization methods. Treatment plant sludges can be composted alone or along with bio wastes. These bio wastes should contain high organic carbon as wood, grass, wood shaving, domestic wastes and waste paper etc. Because the C/N ratio in the mixing most important parameter to mature composting. Bishop and Godfrey (1983) claims that the initial C/N ratio should be in the range of 20:1 to 35:1 by weight. At lower ratios, ammonia given off and odor problem occurs. In the case of C/N ratios exceeding 50:1, the composting process slows because of rapid cell growth and depletion of available N, resulting in reduced cellular growth. As cells die, their stored N becomes available to living cells.

In this regard, grass cuttings from university gardens, sewage sludge from İzmir – Çigli Wastewater Treatment Plant, and semi fermented solid waste which were taken from İzmir–Uzundere Compost Plant were used. In 1st and 3rd experiments, semi fermented solid waste and sewage sludge were mixed in different rates and systems. In 2nd experiment, sewage sludge, semi fermented solid waste and grass cutting were mixed. The capability and possibility of sewage sludge and further its agricultural use were investigated by composting.

1.2 Objective and Scope

There are so many sludge treatment methods which vary depending on sludge characteristic, climate and economy. The chosen method needs to be environmentally friendly and economical. Stabilization processes are used to minimize environmental effects before final disposal. Composting is one of the widely used stabilization methods. In this regard, sewage sludge from treatment plants can be composted either alone or along with municipal solid wastes.

The aim of this study is to investigate the agricultural usage of sewage sludge which is produced in İzmir – Çiğli Wastewater Treatment Plant. In İzmir – Çiğli Wastewater Treatment Plant, 12000 m^3 sludge is produced and processed per day. After mechanical dewatering process, the sludge decreases to 600 m^3. Annual sludge production is approximately 43800 tons (dry weight) provided that the sludge contains 20% dry matter.

Sewage sludge is an inevitable end product of wastewater treatment process. Composting the sewage sludge is increasingly receiving the interest of many municipalities throughout the world because it has several advantages over other disposal strategies. Land application of composts to agricultural soils has many advantages, which include supplying nutrients to the soil, increasing soil acidity, as well as beneficial soil organisms, reducing the need for fertilizers and pesticides, improving soil physical and biological properties, and decreasing the load on landfills.

The appropriate C/N ratio during composting of sludge should be supplied by cellulosed carbon containing materials which must be low in cost, plenty and easy to reach. In İzmir, a composting plant exists in Uzundere and produces compost from city garbage which can be blended with sludge. This material can regularly be conveyed to the treatment plant, and mixed in appropriate ratio to produce waste-sludge compost.

Additionally, in order to widen the C/N ratio in treatment sludge, wood, grass, wood shaving, domestic wastes and waste paper which contain high organic carbon can be used. In İzmir, there are numerous recreation areas with lawns. For this purpose, the lawn is mown at least once a month.

Three experiments were performed to examine the usability of treatment sludge in the agricultural lands. In the 1st experiment; sewage sludge and semi fermented solid waste which was taken from İzmir Uzundere Compost Plant were used to make compost by using the method of the static pile. In the 2nd experiment; sewage sludge, semi fermented solid waste, and grass cutting were used to make compost in the barrels which of volume 70L. It should be noted that upper surface of barrels was open. In the 3rd experiment; sewage sludge and semi fermented solid waste were used to make compost in the barrels.

Moisture, pH, temperature, and organic matter were determined during the study. Primary macro (P, K), and secondary plant nutrients (Fe, Cu, Zn, Mn), and heavy metals like Cr, Ni were also examined to investigate for agricultural use of using final products.

1.3 Literature Review

Zorpas et al. (2002) researched that waste paper and clinoptilolite as a bulking material with dewatered anaerobically primary sewage sludge (DAPSS) for compost. The composting process was carried out in the laboratory using an in-vessel reactor of 1 m^3 active volume. The major limitation of land application of sewage sludge compost is the potential for high heavy metal content in relation to the metal content of the original sludge. Composting of sewage sludge with natural zeolite (clinoptilolite) can enhance its quality and suitability for agricultural use. However, the dewatered anaerobically stabilized primary sewage sludge (DASPSS) contained a low concentration of humic substances (almost 2 %), the addition of the waste paper was necessary in order to produce a good soil conditioner with high concentrations of humics. The final results showed that the compost produced from DASPSS and 40 –

50 % w/w of waste paper was a good soil fertilizer. Finally, in order to estimate the metal leachability of the final compost product, Generalized Acid Neutralization Capacity (GANC) procedure was used, and it was found that by increasing the leachate pH, the heavy metal concentration decreased. When the amount of the waste paper was increased the concentration of the organic matter in the final product increased. The pH was initially low due to the acid formation, then the pH increased and at the later stage pH was constant. The C/N ratio for that stabilized compost was considered very satisfactory for agricultural use. The final product contained a low concentration of heavy metals and that is not problem for the use of compost for agricultural purposes. That increases the quality of the compost. Zeolite was helpful in the uptake of heavy metals. Using the GANC procedure it was found that by increasing the leachate pH, the heavy metal concentration decreased. The GANC test procedure showed that in the case of oxic rain the zeolite had the ability to retain the heavy metals (significant different at $P<0.05$) and not let them pass to the groundwater. Using a sequential extraction procedure in the raw sludge (DASPSS) and final products (compost after 150 days of maturity) it was found that a significant ($P<0.05$) amount of sludge metals was bound in the residual fraction, in an inert form. Clinoptilolite had most readily taken up the metal content bound in the exchangeable and carbonate fractions.

Amir et al. (2004) researched that sequential extraction of heavy metals during composting of sewage sludge. The major limitation of soil application of sewage sludge compost is the total heavy metal contents and their bioavailability to the soil-plant system. That study was conducted to determine the heavy metal speciation and the influence of changing the physico-chemical properties of the medium in the course of composting on the concentrations, bioavailability or chemical forms of Cu, Zn, Pb and Ni in sewage sludge. Principal physical and chemical properties FTIR spectroscopical characterization of sludge compost during treatment show the stability and maturity of end product. The total metal contents in the final compost were much lower than the limit values of composts to be used as good soil fertilizer. Furthermore, it was observed by using a sequential extraction procedure in sludge compost at different steps of treatment, that a large proportion of the heavy metals

were associated to the residual fraction (70 – 80%). The agricultural use of sewage sludge compost implies knowing its degree of stability, as well as its content and biogeochemical forms of the heavy metals present. Not only are those elements not biodegradable and become toxic at some concentrations, they tend to accumulate along the food chain where man is the last link. The determination of total heavy metal content does not provide useful information about the risks of bioavailability, the capacity for remobilization and the behavior of the metals in the environment. While, the chemical forms of a metal or speciation allows the estimation of heavy metal bioavailability and is related to the different natures of the metals, their bonding strength, either in free ionic form or complexed by organic matter, or incorporated in the mineral fraction of the sample. That study is characterized by C/N ratio of 14 and metal contents of 275; 71; 135; 24 mg/kg^{-1} respectively for Zn, Cu, Pb, Ni (the Cd concentration was below the limit of detection). The mixture of sludge (89%) with straw (11%), increased the C/N ratio to 23.9. the C/N ratio reached the optimal range of stable compost. The compost can supply all macro-nutrients necessary for plant growth. The total concentration of Zn, Cu, Ni and Pb was very low rendering final compost acceptable for agricultural use (Amir et al., 2004).

In the study which reported by Manios, (2003), materials such as olive cake, olive tree leaves (OTL) and branches, vine branches (VB), pressed grape skins (PGS), pig manure (PM), sewage sludge and the organic fraction of municipal solid waste (OFMSW) have been evaluated for their behavior during composting, their compatibility in mixtures and quality of the end product. The quality evaluation included both a detailed physiochemical (pH, electrical conductivity (EC), nutrients concentration, heavy metal concentration, etc.) and biological analyses (pathogenic microorganisms). It also included an agronomic evaluation, in which composts were used either as a soil amendment or as a component for substrates in open air or covered (greenhouse) cultivation mainly of local vegetables (tomatoes, cucumbers, etc.). All materials were composted successfully, especially when mixed. The end products contained large amounts of organic matter, usually combined with increased EC value. Pressed grape skins should be considered as the ideal raw material,

producing high quality compost, with the lowest EC value and the largest organic matter concentration (84.50%), compared to all other materials. When any of the produced compost was used in a ratio of 30% by volume (v/v), it increased plant growth, whereas in larger volumes, it presented phytotoxic behavior, inhibiting both root and shoot development. The raw materials that can be used to produce high quality composts are mainly the residues of local cultivations and agricultural industries. A secondary source, both in amount and quality, is the organic fraction of municipal solid waste (OFMSW) (when source separated) and sewage sludge, when mixed with green waste or other bulky organic materials. However, given the bulky nature of those materials and the large transportation cost, composting should take place as close as possible to place of waste production to ensure that is an economically viable and affordable option for growers. Green waste in particular has a strong insulating ability, allowing energy trapping in the core of pile, resulting in a higher temperature for a longer period of time. The thermophilic phase of sewage sludge composting depends on the mixture, especially the ratio of sludge to bulking agent, but is independent of the nature of the agents. When 1:2 or 1:3 (v/v) mixtures were used, the thermophilic phase was 6–8 weeks. With a required minimum number of six turnings. The main problem with sewage sludge was the metal concentration that high, resulting to a increased metal concentration in the end product. Mixtures should be used to ensure a good final product. Other advantages include easy handling of materials during composting and reduced odor emissions, as well as fewer turning, less need for C/N ratio correction and moisture adding, and a shorter thermophilic and maturation phase.

Manios et al. (2003) researched that, shredded green wastes were composted in windrow. Landfill leachates were added twice during the second and fourth week of the process in two piles. One pile was turned once every week for eight weeks and the other was turned twice, during the same period. Each time approximately, 2 m^3 of leachate was added, into each pile. The two piles each contained about 45 m^3 of shredded green waste. The effect of adding leachate on the sanitization of the green waste during composting was evaluated based on the changes in the levels of faecal streptococci. The results suggested that using leachate as the moisture source had no

significant effect (tested with two factors ANOVA test) on the sanitization process when compared with two similar piles, used as the control, for which tap water was used for moisture addition. In all four piles sanitization was almost complete and below the acceptable levels. Additionally, the results indicated that there was no significant effect on the sanitization process of turning frequency. The results indicate that partially treated landfill leachate can be reused as a water source during composting of green waste, since it did not produce any negative effect in the sanitization process. This use can be supported only when such wastewater is readily available and can be transported at small cost. In the case considered the site for leachate collection and treatment was only 800 m away from the composting site and on the same controlled site as the composting plant. No analyses for heavy metals and other chemical accumulation in the green waste were carried out. To support the use of leachate in that way those parameters need to be monitored.

According to Elmacı et al. (2003), the solids wastes of factories, which processes medicinal and aromatic plants, are analyzed in respect of content and investigated their suitability to agricultural uses. In the materials, which contains in the majority wastes of oregano and cumin, moisture, pH, salt (EC), organic matter, organic C and C/N values were determined. Besides macro (N, P, K, Ca, Mg, and Na) and micronutrients (Fe, Cu, Zn, Mn, and B), heavy metals like Co, Cd, Cr, Pb and Ni contents were also obtained. Results were compared with the values of some other plant wastes. They found that the wastes could be used in agricultural soils after the composting process and to fit their effect on soil and plant growth, some vegetation experiments are needed.

According to Tunç & Ünlü (2005) the heavy metal contents and agricultural usage of sludge of drying beds from Elazığ Wastewater Treatment Plant were investigated. For this reason, heavy metal contents, the values of pH and organic matter of samples collected in the sludge drying beds and the final sludge collecting area were determined and evaluated according to Turkish Regulation of Solid Pollution Control. To determine the heavy metal concentrations, sludge were digested with nitric acid. In the result of analyses made, the heavy metal concentrations of sludge

were found in the range of 4000–9824.6 for Fe, 686.3–1674.4 for Zn, 157.5–656.3 for Mn, 13.3–167.5 for Cr, 107.6–550 for Cu, 31.10–126.67 for Ni, 31.80–84.81 for Pb, 0-15.07 for Co and 1.54–6.36 mg/kg dry sludge for Cd. These values were lower than standard values in Turkish Regulation of Solid Waste Control and Soil Pollution Control. However, the values of pH and organic matter in sludge were in the range of 6.82–7.62 and in the range of 40–74%, respectively.

CHAPTER TWO
CHARACTERIZATION OF THE SEWAGE SLUDGE

2.1 Sewage Sludge

Sewage sludge must be treated before its disposal or utilization. Characterization of sewage sludge is very important and it must be carefully characterized in order to make stabilization, dewatering and other processes effective and properly conducted. Various parameters and measurement values are used for characterization. The parameters are selected according to physical, chemical and biological features. Table 2.1 shows a survey of parameters. The list is a selection of the most common and interesting parameters but, because of the complex nature of sewage sludge, it cannot be complete.

Table 2.1 Survey of sludge characterization parameters (Kopp & Dichtl, 2002)

Parameter	Explanation	Process
1. Physical Features		
Solid content	Basic parameter - solid concentration	A - H
Volatile solid content	Basic parameter – organic solid concentration	A - H
Sludge index	Influences clarification and thickening	A
Conditioning	Demand of conditioning agents	C
Particle size	Description of solids	A,C,E
Capillary suction time	Dewatering test	C
Water distribution	Influences the dewatering result	C
Density	Influences the dewatering in centrifuges	C
Floc strength	Influences the dewatering in centrifuges	C
Resistance to filtration	Influences the dewatering in filters	C
Rheology/viscosity	Describes pumping processes	D
Shear stability	Describes stability of landfill polders	G
Heat value	Influences incineration processes	H
2. Chemical Features		
pH/alkalinity	Describes the stability of digestion	B
Fatty acids	Describes the stability of digestion	B
C,N,P concentration	Concentration of sludge and process water with C,N,P	E,F
Pollution level	Heavy metals, org. Hazardous substances	F,G
3. Biological Features		
Pathogenic features	Describes the hygienic aspects of sludge	F
Biological stability	Describes the biogas production	F,G
Bulking	Influences clarification and thickening	A

A : settlement properties, B : stabilization, C : conditioning and dewatering, D : pumping
E : return sludge liquor, F–H:disposa

2.2 Basic Parameters

The solids content, volatile solids content and type of sludge are important parameters for sludge characterization, particularly when sludge solids balances are to be calculated. Because of varying standards, it is often difficult to compare parameters and results. Therefore, it is necessary to relate the parameters to solids content of the sludge, especially when controlling sludge mass balances.

2.2.1 Total Solids

A large fraction of sludge is water. To determine the total solids (TS) content, the sample has to be dried at 105°C. Total solids can be divided into dissolved solids (DS) and suspended solids (SS), as well as into fixed solids (FS) and volatile solids (VS).

2.2.2 Suspended Solids

Suspended solids (SS) are defined as those solids captured on a filter. The term suspended solids is often used as a surrogate of active biomass and therefore is important in sludge stabilization.

2.2.3 Volatile Solids

Volatile solids (VS) generally describe the organic solids content. For measurement the dried sample will be burned at 550°C. This parameter is used for controlling stabilization and biogas production. The residues are inorganic minerals and sand.

2.2.4 Type of Sludge

Sludge characteristics depend on the waste water and the industrial influent and therefore they vary widely. The two most important sludges produced by municipal

treatment plants are primary sludge, which is drawn from the bottom of primary clarifiers, and waste – activated sludge, which is produced in the activated sludge system as excess biomass.

Primary sludge is readily biodegradable; the biogas production from digestion is high and its dewaterability is normally very good. The quality of the primary sludge depends on the waste water and the retention time in the pre-sedimentation tank. Biodegradability and dewaterability of waste – activated sludge strongly depend on the age of the sludge.

Other types of sludge, depending on the treatment plant, are trickling filter sludge (captured in secondary clarifiers in trickling filter plants) and chemical sludges, such as aluminum phosphate sludges, formed during chemical nutrient removal or tertiary treatments.

2.3 Physical Features

The main goal in physical processing is to increase the solids content and to decrease the volume of the sludge by removing water. They are settlement properties, conditioning and dewatering, rheology and viscosity, calorific value.

2.4 Chemical Features

The most important chemical parameters are pH, alkalinity, nutrients content and pollution level.

2.4.1 Process Parameters

Process parameters are primarily used for monitoring the sludge stabilization process and evaluating its digestibility.

2.4.1.1 pH and Alkalinity

In general the pH value of sewage sludge is neutral at 7.0. Digested sludge or sludge in the methanogenous phase shows a slightly alkaline pH value (7.0–7.5), while primary sludge or sludge in the acetogenous phase has a slightly acid pH value (6.0). The sludge pH is, therefore, a good indicator of digestion conditions, as long as there is no industrial contamination.

Because of the existence of various buffer systems, sewage sludge can neutralize certain amounts of added acids. The most important buffer system is the carbonate – hydrocarbonate buffer, which is often described as alkalinity in mg-$CaCO_3$/L. The carbonate– hydrocarbonate buffer system is connected to the ammonia – ammonium buffer system, which is very important for maintaining slightly alkaline conditions during methane fermentation and for the compensation of the volatile fatty acids generated during digestion. Alkalinity is therefore a better parameter than pH for monitoring anaerobic digestion.

2.4.1.2 Volatile Fatty Acids

As mentioned above, low molecular carbonic acids are generated as intermediate products during the digestion process. Concentrations of acetic acid and propionic acid are often used for the characterization of volatile fatty acids. High concentrations of propionic acid indicate an overload or a disturbance in the anaerobic digestion process. According to recent studies, however, the relation of volatile fatty acids to alkalinity is more important than the absolute quantity of volatile fatty acids. As long as alkalinity is several 100 mg-$CaCO_3$/L higher than the amount of volatile fatty acids, the anaerobic digestion process does not seem to be endangered.

2.4.2 Nutrients Content

Sewage sludge contains nutrients which is very important its agricultural use. Stabilized non-infected sewage sludge is characterized not only by its nutrient content, but also by its ability to reclaim soil. Land application of sewage sludge is limited. The criteria for the sludge quality are subject to the relevant legal regulations. Sewage sludges contain significant amounts of nitrogen and phosphorus but only small amounts of potassium. Table 2.2 shows the fertilizing value of 6000 analyzed sewage sludges.

Table 2.2 Survey on nutrients in sewage sludges (Teller *et al.* 1994)

Elements (g/kg-SS)	Min.	Max.	Average
N	0.1	246	38.4
P_2O_5	0.2	344	36.5
K_2O	0.1	95	4.2
MgO	0.1	122	9.7
CaO	0.1	727	73.7
SS (%)	0.1	100	12

2.4.3 Pollution Level

Sewage sludge contains organic and inorganic pollutants, for example heavy metals such as mercury, copper, cadmium and lead. For the agricultural use of sewage sludge, it is first of all important to consider its possible toxicity to plants and the potential health hazard due to transfer in the food chain. When using sewage sludge as a fertilizer or soil conditioner the maximum heavy metal concentrations are subject to legal regulations. Organic pollutants in sludge are often polychlorinated hydrocarbons, including dioxins (PCDD), furans (PCDF), polychlorinated phenyl benzenes (CB), surfactants and adsorbable organic halogen compounds (AOX).

