İSTANBUL TECHNICAL UNIVERSITY ★ INSTITUTE OF SCIENCE AND TECHNOLOGY

COMPOSTING OF YEAST INDUSTRY BIOSOLIDS BY USING HAZELNUT HUSK AND SHREDDED CORNSTALK AS BULKING AGENTS

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

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MAYA ENDÜSTRİSİ ARITMA ÇAMURLARININ KATKI MALZEMESİ OLARAK FINDIK KAVŞAĞI VE PARÇALANMIŞ MISIR SAPI KULLANARAK KOMPOSTLAŞTIRILMASI

YÜKSEK LİSANS TEZİ

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TABLE OF CONTENTS

ABBREVIATIONS

AW	: Agricultural wastes
AS	: Aerobic Sludge
ANS	: Anaerobic Sludge
BCw	: Biosolids mixed with wood shavings
BCt	: Biosolids mixed with yard trimmings
BTEX	: Benzene, toluen, etilbenzene and xylenes
C/N	: Carbon/nitrogen ratio
CCQC	: California Compost Quality Council
Cd	: Cadmium
CEC	: Cation exchange capacity
Cfu	: Colony forming unit
Cr	: Chromium
Cu	: Copper
COD	: Chemical Oxygen Demand
DTPA	: Diethylene Triamine Pentaacetic Acid
EC	: Electrical Conductivity
EEC	: European Economic Community
EU	: European Union
HH	: Hazelnut Husk
Hg	: Mercury
ICP	: Inductively Coupled Plasma
LOI	: Loss of ignition
MPN	: Most probable number
Ni	: Nickel
OFSCCR	: Organic Fertilizers and Soil Conditioners Control Regulation
OM	: Organic matter
Pb	: Lead
PCBs	: Polychlorinated biphenols
SC	: Shredded Cornstalk
SPCR	: Soil Pollution Control Regulation
TMECC	: Test Methods for the Examination of Composting and Compost
TOC	: Total organic carbon
UASB	: Upflow anaerobic sludge blanket
UK	: United Kingdom
USA	: United States
WC	: Wood chips
WS	: Wood sawdust
VOM	: Volatile organic matter
YT	: Yard trimmings
YTL	: New Turkish Lira
Zn	: Zinc

LIST OF TABLES

LIST OF FIGURES

LIST OF PHOTOGRAPHS

COMPOSTING OF YEAST INDUSTRY BIOSOLIDS BY USING HAZELNUT HUSK AND SHREDDED CORNSTALK AS BULKING AGENTS

SUMMARY

Although composting of biosolids is a widespread method used in all over the world, in Turkey there isn't any plant evaluating their wastes by this method. In the present study, it is accomplished by applying the composting process to the biosolids from Yeast Industry Wastewater Treatment Plant. The main goal of this investigation was to find the optimal ratio of bulking agent to the biosolids. To achieve this aim, four compost piles with a size of $5m^3$, were constructed at the Düzce Pakmaya plant during the fall 2007. The composting process was carried out in open air piles and consisted of a first stage (active composting) lasting one month, during which aeration was ensured by forced ventilation and a second, maturation stage (curing), lasting one month in piles. The overall ratios of bulking agents to biosolids were kept constant as 2:1 for all piles. However, different ratios of hazelnut husk and shredded cornstalk were used within these piles. Bulking agents were applied to lower the moisture content of the biosolids, to increase porosity and to add a source of carbon. The mixing ratios were selected as to decrease the usage of the shredded cornstalk and to see the effect of the composting process. Although shredded cornstalk offers an ideal condition for composting process, it is more expensive than hazelnut husk. After pilot-scale study, the effect of the compost product on the corn crop was searched by pot studies, which were performed at Sabancı University, Engineering and Natural Sciences Department. Corn crop was preferred because it is grown and consumed in the locality. During this study, necessary physical, chemical, and microbiological analyses were conducted to determine the stability of the compost. Finally, it has been proven in this study that composting of the biosolids from yeast industry is a sustainable solution for improving the low organic matter content of our soils.

MAYA ENDÜSTRİSİ ARITMA ÇAMURLARININ KATKI MALZEMESİ OLARAK FINDIK KAVŞAĞI VE PARÇALANMIŞ MISIR SAPI KULLANARAK KOMPOSTLAŞTIRILMASI

ÖZET

Arıtma çamurlarının kompostlaştırılması dünyada yaygın olarak kullanılan bir metot olmasına karşın Türkiye'de atıklarını bu metotla değerlendiren bir arıtma tesisi mevcut değildir. Bu çalışmada, maya endüstrisi arıtma çamurlarının kompostlaştırılabilirliği araştırılmıştır. Çalışmada optimum arıtma çamuru katkı malzemesi oranını bulmak amacıyla 2007 güz döneminde $5m^3$'lük dört kompost yığını Düzce'deki Pakmaya tesislerinde oluşturulmuştur. Yığınlarda gerçekleştirilen kompostlaştırma prosesi iki aşamadan oluşmaktadır. İlk aşaması bir ay boyunca yığınlara basınçlı hava verilen aktif kompostlaştırma, ikincisi ise yine bir ay süren olgunlaştırma sürecidir. Bütün yığınlarda toplam katkı malzemesi:arıtma çamuru oranı 2:1 olarak sabit tutularak, yığınlarda farklı oranlarda fındık kavşağı ve parçalanmış mısır sapı katkı malzemesi olarak kullanılmıştır. Katkı malzemeleri arıtma çamurunun su muhtevasını düşürmek, porozitesini artırmak ve karbon ilavesi için kullanılmıştır. Parçalanmış mısır sapı kompostlaştırmada uygun koşullar oluştursa da fındık kavşağından daha pahalı olduğu için yığınlarda kullanılan karışım oranları, parçalanmış mısır sapının kullanımını azaltacak şekilde seçilmiştir. Pilot ölçekli çalışmadan sonra kompost ürününün mısır bitkisi üzerindeki etkileri Sabancı Üniversitesi, Mühendislik ve Doğa Bilimleri Bölümünde gerçekleştirilen saksı denemeleriyle araştırılmıştır. Mısır bitkisi yörede yetiştirilen ve tüketilen bir bitki olduğundan seçilmiştir. Bu çalışma sırasında kompostun stabilitesini belirleyebilmek için gereken fiziksel, kimyasal ve mikrobiyolojik analizler yapılmıştır. Sonuçta, bu çalışmayla maya endüstrisi arıtma çamurlarının kompostlaştırılmasının organik madde miktarı düşük topraklarımızın iyileştirilmesinde sürdürülebilir bir çözüm olduğu ortaya konmuştur.

1. INTRODUCTION

1.1. The Meaning and the Importance of the Thesis

Industries and, in parallel to that, waste generation rates increase rapidly which in turn results in certain pollution problems because of uncontrollable dumping of wastes. Most of the industries have a treatment plant and so have a waste at the end of the treatment. It is called as sewage sludge (the name for the solid, semisolid or liquid untreated residue generated at the end of the wastewater treatment facility). Biosolids are the nutrient rich organic materials resulting from the treatment of sewage sludge. When treated and processed, sewage sludge becomes biosolids, which can be safely recycled and applied as fertilizer to sustainably improve and maintain productive soils and stimulate plant growth [1].

In Turkey, there aren't any more alternatives for disposal of biosolids because some limitations exist for the methods, which are disposal in landfills or direct application to the land or incineration. For instance, the stability of the landfill is adversely affected when the biosolids are placed. In addition, bans on disposal of biosolids in landfills, landfill capacity concerns, and landfill closures have greatly hindered the use of landfills as a disposal option. Also, direct application to the land is restricted by "Soil Pollution Control Regulation". The other option is incineration but it is costly and inadequate capacity of the incineration facility in Turkey has restricted this option.

Therefore, other alternatives should be considered for the disposal of biosolids. Composting process is one of the alternatives for the treatment of the biosolids especially from food industry. Because of rich nutrient content, low amount of heavy metals and compost is a solution for improving the low organic matter content of soils.

From this point of view, the importance of this study may be accomplished by composting of biosolids from yeast industries. Raw biosolids contained high numbers of pathogen microorganisms but when this material was submitted to composting process, microorganisms decreased to suitable level. Therefore, we can say that composting process decompose biosolids into a beneficial product.

1.2. The Objective and the Scope of the Thesis

The purpose of this study was to investigate the feasibility of composting of yeast industry biosolids. In order to achieve this goal, the objective of the thesis was carried out in two consecutive stages:

1.2.1. Pilot Work

Pilot scale compost trials were conducted at Düzce Pakmaya Plant. The scope of this investigation was to find the optimal ratio of bulking agents to the biosolids. By using this pilot plant, process control variables were monitored. Parameters were measured and were checked according to the relevant regulations in order to satisfy the criteria as a proper soil conditioner.

1.2.2. Pot Studies

The scope of pot study was to see the effects of the compost product on soil improvement. To prove this, pot studies were performed at Sabanci University, Engineering and Natural Sciences Department. At the end of the study, the finished compost should have certain properties in order to find customer as a soil conditioner.

2. LITERATURE REVIEW

2.1. Definition

Generally speaking, composting can be defined as the biological decomposition of the putrescible organic materials of wastes under controlled conditions. More specifically, different definitions can be given such as, it is the decomposition of heterogeneous organic matter by a mixed microbial population in a moist, warm, aerobic environment [2]; or it is the process of converting putrescible residues to more stable organic materials for use as fertilizers and soil conditioners [3]; or it is the process in which aerobic biological decomposition takes place so that some of the organic material is decomposed to carbon dioxide and water while stabilized products, principally humic substances, are synthesized [4]. As it can be understood from different definitions, basically, composting includes biological breakdown or decomposition of organic materials of waste by the help of microorganisms under certain environmental conditions. Furthermore, Epstein summarized the composting process in the following sentence; "*Composting is the highest form of recycling and it is an organic matter resource and properly produced compost adds humus to soils*" [5].

2.2. Composting Systems

Composting involves mixing dewatered biosolids with a bulking agent (such as wood chips, municipal yard trimmings, bark, rice hulls, straw, or previously composted material) and allowing the biosolids mixture to decompose aerobically (in the presence of oxygen) for a period of time. The bulking agent must be used to lower the moisture content of the biosolids, to increase porosity, and to add a source of carbon. Depending on the method used, the biosolids compost can be ready in about 3 to 4 weeks of active composting followed by about one month of less active composting (curing).

Three different composting processes are typically used: windrow composting, aerated static piles, and in-vessel composting. In windrow composting, the biosolids and bulking agent mixture are formed into long, open-air piles. The piles are turned frequently to introduce oxygen into the pile, ensure that adequate moisture is present throughout the pile, and ensure that all parts of the pile are subjected to temperatures of 55^{o}C for destruction of pathogens. Aerated static piles are rectangular piles supplied with oxygen via blowers connected to perforated pipes or grates running under the piles. In-vessel composting takes place in a completely enclosed container where temperature and oxygen levels can be closely monitored and controlled. Also, in-vessel composting produces very little odor. It is known that various odor control measures, such as frequent turnings, are used in conjunction with most composting operations. Frequent turnings help reduce odor producing anaerobic pockets in the composting biosolids by introducing oxygen and remixing pile ingredients. This approach, however, might not work well for large operations near residential areas because the turnings themselves (while adding more oxygen to the process) generate more odors initially. In these cases, timing the turnings to occur when conditions are ideal (such as when climate conditions are most advantageous) is used to minimize odors as well as collecting and scrubbing the off gasses chemically or biologically (through packed towers, mist towers, or constructed biofilters) [6].

2.3. The Process Steps in a Composting Plant

Certain sequential steps must exist in any composting plant regardless of its type. These are namely as; mixing, composting, screening, and storage.

In a composting facility, the dewatered biosolids is mixed with one or more bulking agents to adjust the moisture content, to improve the structure of the feedstock and/or to add carbon for the adjustment of energy balance and carbon/nitrogen ratio (C/N). The mixture is then moved to the composting area. The three main current composting technologies are open windrow, open aerated static piles and reactor systems. Various process control strategies attempt to optimize the conditions for the degrading microorganisms and the destruction of pathogens in the compost [7].

Composting phase is actual operational phase of bacterial decomposition during which waste organic matter is decomposed into humic substances and harmless material. This step can be considered as the heart of whole process because the conditions within this step (temperature, humidity, oxygen, etc.) directly affect the system. In fact, composting process, as it can be understood from its name, depends on this step. Compost or, after screening, like wood chips, can be recycled for reuse. After screening, which in many cases is conducted during composting as an intermediate step, the final step comes in which composted material is let to get mature before marketing. Its another name is curing stage and it directly affects the area requirement [7]. Figure 2.1 shows typical process steps in a full-scale plant.

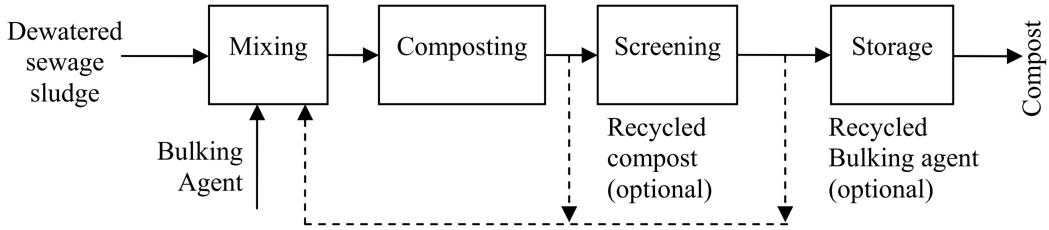


Figure 2.1. Typical process steps in a full-scale plant

2.4. Environmental Factors

Since the nature of the reactions within the compost reactor is biochemical, the environmental conditions should be suitable for the working microorganisms. The duration of the composting can be reduced, hence the capital cost can be minimized; further a good product can be obtained only after creating suitable environmental conditions for the bacteria. There are certain factors, which should be considered as important for the efficiency of a composting unit;

2.4.1. C/N Ratio

The two most important nutrients are carbon and nitrogen for the composting process. The C/N ratios during composting affect the process and the product. The important parameter is the carbon available to microorganisms, not the total carbon in the material. The C is utilized for cellular growth. On the other side, microorganisms need N for protein synthesis [8].

The amount of nutrients necessary for composting depends on the chemical composition of the decomposing microorganisms and additional elements that are involved in the metabolism. With the exception of nitrogen, biodegradable wastes generally contain enough macronutrients including carbon, sulphur, phosphorus, potassium, magnesium, calcium, and micronutrients to sustain the composting process. Very uniform feedstocks can create exceptions [7].

Suitable C/N ratios at the beginning of the composting process are between 20:1 to 30:1 for most wastes. However, it must be emphasized that this ratio varies depend on the feedstocks. Higher C/N ratios slow down the microbial degradation and lower C/N ratios result in the release of nitrogen as ammonia. The most important method of controlling this ratio is by varying the composition of the initial feedstock [7].

2.4.2. Moisture Content

Moisture is required for the growth and multiplication of the microorganisms within the compost unit. It should be within certain limits in order to get acceptable composting durations and to reach the thermophilic conditions. Optimum moisture content should be around 55% [3]. If moisture content below 20%, the biological reaction stops; if it is higher than 60%, undesirable anaerobic conditions develop due to the fact that pores are not open for oxygen diffusion (penetration) to reach microorganisms [2].

Also, moisture in the composting process can affect microbial activity and thus influence temperature and rate of decomposition. In addition, moisture can affect the composition of the microbial population [9]. Moisture is produced as a result of microbial activity and the biological oxidation of organic matter. On the other hand, water is lost through evaporation. Based on work using a laboratory composter, Viel et al. (1987) reported that water released through microbial activity was greater than water lost through evaporation [10].

2.4.3. pH

The literature indicates no pH control problem during composting process as long as the system is kept under aerobic conditions. However, pH is an important process evaluation (control) parameter during the decomposition. To achive an optimum aerobic decomposition, pH should remain at 7 to 7.5 range. To minimize the loss of nitrogen in the form of ammonia gas, pH should not rise above 8.5 [11].

2.4.4. Temperature

Temperature is the primary factor affecting microbial activity in composting [5]. It is a bio-oxidative microbial degredation process of mixed organic matter. This exothermic process produces a relatively large quantity of energy. Only 40-50% of this energy can be utilized by microorganisms to synthesize ATP; the remaining energy is lost as heat in the mass. This large amount of heat causes an increase of temperature in the mass and can reach temperatures of the order of 70-90ºC. High temperatures inhibit microbial growth, slowing the biodegradation of organic matter. Only few species of thermophilic bacteria show metabolic activity above 70ºC. For the most efficient operation, the temperature in the compost should range between 55 and 65^{o}C but not above 80^{o}C. High temperatures are also required for the inactivation of pathogens in the biosolids. The temperature distribution in a compost pile is affected by the following factors [12]:

- Moisture content
- Aeration rates
- Size and shape of pile
- Atmospheric conditions
- Nutrients

For example, temperature elevation will be less for a given quantity of heat released if excessive moisture is present, as heat will be carried off by evaporation. On the other hand, low moisture content will decrease the rate of microbial activity and thus reduce the rate of heat evaporation [13].

The time-temperature relationship affects the rate of decomposition of the organic matter and therefore it is important for the production of a stable and mature product for consumer use. It should be kept in mind that temperatures exceeding 55^{o}C must be maintained for several days if waste contains pathogens.

2.4.5. Microorganisms

During the aerobic composting process, a succession of facultative and obligate aerobic microorganisms is active. As a biological process, composting involves a myriad of microorganisms. These organisms decompose organic matter and organic compounds. Several important factors affect the microbiological population. These include oxygen, moisture, temperature, nutrients and pH. Because of complex nature of organic matter and many organic compounds, both natural and xenobiotic, many microbes and other organisms are involved in the decomposition process [5].

In the beginning phases of the composting process, mesophilic bacteria are the most prevalent. After the temperatures in the compost rise, thermophilic bacteria predominate, leading to thermophilic fungi, which appear after 5 to 10 days. In the final stages, or curing period as it is sometimes known, actinomycetes and molds appear. The die-off of pathogens is a function of time and temperature. For example, the Salmonella species of bacteria can be destroyed in 15 to 20 minutes when exposed to a temperature of 60^oC, or in one hour at 55^oC.

2.4.6. Aeration

During aerobic metabolism, sufficient supply of oxygen is essential. Besides supplying oxygen, aeration has the function of drying the compost and controlling temperatures in the compost that could be detrimental to microorganisms [7].

Oxygen can be provided by active aeration (forced-pressure or vacuum-induced aeration), by natural ventilation (diffusion and convection) or to a lesser extent by turning. Forced-pressure aeration is more energy-efficient than vacuum-induced aeration. However, vacuum-induced aeration has the advantage that the off-gases can easily be captured for the treatment [7].

If active aeration is used, the airflow rate, frequency and length of aeration periods, the direction (forced-aeration, vacuum-induced), type (fresh recirculated off-gases), and condition (temperature, humidity) of the aeration air can be varied [7].

2.4.7. Bulking Agents

All biosolids composting methods require the use of bulking agents, but the type of agent varies. Wood chips, sawdust, and shredded tires are commonly used, but many other materials are suitable. The U.S Composting Council lists the following materials as suitable for use as bulking agents:

- Agricultural by-products, such as manure and bedding from various animals, animal mortalities, and crop residues.
- Yard trimmings, including grass clippings, leaves, weeds, stumps, twigs, tree prunings, Christmas trees, and other vegetative matter from land clearing activities.
- Food by-products, including damaged fruits and vegetables, coffee grounds, peanut hulls, egg shells, and fish residues.
- Industrial by-products from wood processing, forestry, brewery and pharmaceutical operations. Paper goods, paper mill residues, and biodegradable packaging materials are also used.
- Municipal solid waste.

2.5. Design Considerations

The principle design considerations associated with the aerobic sludge composting are summarized in Table 2.1. It can be concluded from this table that the preparation of a composting process is not a simple task, especially if optimum results are to be achieved. For this reason, most of the commercial composting operations that have been developed are highly mechanized and are carried out in specially designed facilities [14].

Table 2.1. Design Considerations for Aerobic Sludge Composting Processes

Item	**Comment**
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
Amendments and bulking agents	Amendment 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.
Carbon-nitrogen 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
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
Moisture content	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
pH control	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
Temperature	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
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 h. For temperatures and times of exposure required for the destruction of common pathogens.
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
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 the product

2.6. Advantages & Disadvantages

Biosolids composting has grown in popularity for the following reasons [15]:

- Lack of availability of landfill space for solids disposal.
- Composting economics are more favorable when landfill tipping fees escalate.
- Emphasis on beneficial reuse at national and local levels.
- Ease of storage, handling, and use of composted product.
- Addition of biosolids compost to soil increases the soil's phosphorus, potassium, nitrogen, and organic carbon content.

Composted biosolids can also be used in various land applications. Compost mixed with appropriate additives creates a material useful in wetland and mine land restoration. The high organic matter content and low nitrogen content common in compost provides a strong organic substrate that prevents overloading of nitrogen, and adsorbs ammonium to prevent transport to adjacent surface waters [16]. Compost amended strip-mine spoils produce a sustainable cover of appropriate grasses, in contrast to inorganic-only amendments, which seldom provide such a good or sustainable cover [17]. Compost enriched soil can also help suppress diseases and ward off pests. These beneficial uses of compost can help growers save money, reduce use of pesticides, and conserve natural resources. Compost also plays a role in bioremediation of hazardous sites and pollution prevention. Compost has proven effective in degrading or altering many types of contaminants, such as wood-preservatives, solvents, heavy metals, pesticides, petroleum products, and explosives. Some municipalities are using compost to filter storm water runoff before it is discharged to remove hazardous chemicals picked up when storm water flows over surfaces such as roads, parking lots, and lawns. Additional uses for compost include soil mulch for erosion control, silviculture crop establishment, and sod production media [18]. In addition to these, some limitations of biosolids composting may include:

- Survival and presence of primary pathogens in the product.
- Lack of consistency in product quality with reference to metals, stability, and maturity.

- Odor and bioaerosol emissions can occur during the process. These odors and bioaerosols can be controlled through better facility design and operations management [5].
- Composting facilities take up more space than some other waste management technologies. Space requirements are often related to storage and market demand [5].

2.7. Compost Quality Standards

Some properties of the finished compost should be satisfied by the regulations before applying to the land. In Turkey, regulations about composting such as Organic Fertilizers and Soil Conditioners Control Regulation (OFSCCR) and Soil Pollution Control Regulation (SPCR) are not very illustrative.

Organic Fertilizers and Soil Conditioners Control Regulation (OFSCCR, 2004) give some limitations for application of compost to the land. For instance, total inert matters in the compost should not be higher 2% of the total weight. Minimum organic matter should be 25%. The maximum moisture content should be 20%. Arsenic in the dry matter should not exceed 20mg/kg. Maximum salinity value should be 4mmhos/cm. Also, the highest heavy metal concentrations permitted in organic fertilizers are shown in Table 2.2, which is given in Organic Fertilizers and Soil Conditioners Control Regulation [19] .

Table 2.2. The highest heavy metal concentrations permitted in organic fertilizers (mg/kg)

Parameter	Symbol	Value
Cadmium	(Cd)	3
Copper	(Cu)	450
Nickel	(Ni)	120
Lead	(Pb)	150
Zinc	(Zn)	1100
Mercury	(Hg)	5
Chromium	(Cr)	270

On the other hand, the present requirements as to disposal of sludge on soil are stated in the Turkish regulation "Soil Pollution Control Regulation", 2005 (SPCR). Many clauses of this regulation are in line with the requirements of the EU directive, and all specific parameter limits are identical to the directive requirements. The tables below provide a comparison between the Turkish requirements and the directive requirements [20].

According to SPCR, the compost product should provide the following criteria:

- If C/N ratio is higher than 35, N should be added to compost reactor in order to provide optimum conditions for composting process.
- The organic matter content of compost should be at least 35% of dry solid.
- Water content of marketed compost should not exceed 50%.
- Materials such as glass, slag, metal, plastic, leather should not exceed 2% of total weight in the marketed compost.
- The heavy metal content of produced compost should be determined in every 6 months by analyzing the dry solid content, lead, calcium, chromium, copper, nickel, mercury and zinc concentrations.
- The parameter analysis found in Soil Analyze Document (in Annex II-A of this Regulation) should be done in every 12 months in the soil in which the compost product will be used.
- The soil and compost samples should be taken as appropriate to the sampling techniques and should represent all mass.
- In case the heavy metal contents of the soil exceed the values given in Table 2.3, compost should not be applied to this soil.
- Limit values for quantities of heavy metals, which may be added annually to agricultural land, based on a 10-year average, is given in Table 2.4.

Table 2.3. Limit values for heavy metals in soil

Parameter in mg/kg oven dry soil	**EU 86/278/EEC**	**Turkish SPCR 24609**	
	-	**pH < 6**	**pH > 6**
Cadmium (Cd)	1-3	1	3
Copper (Cu)	50-140	50	140
Nickel (Ni)	30-75	30	75
Lead (Pb)	50-300	50	300
Zinc (Zn)	150-300	150	300
Mercury (Hg)	1-1.5	1	1.5
Chromium (Cr)	-	100	100

Table 2.4. Limit values for quantities of heavy metals which may be added annually to agricultural land, based on a 10-year average

Parameter in kg/ha/year	EU 86/278/EEC	Turkish SPCR 24609
Cadmium (Cd)	0.15	0.15
Copper (Cu)	12	12
Nickel (Ni)	3	3
Lead (Pb)	15	15
Zinc (Zn)	30	30
Mercury (Hg)	0.1	0.1
Chromium (Cr)	-	15

Because TOC content of the wastewater treatment sludges from food industry is so high, they are classified as hazardous waste according to the Hazardous Waste Control Regulation (Table 2.5). The most appropriate way of decreasing the carbon content of waste is applying composting procedure to the treatment sludges. Moreover, the treatment sludges are stabilized by composting process. Because of these reasons, composting is accepted as an appropriate method for the disposal of treatment sludges.

Table 2.5. The criteria given for the wastes, which can be, stored in sanitary landfill plants (Annex-11 A)

		Wastes which will be considered as Inert Waste (mg/lt)	Wastes which will be considered as Non-Hazardous Waste (mg/lt)	Wastes which will be considered as Hazardous Waste (mg/lt)
2	Criteria which will be considered in original waste	(mg/kg)	(mg/kg)	(mg/kg)
2.1	TOC(total organic carbon)	≤30000 (%3)	50000 (% 5)- pH ≥ 6 (2)	60000 (%6)
2.2	BTEX(benzene, toluen, etilbenzene and xylenes)	6		
2.3	PCBs	1		
2.4	Mineral oil	500		
2.5	LOI (Loss of ignition)			10000 (%10)

Note: (2) Gypsum based non-hazardous wastes should be stored in a separate cell in which the wastes solubilized in domestic waste sanitary landfill area is not accepted. The wastes stored with gypsum based wastes have to provide these limits.

Aside from heavy metal concentrations, there are no standards for finished compost. Some countries are in the process of developing standards to minimize negative environment effects (pathogens, heavy metals and organic pollutants). Others require tests for biological stability and compost use related properties (salt content, pH, C:N ratio). In Table 2.6, the standards of the different countries are summarized.

Table 2.6. Standards for different countries

Parameters /Element	STANDARDS							
	SPCR	OFSCCR	Europe Eco Label Standards	86/278/EEC	Canada	USA	Austria	Germany
Org. Matter, %	> 35	> 25	>20	-	-	>30	>20	>15
Moisture, %	<50	< 20	<75	-	-		-	<45
EC, (mmhos/cm)	-	< 4	-	-	-	-	-	-
C/N	<35	-	-	-	<25	-	-	-
Salmonella	-	-	Not detected in 25g	-	<3MPN/4g	-	-	-
Cu, mg/kg	1750	450	70	50	100	1500	70	100
Zn, mg/kg	4000	1100	200	150	500	2800	200	400
Cd, mg/kg	40	3	1.0	1.0	3	39	0.7	1.5
Pb, mg/kg	1200	150	100	50	150	300	45	150
Ni, mg/kg	400	120	75	30	62	420	25	50
Cr, mg/kg	1200	270	50	50	210	1200	70	100
Co, mg/kg	-	-	-	-	34	-	-	-
Hg, mg/kg	25	5	1.0	1.0	0.8	17	0.4	1
As, mg/kg	-	-	-	-	13	41	-	-

Note: 86/278/EEC = Sewage Sludge Directive, European Economic Community

2.8. Applicable to Soil

Application of biosolids compost to agricultural soils has many advantages, which include providing a whole array of nutrients for plant growth (e.g. phosphorus, nitrogen and organic matter), increasing beneficial soil organisms, reducing the need for fertilizers and pesticides, and improving soil physical and biological properties [21]. However, land application of biosolids compost has been limited by its enriched heavy metal contents [22, 1, 23].