2.5 Biological Features

In order to assess the biological processes, it is necessary to consider the degree of degradation involved, and the microbiological parameters in regard to hygienic aspects.

2.5.1 Biological Stability

When characterizing the biological stability of sewage sludge, it is most important to monitor the degradation of solids and evaluate the remaining bioactivity of the sludge to be disposes of.

2.5.2 Pathogenic Features

Primary sludge can contain all pathogenic organisms and worm eggs existent in human and animal faeces. Therefore, this type of sludge must be considered to be a possible health hazard. During digestion, pathogenic germs and worm eggs cannot breed or grow because they are weakened or killed depending on digestion time and temperature. When sludge is composted according to the rules it is almost disinfection can only be achieved by pasteurization at more than 70°C or by drying the sludge (Kopp & Dichtl, 2002).

CHAPTER THREE
COMPOSTING OF THE SOLID WASTES

3.1 Composting

Composting is the biological decomposition of organic matter under controlled aerobic conditions. In contrast, fermentation is the anaerobic decomposition of organic matter. Composting is a process in which organic material undergoes biological degradation to a stable end product. Sludge that has been composted properly is a nuisance – free, humus like material. Approximately 20 to 30 percent of the volatile solids are converted to carbon dioxide and water. As the organic material in the sludge decomposes, the compost heats to temperatures in the pasteurization range of 50 to 70°C (120 to 160°F), and enteric pathogenic organisms are destroyed. Properly composted biosolids may be used as soil conditioner in agricultural or horticultural applications, subject to any limitations based on the constituents in the composted biosolids. Although composting may be accomplished under anaerobic or aerobic conditions, essentially all municipal wastewater biosolids composting applications are under mostly aerobic conditions (composting is never completely aerobic). Aerobic composting accelerates material decomposition and result in the higher rise in temperature necessary for pathogen destruction. Aerobic composting also minimizes the potential for nuisance odors. The anticipated daily production of biosolids from a wastewater-treatment facility will have a pronounced effect on the alternate composting systems available for use, as will the availability of land for the construction of the composting facility. Other factors affecting the type of composting system are the nature of the biosolids produced; stabilization, if any, of the biosolids prior to composting; and the type of dewatering equipment and chemicals used. Biosolids that are stabilized by aerobic or anaerobic digestion prior to composting may result in reducing the size of the composting facilities by up to 40 percent (Tchobanoglous et al., 2003).

The basic composting process is depicted in Figure 3.1. The major factors affecting the decomposition of organic matter by microorganisms are oxygen and moisture. Temperature is an important factor in composting process; however,

temperature is the result of the microbial activity. Other important factors that could limit the composting process are nutrients and pH. Nutrients, especially carbon and nitrogen, play an important part in the process as they are essential for microbial growth and activity. Carbon is the principal source of energy, and nitrogen is needed for cell synthesis. Phosphorus and sulfur are also important, but less is known about their role in composting. Microorganisms require the same micronutrients as plants and compete for available micronutrients (Stevenson, 1991). Micronutrients such as Cu, Ni, Mo, Fe, Mg, Zn, and Na are necessary for enzymatic functions, but little is known about their importance to the composting process.

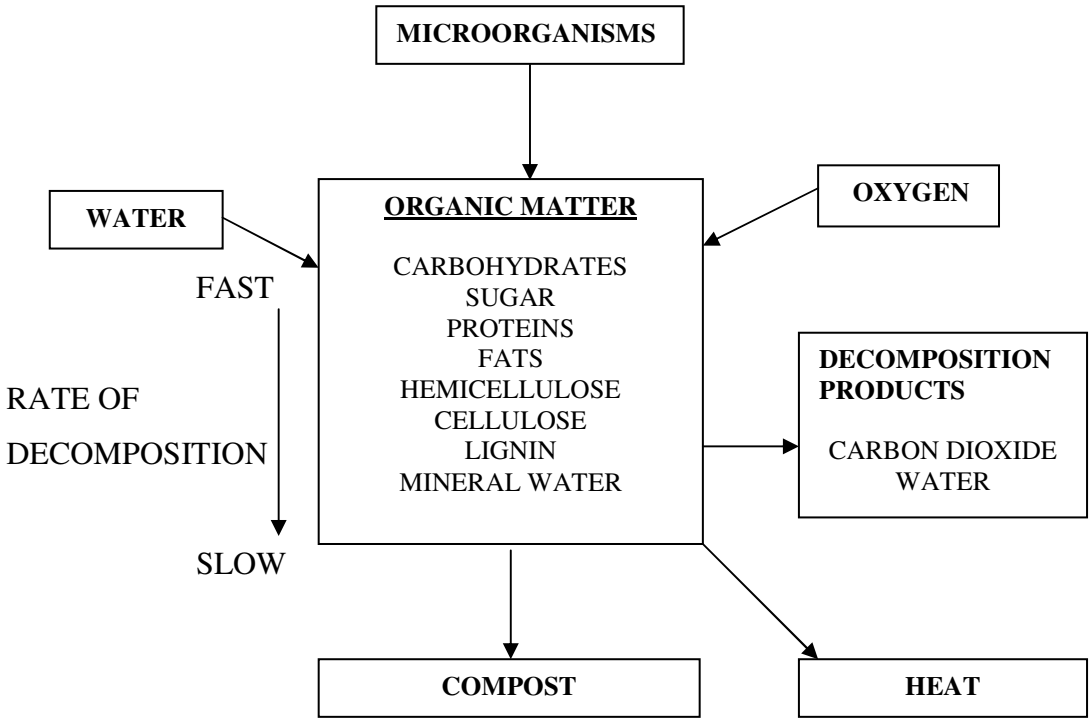

Figure 3.1 The composting process. (Epstein, 1997)

Most of the self–heating of organic matter is the result of microbial respiration (Finstein & Morris, 1975). That is, when the mass is insulated, the heat generated increases the temperature of the mass. An increase in temperature affects the microbial population through changes in mesophilic and thermophilic organisms, which in turn affects the rate of decomposition. Microbial respiration can therefore be used as an indicator of decomposition and the stability of a compost product.

During the process oxygen is consumed, and CO_2 and water are released. In the early days of composting, it was very time consuming or difficult to monitor CO_2 or O_2 continuously during large – scale composting. Consequently, most of the data in the literature are from small – scale or laboratory process.

In addition to CO_2, ammonia and other volatile compounds are emitted to the atmosphere. In comparison to CO_2 and H_2O these represent very small amounts, however. Wiley and Pierce (1955) represented the aerobic composting process in the following chemical equation 3.1:

$$\underset{\text{Organic matter}}{C_PH_qO_rN_s.aH_2O} + \underset{\text{oxygen consumed}}{bO_2} = \underset{\text{compost}}{C_tH_uO_vN_w.cH_2O} + \underset{\text{water evap.}}{dH_2O} + \underset{\text{water prod.}}{eH_2O} + \underset{\text{carbon dioxide prod.}}{CO_2} \quad (3.1)$$

(The small letter represents constants for different conditions.)

3.2 Process Microbiology

The composting process involves the complex destruction of organic material coupled with the production of humic acid to produce a stabilized end product. the microorganisms involved fall into three major categories : bacteria, actinomycetes, and fungi. Although the interrelationship of these microbial populations is not fully understood, bacterial activity appears to be responsible for the decomposition of proteins, lipids, and fats at thermophilic temperatures, as well as for much of the heat energy produced. Fungi and actinomycetes are also present at varying levels during the mesophilic and thermophilic stages of composting and appear to be responsible for the destruction of complex organics and the cellulose supplied in the form of amendment or bulking agents.

During the composting process, three separate stages of activity and associated temperatures are observed: mesophilic, thermophilic, and cooling. In the initial mesophilic stage, the temperature in the compost pile increases from ambient to approximately 40^oC with the appearance of fungi and acid producing bacteria. As

the temperature in the composting mass increases to the thermophilic range of 40 to 70°C, these microorganisms are replaced by thermophilic bacteria, actinomycetes, and thermophilic fungi. It is in the thermophilic temperature range that the maximum degradation and stabilization of organic material occur. The cooling stage is characterized by a reduction in microbial activity, and replacement of the thermophilic organisms with mesophilic bacteria and fungi. During the cooling period, further release of water from the composted material will occur, as well as stabilization of humic acid formation.

3.3 Process Description

Most composting operations consist of the following basic steps.

1. *Preprocessing, the mixing of dewatered sludge with an amendment and/or a bulking agent;*
2. *High – rate decomposition, aerating the compost pile either by addition of air, by mechanical turning, or by both;*
3. *Recovery of the bulking agent (at the end of either the high – rate decomposition or curing phase, if practicable);*
4. *Further curing and storage, which allows further stabilization and cooling of the compost;*
5. *Post processing, screening for the removal of non – biogradable material such as metals and plastics or grinding for size reduction,*
6. *Final disposition. A portion of the final product is sometimes recycled to the preprocessing step to aid in conditioning the compost mixture.*

The high rate decomposition stage of composting has been more engineered and controlled due to the need to reduce odors, supply high aeration rates, and maintain process control. The curing stage is often less engineered, less controlled, and given only small consideration in some designs. The curing stage is an integral part of the system design and operation, both stages need to be designed and operated properly to produce mature compost.

According to Tchobanoglous et al. (1993), the two principal methods of composting now in use in the United States may be classified as agitated or static. In the agitated method the material to be composted is agitated periodically to introduce oxygen, to control the temperature, and to mix the material to obtain a uniform product. In the static method, the material to be composted remains static and air is blown through the composting material. The most common agitated and static methods of composting are known as the windrow and static pile methods, respectively. Proprietary composting systems in which the composting operation is carried out in a reactor of some type are known as in–vessel composting systems.

An amendment is an organic material added to the feed substrate primarily to reduce the bulk weight, reduce moisture content, and increase the air voids for proper aeration. Amendments can also be used to increase the quantity of degradable organics in the mixture. Commonly used amendments are sawdust, straw, recycled compost, and rice hulls. A bulking agent is an organic or inorganic material that is used to provide structural support and to increase the porosity of the mixture for effective aeration. Wood chips are the most commonly used bulking agents and can be recovered and reused.

3.4 Design Considerations for Aerobic Sludge Composting Processes

3.4.1 Type of Sludge

Both untreated sludge and digested biosolids can be composted successfully. Untreated sludge has a greater potential for odors, particularly for windrow systems. Untreated sludge has more energy available, will degrade more readily, and has higher oxygen demand.

3.4.2 Amendments and Bulking Agents

Amendments and bulking agent characteristics (i.e., moisture content, particle size, and available carbon) affect the process and quality of product. Bulking agents should be readily available.

3.4.3 Carbon – Nitrogen (C/N) Ratio

The initial C/N ratio should be in the range of 20:1 to 35:1 by weight. At lower ratios, ammonia is given off. Carbon should be checked to ensure it is readily biodegradable. If C:N ratio lower than 25:1 than odor problem occurs.

The two most important nutrients are carbon and nitrogen. Few other inorganic chemical reactions have been studied. The C to N ratios during composting affects the process and the product. As indicated earlier, the important parameter is the carbon available to microorganisms, not the total carbon in the material. During microbial growth, approximately 25 to 30 parts of C are needed for every unit of N (Gotass, 1956; Waksman, 1938). Carbon is provided to the microbial community from decomposing plants and wastes from animals and humans. The C is utilized for cellular growth. Some of the microbial biomass returns C to the cycle. During microbial activity, respiratory CO_2 *is evolved and emitted to the atmosphere. The readily available C utilized initially. As the composting process continues, however, the rate of* CO_2 *evolution decreases as result of decreased metabolic activity and the decrease of available carbon.*

Microorganisms needed N for protein synthesis. Bacteria may contain 7% to 11% N on dry weight basis and fungi from 4% to 6% (Anderson, 1956). The amount of N in a waste varies with the type of waste. For example, food wastes and biosolids have higher N content than yard waste. Microorganisms utilized C and N at ratio of 30:1. Low C/N ratios in feedstock result in nitrogen volatilization in the form of ammonia. This is particularly true under alkaline conditions. The imbalance of C/N is illustrated by problem encountered by many facilities that receive large volumes of

grass in the summer and do not have a sufficient carbon source to offset the low C/N ratio. Anaerobic or partially aerobic conditions can result in ammonia release to the atmosphere (Knuth, 1970). The loss of N reduces the value of compost as a fertilizer.

According to Bishop & Godfrey (1983), at C/N ratios exceeding 50:1, the composting process slows because of rapid cell growth and depletion of available N, resulting in reduced cellular growth. As cells die, their stored N becomes available to living cells.

3.4.4 Volatile Solids

The volatile solids of the composting mix should be greater than 30 percent of the total solids content. Dewatered sludge will usually require an amendment or bulking agent to adjust the solids content.

3.4.5 Air Requirements

O_2 is required for metabolisms and respiration of aerobic microorganism and oxidation of organic molecules in the waste. Initial in the compost pile O_2 is 15-20%, and CO_2 is 0.5 – 5. O_2 goes down and CO_2 goes up when biological activity progresses. If O_2<5% than regional anaerobic conditions occur so aeration is considered important. O_2 inside the pile is 6 – 16 %, and outside the pile 20 % at compost plant which works well.

Air with at least 50 percent of the oxygen remaining should reach all parts of the composting material for optimum results, especially in mechanical systems. Oxygen is essential for the microbial activity in composting since it is an aerobic process. Three principal aeration methods provide O_2 during composting; physical turning of the mass, convective air flow, and mechanical aeration. Windrow methods use the former two ways, whereas static systems provide O_2 by using blowers or through convective air flow. The latter, often called passive aeration is highly dependent on the porosity of the matrix.

3.4.6 Moisture Content

Moisture is one of the limiting factors in composting processes. Dominant species and their growth abilities depend on the relative humidities. Bacteria can be multiply at relative humidities of 100%, whereas fungi grow at lower humidities. Thus, moisture enhances the activity of some species and inhibits others at the same time. In general, at moisture contents below 40% the microbial activity diminishes and degradation capacity of microbial population ceases. At moisture levels over 60%, water that fills the pores prevent oxygen transfer in the compost mass and as oxygen is depleted the aerobic conditions can no longer be dominant. Aerobic species and their activities depend on the oxygen provided during process (Epstein, 1997).

Moisture in the composting process can affect microbial activity and thus influence temperature and rate of composition. In addition, moisture can affect the composition of the microbial population. Moisture is produced as a result of microbial activity and the biological oxidation of organic matter. In addition water is lost through evaporation.

Moisture content of the composting mixture should be not greater than 60 percent for static pile and windrow composting and not greater than 65 percent for in – vessel composting. Moisture of compost evaluates as Table 3.1:

Table 3.1 Moisture of compost evaluates *(Epstein, 1997)*

Moisture; (%)	**Evaluation**
40 – 70 %	optimal aerobic digestion
< 30 %	bacterial activity is prevented
> 65 %	process of breaking down slows down

3.4.7 pH Control

pH is a common measure of alkalinity or acidity. The pH value of composting material drops in association with the acid formation at the early stages of composting due to the simple organic acids produced at the initial phase of decomposition as a result of fermentative activity carried on. Organic acids synthesized serve as substrate for microorganisms while decreasing the pH. The subsequent rise afterwards is the indication of acid utilization. Buffering is not necessary and could even have adverse consequences. With the progression of degradation alkaline characteristics in pH dominate as proteins are attacked an ammonia is releases. Highly alkaline conditions will lead to excessive loss of nitrogen as ammonia whereas highly acidic initial conditions may lead to failure in the warming up of the matrix. Proper adjustments in feed preparation leads to controlled pH values. Nakasaki et al. (1993) concluded that the degradation rate of organic matter in the pH–controlled experiments was faster than that without. Nitrogen loss was enhanced by the control of pH value. High pH values indicate that anaerobic conditions are present and followed by odors and toxic by-products. On the other hand, pH value lower than 5 leads to increase in the metal solubility and corrosion in the equipments used. The pH value indicates the type and intensity of microbial activity and the corrosiveness of the composting material.

pH of the composting mixture should generally be in the range of 6 to 9. To achieve optimum aerobic decomposition, pH should remain in the 7 to 7.5 range.

3.4.8 Temperature

Temperature plays a major role in the composting process. At the same time, it is also a function of the process. Probably the most important aspect of temperature is its impact on the microbiological community. Thus, other vital reaction and elements of the composting process are affected and change with temperature. Temperature also affects the moisture relationships, which in turn affect microbiological activity.

The interaction between various parameters and temperature often makes it difficult to separate cause and effect.

For best results, temperature should be maintained between 50 and 55° C for the first few days and between 55 and 60° C for the remainder of the active composting period. If the temperature is allowed to increase beyond 65°C for a significant period of time, biological activity will be reduced.

3.4.9 Mixing and Turning

To prevent drying, caking, and air channeling, material in the process of being composted should be mixed or turned on a regular schedule or as required. Frequency of mixing or turning will depend on the type of composting operation.

3.4.10 Heavy Metals and Trace Organics

Heavy metals and trace organics in the sludge and finished compost should be monitored to ensure that the concentrations do not exceed the applicable regulations for end use of the product.

3.4.11 Site Constraints

Factors to be considered in selecting a site include available area, access, proximity to treatment plant and other land uses, climatic conditions, and availability of buffer zone.

3.4.12 Control of Pathogens

If properly conducted, it is possible to kill all pathogens, weeds, and seeds during the composting process. To achieve this level of control, the temperature must be maintained between 60 and 70° C for 24 hours. Temperatures and times of exposure

required for the destruction of common pathogens and parasites are shown in Table 3.2.

Table 3.2 Temperatures and times of exposure required for the destruction of common pathogens and parasites (Tchobanoglous et al.; 1993):

Organism	**Observations**
Salmonella typhosa	No growth beyond 46°C; death within 30 min at 55–60°C and within 20 min at 60°C; destroyed in a short time in compost environment.
Salmonella sp.	Death within 1 h at 55°C and within 15 – 20 min at 60°C
Shigella sp.	Death within 1 h at 55°C
Escherichia coli	Most die within 1 h at 55°C and within 15 – 20 min at 60°C
Entamoeba histolytica cysts	Death within a few minutes at 45°C and within a few seconds at 55°C
Taenia saginata	Death within a few minutes at 55°C
Trichinella spiralis larvae	Quickly killed at 55°C; instantly killed at 60°C
Brucella abortus or Br. Suis	Death within 3 min at 62 – 63 °C and within 1 h at 55°C
Micrococcus pyogenes var. aureus	Death within 10 min at 50°C
Streptococcus pyogenes	Death within 10 min at 54°C
Mycobacterium tuberculosis var. hominis	Death within 15–20 min at 66°C or after momentary heating at 67°C
Corynebacterium diphtheria	Death within 45 minutes at 55°C
Necator americanus	Death within 50 minutes at 45°C
Ascaris lumbricoides eggs	Death in less than 1 h at temperatures over 50°C

3.5 Operation and Performance Parameters

Commonly used operational parameters include these eight: oxygen uptake, temperature, moisture content, pH, odor, color, destruction of volatile matter, and stability. With respect to the first four, the distinction between their status as environmental factor and that as operational parameter is very difficult to define because the two overlap in that operational parameters evolve from environmental factors.