2.9. Compost Research for Vegetable Cropping Systems

Feedstocks for composts evaluated on vegetable crops may affect soil characteristics, crop growth and, ultimately, yield in distinct ways. Research projects also generally center on crops that are grown and consumed in the local area or country where the work is performed. Therefore, research results are difficult to categorize. Nevertheless, worldwide compost quantities are increasing, compost quality is improving, and more commercial vegetable growers are evaluating compost or integrating it into their production systems.

A summary of recent research reporting effects of compost on vegetable crop growth and yield is provided in Table 2.7 [24].

Table 2.7. Summary of recent research reporting effects of compost on vegetable crop growth and yields

Crop	Compost	Growth Response	Yield Effects	Reference
Alliaceae Onion	BS/AW	NA	+, =	Smith et al., 1992
	BS/WC	NA	+	Bevacqua and Mellano, 1993
Asteraceae Lettuce	BS/WC	NA	+	Bevacqua and Mellano, 1993
Cabbage	BS/AW	NA	+	Smith et al., 1992
Chenopodiaceae Spinach	BS	NA	+, =	Mellano and Bevacqua, 1992
Poaceae Corn	BS/YT	NA	-	Hornick, 1988
Pepper	BS/YT	NA	=	Roe and Stoffella, 1994b
	BS/YT		+	Roe et al., 1997
Tomato	BS/YT	NA	=	Roe and Stoffella, 1994a
	BS	NA	+	Allen and Preer, 1995

Note: BS, biosolids; AW, agricultural wastes; WC, wood chips; YT, yard trimmings.NA, +, –, = represent: information not available, increased, decreased, or equal, respectively.

2.10. Researches

The principal researches about composting of biosolids are summarized below:

F. Laos et al. (2002), investigated to compost lime treated biosolids (15% solid content) with wood shavings and yard trimmings during the summer of 1996 and winter of 1997 in NW Patagonia using turning piles. In this study, biosolids was mixed with wood shavings (BCw) and yard trimmings (BCt) at 1:1 ratio by volume, using piles 3×3×1.40m. It was observed from this study that composting of biosolids was affected by the type of bulking agent during winter. For example, temperatures were found low during the first 48 days of the static pile trial. Because of that, piles were taken to an open site and changed to the turning system, then higher temperatures were obtained. Furthermore, four more turning were conducted when temperature declined. It was found that BCw and BCt were reached ambient temperature, after a composting period of 150 days. Also, thermophilic temperatures were sustained to reduce pathogens in BCw and BCt. In the summer, both agents, wood shavings and yard trimmings, exhibited optimal behavior, while in the winter yard trimmings were observed more adequate to achieve temperatures requirements for pathogen reduction. Therefore, it can be concluded that for activated biosolids with low solid contents, the static pile method proved to be ineffective [25].

C. Liang et al. (2003), searched to understand the relationship between temperature, moisture content, and microbial activity during the composting of biosolids (municipal wastewater treatment sludges). Controlled incubation experiments were conducted using 2-factor factorial design with six temperatures (22, 29, 36, 43, 50, and 57^oC) and five moisture contents (30, 40, 50, 60, and 70%). The microbial activity was measured as O_2 uptake rate (mg $g^{-1}h^{-1}$). In this study, it was found that the maximum O_2 uptake rate was not significantly different in the treatments at 50%, 60%, and 70% moisture content. However, treatments with moisture content 50% or greater were observed significantly different from the treatment at 40% moisture, which was higher and significantly different from the treatment at 30% moisture content. Also, the magnitude of cumulative O_2 uptake was found to be highest at 43^oC. Although this cumulative uptake at 43^oC was significantly higher than that at 22, 29, and 36^oC, there was no significant difference between cumulative uptakes at 43, 50 and 57^oC. At lower moisture contents of 30% and 40%, 43^oC was observed as the optimal temperature setting for the 10 day cumulative O_2 uptake. However, it was noticed that at higher moisture contents (50%, 60%, and 70%), this was not always the case. When moisture was 50%, 29^oC had significantly higher cumulative O_2 uptake than 43^oC, while at 60% moisture, no significant difference in the 10 day cumulative O_2 uptake between 43 and 57^oC, both of which had the highest in comparison with other temperature settings was observed. In this study, it was found that moisture content effects are more influential than temperature [26].

Banegas et al. (2006), explored the most suitable ratio of sludge:sawdust for sludge composting and the influence of the sludge nature (aerobic or anaerobic) on the composting reaction rate. In this study, two different sewage sludges (aerobic, AS, and anaerobic ANS) were composted with wood sawdust (WS) as bulking agent at two different ratios (1:1 and 1:3 sludge:sawdust, v:v) and submitted to a process of aerobic composting with periodic turning. Triplicate 3m^3 piles were prepared with each mixture. Samples were taken randomly from within the piles and from the outer layer 1, 15, 30, 45, 60, and 90 days after the beginning of the composting process. The moisture content of the piles was maintained at about 60-70% of their water holding capacity throughout the composting period. The maximum thermophilic temperatures reached in the both aerobic sludge piles. On the other hand, the anaerobic sludge showed significantly lower thermophilic temperatures in the 1:1 piles than in the 1:3. This particular behavior of ANS + WS 1:1 was explained as the toxic substances derived from the anaerobic treatment. Also, in the 1:3 mixtures this toxic effect would be diluted by higher proportion of bulking agent. The anaerobic sludge showed a slower organic matter (OM) mineralization rate than the aerobic sludge, decreases in OM concentration with composting being 12.69% and 6.30% for AS+WS 1:1 and 1:3 mixtures, respectively. This was explained by the more stable nature of the OM of the anaerobic sludge with lower content of easily biodegradable compounds. The authors concluded that sawdust was a good bulking agent for use with sewage sludges. Both the proportions assayed allowed composting to develop adequately in the case of the aerobic sludge mixture. However, the 1:1 proportion appeared more suitable for aerobic sludges, with its low concentration of phytotoxic substances, because of lower dilution effect on the nutritional components of the compost and less expenses in transport and bulking agent. Anaerobic sludge mixture studied with its higher conductivity and the presence of other toxic and phytotoxic substances, a 1:3 proportion was recommended because of the dilution effect on these parameters [27].

Yamada and Kawase (2006), investigated kinetics for microbiological reaction and oxygen consumption in composting of waste activated sludge in order to examine the optimal design and operating parameters using 4 and 20L laboratory scale bioreactors. In this study, aeration rate, compositions of compost mixture and height of compost pile were investigated as main design and operating parameters. The optimal aerobic composting of waste activated sludge was found at the aeration rate of 2.0 L/min/kg (initial composting mixture dry weight). A simple model for composting of waste activated sludge in a composting reactor was developed by assuming that a solid phase of compost mixture was well mixed and the kinetics for microbiological reaction was represented by a Monod type equation. In addition, oxygen consumption was represented by this equation and the axial distribution of oxygen concentration in the composting pile was described by a plug flow model. Thus, the results of this paper presented that, even if kinetic studies of composting processes wasn't elucidated a complete picture of the composting process, they improved understanding of phenomena occuring in composting reactor and, as a result, were useful to the design and operation of composting reactors for waste activated sludge [28].

Hernández et al. (2006), investigated that aerobic composting of two sewage sludges (aerobic, AES, and anaerobic, ANS) mixed with sawdust (S) as bulking agent at two different ratios (1:1 and 1:3 sludge:sawdust, v:v) with periodic turning, using 3m^3 triplicate piles. The composting piles were turned periodically (every 4–5 days) during 3 months (Indore system) to maintain adequate O_2 levels. The moisture content of the piles was maintained at about 60–70% of the water holding capacity throughout the composting period, and the temperature of the surface and the interior of each pile was monitored daily. Samples were taken for analysis 1, 30, 60 and 90 days after the beginning of the composting process. It was observed that the volatile organic matter (VOM) content decreased in all of the composted mixtures throughout composting. Differences were observed between the two sludges as influenced by the proportion of bulking agent in the composting mass. Thus, for the aerobic sludge, the losses of VOM were greater in the 1:1 mixture (15.9%) than in the 1:3 mixture (10.5%), which can be explained by the higher proportion of labile organic matter present in the AES + S 1:1 pile than in the AES + S 1:3 pile. However, the anaerobic sludge behaved in the opposite way, with VOM losses being lower in the 1:1 mixture (8.45%) than in the 1:3 mixture (15.3%), suggesting that, in this case, due to the more stable character of the anaerobic sludge, the higher oxygenation reached in the ANS + S 1:3 pile than in the ANS + S 1:1 pile resulted in a higher microbial activity and hence greater organic matter mineralization. It is known that water soluble carbon is one of the most labile fractions of the organic matter; it is easily decomposed by microorganisms and contributes to maintaining a high level of microbial activity. This fraction is composed of compounds such as carbohydrates, polyphenols and amino acids, besides the soluble fraction of fulvic acids. In this study, this fraction decreased throughout the composting process. The addition of bulking agent decreased the water soluble carbon content of the mixtures, the 1:3 mixtures showing lower values of this fraction than the 1:1 mixtures, which indicates that the bulking agent has a lower content of water soluble carbon compounds than the sludges being composted. The proportion of bulking agent in the composting mixture seems to influence the evolution of this fraction during composting; for example, the 1:3 mixtures showed a steady decrease during composting whereas in the 1:1 mixtures the values of this carbon fraction fluctuated along the process. These fluctuations are due to the fact that the water soluble fraction is a dynamic fraction and this kind of carbon substrate is continuously formed and degraded during composting. Hemicellulose and cellulose fractions are degraded during composting and may give rise to more labile substrates. Likewise, new water soluble carbon compounds of microbial origin may be formed during composting, since composting is a synthesis process. The decrease of this carbon fraction during composting indicates that microorganisms use these water soluble compounds as a carbon source to build their own structures and to alter other more resistant carbon fractions, reflecting the greater stability of the organic matter of the final product (compost). In conclusion, the sludge composts showed a lower labile organic matter fraction than the starting sludges. When sludge composts added to the soil, it will be slower than that of a fresh sludge; it will therefore remain longer in the soil thus exerting a more durable positive effect on the physical characteristics of the soil and acting as gradual effect fertilizers. Due to the more humified character of compost, it will make a better contribution than fresh sludge to the humic substances pool of a soil [29].

T. A. Butler et al. (2001), tested three methods for determining compost maturity. Vacuum-filtered, lime-stabilized biosolids was mixed with wood chips in a ratio of 4:3 parts wood chips to biosolids by volume. Individual piles were 3.0×6.1×30m in dimension and contained approximately $549 m^3$ of material. Days 1 through 28 comprised the "actively composting" pile (Stage I). After Day 28, the pile was torn down and sieved to remove large wood chips. The sieved material was moved to the curing building, where a new aerated pile (Stage II) was constructed. In this study, researchers investigated the changes occuring in the following three variables with composting time and length of storage period: (i) Dewar flask self-heating capacity, (ii) oxygen uptake rate, and (iii) cation exchange capacity (CEC). Based on the results, mathematical models were developed that predict change in the variables with time and storage at 4°C. As temperatures decline and the readily available substrate is used up, actinomycetes and fungi become dominant. Actinomycetes and fungi are important in the degradation of cellulose and lignin, which are more resistant to attack. There was less biological activity found in stored samples than in samples tested fresh, which may be due to the decrease in readily available substrate after Day 15 of composting. Other reasons for reduced biological activity could be (i) the microorganisms were more vulnerable to storage effects and were less able to re-bound after cold storage or (ii) a change in microbial population occurred and these organisms are less tolerant of cold storage. Storage effects on unstable composts are small but as composts mature, extended storage will alter the maximum temperature rise, suggesting a more stable compost than recorded for a compost tested fresh. It appears from the CEC data that biodegradation continues under refrigeration, possibly due to the activity of psychrotrophs, which may metabolize the substrate under refrigeration. The Dewar flask self-heating test was the most useful indicator of compost maturity. This test showed change throughout the 57d biosolids composting period while oxygen respirometry did not change after 29d. The CEC was found to increase with age and storage. Storage effects varied for the different tests. Except for Days 1 and 57, composts continued to stabilize during storage. Testing stored composts may produce erroneous results that suggest the compost is mature. Results of this study indicate the necessity of timely analysis in order to avoid the problem of prolonged sample storage. Results showed that changes in indicator values in samples refrigerated for up to 3 month [30].

2.11. General Information about the Pakmaya Izmit Plant

In this work, biosolids from Pakmaya Yeast Industry Wastewater Treatment Plant is used. General information about the treatment plant is given below.

Pakmaya manufactures baker's yeast in its Izmit plant. Baker's yeast, a fermented product used in the preparation of bread, is manufactured by the aerobic fermentation of selected strains of Saccharomyces cerevisiae [8]. The production of baker's yeast using sugar beet molasses includes processes such as molasses preparation, fermentation, and separation and drying of the yeast. Chemicals such as sulfuric acid, phosphoric acid, mono ammonium phosphate, ammonium hydroxide, sodium hydroxide, sodium hypochlorite, and various salts are used in the different stages of the production process and during the cleaning of the equipment. High strength process wastewaters originate from yeast separators such as centrifuges and rotary vacuum filters. Medium and low strength process wastewaters originate from floor washing and equipment cleaning. The high strength process wastewaters are routed to the on site waste treatment plant where the wastes are treated in a two stage anaerobic-aerobic process. A flow diagram of the wastewater treatment plant is shown in Figure 2.2. The medium and low strength process wastewaters and domestic wastewaters are sent directly to the aerobic treatment facility. The anaerobic reactors are of the upflow anaerobic sludge blanket (UASB) type and the aerobic system is of the extended aeration activated sludge type. The excess sludges are centrifuged at the sludge facility. The waste sludges generated are either composted or disposed of by land application. A flow diagram of the sludge processing is included in Figure 2.2.

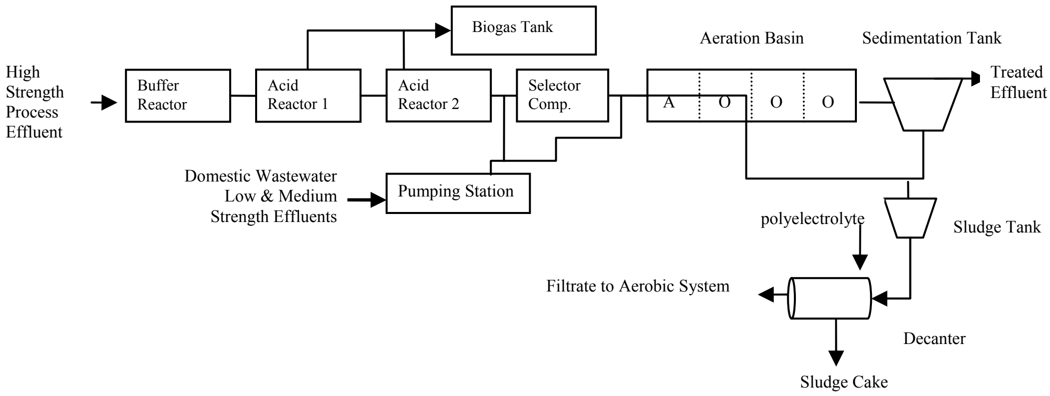


Figure 2.2. The flow diagram of the wastewater treatment plant at Pakmaya

Note: A=Anoxic, O=Oxic

3. MATERIAL & METHODS

3.1. Experimental Design

In the present work, the composting process was used to treat biosolids (Photograph 3.1) from Yeast Industry Wastewater Treatment Plant of Pakmaya.

Two types of bulking agents were used to lower the moisture content of the biosolids, to increase porosity and to add a source of carbon. It is known that woodchips was generally used for the composting of biosolids. However, it was found from the previous studies [31] that woodchips wasn't good for this kind of biosolids composting. When woodchips was used as a bulking agent, high temperatures couldn't be reached during the composting process.

For this reason, different bulking agents of hazelnut husk (HH) and shredded cornstalk (SC) were evaluated for the composting process. (Photograph 3.2). These bulking agents were easily obtained from the local area.

Photograph 3.1. The view of biosolids from yeast industry

Photograph 3.2. The view of bulking agents. HH (left) and SC (right)

Before the piles were formed, the characteristics of each feedstock were determined. The data were summarized in Table 3.1. As it seen in the table, chromium (Cr), and especially lead (Pb) were higher in hazelnut husk than other feedstocks. These heavy metal concentrations in the crops increased in direct relation to the increasing concentration in the soil.

Table 3.1. The characteristics of feedstocks.

Parameters/Elements	Biosolids	HH	SC
pH	7.65	6.08	6.87
Water Content (g/g)	76.2	9.87	75.58
Organic Matter (g/g)	47.06	91.06	89.7
EC (µmhos/cm)	3600	4250	3500
COD (g/kg)	2.74	10.03	12.11
NH_3 (g/kg)	522	20.39	90.58
C (%)	28.3	43.2	40.3
N (%)	4.6	1.5	1.7
C/N	6.2	28.5	23.9
Coliform (cfu/gr)	2.70E+04	1.40E+05	4.30E+06
Total bacteria (cfu/gr)	4.30E+06	5.60E+06	1.20E+08
Salmonella	Absence	Absence	Absence
Respirometry ($mgCO_2/gTS/d$)	17.47	14.26	27.79
Cu (mg/kg)	70.84 ± 0.97	11.76 ± 1.28	14.44 ± 0.36
Zn (mg/kg)	183.96 ± 2.47	19.18 ± 0.95	30.25 ± 0.61
Cd (µg/kg)	189 ± 14	213 ± 40	172 ± 13
Co (mg/kg)	2.98 ± 0.06	2.70 ± 0.29	2.13 ± 0.17
Cr (mg/kg)	13.08 ± 0.68	18.83 ± 6.63	4.77 ± 0.73
Ni (mg/kg)	22.67 ± 0.02	7.30 ± 0.84	5.15 ± 0.40
Pb (mg/kg)	4.41 ± 0.23	55 ± 23	1.97 ± 0.06

Pilot scale compost trials were conducted at the Düzce Pakmaya plant during the fall 2007. In this study, four piles were formed and different ratios of bulking agents (as shown in Table 3.2) were used within these piles. The mixing ratios were selected as to minimize the usage of the shredded cornstalk. Although shredded cornstalk offers ideal conditions for composting process, it is more expensive than hazelnut husk. The cost of the shredded cornstalk is 100YTL/ton. On the other side, hazelnut husk is obtained free in the locality.

Generally, the proper mixing ratios of bulking agent to biosolids were ranged from 2:1 to 3:1 [32]. Therefore, in this work, four different mixing ratios were used to decrease the usage of shredded cornstalk and to see the effect of the composting process. The ratio of bulking agent/biosolids were kept constant as 2:1 (bulking agents:biosolids v:v) for all piles.

Table 3.2. Ratios of different bulking agents with biosolids

Pile No	Materials	Ratio of each material (by volume)	Biosolids:total bulking agents ratio (by volume)
1	Biosolids:SC:HH	1:2:0	1:2
2	Biosolids:SC:HH	1:1:1	1:2
3	Biosolids:SC:HH	1:0.5:1.5	1:2
4	Biosolids:SC:HH	1:0:2	1:2

The hazelnut husk was used as a bedding material (Photograph 3.3) for all piles. The composting process was carried out in open air piles and consisted of a first stage (active composting) lasting one month, during which the piles were turned three times, aeration was ensured by forced ventilation (Photograph 3.4) and a second, maturation stage (curing), in which the products were allowed to stand untouched for one month in piles. Therefore, aerated windrow composting system was used for this study.

Photograph 3.3. Hazelnut Husk used as a bedding material

Photograph 3.4. Forced ventilation provided by a perforated pipe

22L pail was used to determine the volume of the piles. For example, for the first pile, 27 pail of biosolids were mixed with 54 pail of shredded cornstalks to obtain 1:2 ratio by volume (Photograph 3.5). Also, 6 pail of hazelnut husk was used for the base. The weights of materials in the piles were calculated by using the density of the feedstocks. The amounts of the materials in the piles were summarized in

Table 3.3.

Photograph 3.5. Forming the pile

Table 3.3. Amount of the materials used for the piles

Pile No	Weight (kg)			
	Biosolids	SC	HH	Total
1	467.10	84.24	0	551.3
2	467.10	42.12	52.92	562.1
3	467.10	20.67	77.91	565.7
4	467.10	0	105.84	572.9

The view of the piles at the beginning and end of the process was shown in Photograph 3.6 and Photograph 3.7.

Photograph 3.6. View of the piles at the beginning of the study (t=0d)

Photograph 3.7. View of the piles at the end of the study (t=60d)

When the weather was rainy, the piles were covered with a plastic material to protect variation of the moisture content in the piles (as shown in Photograph 3.8).

Photograph 3.8. View of the piles covered with plastic material

All the piles were turned on days 10, 20 and 30 after start up. The mixing was realized as shown in Photograph 3.9. First, the piles were transferred an empty place next to the piles, then mixed with shovels and transferred back on the ventilation system (Photograph 3.10). Composite samples were collected from each pile on days 0, 10, 20, 30, and 60. After collection, samples were transported in cool boxes to the laboratory, and stored at 4^{o}C, and then analyzed. A temperature datalogger (WatchDog 100 data logger, Spectrum Technologies, Plainfield, IL, USA) inserted in each pile to measure temperature during composting.

Photograph 3.9. Turning of the piles before the sample collection

Photograph 3.10. Transferring the piles back on the ventilation system

3.2. Analyses of the Parameters

The samples, which were collected as described in the previous section, were analyzed according to "Test Methods for the Examination of Composting and Compost (TMECC)" [33]. Physical, chemical, and microbiological analyses are summarized below.

3.2.1. Physical and Chemical Analyses

Several parameters have been measured in order to monitor the system performance. These were; moisture content, organic matter, respirometry (CO_2 evolution rate), C/N, COD, pH, EC, ammonium, heavy metals (cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu). nickel (Ni), lead (Pb), and zinc (Zn)), total bacteria, total coliform, salmonella.

Moisture Content

Well mixed, bulk sample was weighed, oven dried at 105±5ºC to steady state and reweighed. The remaining dry solids fraction represents the total solids, and the evaporated fraction represents percent moisture. Total solids and percent moisture contents of sample were calculated by using following formula [33].

$$TS = dw \div A \times 100 \qquad \textbf{(3.1)}$$

$$M = 1 - [dw \div A] \times 100 \qquad \textbf{(3.2)}$$

where;

TS = percentage solid material in sample, wet basis, % g/g^{-1},

M = percentage moisture in sample, wet basis, % g/g^{-1},

dw = net dry weight, oven at 105 ± 5ºC, g, and

A = net sample weight at as-received moisture, g.

Volatile Solids Content

An air dried (dried for 24 hours at 75ºC), milled sample was combusted at 550ºC for 2h to determine volatile solids content. Organic matter and ash content as percentages of total solids on an oven dry weight basis were calculated by using following formula [33].

$$Ash = [AshW \div dw] \times 100 \qquad \textbf{(3.3)}$$

$$VS = [1 - (AshW \div dw)] \times 100 \qquad \textbf{(3.4)}$$

where;

Ash = percentage solids at 550ºC, % g/g-1,

VS = percentage of solids volatilized at 550ºC, % g/g-1,

AshW = sample net weight after ignition at 550ºC, g,

dw = net oven-dry weight, at 70 ± 5ºC, g, and

A = net ash weight at 550ºC, g.

Respirometry - Carbondioxide Evolution Rate

The amount of CO_2 gas generated from the decomposition of organic matter during is determined by respirometry analysis [33].

25g compost sample was allowed to pre-incubate at room temperature (25-28^{o}C) for 24h. Sample moisture loss was minimized by maintaining high humidity conditions in the incubator. The moisture content of the sample was determined in the preparation for this respirometry test. After pre-incubation period, 20ml of 1N NaOH was transferred to biometer flask and then it was placed into the incubation vessel, which is set at 34^{o}C. A blank was set up by placing a 20ml aliquot of 1N NaOH into an incubation vessel without a compost sample. Then, the date and time was recorded. The amount of CO_2 absorbed by each NaOH trap was determined daily over a four day period by back titration of the residual with normalized 0.1N HCl. 0.5ml NaOH was transferred into a beaker. 50ml distilled water and 1ml of 0.5N $BaCl_2.2H_2O$ were added. In addition, two to three drops of phenolphthalein indicator was added. The mixture was back titrated with 0.1N HCl until the solution begins to turn clear. The sample was placed back into the incubation vessel with a fresh amount of NaOH. Calculations for each of the four titrations were performed. CO_2 evoluation for each titration was calculated by using following formula.

$$A = [(B - C) \times (D \times E)] \div [F \times G] \qquad \textbf{(3.5)}$$

where;

A = mg CO_2-C g^{-1}(TS, OM) $d^{-}1$,

B = volume of standardized HCl used for blank titration, mL,

C = volume of standardized HCl used for sample titration, mL,

D = normality of standardized HCl, mol L^{-1},

E = 22 = equivalent weight of CO_2 in NaOH,

F = moist weight or organic matter of sample in container, g, and

G = mass unit, fraction of total solids (TS), and organic matter (OM)

$$H = \sum A \div I \qquad \textbf{(3.6)}$$

where;

H = average mg CO_2-C g^{-1}(TS,VS) d^{-1}

$\sum A$ = tally CO_2 evolution measures from days one through four,

I = duration of experiment, four d.

C and N

Firstly, an air-dried (dried for 24 h at 75ºC), sample was prepared and 300-500mg of compost samples were weighed. Finally, C and N were measured with an elemental analyzer (Leco TruSpec, USA).

COD value

1:20 solids: liquid mixture of shredded samples and deionized water were blended at ambient laboratory temperature (approximately 23ºC) to determine the COD. The mixture was shaken in a 500mL closed container at 180 excursions per minute for 20 minutes. The mixture was centrifuged at 9000 rpm for 15 minutes. Then COD was measured within the supernatant [32]. COD was analyzed according to “Standard Methods” 35.

pH, EC and Ammonium

A slurry of compost and deionized water was blended at a ratio of 1:5, w/w basis. The mixture was shaken in a 250mL closed container at 180 excursions per minute for 20 minutes. After that, pH was measured by electronic pH meter (Orion 720) directly in the slurry. The mixture was centrifuged at 9000 rpm for 45 minutes. Then, Electrical Conductivity (EC) was analyzed within the supernatant [33]. Remaining supernatant was passed through 0.45µm filter and then ammonia was measured using a probe (Orion 95-12).

Heavy Metals

250mg blended sample was weighed and then 3ml HNO_3, 9ml HCl solutions were added to the sample. Then the mixtures were digested for 30 minutes in a microwave digestion system (CEM MarsExpress, USA) and heavy metals (Cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), nickel (Ni) and lead (Pb), zinc (Zn)) were determined by an ICP-OES (Varian Vista-Pro, Australia).

3.2.2. Microbiological Analysis

For bacteriological determinations, the solid samples were suspended in a liquid for the bacteria to distribute themselves evenly throughout the samples.

For total bacteria, total coliforms analyses, 20g of compost were weighed and 180ml ringer solution was prepared. Then it was mixed after a homogenous solution was obtained.

Total Bacteria

In this study, nutrient agar was used for the estimation of the total bacteria. Following procedure was applied to prepare nutrient agar; 3g beef extract, 5g pepton, 15g agar and 10g yeast extract were weighed and then this mixture completed with 1L distilled water. The mixture was sterilized in the autoclave for 15min. 1 ml of sample was placed from 10^{-5}, 10^{-6}, 10^{-7}, 10^{-8}, 10^{-9}, 10^{-10} dilutions to the Petri-dishes. Sample spreading procedure was facilitated by the use of a rotating Petri-dish holder.

All plates were incubated for 48 hours at 32.5°±2.5°C. The results expressed in colony forming unit (cfu).

Total Coliform

The chromogenic rapid e.coli culture (Biored agar) was used to estimate cfu of total coliforms. The mixture was sterilized in the autoclave for 15min. 1 ml of sample was placed from 10^{-3}, 10^{-4}, 10^{-5} 10^{-6} dilutions to the Petri-dishes. Sample spreading procedure was facilitated by the use of a rotating Petri-dish holder. All plates were incubated for 12-24 hours at 35±2°C. The results expressed in colony forming unit (cfu).