3.5.1 Oxygen Uptake

Oxygen uptake is a very useful parameter, because it is a direct manifestation of oxygen consumption by the microbial population and, hence, of microbial activity. Microbes use oxygen to obtain the energy to carry on their activities.

A very effective means of monitoring for adequacy of oxygen supply is by way of the olfactory sense, namely, detection of odors. The emanation of putrefactive odors from a composting mass is a positive indication of anaerobiosis. The intensity of the odors is an indication of the extent of anaerobiosis. Attempts to measure odoriferous constituents (e.g. H_2S) have been only indifferently successful. Because of their anaerobic origin, the malodors soon decrease after aeration is intensified. Although reliance upon the detection of objectionable odors may seem to be rather primitive, nevertheless it is a useful supplement in routine monitoring. It does have the disadvantage of being an "after – the fact" indicator. Therefore, in operations in which an oxygen probe can be used or the oxygen of input and output airstreams can be measured, a direct monitoring of oxygen is advisable.

An important operational consideration is that although the input air stream may be sufficiently great to meet the theoretical microbial oxygen demand and the discharge air stream may contain some oxygen, localized anaerobic zones may be present. The zones may be due to inadequate mixing or to short-circuiting of air through the mass. In practice, the complete prevention or elimination of these zones would be economically, if not technologically, unfeasible. Fortunately, the complete elimination is not essential for a nuisance-free operation, provided the number and size of the zones does not become excessively large.

According to Diaz et al. (1982), four generalizations can be made, despite the many uncertainties mentioned or implied in the preceding paragraphs. The generalizations are:

1. *An oxygen pressure greater than 14 percent of the total indicates that not more than one-third of the oxygen in the air has been consumed.*
2. *The optimum oxygen level is 14 to 17 percent.*
3. *Aerobic composting supposedly ceases if the oxygen concentration drops to 10 percent.*
4. *If CO_2 concentration in the exhaust gas is used as a parameter for oxygen concentration, then the CO_2 in the exhaust gas should be between 3 and 6 percent by volume.*

3.5.2 Temperature

Temperature is a very useful parameter because it is a direct indicator of microbial activity. However, in the application of temperature as an operational parameter, it must be remembered that in a practical operation, the desired temperature range should include thermophilic temperatures. The reasons are: (1) some of the organisms involved in the process have their optimum level in the thermophilic range; (2) weed seeds and most microbes of pathogen significance cannot survive exposure to thermophilic temperatures; and (3) unless definite countermeasures are taken, thermophilic levels will be reached during the active stage.

In general, any abrupt and unexplained deviation from the normal course of temperature rise and fall is an indication of an environmental or operational deficiency that requires attention. An exception to this general rule is the need to prevent the temperature from exceeding 55 to 60°C (i.e., reaching a level that is inhibitory to most microbes). Probably the most effective remedial measure is ventilation.

3.5.3 Moisture

The numerical value of the operational parameter, moisture, is the maximum permissible moisture content. As stated earlier, this value varies from substrate to substrate. Regardless of substrate, the lowest permissible moisture content for efficient composting is about 45 percent. Unfavorably low moisture content is a common problem in compost practice, because conditions in a composting mass are conducive to evaporation (i.e., water loss). Unless this water is replaced, moisture is likely to become limiting.

3.5.4 pH

Unless the substrate is unusually acidic, which rarely is the case with Municipal Solid Waste, pH level has little value as an operational parameter. If the pH level is lower than 4.5, some buffering may be indicated (e.g., adding lime).

3.5.5 Odor

Odor as an operational parameter received some attention in the discussion of aeration. Attempts to develop a quantitative standard for odor, based on hydrogen sulfide concentration, have met with little if any success, because the olfactory nerve senses H_2S concentrations lower than the detection of H_2S analytical tests. In waste treatment practice, all odors are regarded as being objectionable to the public.

3.5.6 Color

Although the color of the composting mass progressively darkness, it is a crude parameter and at best is roughly qualitative and highly subjective.

3.5.7 Destruction of Volatile Solids

In as much as composting is a decomposition process, it is characterized by some destruction of volatile solids. Complete destruction is neither desirable nor necessary because the value of the compost product, particularly as a soil conditioner, is mostly due to its volatile (i.e., organic) solids content. Hence, rate rather than extent of destruction would be the useful parameter. The problem is in the establishment of a standard rate. Rates vary with several important factors. The best indicator that is presently available is to the effect that volatile matter is being destroyed.

3.5.8 Stability

"Stability" is a broad term that may refer to chemical and physical stability and/or to biological stability. As applied in composting, the composting mass is judged "stable" when it has reached a state of decomposition at which it can be stored without giving rise to health or nuisance problems. This excludes the temporary stability due to dehydration or other condition that inhibits microbial activity. Despite many claims to the contrary, a satisfactory quantitative method for determining degree of stability has yet to be developed, at least one that can be used as a "universally" applicable standard.

The search for a method of determining stability that can be sufficiently standardized is almost as old as the compost practice. The list of proposed methods is correspondingly lengthy. It includes final drop in temperature, degree of self-heating capacity, amount of decomposable and resistant organic matter in the material, rise in the redox potential, oxygen uptake, growth response of the fungus Chaetolnium gracillis, and the starch test. Of this array of tests, the final drop in temperature is the most reliable, because it is a direct consequence of the entire microbial activity, as well as of the intensity of the activity. The weakness of temperature decline as a parameter is its time element. Because the decline represents a trend, it involves a succession of readings taken over a period of days. The other tests lack the necessary universality. For example, a redox potential that

characterizes stability under one set of compost conditions does not necessarily do so under another set. With certain tests, lack of universality is aggravated by the difficulty of conducting them (e.g., the Chaetomium test).

Phytoxicity frequently is regarded as being an indication of stability, although it is true that in the early stages of maturation, composting material often contains a substance that is inhibitory to plants (phytoxic), and which almost invariably disappears as maturation progresses. However, the disappearance does not always coincide with the attainment of the required degree of stability.

3.6 Composting Systems

In general, three types of composting operation systems employed in sludge stabilization. They include (1) the aerated static pile, (2) the windrow process, and (3) the mechanical in-vessel systems. Each system varies in operational complexity and therefore has unique advantages and disadvantages. The final decision about this system to employ depends on available land area, purchase price

3.6.1 Aerated Static Pile

The aerated static pile system consists of a grid of aeration or exhaust piping over which a mixture of dewatered sludge and bulking agent is placed as Figure 3.2. In a typical static pile system, the bulking agent consists of wood chips, which are mixed with the dewatered sludge by a pug – mill type or rotating – drum mixer or by movable equipment such as a front – end loader. Material is composted for 21 to 28 days and is typically followed by a curing period of 30 days or longer. Typical pile heights are about 2 to 2.5 m. A layer of screened compost is often placed on top of the pile for insulation. Disposable corrugated plastic drainage pipe is commonly used for air supply and each individual pile is recommended to have an individual blower for more effective aeration control (Tchobanoglous et al 2003).

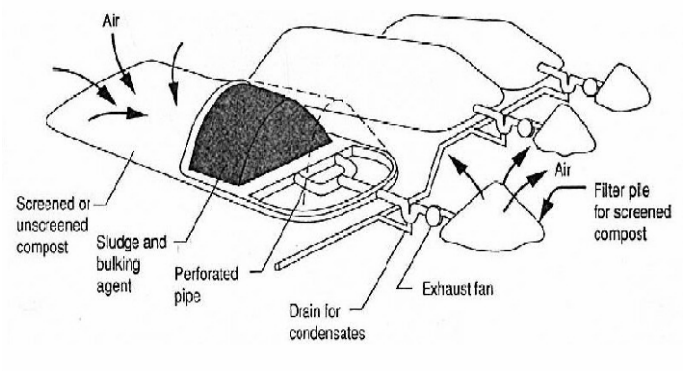

Figure 3.2 Aerated Static Piles

3.6.2 Windrow

In a windrow system, the mixing and screening operations are similar to those for the aerated static pile operation. Windrows are constructed from 1 to 2 m high and 2 to 4.5 m at the base. The rows are turned and mixed periodically during the composting period. Supplemental mechanical aeration is used in some applications. The composting period is about 21 to 28 days. Under typical operating conditions, the windrows are turned a minimum of five times while the temperature is maintained at or above 55°C. In windrow composting, aerobic conditions are difficult to maintain throughout the cross-sectional area of the windrow. Thus, the microbial activity within the pile may be aerobic, facultative, anaerobic, or various combinations thereof, depending on when and how often the pile is turned. Turning of the windrows is often accompanied by the release of offensive odors. The release of odors occurs typically when anaerobic conditions develop within the windrow. Specialized equipment is available to mix the sludge and bulking agent and turn the composting windrows as Figure 3.3. Some windrow operations are covered or enclosed, similar to aerated static piles. (Tchobanoglous et al 2003)

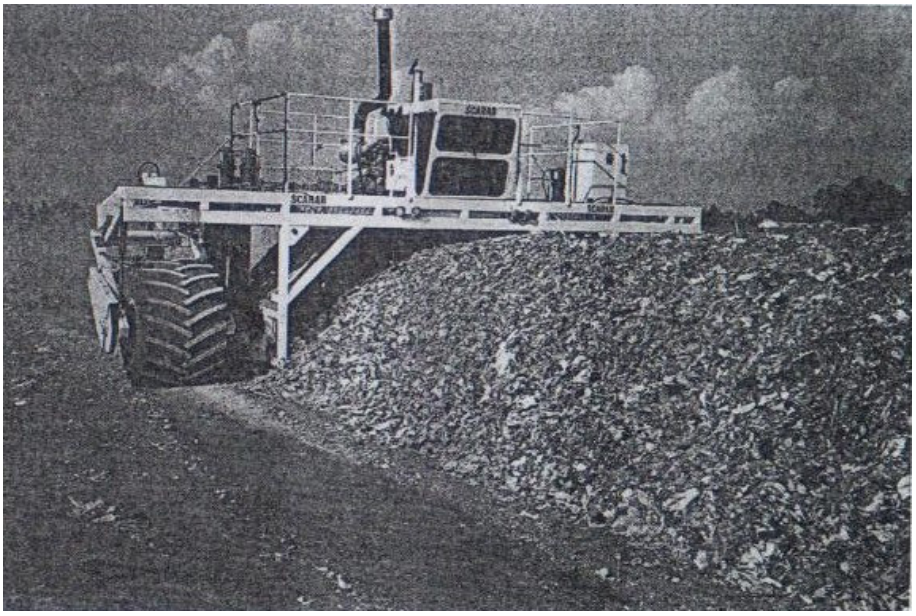

Figure 3.3 Compost Windrow Systems

3.6.3 In – Vessel Composting Systems

In – vessel composting is accomplished inside an enclosed container or vessel. Mechanical systems are designed to minimize odors and process time by controlling environmental conditions such as air flow, temperature, and oxygen concentration. The advantages of in vessel composting systems are better process and odor control, faster throughput, lower labor costs, and smaller area requirement. In – vessel composting systems can be divided into two major categories: plug flow and dynamic (agitated bed). In plug flow systems, the relationship between particles in the composting mass stays the same throughout the process, and the system operates on the basis of a first in, first out principle. In a dynamic system, the composting material is mechanically mixed during the processing. In vessel systems can be further categorized based on the geometric shape of the vessels or containers used. Examples of plug – flow reactors are shown on Figure 3.4, and examples of dynamic type systems are illustrated on Figure 3.5.

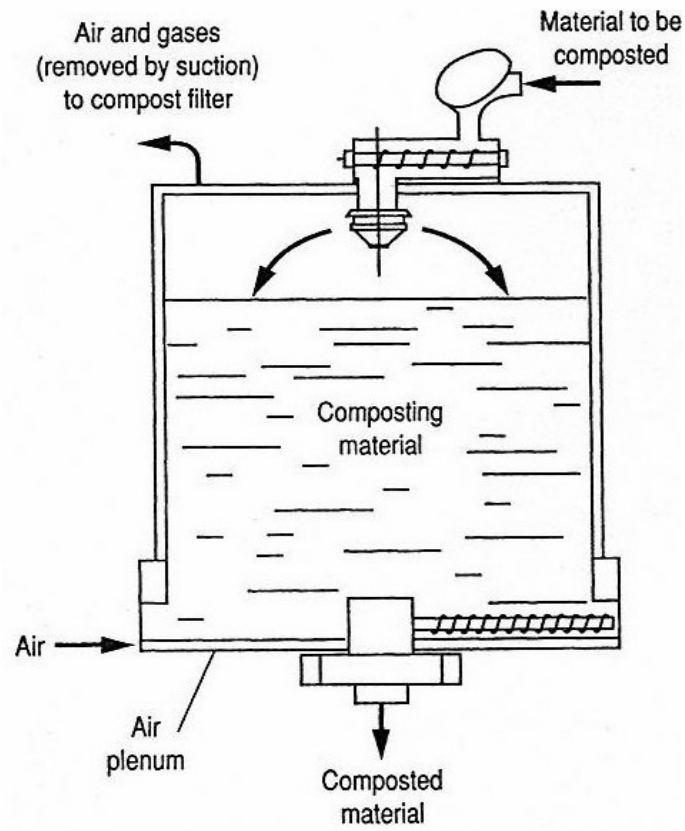

Figure 3.4 Plug – Flow in Vessel Composting Reactor

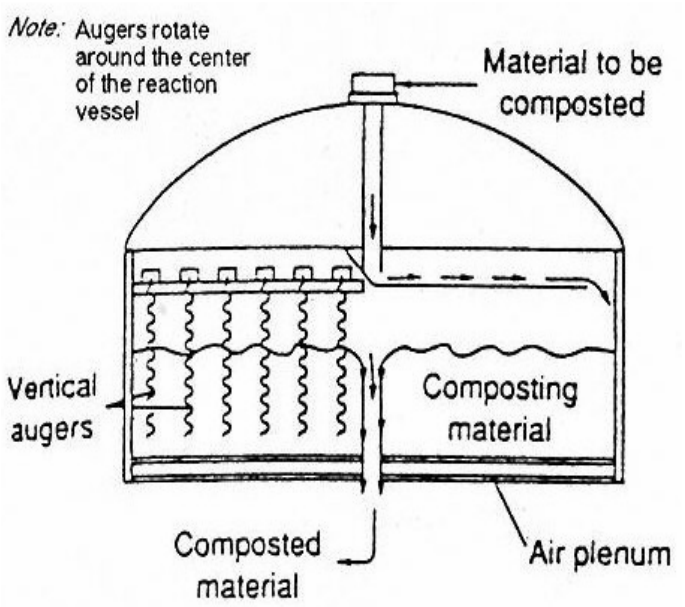

Figure 3.4 Dynamic (Mixed) in Vessel Composting Reactor

3.7 Co-Composting with Municipal Solid Wastes

Co-composting of sludge and municipal solid wastes is a possible alternative where integrated waste disposal facilities are considered. Mixing the sludge with the organic fraction of municipal solid waste or source separated yard wastes is beneficial because:

1. *Sludge dewatering may not be required,*
2. *The overall metals content of the composted material will be less than that of the composted sludge alone.*

Liquid treatment plant sludges typically have a solids content ranging from 3 to 8 percent. A 2 to 1 mixture of compostable municipal solid or yard wastes to sludge is recommended as a minimum. Both static and agitated compost systems have been tried (Tchobanoglous et al., 1993).

CHAPTER FOUR
MATERIAL AND METHOD

4.1 Composting Ingredients

Dewatered sewage sludge were taken from İzmir–Çiğli Waste Water Treatment Plant from belt – press outlet, semi fermented solid wastes were taken from İzmir – Uzundere Compost Plant and grass cuttings from university gardens were used in this study to make a final product as a compost for using in agricultural.

4.1.1 Sewage Sludge

In İzmir – Çiğli Wastewater Treatment Plant, 12000 m^3 sludge is produced and processed per day. After mechanical dewatering process, the amount of sludge decreases to 600 m^3. Annual sludge production is approximately 43800 tons (dry weight) when provided the sludge contain 20% dry matters.

Due to could inefficient stabilization of sludge by lime as dewatering process in this plant, in Spring and Summer seasons odor problems occur. As a temporary solution, a soil layer of 40 – 50 cm is covered over the sludge heap to prevent odor problems as well as preventing the increasing environmental complaints. Chemical characterizations of the sewage sludge is shown in Table 4.1

Table 4.1 Characterization of the sewage sludge, (Seyman et all. May, 2005)

Parameters	Values (mg/kg)	Parameters	Values (mg/kg)
Total-N	38636	B	36
Total-P	5600	Cd	1.5
Fe	123300	Cr	150
Mn	1245	Ni	45
Cu	202	Pb	94
Zn	1312	Mo	4.7
Al	111700	Co	4.3

The amounts of Fe and Al in the sewage sludge are very high with a value of 12.33% for Fe and 11.17% for Al. The composition of Fe and Al in sewage sludge is given in Table 4.2. The Fe and Al results in Table 4.1 are given by Seyman et al. (2005) are thought to be a relatively higher values according to our findings and according to previous studies (Sabey, 1980).

Table 4.2 The composition of Fe and Al in sewage sludge (Sabey, 1980)

	Concentration (%)		
	Min	**Max**	**Median**
Fe	< 0.10	15.3	1.1
Al	0.10	13.5	0.4

4.1.2 Semi Fermented Solid Waste

Semi fermented solid waste (raw compost) was taken from İzmir – Uzundere Compost Plant. Characterization of the semi fermented solid waste is shown in Table 4.3

Table 4.3 Characterization of the semi fermented solid waste (A descriptive brochure of İzmir Uzundere Compost Plant)

Parameters		**Values**	**Parameters**		**Values**
pH		7.5	Total Mg	%	0.45
Total Salinity	%	0.54	Total Na		0.54
Org. Matter		30.44	Total Fe		1.10
Total N		1.18	Total Zn	ppm	540
Total P		0.41	Total Mn		238
Total K		1.08	Total Cu		250
Total Ca		4.35	Total B		70

4.1.3 Grass Cuttings

In İzmir City, there is green recreation area of 500 ha. Maintenance of the green area has been carried out by İzmir City's Town Hall Directorate of Park and Gardens. Grasses are cut two times in a month in May, June, July, August and September and once in the other months. 50 trucks (600 m^3) grass are collected after each cutting process (Seyman, et al, 2005). In this study, the grasses in the university campus area are harvested for using a waste material to make compost.