Salmonella

Salmonella was analyzed by using Oxoid Salmonella Rapid Test method (OSRT, product code FR0201A)

3.3. Pot Study

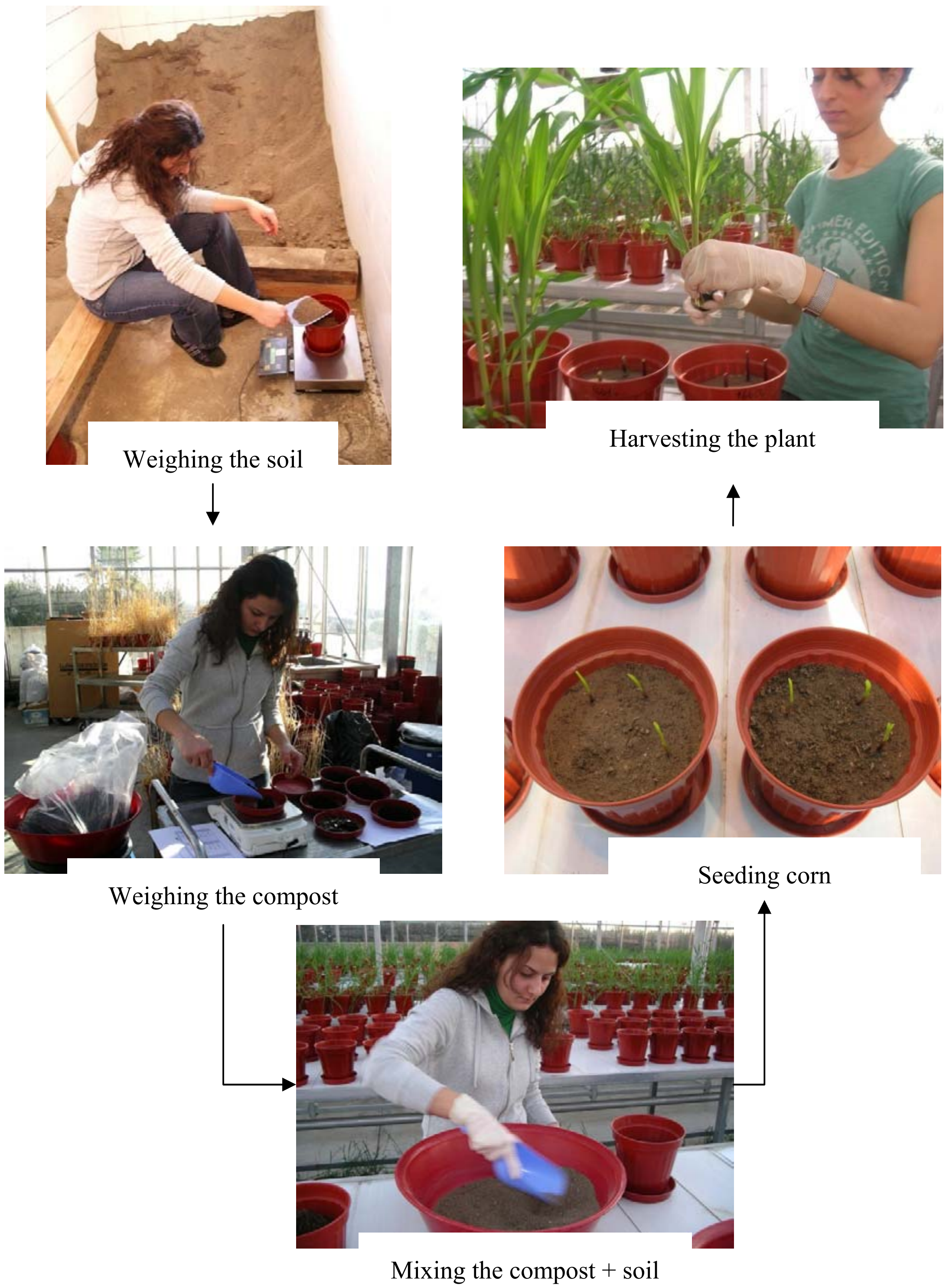
The application of compost to soil is of considerable interest as a means of maintaining a suitable soil structure, as well as a means of adding organic material to soil whose organic matter content has been reduced by the practice of intensive agriculture, especially in our country. To prove the improvement effect of compost, 3 trial pot studies were realized in a greenhouse. Pots were filled with soil (from Eskisehir – Sultanonu), compost (screened through 7mm) at these rates 0, 2.5, 5, 10%. and they were mixed until a homogeneous mixture was obtained. The characteristics of the soil were given in the Table 3.4. Then fertilizers were added at rates 0, 33, and 100%. Finally, five seeds were sown in each pot and allowed to germinate and grow. After 30 days, the crops were harvested Photograph 3.11.

Table 3.4. The characteristics of the soil

Parameter	Values
pH	8.1 ± 0.4
EC	130 ± 1
Total C (%)	1.8 ± 0.1
C/N	10 ± 0.4
DTPA Na (mg/kg)	5.7 ± 1.3
DTPA Fe (mg/kg)	2.7 ± 0.2
DTPA Mn (mg/kg)	12 ± 1
DTPA Cu (mg/kg)	1.04 ± 0.03
DTPA Zn (mg/kg)	0.18 ± 0.02
DTPA B (mg/kg)	0.16 ± 0.02
DTPA Cd (μg/kg)	18.0 ± 1.0
DTPA Co (μg/kg)	93 ± 8
DTPA Cr (μg/kg)	0.77 ± 0.32
DTPA Mo (μg/kg)	2.1 ± 0.7
DTPA Ni (μg/kg)	2253 ± 70
DTPA Pb (μg/kg)	840 ± 46

Note:DTPA=Diethylene triamine pentaacetic acid

The samples were dried at 75°C during 1 week for dry matter determination. In addition, the samples were blended to determine the heavy metals (cadmium (Cd), cobalt (Co), chromium (Cr), nickel (Ni) and lead (Pb)) using ICP-OES.



Photograph 3.11. View from the pot study

4. RESULTS AND DISCUSSION

4.1. Composting Process

4.1.1. Physical and Chemical Analyses

Temperature

Temperature plays a major role in the composting process. At the same time, it is also a function of the process. The most important aspect of temperature is its impact on the microbiological community. The time temperature relationship affects the rate of decomposition of the organic matter and therefore is important for the production of a stable and mature product for consumer use. Also, other reactions of the composting process are affected and change with temperature. The interaction between various parameters and temperature often makes it difficult to separate cause and effect.

Figure 4.1 shows temperatures in the piles during composting. Temperature generally rises initially and then levels off for all piles. At some point when microbial activity slows down, temperatures begin to descend. After remixing the piles, temperature rises again. However, this increase gradually slows down because a stable product is formed.

Initially the temperature of the composting piles ranged from 20 to 40°C (mesophilic phase). This rose to 65-50°C in 10-20 days (thermophilic phase) and then temperatures of piles was between 30 and 60°C in 25-30 days. Finally, the temperature fell gradually before reaching ambient temperature.

The temperature of the first and second piles exceeded the 60^{o}C. On the other side, the third and fourth piles' temperatures just exceeded the 50°C. Therefore, in both piles temperatures exceeded 50°C to ensure hygienization.

The maximum temperature immediately captured only with the first pile. This is due to the shredded cornstalk, which is easily decomposable matter. When the content of the shredded cornstalk decreases in the piles, the access time to the maximum temperatures increases.

The maximum temperatures of the piles were different. One reason for this is that decomposition rates of bulking agents were different. In this study, the amount of hazelnut husk was too much in the third and fourth piles than others. It is known that this material had less available carbon for microbial activity. Therefore, it can be concluded that the temperatures were lowest with hazelnut husk.

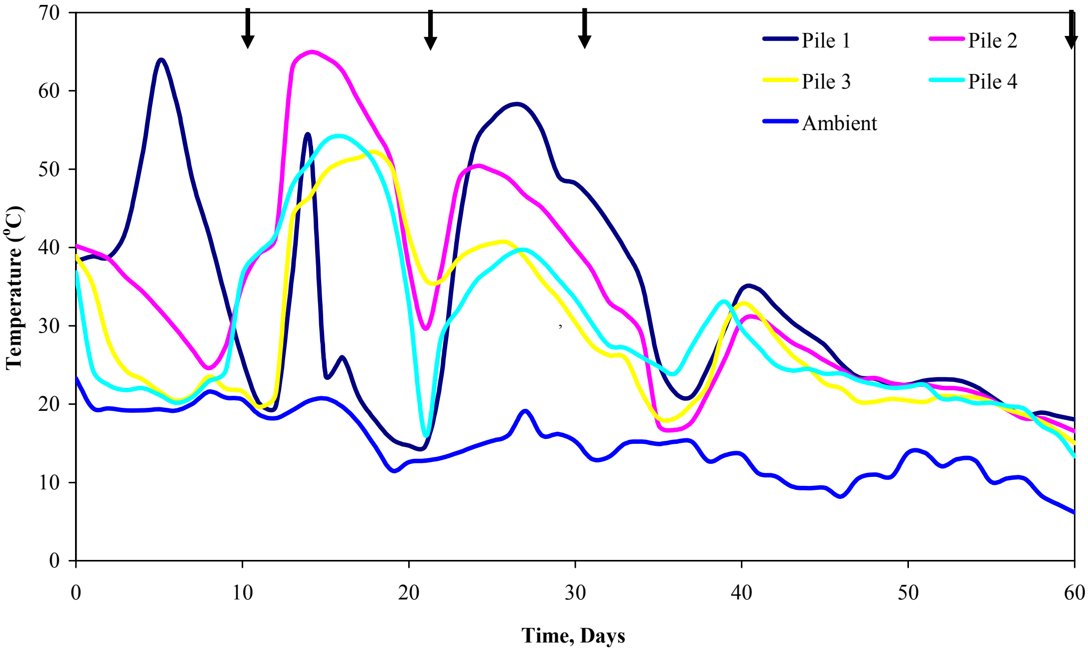


Figure 4.1. Temperature changes during the composting of the piles.

Note: The arrows indicate remixing of compost materials.

pH

The pH value also affects the composting process. Changes in the pH of the piles are presented in Figure 4.2. In the beginning of the process, the pH in the range of 7.00-8.00 for all piles. This remained almost constant over most of the incubation period in both piles owing to the high buffer capacity of the biosolids components. However, the general trend was that the initial pH decreased during the composting. This might be contributed by the organic acid formation during the decomposition of organic matter, contained in the sludge. Thereafter the pH rose slightly and then leveled off. The acids served as substrates for succeeding biological decomposition. It has been said, in general, that pH of the composting mixture should be in the range of 6–9 [14].

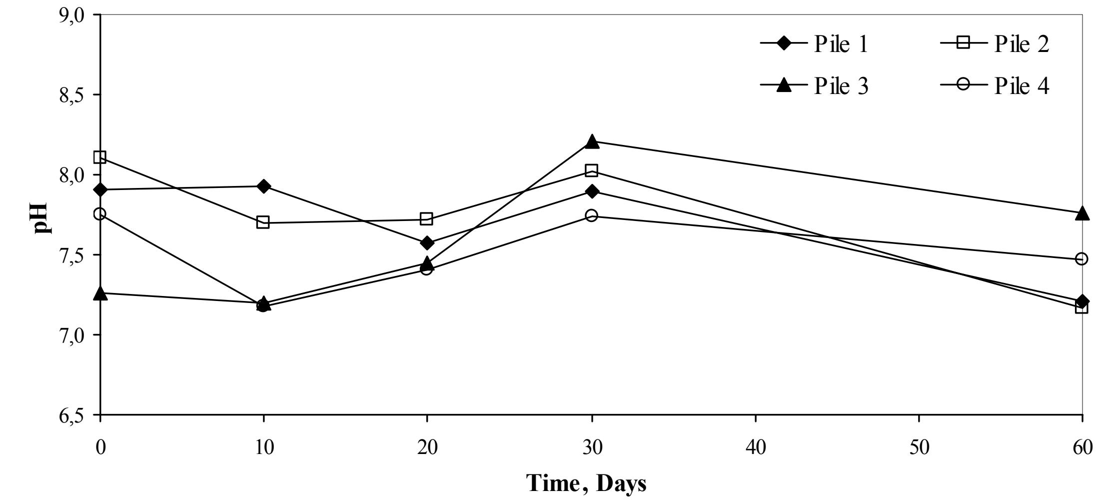


Figure 4.2. pH of the piles during the composting process

Moisture Content

Moisture in the composting process can affect microbial activity and thus influence temperature and rate of decomposition. In addition, moisture can affect the composition of the microbial population [9] Moisture is produced as a result of microbial activity and the biological oxidation of organic matter, in addition water is lost through evaporation. Based on this work, the moisture content of the piles was maintained at about 50–75% throughout the composting period (Figure 4.3).

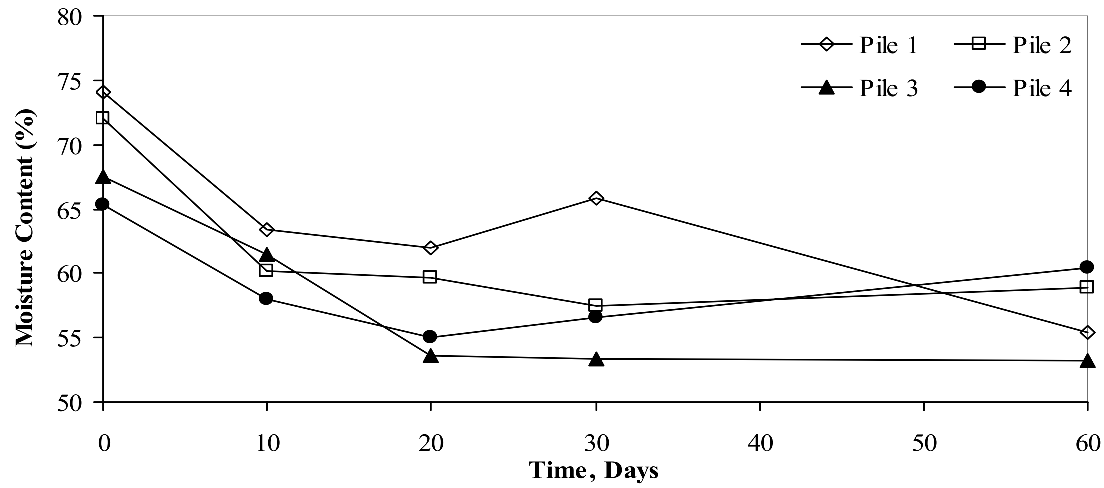


Figure 4.3. The moisture content of the piles throughout the composting period.