4.2 Experimental Research

4.2.1 Composting at the Static Pile (Experiment 1)

In this study, four different piles were constituted. Semi fermented solid waste and sewage sludge were mixed in different ratios by weights. The static piles were mixed three times in a week for aeration. Amount of the mixing ratio is shown in Table 4.4 and a picture of the static pile is shown in Figure 4.1.

Table 4.4 Amount of the mixing ratio in the static piles

The Piles	**Composition of the Solid Waste**		**Amount of Solid Waste, (kg)**
Pile 1	Sewage Sludge	33.3 %	6
	Semi Fermented SW	66.7 %	12
Pile 2	Sewage Sludge	25 %	4
	Semi Fermented SW	75%	12
Pile 3	Sewage Sludge	50 %	7
	Semi Fermented SW	50 %	7
Pile 4	Sewage Sludge	100%	8

Figure 4.1 Static Pile

4.2.2 Composting at the Barrels (Experiment 2)

Sewage sludge, semi fermented solid waste and grass cutting were used for this study. They were mixed in different ratios as volumetric. Three different piles were constituted. Barrels' height was 50 cm and diameter was 25 cm. Amount of the mixing ratio is shown in Table 4.5, and a picture of the barrels is shown in Figure 4.2 and a picture showing the raw compost, sewage sludge and green waste mixture is shown in Figure 4.3.

Table 4.5 Amount of the mixing ratio in the barrels in Experiment 2

The Piles	**Composition of the Solid Waste**		**Amount of Solid Waste, (volumetric)**
Pile 1	Sewage Sludge Semi Fermented SW Grass Cutting	33.3 % 33.3 % 33.3 %	1:1:1
Pile 2	Sewage Sludge Semi Fermented SW Grass Cutting	25 % 25 % 50 %	1:1:2
Pile 3	Sewage Sludge Semi Fermented SW Grass Cutting	20 % 20 % 60 %	1:1:3
Pile 4	Sewage Sludge	100%	15(kg)

4.2.3 Composting at the Barrels (Experiment 3)

Four different piles were constituted in this study. Sewage sludge and semi fermented solid waste were mixed in different ratios in weight. Composition of the mixing is shown in Table 4.6. A picture of mixed raw compost and sewage sludge is also shown in Figure 4.4.

Table 4.6 Composition of the mixing in Experiment 3

The Piles	**Composition of the Solid Waste**		**Amount of Solid Waste, (kg)**
Pile 1	Sewage Sludge	25 %	5
	Semi Fermented SW	75 %	15
Pile 2	Sewage Sludge	33.3 %	7
	Semi Fermented SW	67.7 %	14
Pile 3	Sewage Sludge	50 %	10
	Semi Fermented SW	50 %	10
Pile 4	Sewage Sludge	100 %	15

Figure 4.2 The picture of the barrels

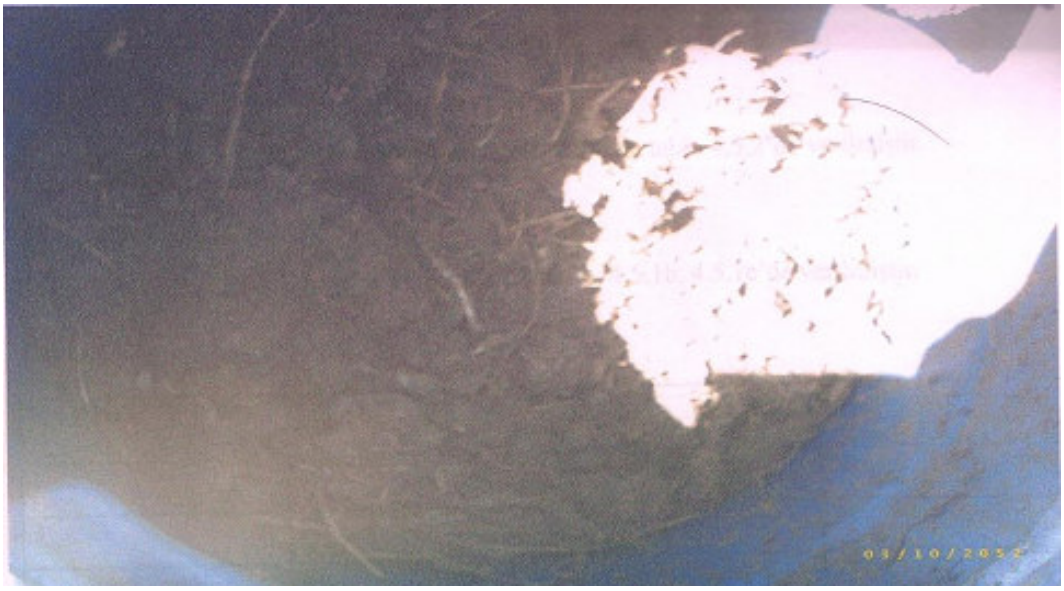

Figure 4.3 Picture which is mixing of the semi fermented solid waste, sludge and grass cuttings

Figure 4.4 The picture of mixed semi fermented solid waste and sludge

4.3 Experimental Methods

4.3.1 Moisture

Due to difference between vapor pressures of liquid and solid materials, moisture content is directly related to the total loss of weight a sample is dried at 65°C. (Kacar, 1972). Sample was dried at 65°C because Volatile Solids (VS) must not leave.

4.3.2 Temperature

Temperature was measured periodically by thermometer.

4.3.3 pH

10 gr of dry sample was mixed 100 mL of distilled water and shaked for an hour. After than it was waited for its settling. The pH value of the previously homogenized samples were measured and recorded at every sample by using pH meter (Kacar, 1995).

4.3.4 Organic Carbon

Samples were determined by loss ignition. Empirical carbon content was used in the calculation which is given in equation 4.1.

$$C(\%) = VS(\%)/a \tag{4.1}$$

Where

C = Carbon content,

a = Coefficient of carbon content with respect to the volatile solids (1.72) (Kacar, 1995).

4.3.5 Total Nitrogen

Nitrogen was measured as Total Kjeldahl Nitrogen by wet digestion. (Kacar, 1972)

4.3.6 Primary (P, K), and Secondary Plant Nutrients (Fe, Cu, Zn, Mn), and Heavy Metals (Cr, Ni)

Samples were prepared by wet digestion procedure. P was analyzed with Spectrophotometer, K, Fe, Cu, Zn, Mn, Cr, Ni were analyzed by ICP (Kacar, 1972, and 1995; APHA, 1998).

CHAPTER FIVE
RESULTS AND DISCUSSION

5.1 Experiment 1

The duration of the Experiment 1 was 33 days. Moisture, temperature, pH, and organic carbon were determined during the experiment, and total nitrogen, primary (P, K), and secondary (Fe, Cu, Zn, Mn) plant nutrients and heavy metals (Cr, Ni) were determined at beginning and end of the experiment. .

5.1.1 Moisture

Table 5.1 Moisture contents change during the Experiment 1

	Moisture, (%)			
Days	**Pile 1**	**Pile 2**	**Pile 3**	**Pile 4**
1	55	44	55	82
3	46	43	55	82
5	43	39	54	80
7	46	50	38	81
9	42	41	51	80
11	42	38	49	78
13	38	34	48	76
15	38	35	45	78
17	38	35	45	79
19	39	44	31	76
21	38	32	44	75
23	36	31	44	77
25	35	29	43	77
27	36	31	47	78
29	36	31	41	74
31	33	27	35	72
33	33	27	33	70

Table 5.1 shows the moisture during the composting process. Results revealed that initial ratio of moisture changed between 44 – 82 %. The moisture level decreased to 27 – 70 % at end of the experiment. The moisture losses in the piles 40, 39, 40 and 15 % respectively. Moisture losses can be attributed to open air piles and evaporation. According to Epstein (1997), ideal moisture rates are 40 – 70 % in the

compost materials due to the optimal aerobic digestion occurrence in these ranges. Because if moisture rate is lower than 30%, bacterial activity is prevented. On the other hand, when moisture is greater than 65%, the breaking down process slows. If the above cited informations taken into account, the optimal aerobic digestion occurred in all Piles except Pile 4 which included only sludge.

5.1.2 Temperature

Table 5.2 Results of the temperature for Experiment 1

	Temperature, (^oC)				
Days	**Pile 1**	**Pile 2**	**Pile 3**	**Pile 4**	**Air**
1	20	18	19	16	7
3	22	22	21	21	7
5	16	16	16	16	9
7	15	15	15	16	14
9	15	15	15	16	18
11	18	17	17	17	23
13	19	19	19	18	25
15	19	17	17	17	12
17	20	19	19	19	17
19	17	17	18	18	18
21	20	20	20	19	17
23	22	21	23	19	16
25	26	25	26	26	15
27	23	24	22	21	21
29	22	23	20	19	21
31	20	21	21	19	16
33	20	22	20	18	18

Results of the temperature are given in Table 5.2. Temperature plays a major role in the composting process. Temperature is a major function of composting process because its impact on the microbiological community is strong. Epstein (1997) suggests to maintenance the temperature change during composting between 50 - 55^oC for ideal fermentation. The initial temperature values changed in the range of 16 – 20^oC in the Experiment1. The highest value was 26^oC during the composting process in all Piles except Pile 2 at 25th day. Final temperatures were measured as 20 – 22 – 20 and 18^oC respectively. Consequently temperature did not increase significantly. Despite the fact that it was desired to reach in the range of 50 to 60 ^oC

in the first week during the process. The results could be associated to the uncovered situation of piles and to the semi fermented raw compost materials used in composting.

5.1.3 pH

pH were measured during the composting process are given in Table 5.3. pH values varied between 6.48 and 7.63 at the beginning of the experiment. The lowest value was 6.67 in Pile 1 and the highest was 7.26. pH values of the others piles (2, 3 and 4) were in the ranges of 6.80 to 7.63; 6.87 to 7.63; 6.42 to 7.31 respectively. At the end of the experiment final pH values were measured as 7.24; 7.20; 7.29 and 7.25 respectively. pH is a parameter which affects greatly the composting process.

Table 5.3 Results of the pH for Experiment 1

	pH			
Days	**Pile 1**	**Pile 2**	**Pile 3**	**Pile 4**
1	7.26	7.63	7.36	6.48
3	7.02	7.50	7.15	6.51
5	6.87	7.24	7.04	6.57
7	6.98	7.37	7.14	6.42
9	7.07	7.20	7.29	6.74
11	6.86	7.26	7.11	6.54
13	6.92	7.20	7.10	6.57
15	6.79	7.17	7.12	6.60
17	6.92	7.16	7.10	6.65
19	6.85	7.02	7.13	7.12
21	6.67	6.80	7.14	7.15
23	7.34	7.38	6.87	7.31
25	7.25	7.10	7.17	7.15
27	7.06	6.87	6.90	7.10
29	7.25	7.13	7.27	7.24
31	7.20	7.15	7.25	7.22
33	7.24	7.20	7.29	7.25

Kapetanios et al. (1993) researched that, the optimum pH values are 6 – 7.5 for bacterial development, while fungi prefers an environment in the range of 5.5 – 8.0. Composting process is controlled by many factors which include temperature, aeration, particle size, characteristics of raw material, moisture, time and etc. in this

regard, temperature and pH are generally closely associated to the break down of raw materials. No significant variations in the pH of the piles can be related to the temperature which did not rise enough as mentioned above.

5.1.4 Organic Carbon, (%)

Results of the Organic Carbon (Org – C) are given in Table 5.4. Initial Organic Carbon were measured as 32 – 35 – 25 and 20% respectively for four different Piles. Organic Carbon decreased during the composting process. Final results of Organic Carbon in the piles were 25, 30, 21 and 16% respectively. The declines in the Organic Carbon content are a common phenomenon. Hence, the characteristics of the raw materials and their method fermentation strongly affect the process. as a result, the degree of decrease indicates a fully aging.

Table 5.4 Results of the Organic Carbon (Org – C) for Experiment 1

	Organic Carbon, (%)			
Days	**Pile 1**	**Pile 2**	**Pile 3**	**Pile 4**
1	32	35	25	20
3	32	35	25	20
5	31	34	24	20
7	30	34	24	18
9	29	33	23	19
11	30	34	24	18
13	30	32	23	18
15	29	33	22	19
17	29	32	23	17
19	28	31	21	18
21	27	30	21	19
23	28	31	22	19
25	26	30	21	18
27	26	29	23	17
29	25	29	24	17
31	26	30	23	15
33	25	30	21	16

5.1.5 Total Nitrogen

Results of the nitrogen are shown in Table 5.5. The values changed between 1.2 and 1.1%; 1.4 and 1.3%; 1.4 and 1.3%; 1.5 and 1.6% for piles respectively. It is possible that the reason of high nitrogen ratios in mixture was due to the high nitrogen amount of the sewage sludge. Nitrogen variations during the composting are relates to pH changes. Nitrogen losses as NH_3 occur only at higher pHs above 8.0. On the other hand, if N fractions like NH_4^+ and NO_3^- have been measured, time changes in N could have been expected.

Table 5.5 Results of the total nitrogen for Experiment 1

	Pile 1		**Pile 2**		**Pile 3**		**Pile 4**	
	Initial	**Final**	**Initial**	**Final**	**Initial**	**Final**	**Initial**	**Final**
N (%)	1.2	1.1	1.4	1.3	1.4	1.3	1.5	1.6

5.1.6 C/N Ratio

C/N ratio results are given in Table 5.6. The initial C/N ratios changed between 13 and 27, and final values were between 10 and 23. According to Bishop and Godfrey (1983), the initial C/N ratio should be in the range of 20:1 and 35:1 by weight. Results revealed that C/N ratios of Pile 1 and Pile 2 coincided of these values and Pile 3 is close to the range of 20:1. At C/N ratio lower than 25:1 than ammonia given off and odor problem occurs. The C/N ratios of Pile 3 and particularly of Pile 4 were found lower than 20:1, the suggested value which could be related to composition of sewage sludge.

Table 5.6 C/N ratios for Experiment 1

	Pile 1		**Pile 2**		**Pile 3**		**Pile 4**	
	Initial	**Final**	**Initial**	**Final**	**Initial**	**Final**	**Initial**	**Final**
C/N	27	23	25	23	18	16	13	10

5.1.7 Primary (P, K), and Secondary Plant Nutrients (Fe, Zn, Mn, Cu), and Heavy Metals (Ni, Cr)

Results of the analyses are shown in Table 5.7. The initial and final values of primary, secondary plant nutrients and heavy metals varied between 8467 and 8373 for P; 15524 and 15486 for K; 14143 and 13898 for Fe; 787 and 794 for Zn; 506 and 496 for Mn; 161 and 160 for Cu; 25 and 26 for Ni; 35 and 34 for Cr in Pile 1. In pile 2 these values changed from 4481 to 4488 for P; 16627 to 16742 for K; 13774 to 13548 for Fe; 768 to 786 for Zn; 481 to 465 for Mn; 159 to 161 for Cu; 20 to 24 for Ni; 38 to 34 for Cr. In the Pile3 these values were between 5090 – 5023 for P; 17854 – 18065 for K; 17254 – 17342 for Fe; 761 – 798 for Zn; 652 – 655 for Mn; 186 – 184 for Cu; 46 – 48 for Ni; 46 – 47 for Cr. In pile 4, these values changed from 5536 to 5499 for P; 19655 to 19641 for K; 19856 to 19964 for Fe; 1125 to 1165 for Zn; 686 to 687 for Mn; 191 to 192 for Cu; 50 to 51 for Ni; 68 to 69 for Cr. The amount of macro elements, micro nutrients and heavy metals increase from the first Pile to fourth Pile because of the amount of sludge increase. The above measurements were the results of total amounts. Therefore, no differences between the initial and final values could be expected. In spite of measuring the total values, if the extractable or soluble parts of these elements were analysed, changes would have happened.

Table 5.7 Results of the Primary (P, K), and Secondary Plant Nutrients (Fe, Zn, Mn, Cu), and Heavy Metals (Ni, Cr) for Experiment 1

	Pile 1		**Pile 2**		**Pile 3**		**Pile 4**	
	Initial	**Final**	**Initial**	**Final**	**Initial**	**Final**	**Initial**	**Final**
P (mg/kg)	8467	8373	4481	4488	5090	5023	5536	5499
K (mg/kg)	15524	15486	16627	16742	17854	18065	19655	19641
Fe (mg/kg)	14143	13898	13774	13548	17254	17342	19856	19964
Zn (mg/kg)	787	794	768	786	761	798	1125	1165
Mn (mg/kg)	506	496	481	465	652	655	686	687
Cu (mg/kg)	161	160	159	161	186	184	191	192
Ni (mg/kg)	25	26	20	24	46	48	50	51
Cr (mg/kg)	35	34	38	34	46	47	68	69

When these values are compared with Turkish Regulation of Soil Pollution Control (in Add II), (Resmi Gazete, 2001), it is seen on Table 5.8, these values are under this values of regulation.

Table 5.8 Comparing with Turkish Regulation of Solid Waste Control of Experiment 3

mg/kg*	Pile 1	Pile 2	Pile 3	Pile 4	Standards
Cr	34	34	47	69	1200
Cu	160	161	184	192	1750
Ni	26	24	48	51	400
Zn	794	786	798	1165	4000

* Dry soil

5.2 Experiment 2

The duration of the Experiment 2 was 25 days. Moisture, temperature, pH, and organic carbon were determined during the experiment, and nitrogen, primary (N, P, K), and secondary (Fe, Cu, Zn, Mn) plant nutrients and heavy metals (Cr, Ni) were determined at beginning and end of the experiment. .

5.2.1 Moisture

Results of the moisture data are shown in Table 5.9. Moisture is one of the limiting factors in composting process. According to Epstein (1997), at moisture contents below 40%, the microbial activity diminishes and degradation capacity of microbial population ceases. At moisture levels over 60%, water that fills the pores prevent oxygen transfer in the compost mass and as oxygen is depleted the aerobic conditions can no longer be dominant. Aerobic species and their activities depend on the oxygen provided during process.

Table 5.9 Moisture contents change during the Experiment 2

	Moisture; (%)			
Days	**Pile 1**	**Pile 2**	**Pile 3**	**Pile 4**
1	55	58	60	85
3	53	57	58	85
5	52	56	57	84
7	50	54	56	83
9	44	53	54	83
11	40	52	53	82
13	39	49	50	82
15	36	45	46	84
17	35	44	42	81
19	33	40	40	81
21	32	38	39	80
23	30	35	35	82
25	28	33	31	77

Ratios of moisture are changed between 55 – 85 % initially. As it is seen on Table 5.9, the highest moisture was determined as 85 % in the Pile 4 which contained only sludge. The moisture ratios decreased to 28 – 77 %. The moisture losses in the piles were 49, 43, 48 and 9 % respectively. Decreasing of moisture was monitored during the composting process because of evaporation.