After the curing period, moisture content of the piles was ranged about 55-60%. These values were proper for the Europe Eco-Label Standards (<75%).

Volatile Solid Content

The volatile solid content of the piles gradually decreased over time due to mineralization processes (Figure 4.4). Therefore, more stable product was obtained at the end of the process.

The diminishing of the organic matter was higher in Pile1 compost than in Pile 4. because Pile1 compost contains much more shredded cornstalk, which is easily degradable than the hazelnut husk.

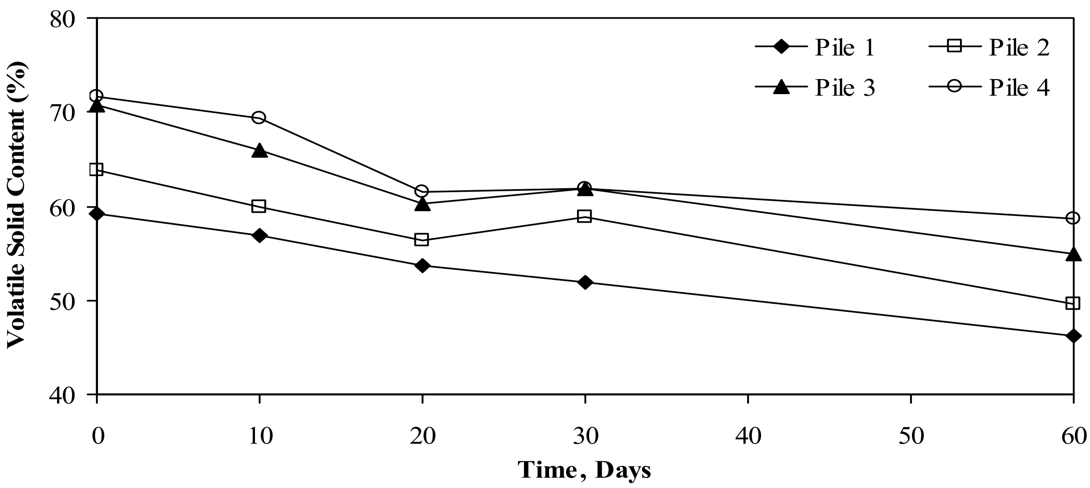


Figure 4.4. The volatile solid content of the piles over time during the composting process.

C/N

The two most important nutrients are carbon and nitrogen. For the composting process. Carbon is provided to the microbial community from decomposing matter and utilized for cellular growth. On the other hand, microorganisms need nitrogen for protein synthesis.

As shown in Figure 4.5, the percentage of the carbon decreases during the composting process because of the organic matter degredation.

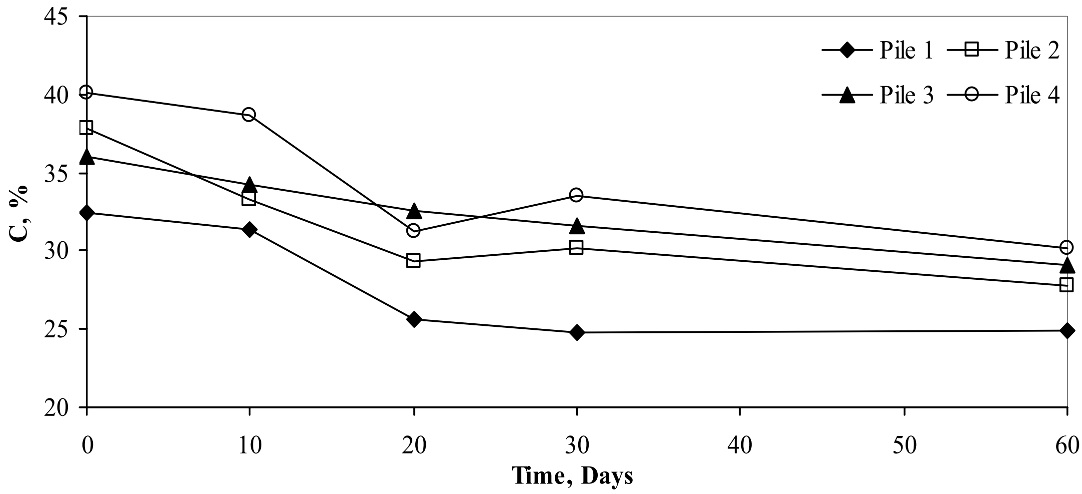


Figure 4.5. The percentage of the Carbon (%)

The percentage of the nitrogen was shown in Figure 4.6. The amount of nitrogen seems to be slightly increased because of the mass loss. However, it was almost unchanged.

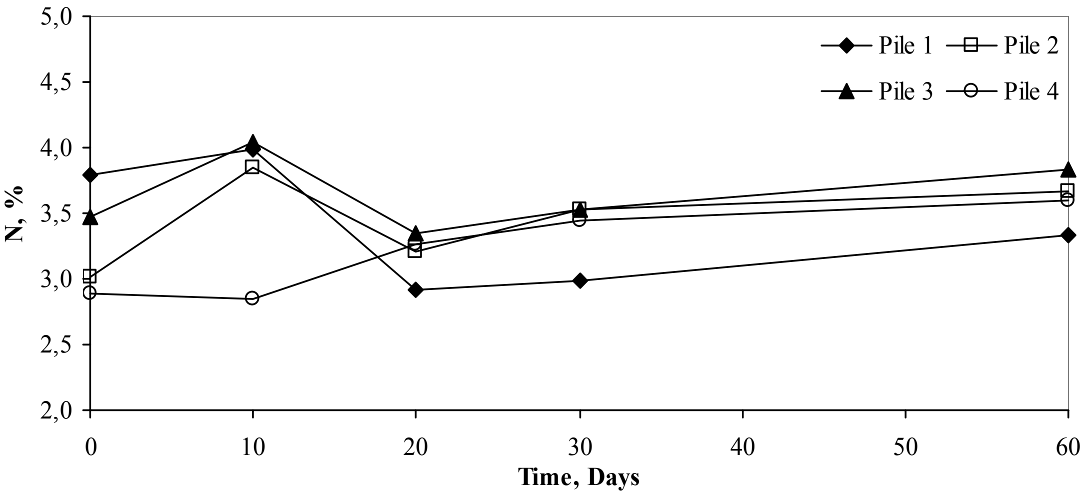


Figure 4.6. The percentage of the Nitrogen (%)

C/N ratio decreased during the composting period for all piles (Figure 4.7). The maximum diminish was observed for the Pile 4 because total carbon was higher in the hazelnut husk. During efficient composting, the C/N ratio is expected to decrease as a consequence of degradation of organic matter and mineralization.

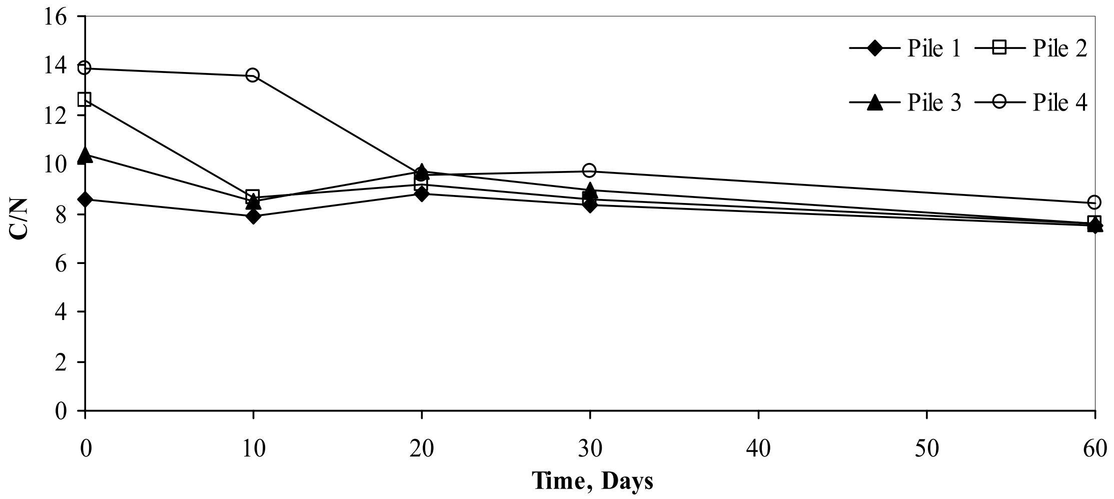


Figure 4.7. The C/N ratio versus time

Final C/N to initial C/N ratio ranged widely (0.49–0.85) for different composting times [38]. This ratio for the each pile in the range of 0.6-0.87 and proper to the range given in the literature (Table 4.1).

Table 4.1. Final C/N to initial C/N ratio for piles

	Pile 1	**Pile 2**	**Pile 3**	**Pile 4**
$C:N_{final}/C:N_{initial}$	0.87	0.60	0.73	0.60

Electrical Conductivity

Electrical Conductivity (EC) is usually measured during composting because it reflects the salinity of the composting product and its suitability for plant growth. For Pile 1, 2, 3 and 4, EC values increased from 4750 to 6500μmhos/cm, from 5600 to 6250μmhos/cm, from 5600 to 5750μmhos/cm, and from 4900 to 4950μmhos/cm, respectively (Table 4.5) due to mainly to the net loss of weight and the release of soluble salts through decomposition activity in the composting process. However, composts can be negatively be affected by an excess of salt since microbial activity can be altered, especially by chlorides. This fact could be considered as a negative aspect in the composting process.

Ammonia

As shown in Table 4.5, the NH_3 concentration increased initially within the ten days then decreased gradually. This condition was seemed for all piles. The increasing was happened due to the rising of pH and temperatures, which causes the volatilization of the ammonia.

Because N was in excess in the biosolids as a result low C:N ratios in the piles. Nitrogen was metabolized in a way that gaseous N compounds (ammonia) were realeased.

COD

The COD in the 1:20 slurry indicating quantity of easily degradable organic compounds is expected to decrease in the composting process. On the whole, the COD for all piles declined at the end of the study (Table 4.2). This suggests that the decomposition of composting material occurred and as a result the COD decreases..

Table 4.2. The result of COD at the beginning and end of the process

COD (g/kg)				
Time (day)	**Piles**			
	1	***2***	***3***	***4***
0	3,79	4,14	2,36	2,13
60	1,46	1,65	1,55	0,17

Respirometry

Respirometry analysis is a measure of the total biological activity in the composting material and results from the degradation of organic material; the formation of CO_2 is the last step of carbon mineralization.

During the process, oxygen is consumed, and CO_2 and water, are released. At the end of the process, respirometry rates decrease because compost becomes stable. For all piles, the respirometry rates decreased from ~22 to ~8 mg CO_2C/gTS/d. This was given in Table 4.3.

Table 4.3. CO_2 evaluation rates at the beginning and end of the process

Respirometry (mg CO_2C/gTS/d)				
Time (day)	**Pile**			
	1	***2***	***3***	***4***
0	24,50	22,37	20,03	19,98
60	8,46	8,04	7,22	8,24

Respirometry of the compost products from piles 1, 2, 3 and 4 were 2.33, 1.91, 1.93, and 1.58 CO_2C/gVS/day, respectively. Composts from Pile 2, 3 and 4 were classified as "very mature", and "mature" for the compost from Pile 1 according to the maturity indices published by the California Compost Quality Council (CCQC) (Table 4.4) [37].

Table 4.4. Maturity Indices (CCQC)

Method	**Units Rating**		
	Very Mature	**Mature**	**Immature**
mg CO_2 C/gVS /day	< 2	2-8	>8

Table 4.5. The results of Physical and Chemical Analyses

Parameters	**Pile 1**					**Pile 2**				
	Initial Mixture	t=10d	t=20d	t=30d	t=60d	Initial Mixture	t=10d	t=20d	t=30d	t=60d
OM (%)	59,2	56,9	53,6	51,8	46,3	63,8	60,0	56,3	58,9	49,7
WC (%)	74,1	63,4	62	65,9	55,4	72	60,1	59,7	57,4	58,9
EC (µmhos/cm)	4750	4100	5600	7500	6500	5600	4400	6750	5250	6250
pH	7,91	7,93	7,57	7,9	7,21	8,1	7,7	7,72	8,02	7,17
NH_3 (mg/kg)	835	1410	1373	2776	274	816	1706	1445	618	201

Parameters	**Pile 3**					**Pile 4**				
	Initial Mixture	t=10d	t=20d	t=30d	t=60d	Initial Mixture	t=10d	t=20d	t=30d	t=60d
OM (%)	70,8	66	60,3	61,9	48,9	71,7	69,4	61,5	61,9	58,7
WC (%)	67,5	61,5	53,6	53,3	53,2	65,3	58	55	56,5	60,4
EC (µmhos/cm)	5600	6000	6200	5500	5750	4900	6500	5250	5750	4600
pH	7,26	7,2	7,45	8,21	7,76	7,75	7,18	7,41	7,74	7,47
NH_3 (mg/kg)	894	1620	2389	693	301	990	1715	1516	903	146

Heavy Metals

Heavy metals are elements with relatively high molecular weight and are comprised of 40 elements. When several of these are taken into the body, they can accumulate in the specific body organs. The term includes the metals cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), mercury (Hg), nickel (Ni), and zinc (Zn). Cd, Hg, and Pb are toxic to humans and animals; yet others such as Cu, Ni and Zn can be phytotoxic.

In this study, heavy metals of the feedstocks, initial mixture and the final compost of the piles were given in Table 4.6. The biosolids from yeast industry contain low heavy metal concentrations. According to the results, the heavy metal concentrations seem to increase for all piles. However, it must be emphasized that the mass reduction during composting happened due to mineralization. It can be said that heavy metal concentrations of the compost products from all piles were proper with the regulations which were shown in the Table 2.6. Furthermore, maximum limits for contents of heavy metal in sludge to be used in agriculture were given in Table 4.6 to compare with the results.

Table 4.6. The results of the heavy metals

		Cu (mg/kg)	Zn (mg/kg)	Cd (µg/kg)
Pile 1	**Initial Mixture**	56.87 ± 1.89	143.34 ± 2.66	157 ± 23
	Compost Product	56.71 ± 0.76	147.93 ± 3.07	261 ± 59
Pile 2	**Initial Mixture**	57.83 ± 4.26	141.78 ± 11.94	191 ± 34
	Compost Product	62.30 ± 1.13	157.87 ± 5.69	257 ± 28
Pile 3	**Initial Mixture**	55.85 ± 2.17	144.76 ± 6.49	178 ± 7
	Compost Product	65.27 ± 2.45	172.84 ± 6.65	228 ± 21
Pile 4	**Initial Mixture**	57.76 ± 0.93	145.94 ± 3.05	189 ± 36
	Compost Product	61.84 ± 2.92	149.64 ± 11.51	249 ± 30
SPCR		**1750**	**4000**	**40000**

		Co (mg/kg)	Cr (mg/kg)	Ni (mg/kg)	Pb (mg/kg)
Pile 1	**Initial Mixture**	2.51 ± 0.05	10.25 ± 0.61	18.38 ± 0.62	3.89 ± 0.20
	Compost Product	4.35 ± 0.22	16.83 ± 0.68	21.82 ± 1.10	4.54 ± 0.20
Pile 2	**Initial Mixture**	2.46 ± 0.06	13.59 ± 2.06	17.80 ± 0.67	21 ± 6
	Compost Product	4.30 ± 0.52	15.18 ± 0.87	21.36 ± 0.50	4.86 ± 0.65
Pile 3	**Initial Mixture**	2.47 ± 0.11	9.60 ± 0.95	17.14 ± 0.56	3.26 ± 0.29
	Compost Product	3.58 ± 0.20	15.84 ± 0.80	21.21 ± 0.48	4.66 ± 0.21
Pile 4	**Initial Mixture**	2.40 ± 0.02	10.18 ± 0.31	18.70 ± 0.53	3.63 ± 0.49
	Compost Product	4.58 ± 0.75	14.20 ± 1.31	21.66 ± 0.66	4.58 ± 0.52
SPCR		**-**	**1200**	**400**	**1200**

4.1.2. Microbiological Analyses

In composting, the primary interest is in the organisms that decompose organic matter at the most efficient temperature and other conditions. One of the problems posed by the direct use of biosolids in agriculture is the risk of contamination by pathogens. Raw sludges showed a high density of Salmonella. During the composting process, total bacteria, total coliform were determined in samples taken at initial mixture, and 1st, 2nd, 3rd, 4th turnings during the composting process. As shown in Table 4.7, the values of total bacteria, and total coliform decreased at the end of the process due to the high temperature were reached during the process.

Salmonella is considered as the most specific and problematic microorganism from a hygienic point of view, since it is a universal bacteria with a high growth capacity. Salmonella wasn't found in the samples. Therefore, these results make composts safer for agricultural use (Table 4.7).

Table 4.7. The results of microbiological analyses

Sample		Coliform (cfu/gr)	Total bacteria (cfu/gr)	Salmonella
Pile 1	**Initial Mixture**	3,6E+06	4,8E+09	N.a
	3rd turning	1,6E+06	2,0E+07	N.a
	4th turning	3,1E+04	2,7E+07	Absence
Pile 2	**Initial Mixture**	1,5E+06	2,3E+07	N.a
	3rd turning	4,2E+06	9,2E+07	N.a
	4th turning	7,4E+05	1,6E+08	Absence
Pile 3	**Initial Mixture**	5,7E+06	1,1E+08	N.a
	3rd turning	2,4E+07	2,7E+08	N.a
	4th turning	1,7E+05	4,6E+07	Absence
Pile 4	**Initial Mixture**	5,1E+06	6,0E+07	N.a
	3rd turning	1,1E+07	1,2E+08	N.a
	4th turning	5,5E+05	2,8E+07	Absence

Note: N.a: Not analyzed.

4.2. Pot Studies

Dry Matter;

As shown in Figure 4.8, when fertilizer was not applied to the pots, both the application rate of the compost (obtained from the first pile) and the growth rate of the corn crops raised. On the other hand, when fertilizer was added to the pots at 33% and 100% ratios, the effect of the compost only observed at 2.5% ratio. Also, according to the Figure 4.8, it can be said that the maximum efficiency was obtained when 33% fertilizer and 2.5% compost was applied to the soil.

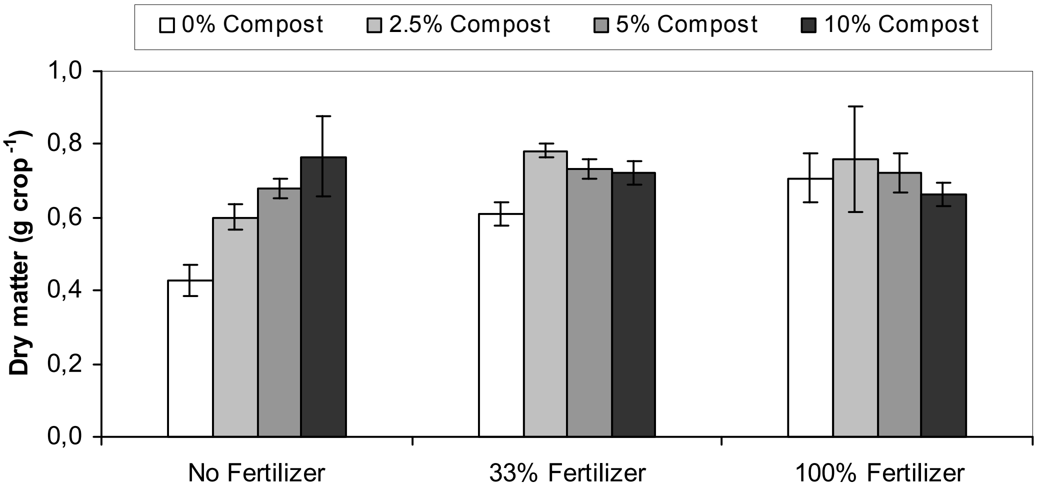


Figure 4.8. The effect of Pile 1 compost on the crop production

If standard derivations were taken into consideration, it can be said from Figure 4.9 that the highest efficiencies were observed for the compost (from Pile 2) at two situations. First is when no fertilizer and 10% compost was applied, second is when 33% fertilizer and 10% compost was applied.

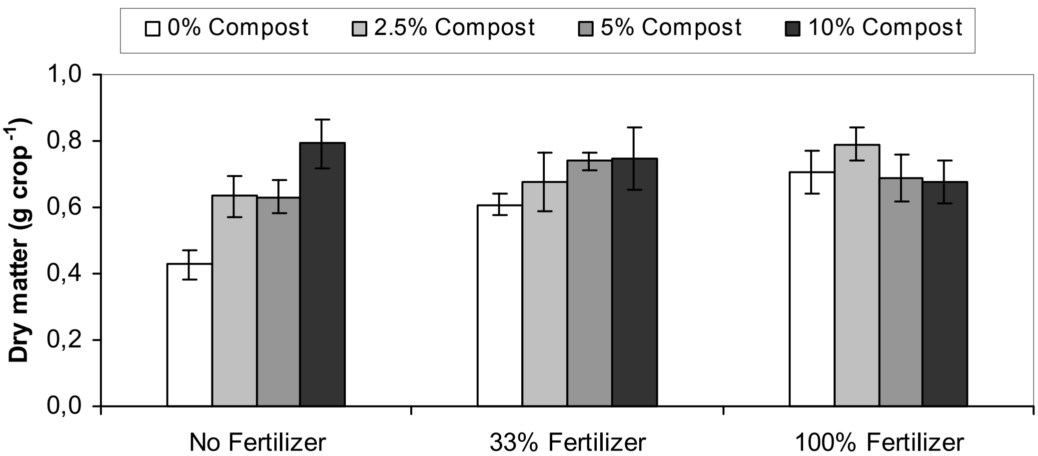


Figure 4.9. The effect of Pile 2 compost on the crop production

If we looked at Figure 4.10, it can be concluded that appropriate efficiencies were obtained for two conditions: firstly when no fertilizer and 10% compost and then as

33% fertilizer and 5% compost were applied to the pots. However, first condition would be more proper than the other because the fertilizer application lessened for this condition.

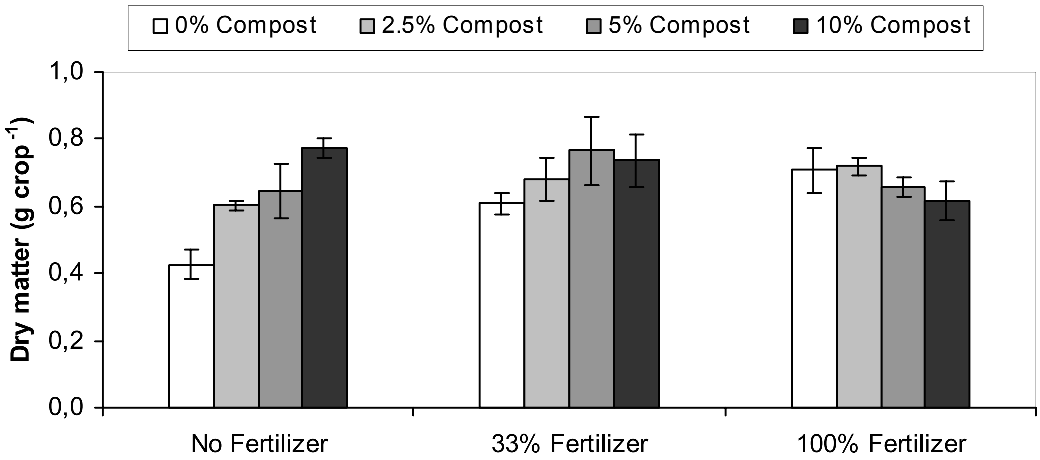


Figure 4.10. The effect of Pile 3 compost on the crop production

Finally, application of the Pile 4 compost to the pots showed that a good effect should be achieved when no fertilizer and 10% compost was applied to the pots (Figure 4.11).

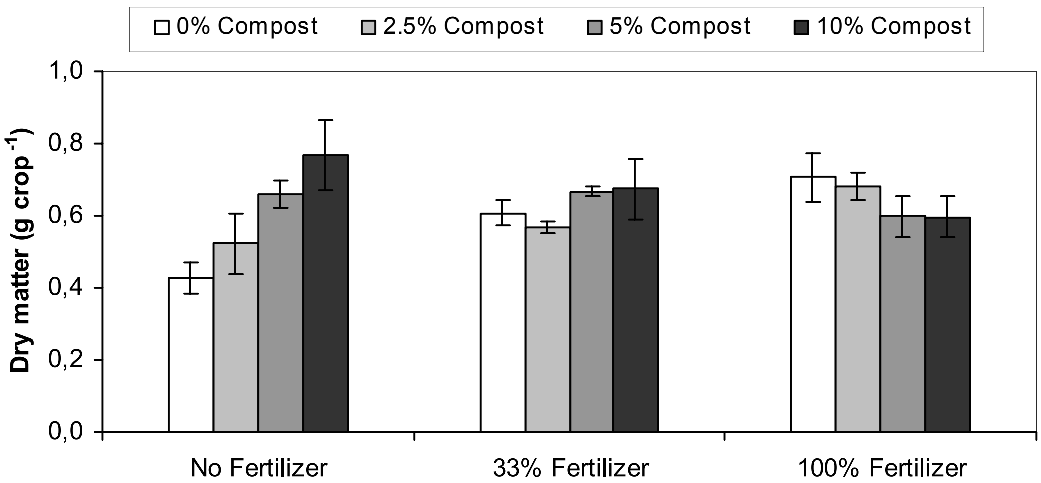


Figure 4.11. The effect of Pile 4 compost on the crop production

Pot studies were also shown in Figure 4.12. From the figure, it was seen that the growth rate of the plants were decreased when both the application rate of the fertilizer and compost increased. It can be better understood from the results of dry matter analyses.

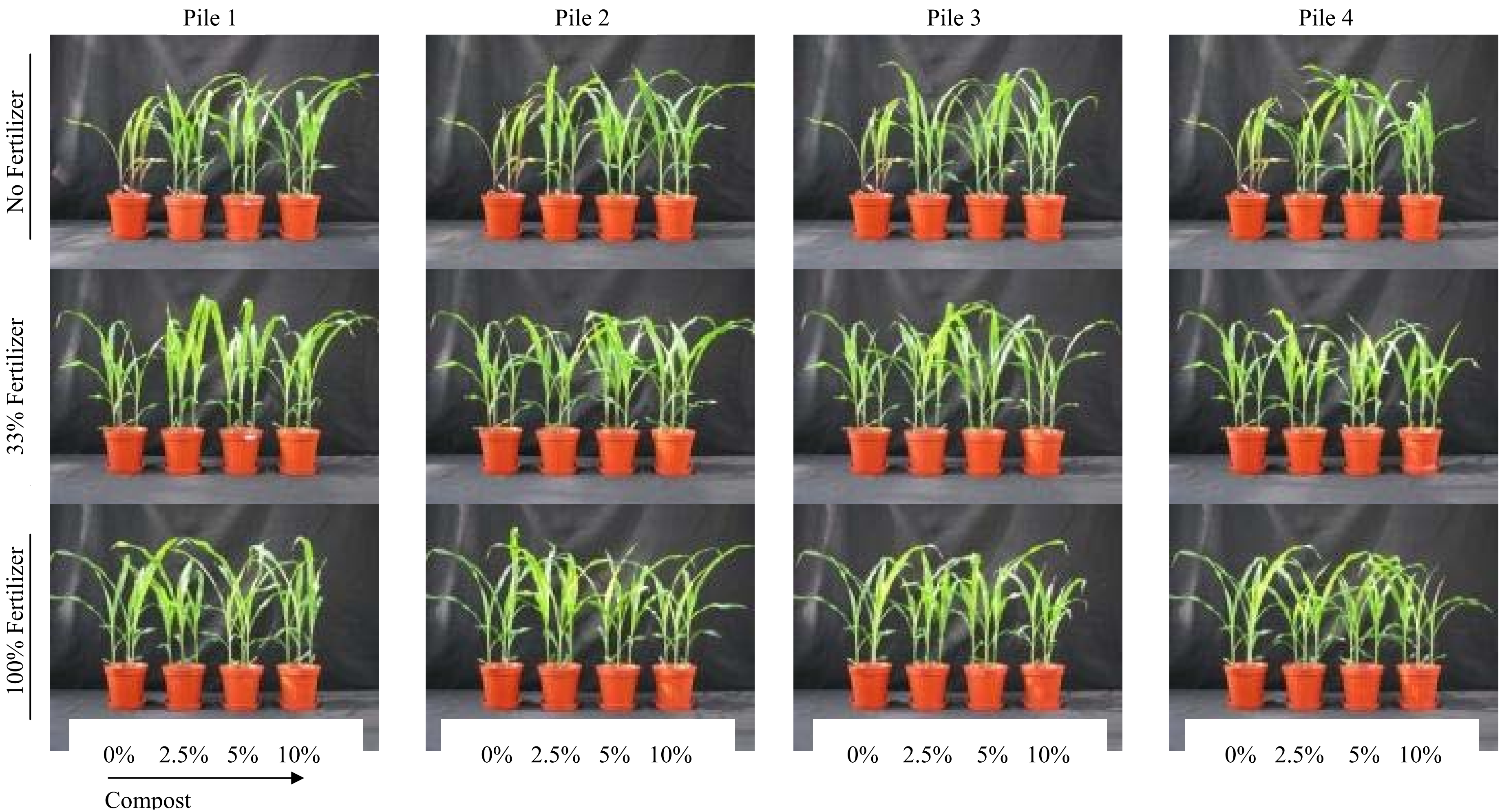


Figure 4.12. Application of Composts

Heavy metals

For the Pile 1 compost product

As shown in Table 4.8, the addition of compost and fertilizer increased the cadmium level. Although the yield of the dry matter increases, the application rate of the compost provides a decrease in the concentration of the heavy metals. Especially, decline of the cobalt was the highest. Also, it can be said that if both compost and fertilizer applied, chromium level generally decreased and the lowest level obtained when 2.5% compost and 100% fertilizer were applied. The addition of compost and fertilizer almost didn't change the nickel level. Finally, the lowest lead level was obtained when 5% compost and no fertilizer was used.