5.2.2 Temperature

Temperature plays a major role in the composting process. At the same time, it is also a function of the process. Probably the most important aspect of temperature is its impact on the microbiological community. According to Epstein (1997); for best results, temperature should be maintained between 50 and 55° C for the first few days and between 55 and 60° C for the remainder of the active composting period. If the temperature is allowed to increase beyond 65°C for a significant period of time, biological activity will be reduced.

5.2.2.1 Temperature at Up of the Piles

Table 5.10 Results of the up temperature for Experiment 2

	Temperature at Up of the Piles, (^oC)				
Days	**Pile 1**	**Pile 2**	**Pile 3**	**Pile 4**	**Air**
1	49	49	50	35	17
2	51	51	52	36	20
3	50	51	53	34	21
4	50	52	54	37	21
5	52	52	55	31	22
6	52	52	54	31	23
7	50	50	52	30	22
8	49	51	53	28	21
9	47	48	51	26	20
10	48	49	49	25	22
11	48	48	47	26	23
12	47	47	47	27	22
13	48	45	46	28	22
14	46	45	45	29	22
15	44	44	46	25	19
16	44	44	44	27	22
17	46	45	43	24	22
18	44	43	43	24	24
19	41	41	44	23	25
20	40	40	43	22	24
21	37	38	40	21	24
22	36	36	38	19	25
23	34	36	37	20	26
24	33	34	35	18	26
25	31	33	35	20	27

Results of the temperature which belongs to up of the Piles for Experiment 2 are given in Table 5.10. Temperature at up of the piles at the beginning was 49°C for Pile 1, 49°C for Pile 2, 50°C for Pile 3, 35°C for Pile 4. Temperature was observed over 50°C for six days and the maximum 52°C at the end of the fifth day for Pile 1. The minimum temperature was measured as 31°C at the end of the study. Temperature was observed over 50°C for seven days and the maximum 52°C at the end of the fourth day for Pile 2. The minimum temperature was measured as 33°C end of the study. The maximum temperature was 55°C for Pile 3. It was measured at the end of the fifth day. Temperature was observed over 50°C for nine days. The

minimum temperature was 35°C measured at the end of the study. Maximum temperature was observed as 37°C at the end of the fourth day for Pile 4. The minimum temperature was also measured as 24°C at the end of the study.

The temperatures which were at up of the piles were very high and reached to thermophilic phase. So, it may be said that the pathogens were inactivate in thermophilic phase during the composting process.

5.2.2.2 Temperature at Middle of the Piles

Table 5.11 Results of the middle temperature for Experiment 2

	Temperature at Middle of the Piles, (°C)				
Days	**Pile 1**	**Pile 2**	**Pile 3**	**Pile 4**	**Air**
1	56	55	56	33	17
2	55	54	57	34	20
3	55	54	56	31	21
4	56	55	57	32	21
5	57	56	58	30	22
6	55	54	59	29	23
7	56	54	57	27	22
8	54	55	57	29	21
9	53	54	56	31	20
10	54	54	54	28	22
11	53	54	54	26	23
12	51	53	53	25	22
13	52	53	52	26	22
14	51	52	50	28	22
15	49	51	51	27	19
16	50	51	50	25	22
17	49	52	49	26	22
18	48	49	49	24	24
19	47	47	47	23	25
20	44	47	47	24	24
21	40	45	45	24	24
22	40	45	46	23	25
23	39	44	43	23	26
24	37	42	43	21	26
25	36	40	41	22	27

Results of the temperature which belongs to middle of the Piles for Experiment 2 are given in Table 5.11. Temperatures at the middle of the piles at the beginning of the composting process were 56°C for Pile 1, 55°C for Pile 2, and 56°C for Pile 3, 33°C for Pile 4. Temperature was observed over 50°C for fourteen days and the maximum 57°C at the end of the fifth day for Pile 1. The minimum temperature was measured as 36°C end of the Experiment 2. Temperature was generally greater than 50°C during the composting process all piles except Pile 4. Temperature was observed over 50°C for seventeen days and the maximum 56°C at the end of the fifth day for Pile 2. The minimum temperature was measured as 40°C at the end of the study. The maximum temperature was 59°C for Pile 3. It was measured at the end of the sixth day. Temperature was observed over 50°C for sixteen days. The minimum temperature was 41°C measured at the end of the study. Maximum temperature was 34°C for Pile 4. The minimum temperature was measured as 21°C in twenty fourth day. Temperature did not reach to thermophilic phase in Pile 4.

The temperatures at the middle were very high and reached to thermophilic phase. So, it may be said that the pathogens were inactivate in thermophilic phase during the composting process.

5.2.3 pH

pH values during the composting process were between 6.80 and 7.10 initially as it is seen in Table 5.12. The lowest pH value was 6.76 and the highest value was 7.42 in Pile 1. pH values of the other piles were between 7.04 and 7.35; 6.94 and 7.42; 6.95 and 7.64 respectively. At the end of the experiment final pH values were measured as 7.40; 7.25; 7.42 and 7.45 respectively. pH is parameter which greatly affects the composting process. Zorpas et al. (2003) reported that, the pH values were within the optimal range for the development of bacteria 6 – 7.5 and fungi 5.5 – 8.0. No significant variations in the pH of the piles can be related to the temperature which did not rise enough as mentioned above.

Table 5.12 Results of the pH for Experiment 2

	pH			
Days	**Pile 1**	**Pile 2**	**Pile 3**	**Pile 4**
1	6.80	7.08	7.10	6.95
3	6.76	7.04	7.12	7.16
5	6.83	7.10	7.06	7.15
7	6.98	7.17	6.94	7.32
9	7.11	7.20	7.17	7.34
11	7.19	7.24	7.38	7.21
13	7.38	7.20	7.25	7.26
15	7.41	7.35	7.10	7.64
17	7.36	7.19	7.37	7.42
19	7.38	7.21	7.27	7.49
21	7.42	7.24	7.33	7.48
23	7.39	7.27	7.36	7.41
25	7.40	7.25	7.42	7.45

5.2.4 Organic Carbon; (%)

Results of the Organic Carbon are shown in Table 5.13. Initial Organic Carbon values were measured as 38 – 40 – 42 – 22% respectively. The amount of Organic

Table 5.13 Results of the organic carbon for Experiment 2

	Organic Carbon; (%)			
Days	**Pile 1**	**Pile 2**	**Pile 3**	**Pile 4**
1	38	40	42	22
3	38	41	41	21
5	37	39	42	21
7	37	39	40	22
9	36	38	41	20
11	37	38	39	20
13	36	39	39	21
15	35	38	38	22
17	36	37	36	21
19	36	37	36	21
21	35	36	34	20
23	34	36	36	20
25	34	35	37	20

Carbon decreased during the experiment. Decreasing of Organic Carbon occurs when composting process is the progress. Finally, Org – C was 34% in Pile1, 35% in Pile

2, 37% in Pile 3 and 20% in Pile 4 respectively. The declines in the Organic Carbon content are a common phenomenon. Hence, the characteristics of the raw materials and their method fermentation strongly affect the process. As a result, the degree of decrease indicates a fully aging.

5.2.5 Total Nitrogen

Results of the nitrogen are given in Table 5.14. It is possible that the reason of high nitrogen ratios in mixture was due to the high nitrogen amount of the sewage sludge. The values varied between 1.2 and 1.1%; 1.3 and 1.2%; 1.1 and 1.2%; 1.5 and 1.4% for piles respectively. The total nitrogen is usually affected by the action of the proteclytic bacteria and by the temperature. At high temperatures the nitrogen is released to the atmosphere (Wagner et al., 1990). It is obvious, from Piles that the total nitrogen seemed to decrease during the composting process.

Table 5.14 Results of the nitrogen for Experiment 2

	Pile 1		**Pile 2**		**Pile 3**		**Pile 4**	
	Initial	**Final**	**Initial**	**Final**	**Initial**	**Final**	**Initial**	**Final**
N (%)	1.2	1.1	1.3	1.2	1.1	1.2	1.5	1.4

5.2.6 C/N Ratio

C/N ratios are shown in Table 5.15. Bishop and Godfrey (1983) claims that the initial C/N ratio should be in the range of 20:1 to 35:1 by weight. At lower ratios, ammonia given off and odor problem occurs. In the case of C/N ratios exceeding 50:1, the composting process slows because of rapid cell growth and depletion of available N, resulting in reduced cellular growth. As cells die, their stored N becomes available to living cells.

Table 5.15 C/N ratios for Experiment 2

	Pile 1		**Pile 2**		**Pile 3**		**Pile 4**	
	Initial	**Final**	**Initial**	**Final**	**Initial**	**Final**	**Initial**	**Final**
C/N	32	31	31	29	37	31	15	14

Initial C/N ratios changed between 15 and 37. Results revealed that C/N ratios of Pile 1 and Pile 2 were in the range of 20:1 to 35:1 by weight.. It can be said that C/N ratios were the best for Pile 1 and Pile 2. It may be said that C/N ratios of Pile 3 was close to the best. Because of it was not higher than C/N:35. Results revealed that the most important reason of high C/N ratios was that piles were included grass cuttings.

5.2.7 Primary (P, K), and Secondary Plant Nutrients (Fe, Zn, Mn, Cu), and Heavy Metals (Ni, Cr)

Results of the analyses are given in Table 5.16. The initial and final values of primary, and secondary plant nutrients and heavy metals varied between 8301 and 8442 for P; 14524 and 14652 for K; 10005 and 10093 for Fe; 811 and 816 for Zn; 270 and 286 for Mn; 176 and 187 for Cu; 30 and 29 for Ni; 31 and 29 for Cr in Pile 1. In pile 2, these values changed from 9535 to 9601 for P; 17080 to 19064 for K; 11052 to 11024 for Fe; 746 to 761 for Zn; 275 to 285 for Mn; 150 to 149 for Cu; 29 to 31 for Ni; 23 to 23 for Cr. In the Pile3 these values were between 9316 – 9461 for P; 16627– 16975 for K; 11424 – 10242 for Fe; 802 – 805 for Zn; 332 – 361 for Mn; 164 – 165 for Cu; 26 – 27 for Ni; 35 – 34 for Cr. In pile 4, these values changed from 5643 to 5716 for P; 16548 to 17120 for K; 22103 to 22212 for Fe; 1216 to 1224 for Zn; 527 to 537 for Mn; 201 to 203 for Cu; 49 to 52 for Ni; 84 to 87 for Cr. The amount of macro elements, micro nutrients and heavy metals increase from the first Pile to fourth Pile because of the amount of sludge increase. The above measurements were the results of total amounts. Therefore, no differences between the initial and final values could be expected. In spite of measuring the total values, if the extractable or soluble parts of these elements were analysed, changes would have happened.

Table 5.16 Results of Primary (P, K), Secondary Plant Nutrients (Fe, Zn, Mn, Cu), Heavy Metals (Ni, Cr) for Experiment 2

	Pile 1		**Pile 2**		**Pile 3**		**Pile 4**	
	Initial	**Final**	**Final**	**Initial**	**Initial**	**Final**	**Initial**	**Final**
P (mg/kg)	8301	8442	9535	9601	9316	9461	5643	5716
K (mg/kg)	14524	14652	17080	19064	16627	16975	16548	17120
Fe (mg/kg)	10005	10093	11054	11024	11424	10242	22103	22212
Zn (mg/kg)	811	816	746	761	802	805	1216	1224
Mn (mg/kg)	270	286	275	285	332	361	527	537
Cu (mg/kg)	176	187	150	149	164	165	201	203
Ni (mg/kg)	30	29	29	31	26	27	49	52
Cr (mg/kg)	31	29	23	23	35	34	84	87

When these values are compared with Turkish Regulation of Soil Pollution Control (Add II), (Resmi Gazete, 2001), it is seen on Table 5.17, these values are under this values of regulation.

Table 5.17 Comparing with Turkish Regulation of Solid Waste Control of Experiment 3

mg/kg*	**Pile 1**	**Pile 2**	**Pile 3**	**Pile 4**	**Standards**
Cr	29	23	34	87	1200
Cu	187	149	165	203	1750
Ni	29	31	27	52	400
Zn	816	761	805	1224	4000

* Dry Soil

5. 3 Experiment 3

The duration of the Experiment 3 was 25 days. Moisture, temperature, pH, and organic carbon were determined during the experiment, and nitrogen, primary (P, K), and secondary (Fe, Cu, Zn, Mn) plant nutrients and heavy metals (Cr, Ni) were determined at beginning and end of the experiment.

5.3.1 Moisture

Results of the moisture during experiment 3 are shown in Table 5.18. Moisture datas were between 42 and 85 % initially as it is seen on Table 5.16. The moisture level decreased to 23 – 77% at the end of composting process. It is defined that the moisture ratios loss in the piles 45 %, 45 %, 49 % and 9 % respectively. The reasons of the moisture loss are open – air pile and evaporation. Epstein (1997) claims that ideal moisture rates are 40 – 70 % in the compost materials due to the optimal aerobic digestion occurrence in these ranges. Because if moisture rate is lower than 30%, bacterial activity is prevented. On the other hand, when moisture is greater than 65%, the breaking down process slows. If the above cited informations taken into account, the optimal aerobic digestion occurred in all Piles except Pile 4 which included only sludge.

Table 5.18 Results of the moisture for Experiment 3

	Moisture, (%)			
Days	**Pile 1**	**Pile 2**	**Pile 3**	**Pile 4**
1	42	51	68	85
3	40	49	67	85
5	39	47	65	84
7	37	46	64	83
9	36	45	61	83
11	36	43	57	82
13	34	42	54	82
15	33	40	51	84
17	31	38	48	81
19	30	35	45	81
21	27	33	42	80
23	27	30	37	82
25	23	28	35	77

5.3.2 Temperature

Temperature plays a major role in the composting process. At the same time, it is also a function of the process. According to Epstein (1997), for best results, temperature should be maintained between 50 and 55° C for the first few days and between 55 and 60° C for the remainder of the active composting period. If the temperature is allowed to increase beyond 65° C for a significant period of time, biological activity will be reduced.

5.3.2.1 Temperature at Up of the Piles

Results of the temperature at up of the piles are shown in Table 5.19. Temperatures at the up of the piles at the beginning were 43°C, 42°C, 42°C, and 35°C respectively. Temperature was observed the maximum 47°C at the end of the 4th day for Pile 1. The minimum temperature was measured as 29°C for Pile 1 at the end of the Experiment 3. Temperature was observed the maximum 46°C at the end of the 4th day for Pile 2. In Pile 3, the minimum temperature was recorded as 28°C at the end of the composting process. Temperature was observed the maximum 46°C at the end of the 6th day. The minimum temperature was measured as 28°C at the end of the composting process. Temperature was recorded the maximum 37°C at the end of the 4th day for Pile 4. The minimum temperature was measured as 24°C at the end of the Experiment 3. The temperatures which were at up of the piles reached to mesophilic phase.

Table 5.19 Results of the temperature at up of the piles for Experiment 3

	Temperature at Up of The Piles, (^oC)				
Days	**Pile 1**	**Pile 2**	**Pile 3**	**Pile 4**	**Air**
1	43	42	42	35	17
2	45	44	44	36	20
3	44	44	43	34	21
4	47	46	45	37	21
5	46	45	45	31	22
6	46	45	46	31	23
7	45	43	44	30	22
8	45	44	45	28	21
9	44	42	43	26	20
10	45	44	45	25	22
11	44	43	43	26	23
12	43	42	43	27	22
13	39	40	40	28	22
14	39	41	41	29	22
15	37	40	37	25	19
16	39	40	38	27	22
17	38	37	36	24	22
18	37	37	36	24	24
19	35	35	34	23	25
20	35	34	34	22	24
21	33	32	33	21	24
22	32	32	32	19	25
23	31	31	30	20	26
24	30	30	30	18	26
25	29	28	28	20	27

5.3.2.2 Temperature at Middle of the Piles

Results of the temperature at middle of the piles are shown in Table 5.20. The temperatures at middle of the piles at the beginning were 49°C for Pile1, 48°C for Pile 2, 47°C for Pile 3, and 33°C for Pile 4. Temperature was observed over 50°C for eight days and the maximum 54°C at the end of the sixth day for Pile 1. The minimum temperature was measured as 39°C at the end of the composting process. Temperature was observed over 50°C for eleven days and the maximum 54°C at the end of the 7th day for Pile 2. The minimum temperature was measured as 38°C at the end of the Experiment 3. The maximum temperature was 52°C for Pile 3. Temperature was observed over 50°C for five days. The minimum temperature

which was 37°C measured at the end of the composting process. Maximum temperature was 34°C for Pile 4. The minimum temperature was measured as 21°C in 24th day. Temperature did not reach to thermophilic phase. The temperatures which were at middle of the piles reached to mesophilic phase.

Table 5.20 Results of the temperature at middle of the piles for Experiment 3

	Temperature at Middle of The Piles, (°C)				
Days	**Pile 1**	**Pile 2**	**Pile 3**	**Pile 4**	**Air**
1	49	48	47	33	17
2	51	47	48	34	20
3	50	49	48	31	21
4	52	51	50	32	21
5	51	51	52	30	22
6	53	52	52	29	23
7	51	54	51	27	22
8	50	54	50	29	21
9	50	53	49	31	20
10	48	54	49	28	22
11	49	52	48	26	23
12	48	50	47	25	22
13	47	51	47	26	22
14	47	52	47	28	22
15	47	49	45	27	19
16	48	49	46	25	22
17	45	47	46	26	22
18	46	48	45	24	24
19	45	46	45	23	25
20	44	44	45	24	24
21	43	44	43	24	24
22	44	41	43	23	25
23	43	41	41	23	26
24	40	38	39	21	26
25	39	38	37	22	27

5.3.3 pH

Initial pH values were between 6.95 and 7.37 which are seen on the Table 5.21. The lowest pH value was 7.12 in Pile 1 and the highest value was 7.42. pH values of the other piles were between 7.18 and 7.50; 7.20 and 7.44; 6.95 and 7.64 respectively. At the end of the experiment, final pH values were measured as 7.14;

7.25; 7.41 and 7.45 respectively. Kapetanios et al. (1993) state that, the optimum pH values are 6 – 7.5 for bacterial development, while fungi prefer an environment in the range of 5.5 – 8.0. Composting process is controlled by many factors which include temperature, aeration, particle size, characteristics of raw material, moisture, time and etc. In this regard, temperature and pH are generally closely associated to the break down of raw materials. No significant variations in the pH of the piles can be related to the temperature which did not rise enough as mentioned above.

Table 5.21 Results of the pH for Experiment 3

	pH			
Days	**Pile 1**	**Pile 2**	**Pile 3**	**Pile 4**
1	7.32	7.37	7.27	6.95
3	7.29	7.40	7.29	7.16
5	7.42	7.44	7.20	7.15
7	7.41	7.42	7.25	7.32
9	7.37	7.39	7.33	7.34
11	7.28	7.50	7.35	7.21
13	7.31	7.29	7.24	7.26
15	7.25	7.18	7.30	7.64
17	7.12	7.19	7.41	7.42
19	7.18	7.25	7.44	7.49
21	7.21	7.27	7.33	7.48
23	7.16	7.21	7.37	7.41
25	7.14	7.25	7.41	7.45

5.3.4 Organic Carbon; (%)

Results of the organic carbon are shown in Table 5.22. Initial Organic Carbon values were measured 35% – 33% – 27% – 22% respectively. The amount of Organic Carbon decreased during the study. Decreasing of Organic Carbon occurs when composting process is in the progress. Finally, Org – C was 30% in Pile1, 28% in Pile 2, 24% in Pile 3 and 20% in Pile 4 respectively. The decreasing in the Organic Carbon content is a common phenomenon. Hence, the characteristics of the raw materials and their method fermentation strongly affect the process. as a result, the degree of decrease indicates a fully aging.

Table 5.22 Results of the organic matter for Experiment 3

	Organic Carbon; (%)			
Days	**Pile 1**	**Pile 2**	**Pile 3**	**Pile 4**
1	35	33	27	22
3	35	32	27	21
5	34	33	26	21
7	34	32	25	22
9	34	31	25	20
11	33	31	26	20
13	32	30	24	21
15	31	30	25	22
17	31	29	26	21
19	30	28	24	21
21	31	29	23	20
23	30	29	25	20
25	30	28	24	20

5.3.5 Total Nitrogen

Results of the Nitrogen are given in Table 5.23. It is possible that the reason of high nitrogen ratios in mixture was due to the high nitrogen amount of the sewage sludge. Wagner et al. (1990) claims that the total nitrogen is usually affected by the action of the proteclytic bacteria and by the temperature. At high temperatures the nitrogen is released to the atmosphere It is obvious, from Piles, that the total nitrogen seemed to decreased during the composting process.

Table 5.23 Results of the Nitrogen for Experiment 3

	Pile 1		**Pile 2**		**Pile 3**		**Pile 4**	
	Initial	**Final**	**Initial**	**Final**	**Initial**	**Final**	**Initial**	**Final**
N (%)	1.2	1.1	1.4	1.3	1.4	1.2	1.5	1.4

5.3.6 C/N Ratio

Table 5.24 C/N ratios for Experiment 3

	Pile 1		Pile 2		Pile 3		Pile 4	
	Initial	**Final**	**Initial**	**Final**	**Initial**	**Final**	**Initial**	**Final**
C/N	29	27	24	22	19	20	15	14

C/N ratios are shown in Table 5.24. C/N ratios were changed between 15 and 29 initially. The initial C/N ratio should be in the range of 20:1 and 35:1 by weight (Bishop and Godfrey, 1983). Results revealed that C/N ratios of Pile 1 and Pile 2 coincided of these values and Pile 3 is close to the range of 20:1. At C/N ratio lower than 25:1 than ammonia given off and odor problem occurs. The C/N ratios of Pile 3 and particularly of Pile 4 were found lower than 20:1, the suggested value which could be related to composition of sewage sludge. .

5.3.7 Primary (P, K), Secondary Plant Nutrients (Fe, Zn, Mn, Cu), Heavy Metals (Ni, Cr)

Results of the analyses are shown in Table 5.25 The initial and final values of primary, secondary plant nutrients and heavy metals varied between 3580 and 3700 for P; 13546 and 13648 for K; 15943 and 15802 for Fe; 888 and 978 for Zn; 350 and 370 for Mn; 148 and 160 for Cu; 30 and 30 for Ni; 39 and 46 for Cr in Pile 1. In pile 2 these values changed from 5088 to 5120 for P; 15421 to 16024 for K; 15548 to 15154 for Fe; 859 to 888 for Zn; 421 to 426 for Mn; 163 to 172 for Cu; 34 to 37 for Ni; 46 to 48 for Cr. In the Pile3 these values were between 5463 – 5501 for P; 14651 – 14985 for K; 18112 – 17958 for Fe; 966 – 1000 for Zn; 446 – 416 for Mn; 196 – 193 for Cu; 42 – 44 for Ni; 68 – 70 for Cr. In pile 4, these values changed from 5643 to 5716 for P; 16548 to 17120 for K; 22103 to 22212 for Fe; 1216 to 1224 for Zn; 527 to 537 for Mn; 201 to 203 for Cu; 49 to 52 for Ni; 84 to 87 for Cr. The amount of primary and secondary plant nutrients and heavy metals increase from the first Pile to fourth Pile because of the amount of sludge increase. The above measurements were the results of total amounts. Therefore, no differences between the initial and final values could be expected. In spite of measuring the total values, if

the extractable or soluble parts of these elements were analysed, changes would have happened.

Table 5.25 Results of Primary (P, K), Secondary Plant Nutrients (Fe, Zn, Mn, Cu), Heavy Metals (Ni, Cr) for Experiment 3

	Pile 1		**Pile 2**		**Pile 3**		**Pile 4**	
	Initial	**Final**	**Initial**	**Final**	**Initial**	**Final**	**Initial**	**Final**
P (mg/kg)	3580	3700	5088	5120	5463	5501	5643	5716
K (mg/kg)	13546	13648	15421	16024	14651	14985	16548	17120
Fe (mg/kg)	15943	15802	15548	15154	18112	17958	22103	22212
Zn (mg/kg)	888	978	859	888	966	1000	1216	1224
Mn (mg/kg)	350	370	421	426	446	416	527	537
Cu (mg/kg)	148	160	163	172	196	193	201	203
Ni (mg/kg)	30	30	34	37	42	44	49	52
Cr (mg/kg)	39	46	46	48	68	70	84	87

When these values were compared with Turkish Regulation of Soil Pollution Control (Add II), (Resmi Gazete, 2001), as it is seen on Table 5.26 these values were under this values of regulation.

Table 5.26 Comparing with Turkish Regulation of Solid Waste Control of Experiment 3

mg/kg*	**Pile 1**	**Pile 2**	**Pile 3**	**Pile 4**	**Standards**
Cr	46	48	70	87	1200
Cu	160	172	193	203	1750
Ni	30	37	44	52	400
Zn	978	888	1000	1224	4000

* Dry soil

CHAPTER SIX

CONCLUSION

The most important technology which can make sewage sludge increase in value is composting. The compost which is produced by this method was evaluated as natural fertilizer for agricultural using. It has been committed three searches which examine usability the treatment sludge composted then implemented into the agricultural land. Three experiments were made at this scope. In the 1st experiment; sewage sludge which was taken from İzmir – Çigli Wastewater Treatment Plant and semi fermented solid waste which was taken from İzmir Uzundere Compost Plant were used to compost as method of the static pile. In the 2nd Experiment; sewage sludge, raw compost, and green waste from university gardens were used to compost in the barrels which volume of 70 L. Upper surfaces of the barrels was open. In the 3rd experiment; sewage sludge and semi fermented solid wastes were used to compost in the barrels.

In the 1st experiment, increasing of the temperature occurred slowly in the piles. The highest temperature was 26°C during the experiment. Since thermophilic phase did not occur, the Experiment 1 was not successful especially for removal of pathogenic microorganisms. Initial ratio of moisture was fluctuated in 44 – 82 %. pH values were fluctuated between 6.48 and 7.63. No significant variations in the pH of the piles can be related to the temperature which did not rise enough as mentioned above. Initial Org – C values were measured 32 – 35 – 25 – 20% respectively. The amount of the Organic Carbon values decreased during the experiment 1. The initial C/N ratios changed between 13 and 27. Results revealed that C/N ratios of Pile 1 and Pile 2 were in the range of 20:1 and 35:1. Primary and secondary plant nutrients and heavy metals increase from the first Pile to fourth Pile because of the amount of sludge increase.

In the 2nd Experiment; temperature reached to thermophilic phase in the barrels which included sewage sludge, semi fermented solid waste, and grass cutting in

different mixing. It can be concluded that reducing pathogens was realized successful during thermophilic phase. The most important reason of using grass cutting was that value of organic matter increased. Carbon and nitrogen ratio was ideal for composting. Final products matured to use of agricultural purpose according to result of the analyses. Values of heavy metals were low level. Results revealed that Experiment 2 was completed successfully.

In the 3rd experiment; it can be concluded that temperature reached to thermophilic phase in the barrels which included sewage sludge and semi fermented solid waste in different mixing. Final products matured to use of agricultural purpose according to result of the analyses. Values of heavy metals were found low level. Results revealed that Experiment 3 was completed successfully. But Pile 4 did not mature. It contained only sludge.

In the result of the studies; it is thought that composting in the barrels has more advantage than composting in the static piles. It can be said that advantages of the composting in the barrels are that increasing temperature to thermophilic phase. Odor problems did not occur.

Moisture, organic matter, temperature, C/N ratios, pH parameters of composting were determined. Primary, (P, K), micro nutrients and secondary plant nutrients (Fe, Cu, Zn, Mn), heavy metals like Cr, Ni contents were also measured to investigate being able to use agricultural purpose of final product.

Results revealed that the method used in Experiment 1 did not end with the expected compost product. However, Experiment 2 and Experiment 3 resulted with a better compost while Experiment 2 being the best in this respect. Effect grass cuttings used in Experiment 2 on composting was positive.

CHAPTER SEVEN

RECOMMENDATION

The present experiments are just the introduction of a more complicated experiment in the composting organic material. Results can be summarized as follows and recommended further researches:

- Grass cuttings had positive effect on composting process.

- Sludge composting with bulking agents which are wood, grass, wood shaving, domestic wastes and waste paper which contain high organic carbon can be conducted for better handling alternatives.

- N fractions like NH_4^+ and NO_3^- have been measured instead of total nitrogen; N variation with time could be expected.

- In spite of measuring of the total amounts of metals, if the extractable or soluble parts of these elements which were primary (P, K), and secondary plant nutrients (Fe, Zn, Mn, Cu), and heavy metals (Ni, Cr), were analysed, changes would have happened.

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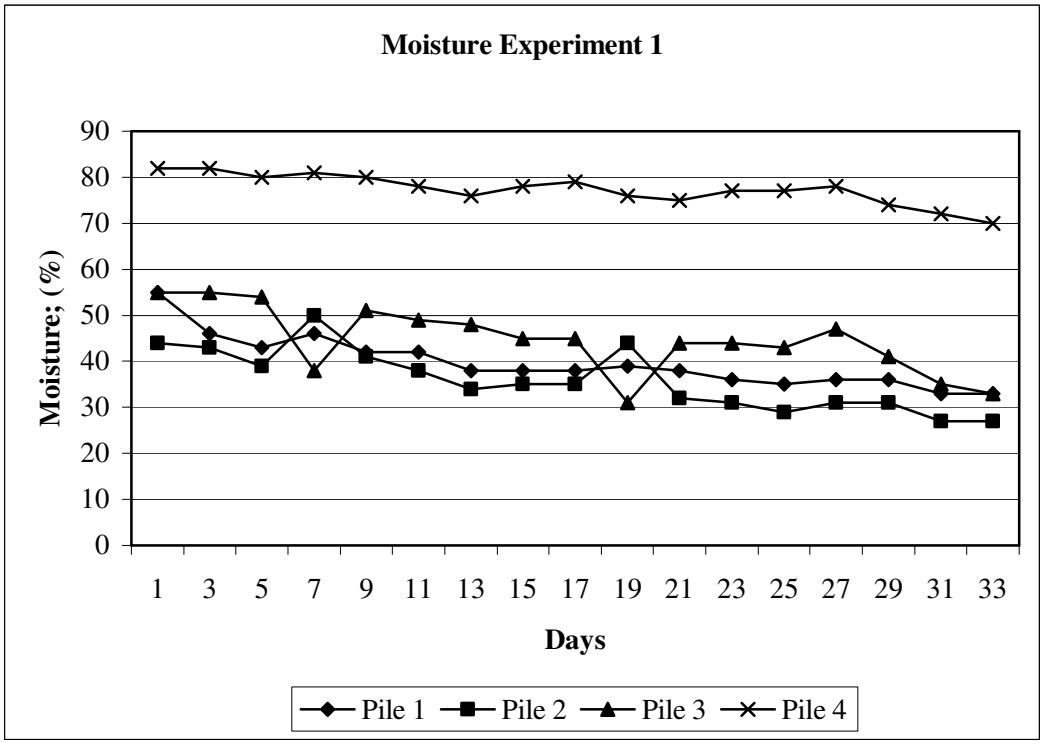
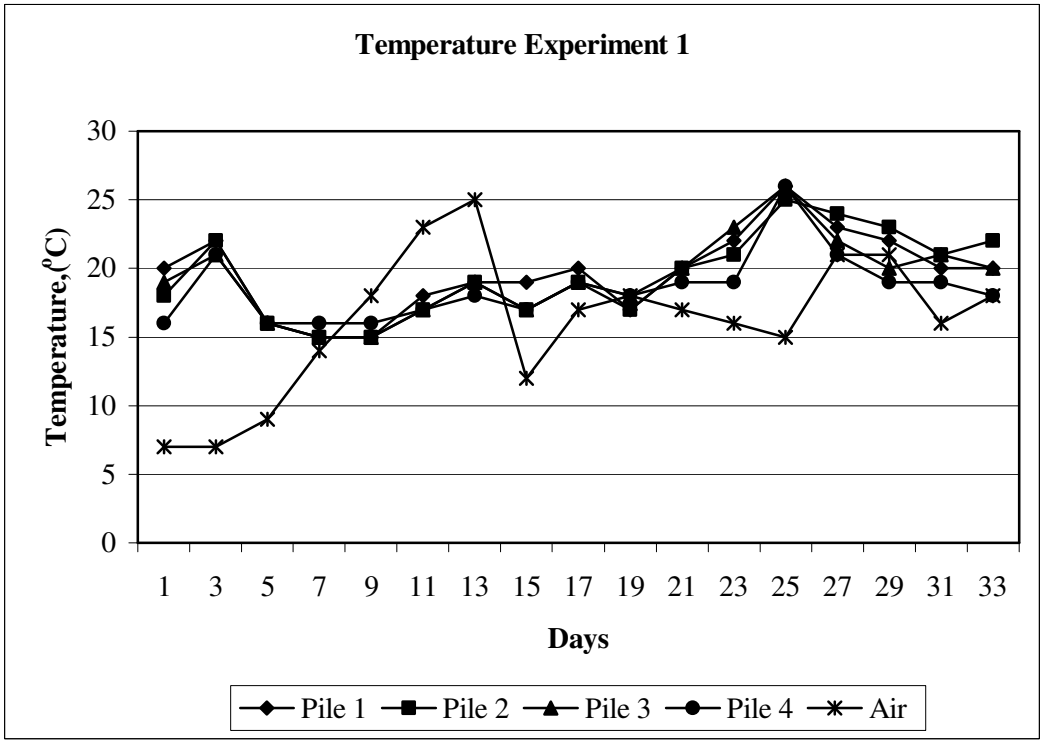
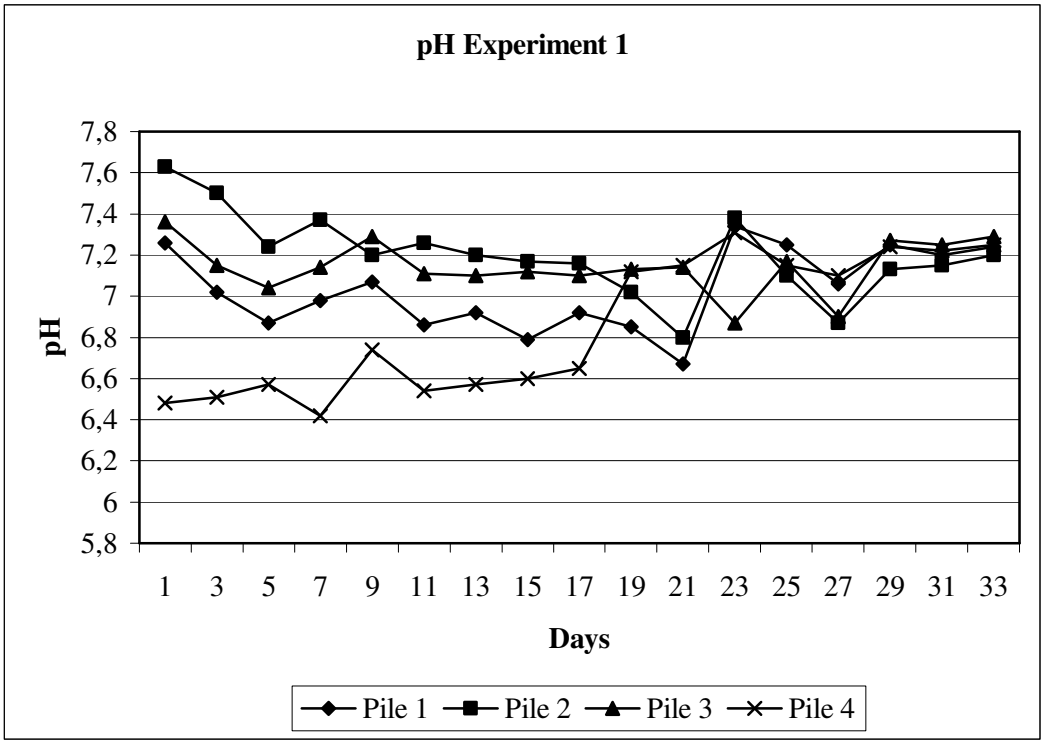
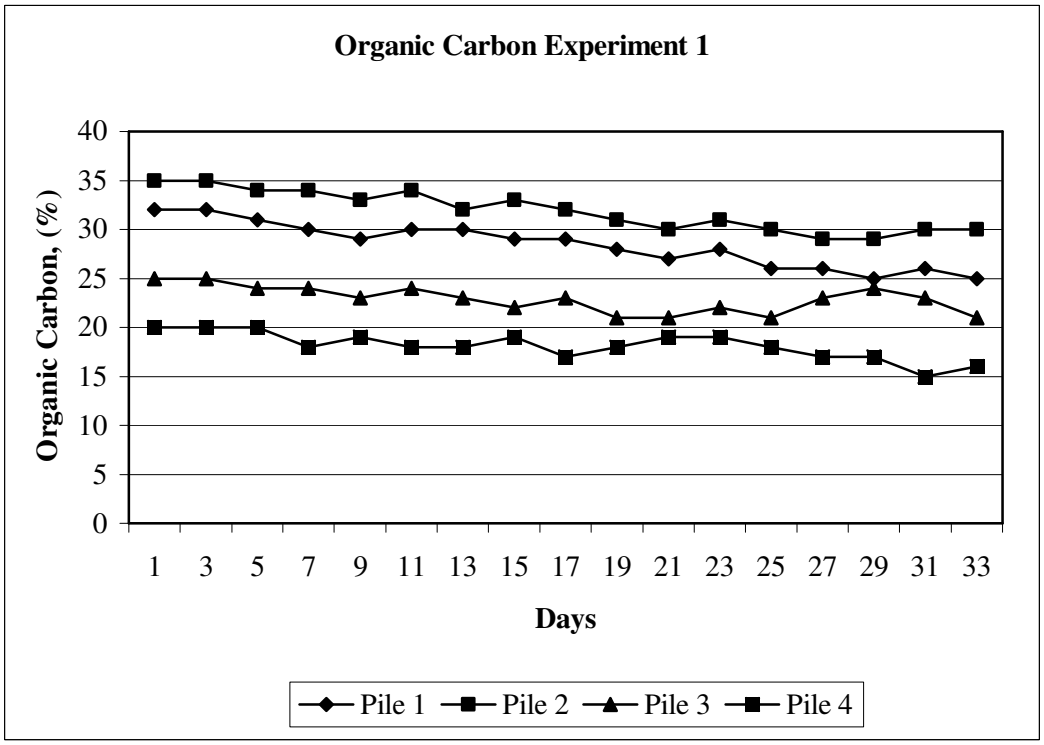
APPENDIX I