Table 4.8. Heavy metal concentrations in the green part of the plant due to the addition of compost product from the Pile 1

Pile 1 (B:SC:HH=1:2:0)					
0% Compost					
	Cd (μg/kg)	Co (μg/kg)	Cr (μg/kg)	Ni (mg/kg)	Pb (μg/kg)
0% Fertilizer	78 ± 3	216.67 ± 0.28	205 ± 5	1.37 ± 0.07	513 ± 88
33% Fertilizer	128 ± 7	248 ± 18	88 ± 15	1.75 ± 0.004	364 ± 121
100% Fertilizer	164 ± 11	302 ± 57	84 ± 5	1.97 ± 0.19	218 ± 92
2.5% Compost					
	Cd (μg/kg)	Co (μg/kg)	Cr (μg/kg)	Ni (mg/kg)	Pb (μg/kg)
0% Fertilizer	150 ± 4	204 ± 8	131 ± 13	1.51 ± 0.12	388 ± 32
33% Fertilizer	176 ± 15	160 ± 22	83 ± 3	1.48 ± 0.07	316 ± 169
100% Fertilizer	203 ± 18	153 ± 25	61 ± 7	1.43 ± 0.05	246 ± 107
5% Compost					
	Cd (μg/kg)	Co (μg/kg)	Cr (μg/kg)	Ni (mg/kg)	Pb (μg/kg)
0% Fertilizer	126 ± 21	163 ± 11	129 ± 22	1.49 ± 0.05	128 ± 45
33% Fertilizer	122 ± 4	145 ± 63	103 ± 10	1.33 ± 0.11	257 ± 6
100% Fertilizer	157 ± 9	127 ± 23	103 ± 20	1.22 ± 0.08	290 ± 236
10% Compost					
	Cd (μg/kg)	Co (μg/kg)	Cr (μg/kg)	Ni (mg/kg)	Pb (μg/kg)
0% Fertilizer	137 ± 11	75 ± 4	103 ± 16	1.03 ± 0.08	273 ± 16
33% Fertilizer	126 ± 5	141 ± 5	93 ± 8	0.98 ± 0.10	340 ± 133
100% Fertilizer	136 ± 12	84 ± 19	94 ± 38	1.03 ± 0.11	346 ± 85

For the Pile 2 compost product

The only increase was seemed in the cadmium when the application of the compost and fertilizer increased. When the addition of the compost and fertilizer increased, cobalt level decreased. Also, the lowest chromium level was observed when 2.5% compost and no fertilizer were applied. The addition of compost and fertilizer almost didn't change the nickel level. Finally, if no fertilizer was applied, the lead level decreased with the addition of compost (Table 4.9).

Table 4.9. Heavy metal concentrations in the green part of the plant due to the addition of compost product from the Pile 2

Pile 2 (B:SC:HH=1:1:1)					
0% Compost					
	Cd (µg/kg)	Co (µg/kg)	Cr (µg/kg)	Ni (mg/kg)	Pb (µg/kg)
0% Fertilizer	78 ± 3	216.67 ± 0.28	205 ± 5	1.37 ± 0.07	513 ± 88
33% Fertilizer	128 ± 7	248 ± 18	88 ± 15	1.75 ± 0.004	364 ± 121
100% Fertilizer	164 ± 11	302 ± 57	84 ± 5	1.97 ± 0.19	218 ± 92
2.5% Compost					
	Cd (µg/kg)	Co (µg/kg)	Cr (µg/kg)	Ni (mg/kg)	Pb (µg/kg)
0% Fertilizer	134 ± 8	194 ± 18	27 ± 5	1.40 ± 0.06	389 ± 67
33% Fertilizer	151 ± 11	199 ± 22	83 ± 20	1.61 ± 0.11	132 ± 138
100% Fertilizer	158 ± 5	159 ± 18	53 ± 23	1.44 ± 0.09	203 ± 73
5% Compost					
	Cd (µg/kg)	Co (µg/kg)	Cr (µg/kg)	Ni (mg/kg)	Pb (µg/kg)
0% Fertilizer	123 ± 11	89 ± 8	86 ± 15	1.34 ± 0.04	304 ± 78
33% Fertilizer	149 ± 6	147 ± 31	55 ± 20	1.40 ± 0.08	146 ± 118
100% Fertilizer	138 ± 29	103 ± 24	68 ± 23	1.14 ± 0.03	133 ± 143
10% Compost					
	Cd (µg/kg)	Co (µg/kg)	Cr (µg/kg)	Ni (mg/kg)	Pb (µg/kg)
0% Fertilizer	129 ± 2	128 ± 7	86 ± 27	1.08 ± 0.09	163 ± 68
33% Fertilizer	133 ± 0.9	92 ± 13	128 ± 51	1.01 ± 0.15	186 ± 92
100% Fertilizer	123 ± 5	80 ± 20	56 ± 27	0.95 ± 0.07	276 ± 70

For the Pile 3 compost product

Again, the highest cadmium level was observed when compost and fertilizer concentarions increased. On the other hand, generally the level of cobalt, chromium and lead decreased when the compost and fertilizer increased. The same condition was seemed for nickel, it was nearly unchanged (Table 4.10).

Table 4.10. Heavy metal concentrations in the green part of the plant due to the addition of compost product from the Pile 3

Pile 3 (B:SC:HH=1:0.5:1.5)					
0% Compost					
	Cd (μg/kg)	Co (μg/kg)	Cr (μg/kg)	Ni (mg/kg)	Pb (μg/kg)
0% Fertilizer	78 ± 3	216.67 ± 0.28	205 ± 5	1.37 ± 0.07	513 ± 88
33% Fertilizer	128 ± 7	248 ± 18	88 ± 15	1.75 ± 0.004	364 ± 121
100% Fertilizer	164 ± 11	302 ± 57	84 ± 5	1.97 ± 0.19	218 ± 92
2.5% Compost					
	Cd (μg/kg)	Co (μg/kg)	Cr (μg/kg)	Ni (mg/kg)	Pb (μg/kg)
0% Fertilizer	114 ± 10	210 ± 35	62 ± 3	1.51 ± 0.20	279 ± 166
33% Fertilizer	138 ± 15	153 ± 19	53 ± 11	1.59 ± 0.15	344 ± 212
100% Fertilizer	162 ± 9	162 ± 31	123 ± 112	1.61 ± 0.13	206 ± 131
5% Compost					
	Cd (μg/kg)	Co (μg/kg)	Cr (μg/kg)	Ni (mg/kg)	Pb (μg/kg)
0% Fertilizer	106 ± 4	129 ± 21	32 ± 3	1.46 ± 0.13	291 ± 166
33% Fertilizer	109 ± 14	130 ± 23	58 ± 47	1.35 ± 0.07	235 ± 139
100% Fertilizer	154 ± 3	149 ± 25	88 ± 81	1.50 ± 0.12	191 ± 139
10% Compost					
	Cd (μg/kg)	Co (μg/kg)	Cr (μg/kg)	Ni (mg/kg)	Pb (μg/kg)
0% Fertilizer	110 ± 2	85 ± 28	47 ± 2	1.15 ± 0.07	220 ± 25
33% Fertilizer	115 ± 11	70 ± 3	54 ± 24	1.19 ± 0.02	234 ± 227
100% Fertilizer	143 ± 12	103 ± 26	60 ± 13	1.12 ± 0.24	321 ± 243

For the Pile 4 compost product

As shown in Table 4.11, the same conditions for cadmium and nickel was observed for pile 4 compost. On the other hand, cobalt and lead levels decreased when the compost and fertilizer increased. Moreover, the lowest chromium level was found when 2.5% compost and 0% fertilizer was carried out.

Table 4.11. Heavy metal concentrations in the green part of the plant due to the addition of compost product from the Pile 4

Pile 4 (B:SC:HH=1:0:2)					
0% Compost					
	Cd (µg/kg)	Co (µg/kg)	Cr (µg/kg)	Ni (mg/kg)	Pb (µg/kg)
0% Fertilizer	78 ± 3	216.67 ± 0.28	205 ± 5	1.37 ± 0.07	513 ± 88
33% Fertilizer	128 ± 7	248 ± 18	88 ± 15	1.75 ± 0.004	364 ± 121
100% Fertilizer	164 ± 11	302 ± 57	84 ± 5	1.97 ± 0.19	218 ± 92
2.5% Compost					
	Cd (µg/kg)	Co (µg/kg)	Cr (µg/kg)	Ni (mg/kg)	Pb (µg/kg)
0% Fertilizer	83 ± 19	164 ± 21	31 ± 20	1.36 ± 0.13	297 ± 185
33% Fertilizer	115 ± 20	178 ± 3	44 ± 39	1.58 ± 0.14	210 ± 65
100% Fertilizer	149 ± 21	144 ± 30	34 ± 23	1.57 ± 0.05	184 ± 48
5% Compost					
	Cd (µg/kg)	Co (µg/kg)	Cr (µg/kg)	Ni (mg/kg)	Pb (µg/kg)
0% Fertilizer	96 ± 4	128 ± 11	48 ± 21	1.35 ± 0.07	436 ± 14
33% Fertilizer	118 ± 2	172 ± 10	72 ± 20	1.47 ± 0.09	328 ± 93
100% Fertilizer	134 ± 5	152 ± 10	45 ± 9	1.36 ± 0.09	338 ± 36
10% Compost					
	Cd (µg/kg)	Co (µg/kg)	Cr (µg/kg)	Ni (mg/kg)	Pb (µg/kg)
0% Fertilizer	90 ± 12	106 ± 6	45 ± 12	1.18 ± 0.09	430 ± 163
33% Fertilizer	96 ± 9	129 ± 15	43 ± 25	1.18 ± 0.18	174 ± 153
100% Fertilizer	99 ± 3	142 ± 86	58 ± 16	1.09 ± 0.15	237 ± 43

It can be concluded that when 10% compost (no addition of fertilizer) was applied, cobalt, chromium, nickel and lead levels decreased but cadmium level increased according to the blank (no compost and fertilizer added).

5. CONCLUSIONS

The composting process provided an acceptable degree of bioremediation for biosolids from yeast industry by using hazelnut husk (HH) and shredded cornstalk (SC) as bulking agents. Sufficient temperatures were reached within the piles to decrease the concentration of pathogenic microorganisms. The results of the investigations enabled one to prove the usefulness of the aerated windrow composting method for utilizing biosolids with hazelnut husk and shredded cornstalk at different ratios. It can be concluded that both hazelnut husk and shredded cornstalk can be considered as a good bulking agent for the composting of biosolids. However, it should be also noticed that when the application rate of shredded cornstalk reduced, the compost quality slightly decreased, too. It is due to the structure of the hazelnut husk, which is not easily degradable as shredded cornstalk. On the other hand, when a larger amount of hazelnut husk was added to the piles, the greater aeration of the composting mass, together with the dilution of possible reducing substances were obtained. Also, it isn't expensive. Therefore, by this study, the optimal ratio for composting biosolids from yeast industry was found as 1:1:1 (Biosolid:Shredded Cornstalk:Hazelnut Husk).

Also, it was proven from this study that the heavy metal concentrations of the compost products wasn't a limiting factor for application to the soil. Heavy metal concentrations of the compost products from all piles were proper with Soil Pollution Control Regulation (SPCR).

Furthermore, it was examined from the pot studies that the use of different compost at varying rates (0%, 2.5%, 10%) with or without additional fertilizers on corn crop. At the end of these studies, it was obviously shown that when compost was applied at high ratios (10%), additional fertilizer was not needed.

Heavy metal concentrations in the green part of the plant due to the addition of compost product showed that when fertilizer and compost added to the soil, the level of the cadmium increased. Cobalt, chromium and lead have the lowest value when compost application increased. Also, addition of compost and fertilizer obviously don’t change the nickel. Therefore, more studies must be performed to explain the effects of heavy metal concentrations.

At the end of this study, it was proven that composted biosolids are a valuable resource for agricultural land. Recycling of composted biosolids as soil amendment is an environmentally friendly and sustainable biosolids management option. In addition, based on the results of our studies, the applicability of the compost from yeast industry by using shredded cornstalk and hazelnut husk was determined. Hence, Pakmaya Yeast Industry decided to construct their own compost facility to recycle their biosolids into a valuable product.

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