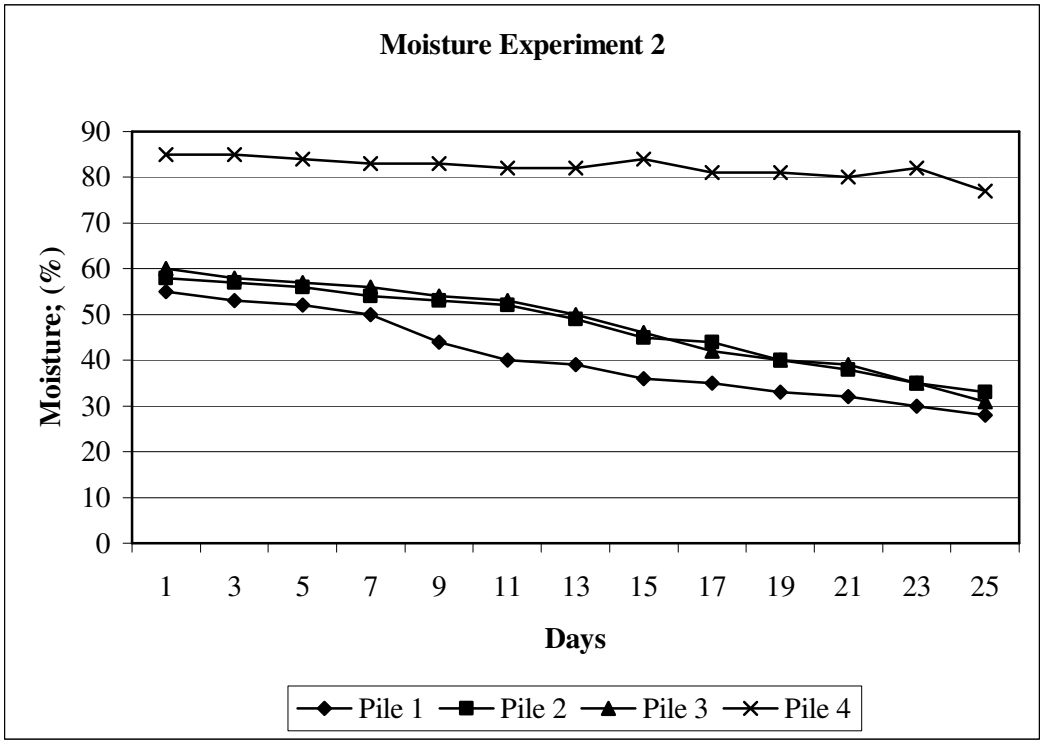
GRAPHICS

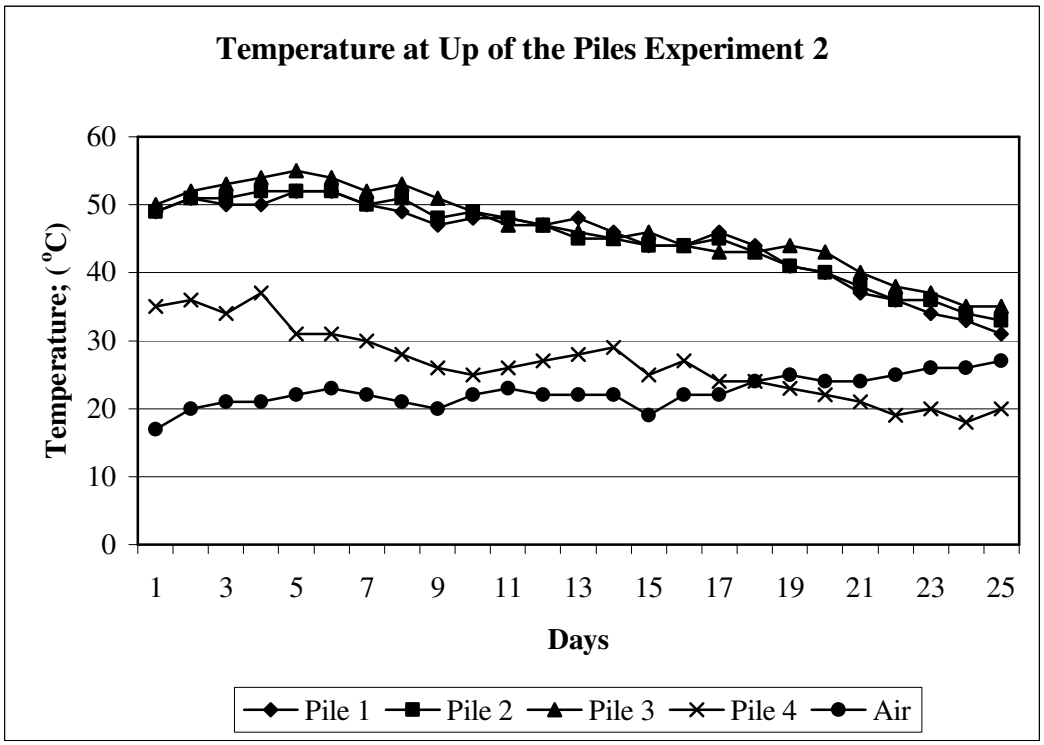


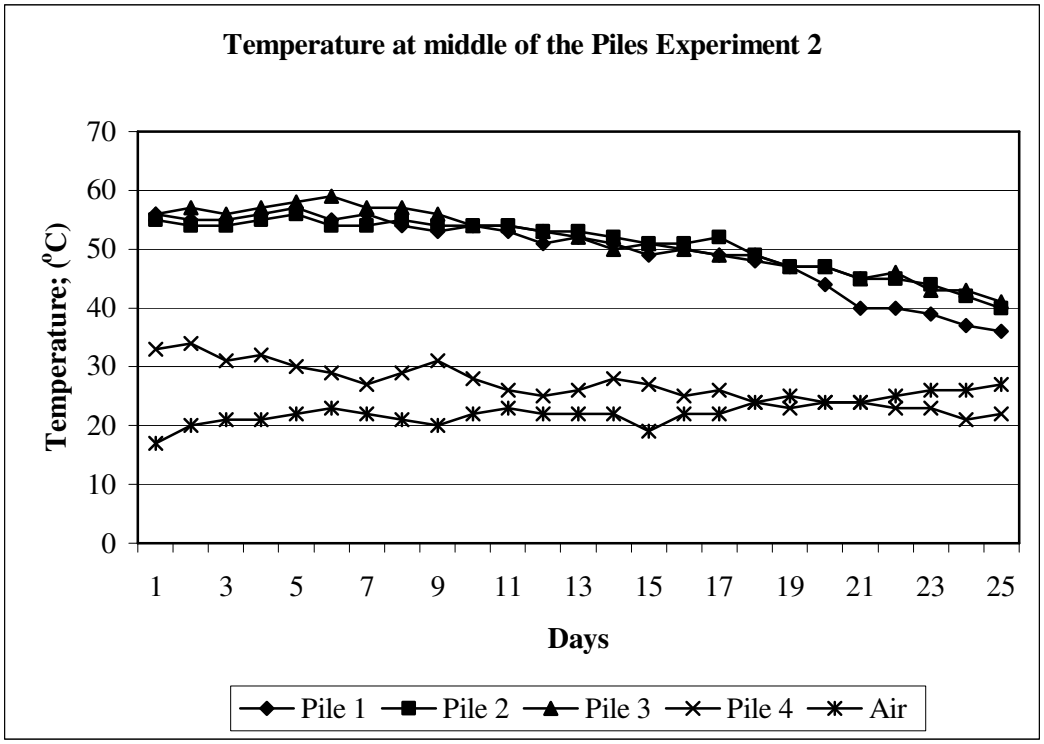


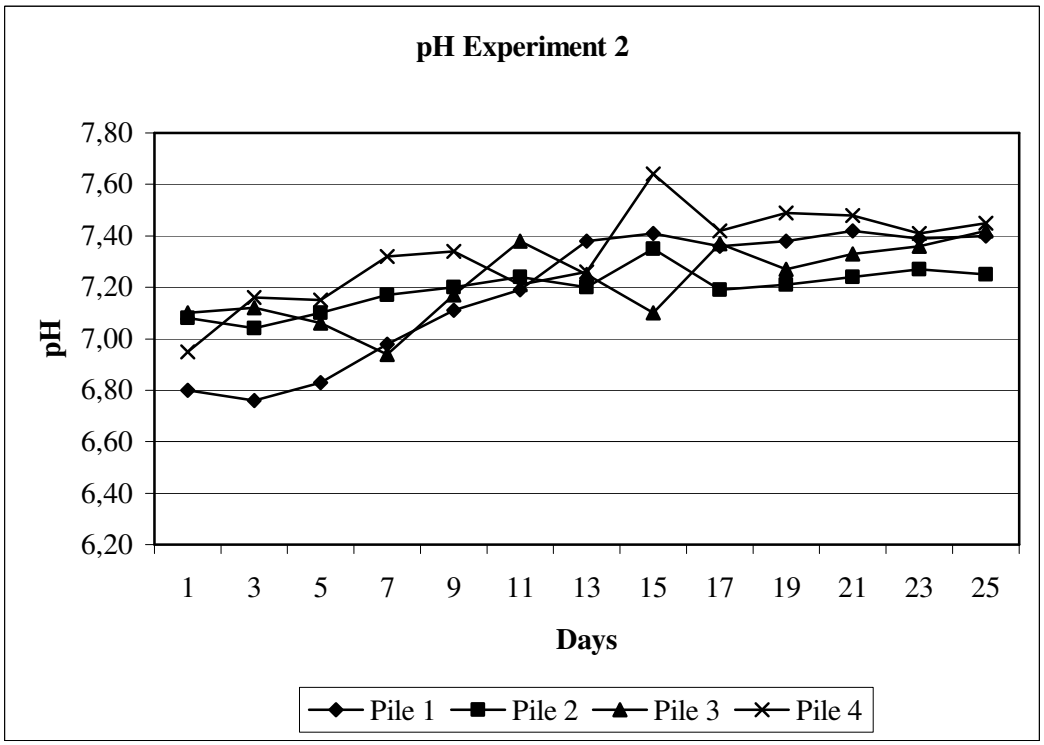

pH Experiment 1
pH
7,8
7,6
7,4
7,2
7
6,8
6,6
6,4
6,2
6
5,8
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33
Days
Pile 1
Pile 2
Pile 3
Pile 4

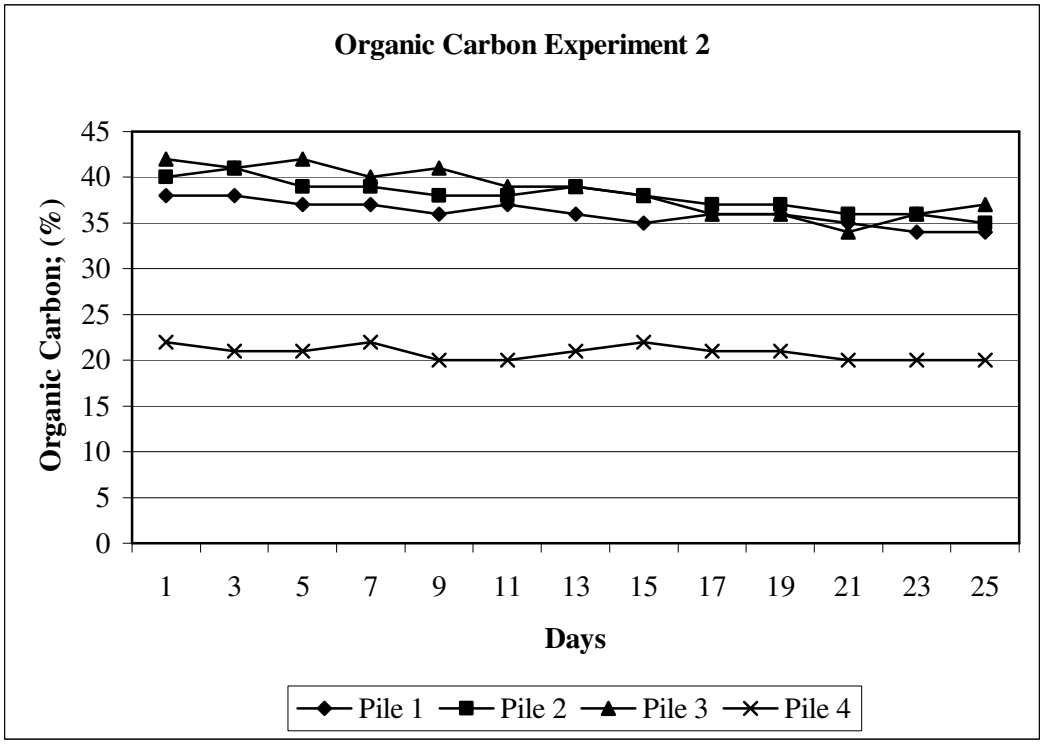

Organic Carbon Experiment 1
Organic Carbon, (%)
40
35
30
25
20
15
10
5
0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33
Days
Pile 1
Pile 2
Pile 3
Pile 4

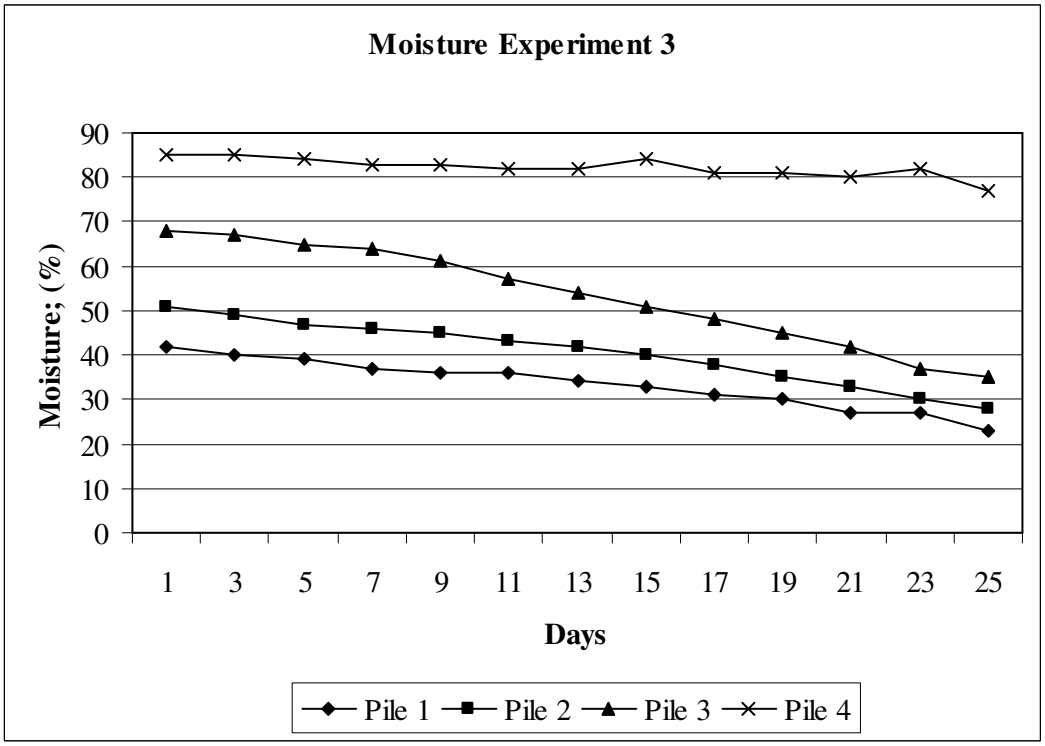

Moisture Experiment 2
Moisture; (%)
90
80
70
60
50
40
30
20
10
0
1
3
5
7
9
11
13
15
17
19
21
23
25
Days
Pile 1
Pile 2
Pile 3
Pile 4

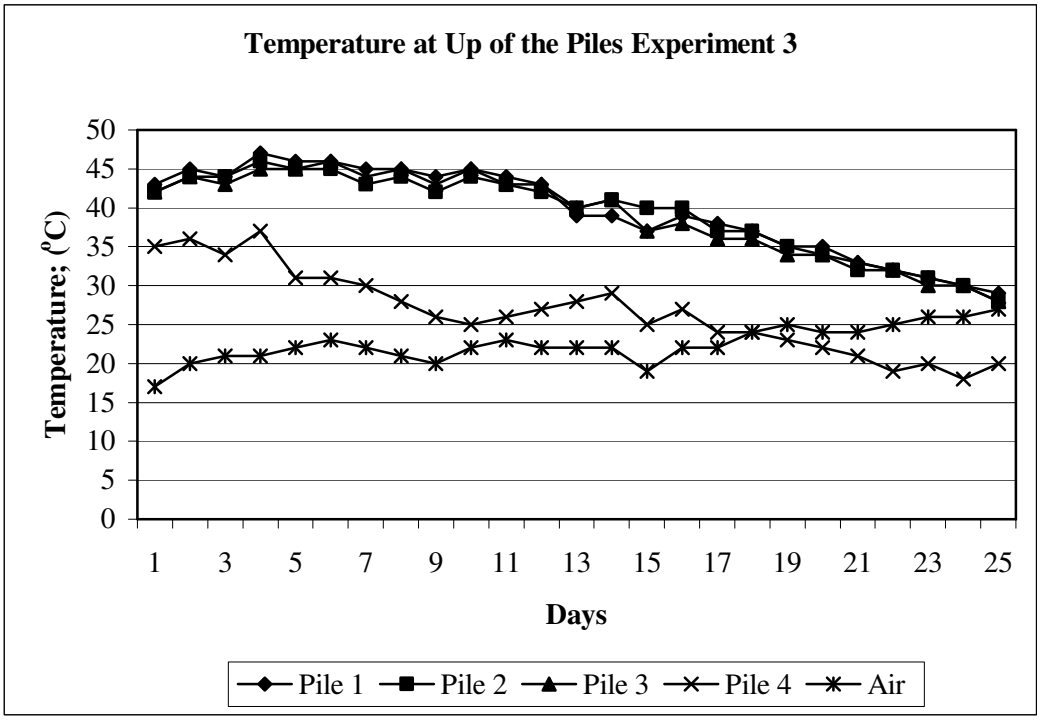

Temperature at Up of the Piles Experiment 2
Temperature; (°C)
60
50
40
30
20
10
0
1
3
5
7
9
11
13
15
17
19
21
23
25
Days
Pile 1
Pile 2
Pile 3
Pile 4
Air

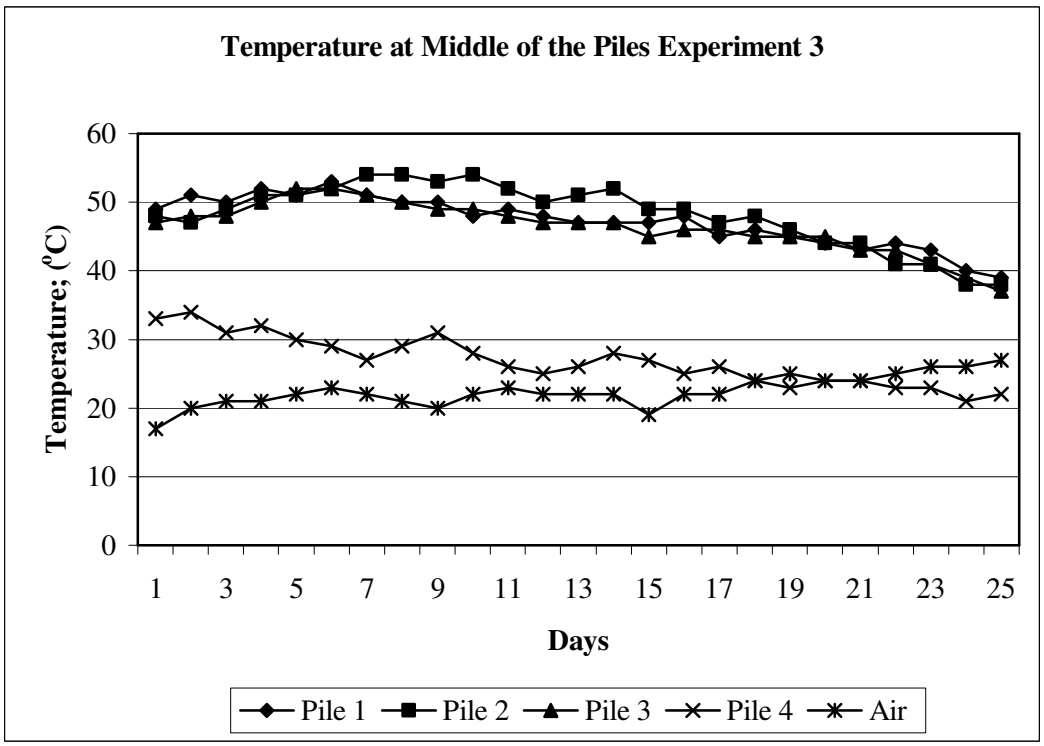

Temperature at middle of the Piles Experiment 2
Temperature; (ºC)
70
60
50
40
30
20
10
0
1
3
5
7
9
11
13
15
17
19
21
23
25
Days
Pile 1
Pile 2
Pile 3
Pile 4
Air

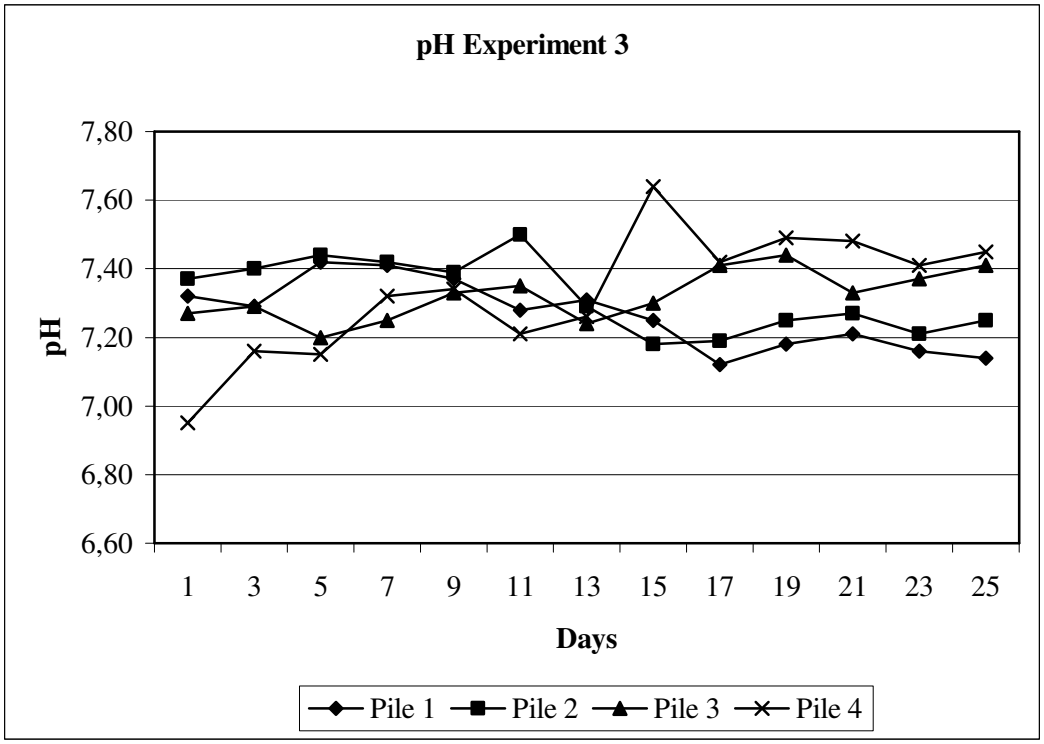

pH Experiment 2
pH
7,80
7,60
7,40
7,20
7,00
6,80
6,60
6,40
6,20
1
3
5
7
9
11
13
15
17
19
21
23
25
Days
Pile 1
Pile 2
Pile 3
Pile 4

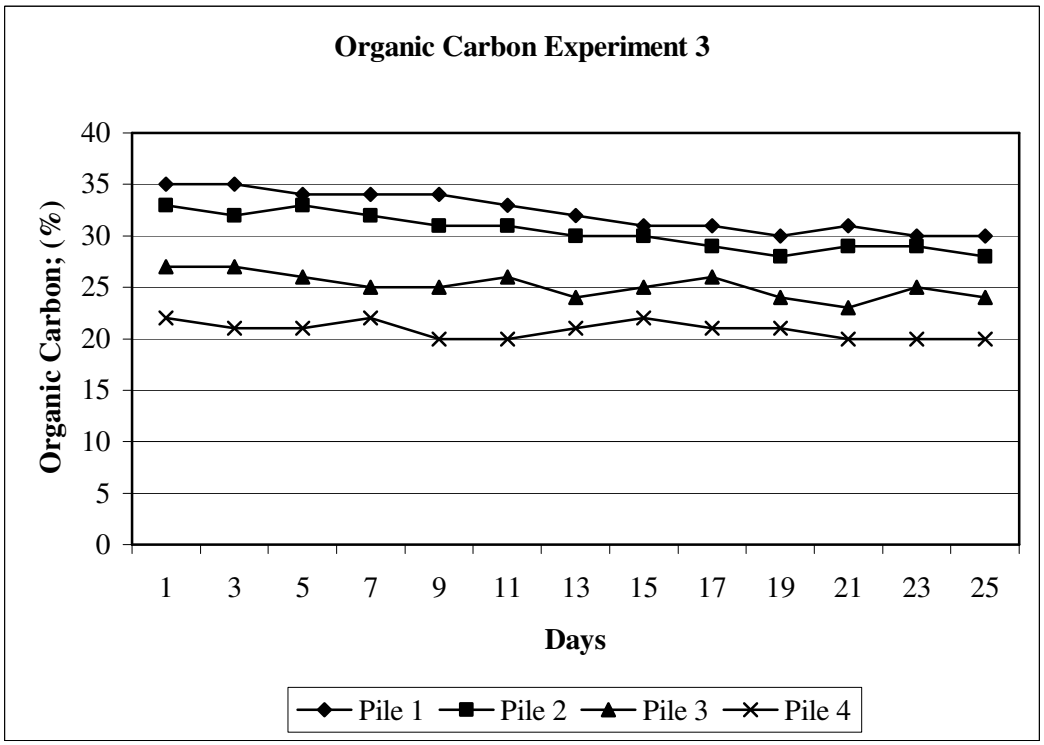

Organic Carbon Experiment 2
Organic Carbon; (%)
45
40
35
30
25
20
15
10
5
0
1
3
5
7
9
11
13
15
17
19
21
23
25
Days
Pile 1
Pile 2
Pile 3
Pile 4


Moisture Experiment 3
Moisture; (%)
90
80
70
60
50
40
30
20
10
0
1
3
5
7
9
11
13
15
17
19
21
23
25
Days
Pile 1
Pile 2
Pile 3
Pile 4


Temperature at Up of the Piles Experiment 3
Temperature; (°C)
50
45
40
35
30
25
20
15
10
5
0
1
3
5
7
9
11
13
15
17
19
21
23
25
Days
Pile 1
Pile 2
Pile 3
Pile 4
Air


Temperature at Middle of the Piles Experiment 3
Temperature; (°C)
60
50
40
30
20
10
0
1
3
5
7
9
11
13
15
17
19
21
23
25
Days
Pile 1
Pile 2
Pile 3
Pile 4
Air


pH Experiment 3
7,80
7,60
7,40
7,20
7,00
6,80
6,60
pH
1 3 5 7 9 11 13 15 17 19 21 23 25
Days
Pile 1
Pile 2
Pile 3
Pile 4


Organic Carbon Experiment 3
40
35
30
25
20
15
10
5
0
Organic Carbon; (%)
1 3 5 7 9 11 13 15 17 19 21 23 25
Days
Pile 1
Pile 2
Pile 3
Pile 4

APPENDIX II

EU DEVELOPMENTS IN COMPOSTING

EU Developments in Sludge Regulation

The shape of sludge regulations in Europe is undergoing a period of great changes: a new Directive on land applications will revise the previous one almost completely, and the production of a new Directive generally addressed to "biowaste" has been undertaken to encourage prevention, reduction, and reuse of sludge. However, to properly perform sludge management, and correctly fulfill the legal requirements, the definition of standardized characterization methods and procedures is necessary. For this reason, the European Committee for Standardization (CEN) has established the Technical Committee 308 (TC308) whose scope is the standardization of methods and procedures employed for sludge characterization, and the production of guidelines for good management practice.

From a general point of view, the sludge management policy is addressed to both:

- The development of treatment methods able to reduce the sludge mass production,
- The application of reuse options instead of simple disposal ones.

From the EU regulatory point of view, the Directive 91/156 on waste, also designated as the "Waste Basis Directive", has been of outstanding significance, as it is always to be observed even with the application of any other listed regulations. This means that the particular requirements deriving from other Directives addressed to particular waste groups, like sludge, apply additionally to the regulations deriving from above Directive. In particular, sludge must fulfil the requirements imposed by specific normative, such as the:

- Directive 91/27/EEC on the treatment of urban wastewaters,
- Directive 86/278/EEC on sludge utilization in agriculture,
- Organic Farming Regulation 91/2092/EEC,

- Landfill Directive 1999/31/EC,
- Commission Decision 2001/688/EC for the ecolabel for soil improvers and growing media,
- Normative on incineration of waste (i.e Directives 89/369, 94/67 and 00/76), when applicable.

It is to be observed that the sludge utilization in agriculture is subjected to great variability over time, depending on crop type and weather conditions, while sludge production is continuous. **Therefore, sludge composting could become a preferred option because it has the advantage of producing a material which can be more easily stored, transported and used on times and sites different from those of production. Composting also involves the production of a more safe and hygienic product. Additionally, the more constant and controlled quality of compost, in comparison to what happens in direct agricultural utilization of sewage sludge, is of major interest.**

To promote the biological treatment of biodegradable waste, including composting, by harmonizing the national measures concerning its management, and to prevent or reduce any impact thereof on the environment, a working document in view of a Directive in this field has been recently drafted by EU.

General principles included into the second draft are, among others:

- The prevention or reduction of biowaste production (e.g. sewage sludge) and its contamination by pollutants;
- The composting or anaerobic digestion of separately collected biowaste that is not recycled into the original material;
- The mechanical/biological treatment of biowaste;
- The use of biowaste as a source for generating energy.

Member states are requested to encourage (i) home and on site composting whenever there are viable up of community composting schemes as a way of

involving the general public in the management of their own waste, reducing transport of waste and increasing awareness in waste recycling practices.

According to this proposal, the composting process has to be carried out in such a way that a thermophilic temperature range, a high level of biological activity under favorable conditions with humidity and nutrients, as well as an optimum structure and optimum air conduction are guaranteed over a period of several weeks. In particular, in the course of the composting process the entire quantity of biowaste has to be mixed and exposed to a temperature ≥55°C for at least 2 weeks or ≥65°C for at least 1 week.

Requirements on location of treatment plants, management of wastewater and leachate, control of odor, minimization of nuisance and hazards are also included in the proposal. (Spinosa, 2005)

Soil Strategy

Where biowaste is composted it can be recycled into the soil thus increasing the soil's organic matter and nutrient level and enhancing the soils ability yo function. Soil function at many levels which the draft strategy for England summarizes as (The Draft Soil Strategy for England – A Consultation Paper DETR/MAFF March 2001):

- Environmental interaction (filtering pollutants, emitting and removing gases, regulating water flow);
- Food and fibre production;
- Providing a platform for development;
- Support of ecological habitat and biodiversity;
- Providing raw material; and
- Protecting cultural heritage.

In terms of biowaste a contribution can be made to the viability of soil in at least three of these functions through the return of organic matter. The declining organic

content of soil is a key concern. Organic matter maintains a central role in soil function, in its fertility and its ability to hold water (Flooding is becoming an increasing issue in Europe, the soil's capacity to hold water is of economic significance) and to diffuse pollution, moreover it is the organic matter in soil which holds its carbon and enables it to act as a carbon sink. Declining organic matter is not just a problem in the Southern Mediterranean (Although the Southern Mediterranean is where it is most significant, the UK does nothave a problem on the scale of, for example, Italy) the EU notes :

"in England and Wales the percentage of soil with less than 3.6% of organic matter rose from 35% to 42,% in the period 1980-1995 probably due to changing management practices (EU Soil Strategy COM(2002) 179 Final)."

Intensive farming and inorganic fertilizers have also depleted the soil of carbon reserves and thereby increased the carbon balance in the atmosphere. This can be reserved by intensive applications of good quality compost material produced from organic waste.

Farming

The application of compost to farm land likely to be more complex than these other outlets, nevertheless there are benefits to further consideration.

Agricultural soils are the highest quality to be productive and are crucial in looking at a soil strategy. The EU soil strategy states:

"S*oil protection policies need to have a special focus on sustainable use and management of agricultural soils, with a view to safeguarding the fertility and agronomic value of agricultural land (COM(2002) 179 Final page 8).*

In fact agricultural land in England is generally good but the point on loss of organic matter still applies and maintaining and restoring the quality of the soil remains important.

Benefits may include:

- Improvement of soil quality through an organic process; and
- The possibility that on farm composting can provide a form of farm diversification – and is already carried out successfully.

There are issues which will need addressing, these include:

- The need to inform farmers about the benefits of the use of compost (its benefits are more fore the environment then for yield – which is why it would be appropriate to look at within the context of agri-environment schemes);
- Concerns from farmers about the quality of compost;
- The different requirements and loading tolerances of soil across the UK, for example the need to protect Nitrate Vulnerable Zones;
- The competing use of land for sewage sludge (important now disposal at sea is not an option);
- The geographical disparity between waste arisings and suitable receptor farms;
- The transport and logistical implications, in particular where farms are remote from waste arisings; and
- The implications of the Animal By Products Order.

In economic terms farmers are seeking to diversify and the processing of compost is one form of income that could prove successful. The economics can be supported either through gate fees, where local authorities would otherwise have to pay dispose or process the material, or form the onward sale of compost.

EU Report Recommendation

Recommendation 10; DEFRA to encourage the development of quality standards for compost. These should inform DEFRA's position during any negotiations on tan EU Bio-waste Directive:

Other European countries benefit from the existence of standards for compost that encourage investment and development of markets. Work has already begun in the UK on a standard for compost through the work of WRAP and the Composting Association. Standards are needed for a range of grades of compost and land cover for a variety different end uses from high grade for food production to land restoration and landfill cover. As technologies change these standards need to be output based and they need to take into account the draft EU biowaste working document in anticipation of it being adopted as a Directive.

This recommendation includes development of a biowaste strategy by DEFRA to build on the work of the draft Soil Strategy. It should be made available to local authorities, farmers and strategic planners where soil requires organic replenishment and where there are nitrate and other loading issues.

The strategy should be include :

- Making available a soil map showing where compost may benefit agricultural land;
- Provision of advice to farmers on the agricultural land environmental benefits of compost;
- The contribution compost can make as a carbon sink for the UK climate change programme; and
- The scope for extending Agri-Environment schemes cover the application of compost to farmland as an environmental soil improver and as part of climate change measures.

Recommendation 16 ; WRAP should take forward four measures to reduce waste volumes (including home composting) :

Home composting is a key part of a strategy to reduce waste. It also allows householders to accept greater responsibility for their waste. Home composting also reduces the demand for commercially produced compost – often based on peat.

Clearly home composting will not be useful in all areas, households without gardens or with no interest or commitment to gardening will not home compost. Those householders prepared to home compost will need support and information, badly composted material will provide no benefit to the soil, will be a home compost bins are, equally, simply adding to the waste stream long term.

Recommendation 17; WRAP should take forward two measures to increase recycling and composting (this includes advice to Las on improvement of collection particularly for organics, and the expansion of markets for organic e.g. landscaping, horticulture and agriculture):

Home composting is not the whole answer. even in areas where it is suitable there will be those who do not wish to compost, cannot and there will be time when there is too much material for home composting (there are also effective community composting schemes where groups of residents take communal responsibility and benefit from composting materials). Local authorities then should look to collection and central composting. The EU Biowaste Directive defines compost as:

“the stable, sanitised and humus-like material rich in organic matter and free from offensive odours resulting from the composting process of separately collected biowaste.”

Which points to compost made from source separated material, and the Directive may require such separate collection as a basic requirement.

To be of benefit to the soil composting must be carried out properly and used appropriately. Where a simple shredding and spreading of whole waste is carried out this constitutes landfill, and is of no benefit to the soil and should not be classifield as recovery composting or recycling. Mixed waste composting (for example as a result of MBT of residual waste) can be used as landfill cover, or for land remediation, but this should only be applied to residual waste. Local authorities should seek separate collection and composting of clean waste streams. (www.strategy.gov.uk/downloads/su/waste/downloads/ah.pdf)